ADVANCES IN COCONUT RESEARCH AND DEVELOPMENT

ADVANCES IN COCONUT RESEARCH AND DEVELOPMENT

ISOCRAD II

Edited by

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FOREWORD

Coconut is probably the only tree crop commercially cultivated extensively in about 90 countries especially on the small and marginal holdings. Because of its many uses, cultivation of this crop has become an important part of lives of inhabitants of these countries. In the earlier part of the century, research efforts were confined to a few Asian and Southeast Asian countries. At present, over twenty countries are actively involved in research and development activities on coconut.

It is appropriate that Central Plantation Crops Research Institute had, in collaboration with other agencies engaged in research and development, organized the second International Symposium on Coconut Research and Development to commemorate the 75th anniversary of coconut research and development in India. The participation of eminent scientists from 17 countries is a pointer to the importance and involvement this crop commands from the scientific community. I understand that the deliberations centred around the current status of research on various aspects and the strategies adopted in transfer of technology. The deliberations and the recommendations of this symposium when implemented should lead us on the path of success in coconut cultivation in the 21st century. I am sure that this publication will be of immense use to the researchers as well as planners in the years to come.

(V.L. CHOPRA)

Director General
Indian Council of Agricultural Research
New Delhi
19 March, 1993.

PREFACE

The importance of coconut, "the Tree of Heaven" or "Kalpavriksha" can be appreciated when we consider its innumerable uses to mankind. In India it has a recorded history of more than 3,000 years. Out of a total estimated annual edible oil production of 5.2 million tonnes in India, coconut's contribution is only about 5.96 per cent. Nevertheless, the tree as well as its products have gone deep into our culture.

Coconut research and development work was initiated in India during the year 1916 with the establishment of four research stations at Pilicode, Nileshwar (2 centres) and Kasaragod under the erstwhile combined Madras Presidency. The Coconut Research Station at Kasaragod from the humble beginning has developed into one of the prominent research institutions under the ICAR system.

The Platinum Jubilee of Coconut Research in India was celebrated at CPCRI, Kasaragod in a befitting manner on 26th November, 1991. This was followed by an International Symposium on Coconut Research and Development from 26th afternoon to 29th November, 1991, wherein the organizers were able to bring together scientists from coconut-growing countries with rich experience in different facets of coconut research and development.

In the inaugural session of the Platinum Jubilee, awards were presented to the scientists, developmental officials, farmers and inventors for their contribution to coconut research, development and industry. A special First Day Cover was brought out to mark the occasion. The occasion was also utilised for bringing out important publications viz. Souvenir, Annotated Bibliography on Coconut in India, Coconut Recipes Around the World, International Directory of Coconut Workers and special issues of select journals. Platinum Jubilee mementos were also presented to all the scientists, technicians, administrative officials and supporting staff who have completed more than 25 years of service to the cause of coconut research and development. An exhibition with the theme "Coconut in India" was presented through 30 stalls depicting various aspects of coconut research, development and industry.

The International Symposium on Coconut Research and Development was organised from 26–29 November, 1991 by the Indian Society for Plantation Crops in collaboration with the ICAR (CPCRI), Coconut Development Board, State Agricultural Universities with a mandate on coconut research, National Bank for Agriculture and Rural Development, Council of Scientific and Industrial Research, Department of Horticulture/Agriculture of Kerala, Tamil Nadu and Goa among others. A total of 257 delegates representing

17 countries took part in the Symposium. The foreign participation consisted of representatives from Africa, South America, Europe, Asia, the Pacific Islands and Australia. There were eight technical sessions: Pest Management, Genetic Resources, Crop Improvement, Biotechnology and Physiology, Crop Management and Farming Systems, Disease Management, Harvest and Post Harvest Technology and Economics, Developmental Programmes and Transfer of Technology.

This book "Advances in Coconut Research and Development" contains the full text of 47 status reports and 27 contributed papers presented at the Symposium along with the discussion and also the extended summarise of 27 poster presentations. The proceedings also contains the recommendations arising out of discussion.

Dr. V.L. Chopra, Director General, ICAR and Secretary, Department of Agricultural Research and Education has written a very thoughtful Foreword to this publication and we would like to convey our sincere thanks and gratitude to him.

Dr. K.L. Chadha, Deputy Director General (Hort.), ICAR and Chairman of the National Organizing Committee was the guiding force in organising the Platinum Jubilee Celebrations and the Symposium. The Indian Society for Plantation Crops would like to place on record the Society's sincere gratitude and thanks to him. We would like to express our appreciation to many of our colleagues for their efforts and cooperation in bringing out the proceedings specially to Messrs K. Ahamed Bava, P.A. Radhakrishnan, K.V. Pillai, C. Venugopal and Smt. Vijaya Dileep. The cover page design was prepared by Mr. M.B. Sukumaran, Artist and Mr. M. Narayanan, Photographer.

We sincerely hope that the original objective of the Symposium, to know the current status of the research and development in different coconut-growing countries and priorities for future research programmes will largely be met by this publication and this will be a very useful reference book to research workers, developmental officials and students involved in coconut research and development.

President
Indian Society for Plantation Crops

(M.K. NAIR)

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GENETIC RESOURCES

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1

IBPGR AND COCONUT GENETIC RESOURCES

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ABSTRACT

Coconut belongs to a 'recalcitrant' category regarding the storability of seeds and the species causes additional problems in the conservation and exchange of its germplasm because of the size of the seeds and the plant's relatively long regeneration cycle.

The problems encountered during collection and exchange of coconut germplasm, mainly caused by the large size of the seeds, led IBPGR to initiate research on *in vitro* collecting and conservation of coconut. The most promising prospects for the long-term storage of coconut germplasm by cryopreservation appear to lie with immature zygotic embryos and perhaps, somatic embryos.

Recently, IBPGR organised a training course on the collection, conservation and characterisation of coconut genetic resources in The Philippines, where students were taught how to apply the latest techniques of *in vitro* collection, characterisation (including isozyme analyses) and conservation.

In cooperation with the Consultative Group on International Agricultural Research, IBPGR organised an International Workshop on Coconut Genetic Resources in Bogor, Indonesia with the main objective of establishing a coconut genetic resources crop network in order to integrate conservation, utilisation and research activities for the benefit of the countries which possess germplasm or produce coconut commercially.

INTRODUCTION

Coconut (*Cocos nucifera* L.), is the most important palm species of the humid tropics. It has a pantropic distribution, mainly in coastal regions between 20° North and South of the equator. Its exact centre of origin is not known. One of the reasons for this is that the wild types spread widely, possibly from South America, before they were domesticated in the Indo-Pacific region (Harries, 1978). Coconut is a multi-purpose palm with many different uses ranging from a staple to an industrial plantation crop. It is reported to be grown in 86 countries on a total of approximately 11.6 million hectares, with a strong

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regional concentration in Asia and the Pacific, accounting for 85 per cent of the total crop production.

In view of the global importance of the crop, the rate of genetic erosion occurring in many parts of the world, the need for more diversity in breeding programmes, the prevailing biological features of the crop (that is, recalcitrant seed producer and the size of the nuts), IBPGR gave attention to the collection, conservation and research on coconut germplasm over the last decade. This paper highlights IBPGR involvement in activities on coconut germplasm, conservation and use, and concludes with a brief description of the planned International Coconut Genetic Resources Network.

EXPLORATION AND COLLECTION

In IBPGR's revised collecting priorities among crops and regions (IBPGR, 1981) coconut was assigned the highest priority in Southeast Asia and the Pacific and second highest priority in other parts of the world. In another consultation on coconut genetic resources, some parts of South Asia were also given the highest priority (IBPGR, 1978). Subsequently, the collecting activities were developed accordingly with active support from IBPGR. The results of IBPGR supported collecting missions are presented in Table 1.1.

Table 1.1: IBPGR supported collecting missions, countries visited, number of accessions collected and distribution of collected material

Year of mission	*Country visited*	*Number of accessions collected*	*Country where collected germplasm is conserved*
1981	Samoa	3	Kasaragod, India
1981	Fiji	4	Kasaragod, India
1981	Papua New Guinea	5	Kasaragod, India
1981	Polynesia	7	Kasaragod, India
1981	Solomon Islands	2	Kasaragod, India
1981	Tonga	3	Kasaragod, India
1982	Indonesia	62	South Sulawesi and Manado, Indonesia
1982	Indonesia	15	South Sulawesi and Manado, Indonesia
1983	Indonesia	12	South Sulawesi and Manado, Indonesia
1983	Indonesia	8	Purwodadi, Indonesia
1983	Mexico	1	Chapingo, Mexico
1981–85	Malaysia	38	Hilio, Malaysia
1980–83	The Philippines	163	Zamboanga and others, The Philippines
TOTAL		323	

DOCUMENTATION

In response to the need to assist in the standardisation of data collection and exchange, IBPGR published a minimum set of descriptors, including morphological and disease reactions in 1978. In preparation for a 1991 workshop on the development of a crop genetic resources network on coconut, a

comprehensive descriptor list was developed, in conjunction with the International Coconut Cultivar Registration Authority. This list was reviewed by participants and after modification will be published by IBPGR in 1992. This descriptor list will provide a reference for the descriptors to be used in the central crop coconut database to be facilitated by this network.

The above network also recommended that a directory of coconut genetic resources collections and researchers be compiled and published. The workshop provided a basis for the information needed for this and after additional information is compiled this will be published by IBPGR.

RESEARCH

Because of its biological features coconut is not an easy crop to conserve. The nuts are large and the embryos survive only for a limited period in the nut. Coconut belongs to the group of species producing recalcitrant seeds which cannot be dried without killing them. This aspect makes collecting and exchange of coconut germplasm rather difficult and expensive. It also leads to the establishment of field gene banks for the conservation of germplasm. Unfortunately, this method is not a very secure conservation system since the field collections are vulnerable and expensive to maintain. The relatively long regeneration cycle and heterozygosity are other aspects which prompted IBPGR to support research activities in the areas of *in vitro* culture and cryopreservation.

In vitro collection: IBPGR has supported a project in Cote d'Ivoire to investigate the use of zygotic embryo culture in the collecting of coconut germplasm. From the results obtained, it can be concluded that the excised embryos can be directly inoculated into culture in the field with a survival rate of 51.4 per cent. This result is not significantly different from the control method where the embryos were cultured in the laboratory (49 per cent of the embryos developed a gemmule). An alternative method where embryos are kept in endosperm cores in a KCl solution for a short period before inoculation into culture in the laboratory gives a lower percentage of embryos with a developed gemmule (that is, 24.4 per cent after six months). The techniques and the equipment used as well as the results of this study are presented in Assy Bah *et al.* (1987). In a later project these techniques were successfully adopted to the local conditions in Indonesia and used in the collecting of coconut germplasm in Indonesia (J.S. Tahardi, personal communication, 1990).

In vitro culture and cryopreservation of immature coconut embryos: This study was carried out as a continuation of the above-mentioned project with the objective of developing procedures to be utilised in culture and cryopreservation for the long-term preservation of coconut embryos. It revealed that immature embryos are very vulnerable to surface sterilisation damage and are particularly slow to develop. They can, however, be satisfactorily germinated under conditions similar to those used for mature ones. For cryopreservation, embryos should be sufficiently small and composed of meristematic

cells not only to survive freezing, but also sufficiently well developed for *in vitro* culture (Assy Bah, 1990).

In search of a coconut zygotic embryo cryopreservation technique, Assy Bah (1990) investigated the following variables: Embryo weight; pre-growth medium composition; duration of pre-growth; duration of dehydration; cryoprotectant composition; freezing in liquid medium or dry freezing and cooling rate. It was found that only embryos weighing less than 10 mg survived freezing. Of the other treatments reported it was found that the recovery growth was slow and that no plantlet establishment was observed. It is considered that the lack of a suitable medium for culturing cryopreserved embryos is still a major limiting factor (Assy Bah, 1990).

It can be concluded that immature embryos can be cryopreserved but that the procedures need to be optimised. For future use, the approach could be to develop artificial seeds from immature embryos before cryopreserving them. The production of artificial seeds from somatic embryos would add to the advantage of cloning (Lyndsey Withers, personal communication, 1991). Recent results presented at the International Workshop on Coconut Genetic Resources at Cipanas, Indonesia have indicated that the cryopreservation of dried mature embryos is a very promising technique (Florent Engelmann, unpublished observation, 1991).

THE SAFE MOVEMENT OF GERMPLASM

IBPGR and FAO convened a meeting of coconut disease experts in October 1991 to discuss the establishment of technical guidelines for the safe movement of coconut germplasm. These guidelines will be published in the IBPGR-FAO Series.

TRAINING

In November 1990, IBPGR and the Philippine Coconut Authority organised jointly a training course in the Philippines on the collection, conservation and characterisation of coconut genetic resources. Sixteen students from South and Southeast Asia and Tanzania attended the two-week long course which consisted of lectures, practical exercises and field work.

REGIONAL COOPERATION AND THE ESTABLISHMENT OF A COCONUT GERMPLASM NETWORK

Since the mid-seventies IBPGR has supported a Regional Committee for South East Asia (RECSEA), which coordinates the cooperation of five Southeast Asian countries in the conservation and use of germplasm. Its working group on palms prepared a comprehensive report on the conservation and use of palms of economic importance in Southeast Asia and also a plan of action.

More recently, IBPGR participated in the discussions within the Consultative Group on International Agricultural Research to identify mechanisms to

support germplasm improvement activities in coconut. This and other initiatives resulted in the organisation of the International Workshop on Coconut Genetic Resources in Indonesia in October 1991 (IBPGR, 1991). The main recommendations of this Workshop are:

a) The implementation of an International Coconut Genetic Resources Network. IBPGR has been asked to be the Executing Agency for Phase I (five years) of the network. It is planned to appoint a full-time Network Coordinator, whose responsibilities will include being secretary of the Steering Committee and monitoring the day-to-day activities of the network.

b) A comprehensive plan of action for the network, which include the following major aspects:

i) Coordination of a worldwide coconut collection through an international database consisting of individual national collections.

ii) Development of complementary conservation strategies, including pollen, zygotic and somatic embryos, cryopreservation technology, as well as *in situ* conservation.

iii) Implementation of a Coconut Germplasm Exchange Programme, including the development of techniques to index collections for the presence of virus/viroids and other diseases.

iv) Collecting of germplasm after the identification of gaps in the existing collections.

v) Establishment of comparative multi-location variety trials.

vi) Development of a single central coconut database, comprising all passport and other data on such accessions, that will be freely available for network participants.

vii) Publication of a revised descriptor list to facilitate the systematic description of collections.

viii) Development and use of modern molecular techniques to assess genetic diversity in coconut collections; the identification of RFLP markers for important traits such as drought tolerance, pest and disease resistance.

ix) Development of minimum common strategies for national breeding programmes related to selection criteria, evaluation of combining ability, long-term breeding approaches and other relevant topics related to coconut improvement.

x) Training and manpower development at all levels, especially in the areas of disease indexing, embryo culture, maintenance of collections, documentation and utilisation of germplasm.

c) Coordination of the network covers the following points:

i) All coconut growing countries can become members of the network, if they accept certain commitments which will then give access to a number of benefits.

ii) A regional approach has been chosen for the activities within the network. The following regions have been agreed upon:

1) Africa and the Indian Ocean Islands

2) Latin America and the Caribbean

3) South Asia

4) Southeast and East Asia

5) Pacific Islands

iii) A maximum of two members per region would be represented on the Steering Committee. The terms of reference of this important body have been agreed upon including details on the chairmanship, the frequency of meetings, associate members of the committee and the decision-making process.

iv) The Coordinator of the network will be an IBPGR staff member and he will be responsible, upon delegation by the Steering Committee, for the preparation of research proposals, yearly work plans and for the monitoring of the agreed activities and administration of the budget. He reports to the Chairman of the Steering Committee and will be an *ex officio* member of this body.

It was agreed by the Workshop that the Coconut Genetic Resources Network should be established as soon as possible after the necessary funds for its operation have been identified.

ACKNOWLEDGEMENTS

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CURRENT STATUS OF COCONUT GENETIC RESOURCES RESEARCH IN THE IVORY COAST

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ABSTRACT

The low genetic variability of the West African Tall coconut prompted the Marc Delorme Research Station (then IRHO Port-Bouet Research Station) in the Ivory Coast to begin setting up a collection that has expanded considerably over the years in line with the informal network of organisations cooperating with IRHO.

The collection comprises 53 accessions representing a wide range of variability, 24 of which have already been reproduced, 152 selfed progenies of parents tested for their general combining ability, seven populations of F_1 hybrids between accessions and four populations of four-way hybrids intended for the search for ortets. All these materials were obtained by open or hand pollination, under conditions guaranteeing their legitimacy and the good representativeness of the parent populations.

The recent development by IRHO of somatic embryogenesis and zygotic embryo-cryopreservation techniques means that consideration can be given to reducing the areas to be planted and that collection duplication will be more reliable.

Techniques for studying variability and assessing accessions and improved materials have gradually been developed, to enable more effective use by breeders.

INTRODUCTION

Coconut was introduced into West Africa fairly recently. It was brought from East Africa by the Portuguese at the end of the fifteenth century. According to Harries (1977), the first trees were planted in the Cape Verde Islands, from where coconut spread to the coasts of the Gulf of Guinea and the Atlantic coast of America.

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Until the recent Dwarf introductions (first few decades of the twentieth century), the West African Tall (WAT) coconut was the only type in the region. Its relative uniformity probably stems from an inbreeding effect due to strong genetic drift.

IRHO's first work on coconut in Africa began in Benin in 1949 and the Ivory Coast in 1951. Researchers quickly detected the lack of variability within local West African Tall populations. At the same time, IRHO was obtaining remarkable results with between-origin crosses on oil palm. Breeders therefore concluded that the best chance of obtaining a marked improvement in coconut productivity in West Africa within a reasonable time was to cross varieties of different origins and with complementary characters. This meant that it was necessary to set up a collection of varieties or strains representing a wide range of variability for the characters the researchers were interested in.

The main purpose of the collection was not therefore genetic resource preservation, but the creation of a gene bank for breeders to draw on, depending on their aims: productivity, product quality, disease tolerance or adaptation to particular ecologies. This led to certain constraints as regards the representativeness of populations, sample size, legitimacy and assessments.

The collection at the Marc Delorme Station in the Ivory Coast was launched in 1952 and has grown over the years as the station's sphere of influence and the informal network of centres and organisations working with IRHO have grown. At the same time, the station developed, and is still perfecting, a set of collection (Lamothe *et al.*, 1980; Assy Bah *et al.*, 1989), assessment (Lamothe and Wuidart, 1982) and preservation techniques that guarantee it an undeniably high profile on an African and international level.

CONSTITUTION OF THE MARC DELORME STATION COLLECTION

The biological characteristics of coconut impose considerable constraints on breeders wishing to set up collections. The lack of seed dormancy, the generally allogamous nature of reproduction, the impossibility of *in vitro* multiplication and bulkiness in the field mean that a large number of trees has to be planted and preserved in a living and utilisable form, covering several dozen to a few hundred hectares.

It is now possible to store partially dehydrated pollens for several years, with no noticeable loss of viability, although there is still room for improvement of the technique. Furthermore, recent work by B. Assy Bah* (unpublished) has shown that it is possible to cryopreserve zygotic embryos.

However, breeders still need living collections. The use of cryopreserved embryos or pollens adds an extra six to eight years to the implementation of a crossing plan.

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The Marc Delorme Station collection currently comprises:

1) Fifty-three strains or varieties, 24 of which have already been reproduced (Table 2.1).

2) One hundred and fifty-two selfed progenies of parents tested for their combining ability.

3) Seven populations of between-strain F_1 hybrids.

4) Four populations of F_2 (four-way) hybrids from which ortets are to be chosen.

It is worth stressing the importance of improved progenies and strains in this. It is essential to safeguard them if the breeding programme is to be continued.

Parent Populations

The main concern of any breeder wishing to introduce a new strain is whether the sample he is going to take is truly representative of the parent population. To make sure, a sufficient number of nuts should be sampled from a sufficient number of trees, and they should be legitimate. This means that the parent population has to be large, if not very large (several hundred trees) for allogamous strains, if the nuts are obtained by open pollination. If there is a risk of intercrossing with other strains, it is essential to harvest only nuts obtained by hand pollination. These rules were generally followed when introducing the strains that make up the Marc Delorme Station collection.

The Strains and Their Representativeness

The zones considered as having the greatest coconut genetic diversity are well represented in the collection: 47 per cent of the strains come from Southeast Asia and 25 per cent from the Pacific (Table 2.1).

Table 2.1: Geographical origins of coconut strains at Marc Delorme Station

	Southeast Asia	*South Asia and Indian Ocean*	*Pacific*	*Africa*	*America*	*Total*	*%*
Tall	14	7	10	4	1	36	68
Dwarf	11	1	3	1	1	17	32
	—	—	—	—	—	—	—
	25	8	13	5	2	53	100
%	47	15	25	9	4		100

The choices made by the breeders at the Marc Delorme Station were prompted by a wish to bring together strains of various origins with characters linked to productivity, such as a high number of nuts per tree, good copra per nut, good fruit composition, precocity, and tolerance to certain diseases or characters enabling them to adapt to certain ecologies. Attempts were made, whenever possible, to introduce strains that expressed one character or another extremely strongly (for example the very high number of nuts per bunch for the Laccadive Micro and the very slow vertical growth of the Niu Leka).

It was thought that a study of enzyme polymorphism might give an idea of the genetic variability of the collection, but the results were disappointing. The variability detected generally appears to be low and does not warrant distinguishing the ecotypes according to the Dwarf-Tall criterion.

HPLC analysis of leaf polyphenol contents seems to be providing better information. The first results for the Marc Delorme Station collection tend to show the existence of four main groups that tally quite well with the geographical zones in Table 2.1. With what is known about strain origin and various planting material movements over the past 50 to 100 years, the coconuts from India and the Indian Ocean fall between the Pacific and African groups, and the variability of WAT, which is known to have undergone significant genetic drift, seems to be much less pronounced than for the other strains. The Ghanaian Yellow Dwarf seems to have the same origin as the Malayan Yellow Dwarf, and the Cameroon Red Dwarf introduced into the country at the turn of the century and which was thought to originate from Micronesia, is classed in the Pacific group. Provided these results are confirmed by studies underway on environment effects, polyphenol analysis, along with RFLP, could become one way of estimating genetic variability. It appears to have confirmed the wealth of the Ivory Coast coconut collection.

If they are to be representative of their population of origin, the strains introduced have to be obtained from legitimate nuts, but there also has to be a sufficient number of individuals. It is generally agreed that at least 60 individuals are needed for an allogamous strain. In fact, to fulfil the requirements of improvement programmes, and given the low multiplication capacity, coconut breeders try to collect a much higher number of individuals — 100 to 200 or 300 and sometimes even more — including for autogamous Dwarfs.

Of the strains in the Marc Delorme Station collection, 46 (87 per cent) are represented by more than 100 trees in the field. Up to 100 individuals of each of the selfed progenies of the parents tested for their combining ability are planted, and hybrid populations are generally numerous.

Site and Design

The collection is planted at a site and on a soil the characteristics of which have often been described (Sangare and Rognon, 1980). The design has changed over the years, from a single-strain block design with a control but no replicates to a plantation with alternate rows and then blocks with replicates. A WAT control for the Tall strains and a Malayan Yellow Dwarf for the Dwarf strains are included whenever introduced, reproduced or improved planting material is planted. It is then possible to compare strain performance.

ASSESSMENT OF THE COLLECTION

In 1978, IBPGR published a list of descriptors for coconut. The Marc Delorme Station has extended this list and striven to standardise character observation methods through a number of individuals observed and study of observation frequency and duration techniques. It is currently one of the rare collection

centres where precise details (means and C.V.) are available for the various coconut development stages: vegetative observations in the seed-bed, when adult, observations on flowering, production and disease and drought tolerance (Lamothe and Wuidart, 1982).

The Marc Delorme Station has passed on the techniques it uses to describe the characters to the many students it has trained and to the centres it works with within the IRHO network. All the observation results are stored on computer on site and in Montpellier, France, after checking and analysing. Individual data are used when choosing parents.

REGENERATION

The long life span of coconut led some people to believe that living collections could be preserved for 50 years before having to be regenerated. However, all breeders know that beyond a certain age, the trees are too tall for the quality of hand pollination operations to be guaranteed. It is therefore important to regenerate the strains before the trees reach this stage; the age at which regeneration is necessary depends on the strain, the ecological conditions, work quality, etc. It is around 20 years for Talls and 25 to 30 years for Dwarfs.

Twenty-two populations have already been reproduced at the Marc Delorme Station. The crossing plan involved a large number of parents: between 70 and 100 for Talls. The seeds were obviously produced by hand pollination, which makes the operation extremely costly (from US $ 3,000 to 4,000 per accession). Very few other collections, if any, are capable of ensuring this regeneration, and it is unlikely that the Marc Delorme Station will be able to continue its efforts alone. This will undoubtedly pose problems for the future coconut genetic resources network, even if zygotic embryo cryopreservation becomes commonplace.

UTILISATION IN THE IMPROVEMENT PROGRAMME

Of the 53 strains in the collection, 25 (15 Talls and 10 Dwarfs) have been used in between-strain combining ability tests and seven to test individual combining ability. The selfed progenies of these individuals have been planted and those of the best individuals kept for use in seed production and intercrossed to make up the basic population for the next improvement cycle. The parent populations of the best F_1 hybrids are being recombined to produce four-way hybrids suitable for exploitation by *in vitro* culture.

THE ROLE OF THE MARC DELORME STATION

The collection built up in the Ivory Coast over almost 40 years has enabled the Marc Delorme Station to implement the most extensive coconut improvement programme to date and to play a role similar to that of an international research centre. It has contributed more than any other centre to distributing the best ecotypes for research and seed production. It has developed and

standardised assessment techniques and trained a large number of foreign breeders. All these factors mean that it plays a regional role in Africa and will be the main centre in the International Coconut Genetic Resources Network.

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DISCUSSION

E.V.V. Bhaskara Rao: Does IRHO conduct regular training programmes on coconut germplasm evaluation?

A. Sangare: Yes. The training section in IRHO Marc Delorme Station, Ivory Coast organises regular training programmes.

R.V. Pillai: What are the criteria for classification of germplasm as intermediates?

A. Sangare: Only hybrids are classified as an intermediate group.

CURRENT STATUS OF COCONUT GENETIC RESOURCES RESEARCH IN INDIA

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ABSTRACT

In India coconut germplasm collection programme dates back to 1924, when some cultivars were introduced mainly from important coconut producing countries in Southeast Asia and Pacific Islands. These introductions formed the nucleus material for the crop improvement research programmes. Subsamples generated by collecting both open-pollinated and selfed seeds were assembled at Kasaragod in the forties which at present can be considered as the main germplasm holding.

In the early fifties, systematic introductions of exotic germplasm as well as indigenous collections were undertaken. The present holding of 86 exotic and 40 indigenous accessions planted at Central Plantation Crops Research Institute, Kasaragod and World Coconut Germplasm Centre, Andamans forms probably the largest collection in the world. These collections comprise 102 talls and 24 dwarfs, with two accessions classified as semi-talls and one MAWA hybrid introduced from Ivory Coast. While the introductions were limited to few seednuts in each accession, the exotic collection from South Pacific consisted of 100 seednuts each.

A limited number of subsamples of germplasm accessions (distinct types) are also being maintained in Agricultural University Research Centres in different coconut growing states. Efforts were made to characterise the germplasm based on the fruit component analysis. Characterisation of indigenous tall types also enabled identification of distinct indigenous types both in respect of morphological characters and fruit components. Efforts made in evaluation indicated the possibility of identifying the elite types by correlating the initial years' yield with the stabilised yield.

INTRODUCTION

Among the coconut growing nations, India is the first country to initiate coconut research in the world. The first priority identified was to collect, conserve and evaluate the coconut germplasm and to exploit the high yielding potential in some of the germplasm accessions through hybridisation. In India,

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coconut germplasm is being maintained at 18 research stations/centres of which four are under Central Plantation Crops Research Institute (CPCRI), while the remaining 14 fall under the University/All India Coordinated Research Project on Palms centres of state agricultural universities.

GERMPLASM COLLECTION

The earliest record of germplasm introduction into the country dates back to the early twenties when few coconut types were introduced from Malaysia and the Philippines. The progenies of these introductions were raised at the Central Farm, Trichur (Kerala) and Government Coconut Farm, Vaithila (Kerala). Emphasis on exotic introduction was given since 1927 and the introduced accessions were raised at Central Coconut Research Station, Pilicode (Kerala). Exotic accessions were made from Vietnam (Indochina), Indonesia, Thailand, Malaysia, Sri Lanka, Fiji, Papua New Guinea and the Philippines. During 1940, the open-pollinated seednuts of the introduced accessions were collected from Central Coconut Research Station, Pilicode and the first germplasm bank was started at the erstwhile Central Coconut Research Station, Kasaragod (Kerala), (Presently the CPCRI, Kasaragod). The programme on survey and collection of indigenous coconut germplasm was initiated in 1952 and the systematic collections from different coconut growing regions of the country were made and added to the germplasm assemblage. In 1981, with the financial assistance from International Board for Plant Genetic Resources, CPCRI has launched a survey collection for coconut germplasm in the Pacific Ocean Islands. This probably is the first attempt (Bhaskara Rao and Koshy, 1981) to systematically collect coconut germplasm with a recommended sample size of 100 nuts for each accession. Earlier introductions comprised only a few nuts (ranging between five and 20) in most of the accessions. During this IBPGR funded project an attempt has also been made to observe strict quarantine regulations both at the collection site as well as at the port of entry. All the collections were subjected to quarantine treatment comprising removal of calyx, giving the nuts a wash in 'teapol' and dipping them in a solution comprising insecticide and fungicide. Further, wherever facilities were available, the nuts were also fumigated at the port of export before shipment from the collection site. All the accessions introduced into India were subjected to quarantine inspections at the port of entry and also were fumigated with methylbromide before the same were transshipped to Andaman Islands for raising an offshore nursery and establishing the World Coconut Germplasm Centre.

The primary purpose of conceiving the offshore germplasm centre is two-fold. As is well known in India, the diseases like root (wilt) disease in Kerala, Thatipaka disease in Andhra Pradesh, Thanjavur wilt and Ganoderma in Tamil Nadu impose restrictions on maintaining germplasm collections as active collections in the field, on the mainland. At a future date if these precious accessions collected from different countries are infected, their utility for breeding programmes will be considerably reduced. At the same time it

also imposes restrictions on drawing subsamples for testing these accessions against different diseases. A given accession susceptible to one disease could be resistant/tolerant to other diseases. These considerations prompted us to establish the offshore germplasm centre in a relatively pest/disease free location in Andaman Islands. Further as the accessions have gone through the strict quarantine check and treatment both at the site of collection as well as at the port of entry, it is safe to assume that no unknown or harmful insect/disease is being introduced and is safe to plant in a protected area (Bhaskara Rao and Koshy, 1984).

GERMPLASM HOLDING

Currently the germplasm holding at CPCRI, Kasaragod (Kerala) and Andaman comprises 126 accessions of which 99 are classified as talls and 24 as dwarfs (Table 3.1). In addition, there are two semi-tall accessions, namely, SS Apricot and Niu Leka and one hybrid PB-121 introduced from Ivory Coast. Considering the morphological characters and growth habit of the two semi-tall accessions it may be appropriate to reclassify SS Apricot as a tall accession and the Niu Leka as a dwarf. Among the Tall accessions, maximum number of 40 are from the Pacific Ocean Islands. Concentrated effort has been made in the germplasm collection programme, to collect the accessions from the South Pacific region which is believed to be the centre of origin of coconut. The second largest collection is from Asia and Southeast Asia with 20 talls and six dwarfs.

Table 3.1: Geographical distribution of germplasm accessions

Region	*No. of collections*			
	Talls	*Dwarfs*	*Semi-talls*	*Hybrids*
Indigenous				
India	29	11	–	–
Exotic				
Asia and Southeast Asia	20	6	1	–
Africa	4	2	–	1
Central and South America	6	1	–	–
Pacific Ocean	40	4	1	–
Total	99	24	2	1

The subsamples generated through collection of both open-pollinated nuts and *inter se* mated nuts were sent to different university centres as well as coordinating centres under the All India Coordinated Research Project on Palms. Maximum number of 62 accessions are at Coconut Research Station, Pilicode (Kerala). These subsamples were generated based on preliminary evaluation done at CPCRI, Kasaragod (Kerala). The primary purpose of distribution of subsamples to different Coconut Research Stations in India is for evaluating these accessions for yield stability in the different agroclimatic

regions. Further, the coordinating centres were also given the mandate to collect the regional germplasm and to utilise the available accessions in the breeding programme.

STATUS OF GERMPLASM HOLDING

In most of the accessions, the number of palms available are less than 30. As mentioned earlier, in the early exotic introductions, only few nuts in each accession were introduced and the seedlings raised from them were planted in the field. Among the exotic accessions, in 28 accessions the number of palms in each is less than 10, while in only seven accessions more than 50 plants are available in the germplasm holdings. In 48 exotic accessions, the number ranged between 10 and 15 palms in each accession.

DOCUMENTATION

Fairly foolproof documentation procedures were conceived for recording the data during different periods of growth of germplasm accessions (Bhaskara Rao and Nayar, 1980). The data collected on nursery characters is recorded in the nursery register. Growth measurements of individual plants in accessions up to the fifth year are recorded annually and subsequently once in five years, in a "vegetative growth measurement register". For the adult palms, the data collected on harvest and fruit analysis are documented in a separate register. Recently computerised data base has been developed at CPCRI.

EVALUATION

Preliminary evaluation is done by laying out replicated trials either in RBD or CRD with three to four replications and with six plants per plot. However in recent years, row-trials with 10 to 49 plants are being planted for evaluating the yield.

Among the exotic accessions, collections from Fiji and the Philippines gave the highest copra outturn of over 20 kg per palm per year (Table 3.2). The nut yield ranged from 64 nuts in San Ramon to 108 nuts in SS Green and Philippines Ordinary. Oil content was between 65 and 68 per cent in these accessions. Among the indigenous accessions two island accessions, namely, Andaman Ordinary and Lakshadweep Ordinary gave the highest number of nuts. Copra outturn was over 21 kg. However, the highest copra outturn of 26.9 kg per palm per year was recorded in an accession 'Kappadam' collected from Kerala.

Lakshadweep Ordinary was tested in four coconut growing states under All India Coordinated Research Project on Palms. In all the four locations, the performance of Lakshadweep Ordinary palms ranging in ages from 12 to 40 years was superior to local popular cultivars of comparable ages (Table 3.3) This was the first coconut variety to be released in India in 1985 with the name 'Chandrakalpa'.

Coconut germplasm evaluation for yield performance is a long drawn process as the stabilisation of the yield is achieved only between 17 and 20

Table 3.2: Performance of promising germplasm accessions

Cultivar	*Mean yield of nuts (17–20 years)*	*Weight of copra/nut (g)*	*Outturn of copra (kg)*	*Oil content (%)*
Exotic				
1. Fiji Tall	106	199.1	21.1	65
2. Fiji Longwan	104	210.5	22.0	66
3. Philippines Ordinary	108	198.1	21.1	66
4. Philippines Laguna	88	258.9	22.7	66
5. SS Green	108	186.1	20.1	68
6. San Ramon	64	349.6	22.4	68
Indigenous				
1. Andaman Ordinary	127	169.0	21.5	66
2. Kappadam	90	299.0	26.9	67
3. Lakshadweep Ordinary	127	172.0	21.8	68
4. West Coast Tall	70	176.0	12.3	66

Table 3.3: Performance of Lakshadweep Ordinary (LO) in different states

Centre	*State*	*Age (years)*	*LO*	*Local*
Ambajipet	Andhra Pradesh	21	135.5	85.2
		12	23.5	14.7
Ratnagiri	Maharashtra	20–25	134.0	88.0
Veppankulam	Tamil Nadu	20	58.7	55.1
		12	43.0	31.0
Kasaragod	Kerala	20	88.3	59.5
		40	100.0	75.0

years. An attempt has been made to correlate the initial years yield with the stabilised yield for drawing early inference on the performance. It was found that the cumulative yield of the first eight annual harvests gave a fairly good indication of the yield potential of a given accession (Bhaskara Rao *et al.*, 1978). Ranking of the accessions after the eight annual harvests was found to be correlated (R^2 = 0.95) with the stabilised yield in the twentieth year (average of 17 to 20 years).

GERMPLASM CHARACTERISATION

Efforts have also been made to discriminate coconut accessions based on nursery characters such as number of days for germination, height of seedlings, number of leaves, length of petiole, and length by breadth of the last fully opened leaf at the twelfth month in the nursery. It was found that the girth at collar, number of days for germination and the number of leaves are important characters based on which five distinct groups can be identified.

Based on the nursery characters an index was also developed by Bhaskara Rao and Mathew (1981) using mean value and CV of these characters for characterisation of germplasm at the nursery stage. For each character the

highest mean value and lowest CV were given first rank and the lowest mean value and highest CV were given the last rank. However, for characters which have negative correlation with yield the ranking was reversed. This has enabled identification of the accessions with higher heterozygocity (accessions with the highest CV) as well as those which are relatively more homozygous (low CV). This procedure will also enable the germplasm collector to assess the population status in a given region, based on which, whether sampling should be extensive or intensive can be decided.

Characterisation of the germplasm was also attempted from the fruit component analysis as proposed by Harries (1978). Among the Southeast Asian types NIU KAFA types had husk percentage ranging between 41 and 52 with percentage copra ranging from 7 to 11 (Table 3.4). NIU VAI type in the Southeast Asian Region had a much lower husk percentage (28 to 38) while the copra ranged between 16 and 30 per cent. Collections from Pacific and African regions showed both NIU KAFA and NIU VAI types. Highest husk percentage in the NIU KAFA type was recorded in accession 'Seychelles' which had 59 per cent husk while the least copra percentage was in Fiji Rotuma (7.7 per cent).

Table 3.4: Fruit components of few coconut germplasm accessions

Accession	*Fresh weight (g)*	*% husk*	*Yield (nuts)*	*% copra*
I. SOUTHEAST ASIAN NIU KAFA TYPES				
1. West Coast Tall	902	52	70	11
2. Benaulim	884	45	73	10
3. ST Kudat	820	44	46	7
4. Ceylon Tall	1013	41	39	8
5. Gonthembili	847	41	49	9
6. P. Dalig	836	42	72	9
II. SOUTHEAST ASIAN NIU VAI TYPES				
1. Kappadam	1806	38	90	27
2. San Ramon	1753	28	64	22
3. P. Laguna	1624	35	91	19
4. Borneo	1288	33	24	16
5. Java	1261	29	101	30
6. FMS	1242	35	82	20
III. PACIFIC NC AMERICA AND AFRICA				
1. Fiji Rotuma	1448	30	40	8
2. Blanchissues	831	29	93	12
3. Zanzibar	826	32	101	22
4. B.S.I.	685	31	106	17
5. Jamaica	1551	39	61	17
6. Panama	1609	42	74	18
7. Seychelles	908	59	73	11

GERMPLASM UTILISATION

In India utilisation of germplasm for hybridisation programme received consideration right from the thirties. West Coast Tall in the west coast and

East Coast Tall in the east coast of India were used as both female and male parents. In addition, Andaman Ordinary and Lakshadweep Ordinary Tall types were also used as female parents for production of hybrids. Among the dwarfs, Chowghat Orange Dwarf and Gangabondam were used as female parents as well as male parents in hybrid production. Promising hybrid combinations with all these parents were released in India during the last decade.

Germplasm is also being used for screening against diseases (root (wilt) disease and Thatipaka disease) and for screening against burrowing nematode, *Radopholus similis* (Sosamma *et al.*, 1980). While a tolerant/resistant type is yet to be located for the root (wilt) disease (Chowghat Green Dwarf is reported to be less susceptible to root (wilt) disease) accessions like Java Tall, Klapawangi and Chowghat Green Dwarf were found to be tolerant to burrowing nematode. Polyphenol assessment and study of the isozyme pattern are also in progress for characterisation of the germplasm.

QUARANTINE CONSIDERATIONS

As mentioned earlier, prevalence of root (wilt) disease in Kerala, Thatipaka disease in Andhra Pradesh, Thanjavur wilt and Ganoderma in Tamil Nadu restrict the movement of germplasm especially in exchange of germplasm with other countries. However, coconut germplasm from India can be obtained with the approval of Indian Council of Agricultural Research (ICAR). The nodal agency for coordinating germplasm exchange in India is the National Bureau for Plant Genetic Resources, while the CPCRI is the authorised agency for phytosanitary clearance. For importing the germplasm into India, the regulations prescribed are as follows:

a) A collection team consisting of breeders and pathologists should identify and document the pests and diseases prevalent in the country of collection. Collections should be restricted to disease/pest free areas.

b) Quarantine treatment is to be given both at the port of export as well as port of entry. A nursery will be raised under strict quarantine precautions in the offshore island of Andamans. The nursery will be inspected periodically by the scientists from germplasm nodal agency, namely, NBPGR, quarantine authority in India (the Directorate of Plant Protection and Quarantine) and CPCRI which has the mandate to maintain the coconut gene bank.

FUTURE PRIORITIES

Future priorities for coconut genetic resources research in India include collection of germplasm from Indian Ocean Islands and from Micronesia; screening the collected accessions for biotic and abiotic strains; and, utilisation of the germplasm especially from those collected from the Pacific Ocean Islands for production of new cross combinations and for evaluating them for yield as well as for disease resistance.

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DISCUSSIONS

Dulce Warwick: How do you screen for resistance to root (wilt) disease?

E.V.V. Bhaskara Rao: The seedlings are planted in 'hot spot' areas and disease reaction is recorded.

B.C. Viraktamath: How do you explain the distinctness of Benaulim Tall as compared to other cultivars?

E.V.V. Bhaskara Rao: It could have naturally evolved from the natural stands in Konkan Coast and later multiplied consciously for its better yield.

4

CURRENT STATUS OF COCONUT GERMPLASM COLLECTION IN INDONESIA

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ABSTRACT

The Indonesian government has launched a programme to increase coconut production by means of extensification, intensification and replanting. Bandar Kuala Research Centre for Estate Crops has started coconut germplasm collection since 1989 and now a collection centre with 35 cultivars is established. In addition, there are several coconut collection centres in the country, that is, CRI (98 cultivars), government owned estates (15 cultivars), private estates, and Bah Lias Research Stations (18 cultivars).

INTRODUCTION

Coconut is one of the most important commercial crops in Indonesia. There is about 3.4 million hectares of coconut plantation widely dispersed in the country and almost 98 per cent is with small holders.

The main problems facing the coconut industry are low price of copra and low productivity (one tonne copra/ha per annum). Therefore, the Indonesian government has launched a programme to increase coconut production by means of extensification, intensification and replanting. These efforts should be supported by production of planting materials in high yielding varieties.

Although the hybrids of IRHO have been introduced, there is potential for evolving high-yielding varieties and hybrids since Indonesia has a wide coconut genetic variability. Coconut germplasm conservation, collection and evaluation are prerequisites for initiating breeding programmes. Collection of germplasm has been done through seed-nuts and also *in vitro* field collection of embryos as a collaborative programme of IRHO and IBPGR (IBPGR, 1987).

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COCONUT COLLECTION ACTIVITIES

Coconut Germplasm Status

Indonesia lies in the Indo-Malaya Centre where several crops were dispersed, such as coconut, sugar cane and banana (Knight, 1979). The preponderance of evidence, now available on the subject is in favour of Malaysia or Indonesia as the most likely place of origin of the coconut palm (Thampan, 1982). A wide range of climatic differences due to natural barriers, such as, sea and mountain, seem to be responsible for a wide genetic variability observed in Indonesia.

Sumardjan (1985) reported Igo Duku (Torpedo Tall) and Igo Ratu (Takome Tall) in Ternate Island. Igo Duku has an oval fruit and kernel with a thin husk and high copra content, while Igo Ratu produces about 60 small sized nuts per bunch. Some other coconuts have been reported by Davis (1983) such as sweet husk, 'onion' and pink husk coconuts. Samosir (1991a) reported a thick husked coconut explored from West Lampung.

Valuable coconut germplasm is being eroded in the country due to factors like senile coconut plantations (about 20 per cent), low price of copra resulting in neglect of plantations and replanting programme with improved varieties. Having realised these facts the government has realised the need for conservation recently (Salim, 1985). The National Germplasm Conservation Committee was established in 1976 (Wahid and Soedarsan, 1988).

History of Coconut Germplasm Exploration

The first survey to explore coconut germplasm was done in the third decade of the twentieth century by the Dutch botanist, P.M.L. Tammes. The area explored was North Sulawesi and Maluku, and he obtained almost 100 collections which were planted at Mapanget, Manado (Davis, 1983). In 1953 to 1957, A.F. Ihne, FAO expert made crossings on 43 selected parents and the progenies were planted in Kima Atas, Manado. Unfortunately, the activities were discontinued due to financial constraint until 1973 (Tampake *et al.,* 1982).

Intensive survey was carried out since 1973 with the UNDP/FAO support, exploring 11 provinces and 25 varieties were collected (Liyanage and Corputty, 1976). Later on in 1982–83 T.A. Davis, an FAO Agronomist, carried out a survey in East Nusa Tenggara, Central Kalimantan and South Kalimantan, from where 27 cultivars were obtained and then planted at Bone-Bone, South Sulawesi (Davis, 1983). These collections are managed by Coconut Research Institute (CRI), Manado. Furthermore, a survey is still being done in other places. Hitherto, the CRI has three germplasm gardens (Mapanget, Bone-Bone, and Pakuwon) with a total of 98 collections (Miftahorrachman, 1990).

Receiving an instruction from the government to take part in a national coconut programme, the PT. Perkebunan (government owned estate) introduced several dwarf, tall and hybrid coconuts from Ivory Coast. Malayan Yellow Dwarf, Malayan Red Dwarf, Cameroon Red Dwarf, West African Tall, Rennell Tall and Polynesian Tall introduced under this programme are now being used as parents in hybrid seed gardens. In addition to introduced

cultivars, the PT. Perkebunan planted also local cultivars, such as Igo Duku (Torpedo Tall) and Igo Ratu (Takome Tall).

Some private estates are also having coconut collection for seed gardens, such as, PT. Multi-Agro Corporation, PT. Riau Sakti United Plantation and PT. Mira Rantih. Besides, there is also a private research institute, Bahlias Research Station of PT. P.P. London Sumatera, located in North Sumatra, which maintain some coconut collections.

COCONUT GERMPLASM OF BKRCEC

The Coconut Research Centre which afterward was named Bandar Kuala Research Centre for Estate Crops (BKRCEC) was established in the early 1982 by PT. Perkebunan II, VI and VII. In 1989, the centre with 11 others were set up under IPARD (Indonesian Planters' Association for Research and Development).

BKRCEC has started coconut germplasm collection for breeding work in 1989. For the first five years (1989 to 1993) a serial survey will be carried out in 15 provinces. Further a serial survey will be planned for the rest of the provinces.

Method

Collection activities are based on IBPGR minimal descriptors (IBPGR, 1978) with few modifications. Vegetative characters (number of fronds, leaf length, number of leaflets, etc.) were added to the descriptors. Three nuts from each of 100 palms were collected and one nut/50 palms was used for fruit analysis. Ten palms were thoroughly observed for vegetative characters such as the length of petiole, leaf axis and leaflets. In special cases less than 100 palms were selected.

Due to financial and time constraints, collection activities were limited to the interesting cultivars only. The location of prospection is selected based on an administrative blocking system. Questionnaires were sent to the "estate extension service" for preliminary selection. A guide book has been issued for detailed manual operation (Asmono and Rangkuti, 1989).

Results

Intensive germplasm collection was started two years ago. Six provinces have been explored, that is, East Java, Central Java, West Java, Lampung, Riau and North Sumatra. BKRCEC now keeps 35 collections both local and introductions. Markam Tall has high meat weight (632.3 g) and copra (356.95 g). Of the dwarfs, Ponorogo Green Dwarf has the highest fruit components, that is, 598.52 g husk, 327.96 g water, 227.96 g shell, 407.41 g meat and 216.63 g copra (Asmono *et al.,* 1990).

Samosir (1991a) obtained a cultivar from West Lampung with a thick husk and fruit analysis indicated that the weight of nut, husk, water, shell, meat and copra were 1195.6 g, 743.6 g (62.19 per cent), 78.0 g (6.52 per cent), 137.4 g (11.49 per cent), 236.6 g (19.79 per cent), and 154.07 g (12.89 per cent), respectively.

For *in vitro* field collecting, a technique of double sterilisation was tried and it gave promising results. In addition, two formulated media have been obtained (modified Monnier and Y3) for the culture of zygotic embryo (Samosir, 1991b). Hopefully, these techniques would be applicable in the future, especially for overcoming transportation problem and pest migration.

CONCLUSION

The coconut germplasm collection is urgently needed for breeding works and conservation to support the national programme in increasing coconut production.

Collection activities in Indonesia were started at the beginning of 1930. Today there are several coconut collection centres in the country maintained by CRI (98 cultivars), government owned estates (15 cultivars), private estates, and Bah Lias Research Station (18 cultivars). In addition, BKRCEC started collection activities in 1989, and now has a collection of 35 cultivars, both local and introduced ones.

In vitro culture and *in vitro* field collecting techniques are now being investigated at BKRCEC which will give promising results. Hopefully, these methods could be applicable for germplasm exchange.

Germplasm conservation is a joint responsibility for the sake of coconut improvement in the future. Therefore, international and regional cooperation is needed to overcome several problems like germplasm exchange, funds and skill.

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GENETIC PROSPECTION OF COCONUT IN PERNAMBUCO, BRAZIL

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ABSTRACT

The coconut palm has been cultivated in Brazil since 1553, but only recently some government actions have been implemented on crop improvement. The Brazilian coconut productivity is very low, 20 to 25 nuts/tree/year, mainly due to lack of superior quality planting materials. The genetic prospection is essential to know the genotypic variability of the tall coconut ecotypes in the country and to support the tall coconut improvement programme.

INTRODUCTION

The coconut palm (*Cocos nucifera* L.) was introduced in Brazil in 1553 with the tall coconut variety. The dwarf coconut has been introduced since 1925 (Siqueira and Franca-Dantas, 1984). However, the programmes implemented have not been sufficient to promote the expected development. This has resulted in low productivity of coconut in the country, varying from 20 to 25 nuts/tree/year. The main cause of this situation is lack of quality planting material.

Ohler (1984) has stressed the importance of collecting coconut germplasm and their utilisation in breeding programmes. In recent years attention is being paid in establishing germplasm banks and their conservation and utilisation.

When the coconut research works started in the Ivory Coast the productivity of the traditional groves was about 24 nuts/tree/year, resulting in 600 kg of copra/ha/year (IRHO, 1984). Eleven years later, in plantations raised from progenies of selected West African Tall, coconut productivity in the country increased to an average of 100 nuts/tree/year, in the Marc Delorme Experimental Station.

The Brazilian coconut improvement programme includes the phenotypic selection of mother palm followed by progeny testing and production of hybrids

and their evaluation. Testing of genetic variability in Brazilian Tall coconut and evaluation of exotic hybrids are the two programmes being undertaken concurrently at present (Ferraz *et al.,* 1987; Ferraz and Pedrosa, 1987).

MATERIALS AND METHODS

From 1987 to 1988 coconut plantations in Pernambuco state were surveyed to locate old (more than 50 years) Brazilian Tall populations isolated from dwarf cultivars. In the selected plantations, 150 healthy palms with uniform growth were selected. The selected palms represent the variability within the Brazilian Tall cultivar. Two seednuts from each selected trees were collected by the same person to avoid personal bias and the nuts were always from the older bunch. The seednuts were sent to the National Coconut Research Centre (EMBRAPA—Brazilian Agricultural Research Company) to be part of the germplasm bank which is being established in the Betume Experimental Station, Ilha das Flores, Sergipe, Brazil. Out of each population, 20 fruits were sampled to determine the polar and equatorial diameter, weight of fruit, nut, coir, coke, liquid albumen, solid albumen and copra and oil content. Information about crop management such as fertilisation, insects and diseases occurrence and other practices was collected.

In the population mass selection by phenotypic selection (Satyabalan, 1984) will be made to identify the best trees for seednuts distribution. Yield attributes like copra/nut, which have better heritability (Bourdeix, 1988) will be used for selection.

RESULTS

At present three populations were identified in the Pernambuco Coast, named, Avenue, Cupe Beach and Santa Rita located at the seaside, 5 km and 10 km from the sea, respectively.

Seed-nuts from Avenue and Cupe Beach populations were collected in 1987 and seednuts from the Santa Rita were collected in 1988. The coconut fruits that were collected from Santa Rita population had not attained normal size due to a prolonged dry period and water stress. They are called 'lixa of coconut' and 'queima of the coconut leaves'. For this reason only the results from the Avenue and Cupe Beach populations are presented here (Table 5.1).

The Cupe Beach population was comparatively in a better location with productivity of 48 nuts/tree/year. The productivity of Avenue population was also 48 nuts/tree/year. Fertilisation was practically the same for the two populations.

DISCUSSION

It is clear that Cupe Beach population presented better results than Avenue population (Table 5.1). In terms of solid albumen and of copra/nut Cupe Beach population presented a difference of 20 per cent over Avenue population. The

Table 5.1: Mean values for fruit components in fruits of two populations

Fruit component	*Population*	
	Avenue	*Cupe Beach*
Polar diameter (cm)	22.50	24.20
Equatorial diameter (cm)	18.80	18.00
Weight of fruits (g)	1409.00	1693.00
Weight of nuts (g)	780.00	932.00
Weight of coir (g)	628.00	761.00
Weight of coke (g)	238.00	251.00
Weight of liquid albumin (g)	168.00	218.00
Weight of solid albumin (g)	371.00	457.00
Weight of copra (g)	218.00	263.05
Oil content (%)	67.64	67.50

causes may be related to the proximity to the sea, better growing conditions and possibly due to the genetic potential. Avenue population fruits were smaller in size than the Cupe Beach population fruits.

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6

COCONUT GERMPLASM COLLECTION IN PAPUA NEW GUINEA

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ABSTRACT

Systematic surveys for coconut germplasm collection were carried out in different regions of Papua New Guinea. Large fruit, nut and high endosperm weights were found in tall ecotypes in the provinces of Madang, Morobe and East Sepik, while relatively small fruit with low endosperm weights were found in East New Britain, New Ireland, Central Manus, Gulf and Milne Bay provinces. High percentage of endosperm/nut (more than 40 per cent) was found nearly in all tall ecotypes, except for ecotypes from Morobe and East Sepik. Nut production and number of female flowers per spadix are more variable than other characters, as shown by very high coefficients of variation. Tall ecotypes are cross-pollinated and heterozygous and thus adapt to a wide range of growing environments and are of special interest to the breeder to utilise more genetically diverse material in the coconut hybridisation programmes. The tall ecotypes from Natava and Raulawat of East New Britain were found to be more tolerant to the dynastids *Scapanes* spp., *Oryctes rhinoceros* and *Rhyncophorus* spp.

INTRODUCTION

Genetic improvement of coconut showed that the most promising materials were obtained from the crosses between two genetically distinct ecotypes (Meunier *et al.*, 1984; Sangare *et al.*, 1988; Bourdeix *et al.*, 1990). It is also suggested that the expression of heterosis was related to the genetic divergence between parental lines used in the hybridisation programmes (Ramanathan *et al.*, 1982; Fremond and Lamothe, 1971). Bourdeix *et al.* (1990) concluded that the continuity of germplasm collection and assessment of large numbers of ecotypes should remain as one of the priorities of coconut improvement programmes. Several notable efforts in coconut germplasm collection have been made in Indonesia, the Philippines and India (Mendoza and Balingasa, 1978; Bhaskara Rao and Pillai, 1982; Carlos *et al.*, 1978; Santos *et al.*, 1984;

Liyanage and Corputty, 1975; Liyanage, 1977; Balingasa *et al.,* 1982; Balingasa and Carpio, 1976). In Papua New Guinea, several attempts have been initiated to select mother palms for seed production and breeding (Dwyer, 1938; Charles, 1961). More systematic surveys and germplasm collection have only been under way since 1988 with the financial support from Australian Centre of International Agricultural Research (ACIAR). Coconut is cultivated extensively throughout the coastal areas and islands of Papua New Guinea (PNG). The local tall is the only variety planted by small holders. Therefore, a wide range of local tall ecotypes are available for germplasm collection.

MATERIALS AND METHODS

Various local tall cultivars, variety Typica, were measured throughout all the copra producing provinces in PNG. The materials include Karkar Tall, Markham Tall, West New Britain Tall, Gazelle Tall, Vailala Tall, New Ireland Tall, Manus Tall, East Sepik Tall, Baibara Tall, Oro Tall and Milne Bay Tall. Coconut prospecting began with the identification of areas to be prospected. In PNG, different provinces were visited indiscriminately with the aid of local inhabitants where sites were selected and measured. Apart from sites where palms with superior endosperm weights (that is, having more than 500 g), were located, all the sites were randomly sampled.

For the selection of potential high yielders as pollen parent biased sampling was conducted on the plantation. Initial selection was done by weighing endosperm from each plam, using at least two nuts. If the weight of the endosperm exceeds that of the population mean and is also more than 400 g, the palm is selected by giving it a number from one to 30.

Fruit Component Analysis

The principal characters recorded were the economic ones of fruit characters and nut numbers. Freshly harvested nuts were selected and labelled with the palm number. The following characters were measured: fruit weight, nut weight, endosperm plus shell weight, endosperm weight, endosperm thickness, nut diameter and nut circumference. From these measurements the following fresh weights were derived: husk weight, shell weight, water weight, per cent husk to fruit, per cent shell to nut, per cent water to nut and per cent endosperm to nut (dehusked fruit). In Table 6.2, husk and nut water weights are expressed as percentage of nut weight after dehusking. The number of nuts on the palms was counted using the spiral method. Counting embraced nuts from a cricket ball (or fist) size to the lowest bunch in which nuts remained entirely green.

A newly opened inflorescence or spathe was removed from the palm. Measurements were taken of the length of spadix, rachis, rachilla and a count was made of the number of female flowers on the spadix. This information can also be used for estimation of percentage of nut sets on each palm. Measurements were also made of the other vegetative characters, for example, frond length, width and length of pinnae.

Table 6.1: Fruit and nut characters of selected Local Tall ecotypes in PNG (mean values)

Ecotypes	*Fruit weight (g)*					*Nut weight (g)*					*Endosperm weight (g)*				
	AVG	MAX	MIN	STD	CV	AVG	MAX	MIN	STD	CV	AVG	MAX	MIN	STD	CV
Madang Province															
Karkar Tall	2276.4	3343.4	1583.8	407.2	17.6	1407.4	2079.8	993.8	246.2	17.8	565.8	548.2	411.0	91.8	16.2
New Ireland Province															
New Ireland Tall	1666.5	2290.5	1090.0	292.0	17.5	1026.5	1418.5	574.0	189.5	18.5	461.5	605.5	265.5	74.0	16.0
Morobe Province															
Markham Tall	3370.5	4787.5	2325.0	466.5	14.5	2163.0	2900.0	1687.5	283.0	14.0	739.0	973.5	567.5	91.5	12.5
East Sepik Province															
East Sepik Tall	2399.3	3338.3	1736.7	402.7	17.0	1619.0	2280.0	1138.3	282.3	17.7	596.7	792.0	424.0	86.0	14.3
East New Britain Province															
Gazelle Tall	1776.0	2763.0	1235.7	318.0	18.3	1018.6	1753.0	684.0	214.5	21.5	441.5	649.2	322.2	70.7	16.3
West New Britain Province															
West New Britain Tall	1827.0	2923.0	1049.5	452.0	25.0	1192.0	2046.5	741.0	315.0	26.5	517.5	849.0	346.0	112.0	17.0
Central Province															
Baibara Tall	1805	2746	1189	333	18	964	1371	638	147	15	422	556	281	54	13
Oro Province															
Oro Tall	1384	2054	839	271	20	638	1336	415	174	21	356	545	165	71	20
Manus Province															
Manus Tall	1681.0	2342.0	1179.0	269.0	16.0	913.0	1245.5	700.0	126.0	14.5	413.5	541.5	313.0	50.0	12.5
Gulf Province															
Vailala Tall	1873.5	2797.0	1101.0	397.0	21.0	1108.5	1708.0	735.0	217.5	20.0	471.0	655.0	323.5	70.5	15.5
Milne Bay Province															
Milne Bay Tall	1703.7	2819.0	1020.0	370.0	21.7	925.7	1566.7	504.0	232.0	25.0	405.7	998.0	254.7	83.0	20.3

AVG = Average; MAX = Maximum; MIN = Minimum; STD = Standard Deviation; CV = Coefficient of Variation.

Table 6.2: Percentage of fruit components from selected Local Talls in PNG (Mean values)

Ecotypes	*Husk/fruit (%)*					*Water/nut (%)*					*Endosperm/nut (%)*				
	AVG	MAX	MIN	STD	CV	AVG	MAX	MIN	STD	CV	AVG	MAX	MIN	STD	CV
Madang Province															
Karkar Tall	37.7	54.2	26.1	6.1	16.2	36.3	45.1	28.8	3.6	10.0	40.5	47.4	31.4	3.4	8.4
New Ireland Province															
New Ireland Tall	38.0	62.3	20.6	7.1	19.0	30.6	37.5	22.3	3.7	12.2	45.2	54.0	39.5	3.1	7.0
Morobe Province															
Markham Tall	35.4	48.8	23.6	6.8	19.2	46.8	54.8	39.6	3.2	6.9	34.5	38.4	31.1	1.9	5.7
East Sepik Province															
East Sepik Tall	30.3	41.9	18.5	5.7	18.3	40.9	46.7	32.1	3.1	7.7	37.1	41.8	32.6	2.0	4.8
East New Britain Province															
Gazelle Tall	43.0	56.0	31.4	6.8	16.2	31.2	44.5	19.2	5.4	17.4	44.0	51.9	34.3	3.8	8.6
West New Britain Province															
West New Britain Tall	34.9	52.3	23.8	9.5	26.3	33.4	41.9	21.7	4.6	14.0	44.1	56.2	36.5	4.2	9.4
Central Province															
Baibara Tall	46.2	57.0	39.5	4.7	10.2	30.6	37.3	19.0	3.9	12.7	40.0	49.1	39.6	2.4	6.0
Gulf Province															
Vailala Tall	39.9	53.6	7.9	9.9	24.8	32.8	42.1	25.0	4.4	13.6	43.0	49.1	35.9	3.3	7.7
Milne Bay Province															
Milne Bay Tall	45.6	58.7	28.1	7.3	16.0	31.0	45.8	15.7	6.9	22.2	44.5	54.4	36.6	4.2	9.5
Manus Province															
Manus Tall	45.6	57.4	29.4	5.0	10.9	29.5	48.0	12.7	7.2	25.4	46.1	54.5	39.7	3.3	7.1
Oro Province															
Oro Tall	39.0	57.1	5.4	9.2	23.6	30.3	54.3	11.4	6.7	22.1	42.8	55.4	26.8	4.5	10.5

AVG = Average; MAX = Maximum; MIN = Minimum; STD = Standard Deviation; CV = Coefficient of Variation.

Table 6.3: Nut production and number of female flowers/spadix (Mean values)

Ecotypes	*Nut number/palm*	*No. of female flowers/spadix*
Madang Province		
Karkar Tall	86	26
Morobe Province		
Markham Tall	76	23
West New Britain Province		
West New Britain Tall	92	27
East New Britain Province		
Gazelle Tall	91	35
East Sepik Province		
East Sepik Tall	46	15
Central Province		
Baibara Tall	95	34
Gulf Province		
Vailala Tall	67	28
Milne Bay Province		
Milne Bay Tall	66	20
Manus Province		
Manus Tall	51	18
New Ireland Province		
New Ireland Tall	75	29
Oro Province		
Oro Tall Saiho	71	22

Vailala Talls

These talls are found in the western end of Gulf province. About 15 sites were prospected in this province using only fruit component analysis. It has been shown that the Vailala Talls are exceptionally good tall ecotypes found in this region.

Manus Talls

Manus Tall ecotype is cultivated extensively in Manus province which consists of several groups of islands.

Milne Bay Talls

The Milne Bay Talls are found in Milne Bay province which includes numerous islands with many inhabitants relying heavily on the coconut products for cash income, food and other domestic uses. On the mainland, *Scapanes* attacks young coconuts but does little economic damage to mature tall populations.

New Ireland Talls

This population is grown in the New Ireland province on mostly reddish or brown clay soils. Introduction of the hybrid (MRD × RLT) was a total failure in this province due to dynastid beetle and palm weevil attacks. However, older local tall populations have survived the attacks perhaps due to a build up of natural tolerance to the insects over a period of time.

Oro Tall

This population is found in the Oro province. About three sites were measured and the population in Saiho was selected for an intensive measurement. Scapanes and palm weevil are also present in this area. Oro Tall is a small-fruited population, with average fruit weight of 1,384 g ranging from 839 to 2,054 g. Variability of nut weight is about the same as fruit weight and endosperm weight which is moderately high. The palms produce on an average of 356 g of endosperm per nut. Husk percentage is high (39 per cent) while the water content is low. The palms produce on an average of 71 nuts and there is a high variability for this character (CV: 33.8). Variability of the number of female flowers on each spadix is also very high (CV = 40.9 per cent).

Baibara Tall

This cultivar originates from the eastern end of the central province which was selected from seven populations measured in the province. Measurements were done on the palms which are about 30 years old. The fruit weighs on an average 1,805 g per nut with nut weight of 964 g. Endosperm weight is good (422 g) with less variability. Husk percentage is high (46.2 per cent) but the water content is low (30.6 per cent). The palms produce on an average of 95 nuts per palm.

Gazelle Tall

This ecotype is another well-known variety that has been widely distributed around the globe. Gazelle Peninsula is regarded as one of the high incidence areas for the *Oryctes*, *Scapanes* and palm weevil. The vast majority of the introduced hybrids (MRD × RLT) in the past have been destroyed by the insects.

DISCUSSION

Various countries adopt different selection procedures for coconut germplasm collection. Thampan (1981) reported that the Malaysian accepted standard is a yield of 100 nuts/annum with endosperm content of 500 g per nut. In India an average yield of 80 to 100 nuts is considered superior with not less than 20 kg of copra per tree per annum. Sri Lankans select palms with an average of 100 nuts or more with husked nut weight of 680 g. Perhaps this criterion may have changed over a period of time as new information became available. Nut number is the main component for yield in coconut (Meunier *et al.,* 1984; Bourdeix *et al.,* 1989). When individual trees were observed over a period of a year, many of them were found to be inconsistent bearers (Charles, 1961). Palm to palm variation was considered to be important for mother palm selection. No correlation was found between the parental ecotypes and their hybrids on copra/palm (Bourdeix *et al.,* 1989). However, Ramanathan (1989) reported that genetic improvement could be made, when selection of mother palms is based on number of nuts/palm and copra/nut.

The present report on the selection of Tall ecotypes in the germplasm collection has so far been based largely on fruit and nut characters. However, this does not imply that Tall ecotypes with other desirable characters are not considered as important in the coconut improvement programmes. Although selection for high yield is the prime objective, selection for highly heritable characters such as big nut with high copra content which could reduce labour and production costs is considered important to the small growers in this country. More than 83 per cent of the growers were reported to be not harvesting all their copra (Livingstone, 1989). Furthermore, the introduction of the hybrid, MRD × Rennel Tall (MAREN) which is highly susceptible to the local form of rhinoceros beetles and *Rhynchophorus* weevil is of little value to the growers unless satisfactory pest control measures can be developed. The local Tall ecotypes 'Natava' and 'Raulawat' were found more tolerant to these pests (Brooks, 1985; Woruba, 1987; and Ovasuru, 1988). This might be attributed to the coexistence of the host and the pest populations over long periods of time which led to the evolution of resistance. Bennett (1970) considered this type of resistance as in the form of 'field' or 'horizontal' resistance, which is of great value to the coconut breeding programme.

There is little doubt that the genetic base of the single cross hybrid 'MAREN' is very narrow. Therefore, it would be expected that MAREN is less able to adapt to adverse environmental changes and is more vulnerable to pests and diseases. A wide range of variability existing among the Tall ecotypes from germplasm collection offers a great opportunity to develop a multiline cultivar. Such multiline cultivars are produced from the mixture of several different types of hybrids having at least one or both of their parental lines from the locally adapted ecotypes. This multiline cultivar is phenotypically uniform but genetically heterogeneous, which may be much more adaptable to a wide range of environments.

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DISCUSSIONS

Bourdeix: Natural selection against Rhinoceros beetle could have occurred in countries other than Papua New Guinea. So, could you find tolerance in other countries also?

T. Ovasuru: Materials are being collected from other parts of the world with a view to broadening the genetic base and at the same time to introduce varieties that may be tolerant to other pests and diseases also.

7

COCONUT EMBRYO CULTURE FOR THE INTERNATIONAL TRANSFER OF GERMPLASM

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ABSTRACT

The need for international transfer of germplasm has facilitated research in the area of collection, transport, growth, and acclimatisation of coconut embryo cultures. It has been shown that embryos may be collected as plugs of tissue or naked embryos and successfully grown in another country after surface sterilisation and transport. Growth *in vitro* is shown to be slower at 25°C than at 30°C. Glucose was found to be a better carbon source than sucrose at the same osmolarity. Liquid media throughout the pre-germination stage and solid media thereafter expedited growth, compared with solid media or liquid media only. Acclimatisation has been achieved with the chance of survival dependent on shoot length but showing little relation to root length. All embryo cultures should be indexed for coconut Cadang-Cadang viroid or related viroids before export to the final destination.

INTRODUCTION

With greater emphasis on the production of high yielding planting material through intraspecific hybridisation, the international transfer of germplasm is becoming increasingly important. At present, embryo culture appears to be the most sensible technique to use for germplasm transfer because it overcomes problems involved with weight, bulk, spoilage and most diseases (Firman *et al.*, 1986).

The aim of the work described here is to develop a method for importing pathogen-free germplasm into Papua New Guinea from other South Pacific countries. The germplasm could then be used for breeding purposes or for genetic conservation.

Three key stages in the embryo culture have been identified as: collection and transport, growth, and acclimatisation.

MATERIALS AND METHODS

Unless otherwise stated, the embryos in these experiments were germinated in a modified MS medium (Assy Bah, 1986) with 6 per cent (w/v) sucrose and 2.5 per cent (w/v) activated charcoal after excision and surface sterilisation according to Ashburner *et al.* (1991). Upon germination, they were transferred to BMY_3 medium (Eeuwens, 1978) with various sucrose concentrations, 2.5 per cent (w/v) activated charcoal, and 8 per cent (w/v) Difco Bacto-Agar. The cultures were grown under cool-white fluorescent lights with an intensity of $90\,\mu mol \cdot m^{-2}s^{-1}$. The embryos were subcultured every eight weeks after germination.

Collection and Transport

Embryos were collected from a population of Gazelle Tall palms at the Cocoa and Coconut Research Institute, Papua New Guinea. A plug of endosperm containing the embryo was removed and sterilised in a 2 per cent (w/v) solution of sodium hypochlorite for 20 minutes. Some plugs were then either placed in vials containing sterile distilled water, or in sterile plastic bags with moist sterile cotton wool. Other plugs were transferred to a laminar flow hood where the embryos were excised, surface sterilised in 1 per cent (w/v) solution of sodium hypochlorite for 15 minutes and rinsed twice in sterile distilled water. They were then placed either into vials containing the germination medium, or sterile distilled water, or alternatively, into sterile plastic bags with moist sterile cotton wool. All embryos were then dispatched to Melbourne, and the time required for transport and clearance through quarantine was seven days. On arrival, the embryos were subcultured directly onto the germination medium, or in the case of the plugs, the embryos were removed, sterilised in 1 per cent solution of sodium hypochlorite for 15 minutes, rinsed in sterile distilled water twice, and then placed onto the germination medium. The embryo cultures were then put in a culture room at 25°C. Infection and germination rates were recorded after one and three months respectively.

Growth

a) Embryos were cultured at 25°C and 30°C and the growth performance recorded over 16 weeks.

b) Embryos were also grown, and performance measured, in either 6 per cent (w/v) sucrose or 3.2 per cent (w/v) glucose for a period of 24 weeks at 30°C.

c) Embryos were maintained at 30°C, unsupported, in germination medium for 0 (control), four, eight, 12 and 16 weeks except for one treatment, where emergence of the plumule (indicating germination) prompted transfer. At the designated time, embryos were transferred to a medium of identical composition except for the addition of 0.8 per cent (w/v) *agar* as a gelling agent. Length of shoots and primary roots was measured at monthly intervals and final growth was measured after 24 weeks.

Acclimatisation

Embryo-derived *in vitro* coconut plantlets of various growth stages, grown at 30°C, were acclimatised in the following manner:

The lids of the tissue culture flasks were loosened for approximately one week prior to deflasking. The plantlets were then deflasked, washed to remove the medium from the roots, and placed in a sterile potting medium of sand, perlite, and vermiculite (1 : 1 : 1 by volume), in three-inch pots. The plants were then drenched with a 0.025 per cent (w/v) solution of benzimidazole to eliminate potential fungal pathogens before encapsulation within clear polyethylene bags. The plants were grown in a glasshouse (14° to 30°C) and the relative humidity was decreased step-wise every two weeks by punching small holes in the plastic bags, until the bags were removed after eight weeks. The survival of the plants after 12 weeks *ex vitro* was recorded.

RESULTS

Collection and Transport

The preferred collection method is extraction and sterilisation of the embryo within a laminar flow hood, prior to transport in sterile distilled water (Table 7.1). Transportation in germination medium decreased germination. Use of sterile plastic bags was found to be inadequate because of contamination and poor germination. Transportation of endosperm plugs with extraction and resterilisation at destination was a satisfactory alternative if facilities were limited at the collection site.

Table 7.1: Effect of sterilisation regime and transportation method on embryo contamination and germination

Tissue	*Transport medium*	*Contamination (%)*	*Germination (%)*
Embryo	Sterile distilled water	0 a	86.7 a
Embryo	Germination medium	6.7 a	42.9 b
Embryo	Sterile plastic bag	20.0 a	25.0 c
Endosperm plug	Sterile distilled water	6.7 a	57.1 b
Endosperm plug	Sterile plastic bag	100 b	0 d

Figures within columns followed by different letters significantly differ (P = 0.05) according to a x^2-test.

Growth

a) Growth and development of embryos were more rapid at 30°C than at 25°C, especially for root growth (Table 7.2).

Table 7.2: Effect of temperature on growth at 16 weeks[1]

Temperature	*Shoot length (mm)*	*Root length (mm)*	*Secondary root number*
25°C	6.63	3.94	0
30°C	19.2	16.1	5.65

[1]Results based on performance of 15 embryos in each environment but results were not analysed because temperature environments could not be replicated.

b) At the same osmolarity, glucose significantly (P = 0.05) improved shoot growth compared with sucrose, without affecting root growth (Table 7.3).

Table 7.3: Effect of carbon source on growth of plantlets at 24 weeks

	Shoot length (mm)	*Leaf number*	*Root length (mm)*	*Secondary root number*	*Weight (g)*
Sucrose	128	5.47	36.0	15.6	4.33
Glucose	205	7.25	40.4	19.4	5.75
LSD (P = 0.05)	56.8	1.41	NS	NS	3.29

c) Liquid media promoted faster embryo growth and germination. An analysis of variance with orthogonal polynomials showed that the response due to liquid culture duration was best described by a cubic regression line. The predicted values of shoot length indicated maximum growth after a period of five weeks liquid culture (Fig. 7.1). The shoot growth of embryos transferred at germination was similar to the four and eight weeks treatment.

An analysis of variance of root growth with orthogonal polynomials showed a significant quadratic effect dependent on liquid culture duration. Using this relationship, the predicted and actual root length values (Fig. 7.1) indicate maximum root growth associated with a period of eight weeks in liquid culture.

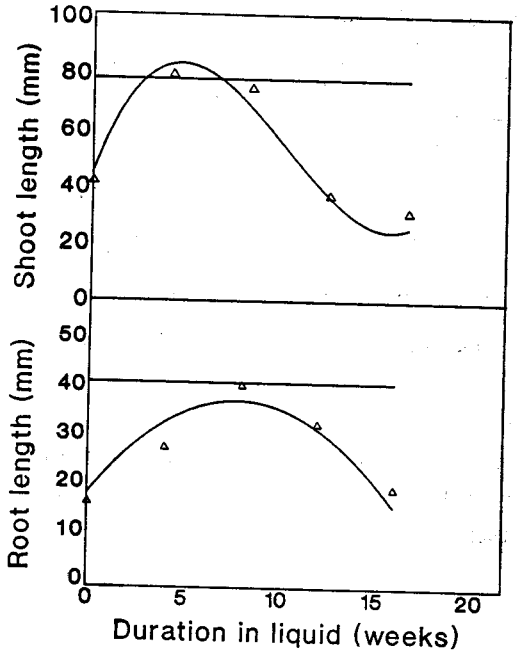

Fig. 7.1: Effect of duration of liquid culture on final shoot and root growth (Ashburner *et al.*, 1991). Curved line represents predicted values. Symbols represent actual values. Horizontal line represents results from the treatment where embryos were transferred to the solid medium at germination.

Acclimatisation

Using the given system of acclimatisation, shoot length appeared to be a primary factor leading to successful establishment *ex vitro* (Fig. 7.2). Results indicated that shoot length of approximately 150 mm was necessary for survival during acclimatisation.

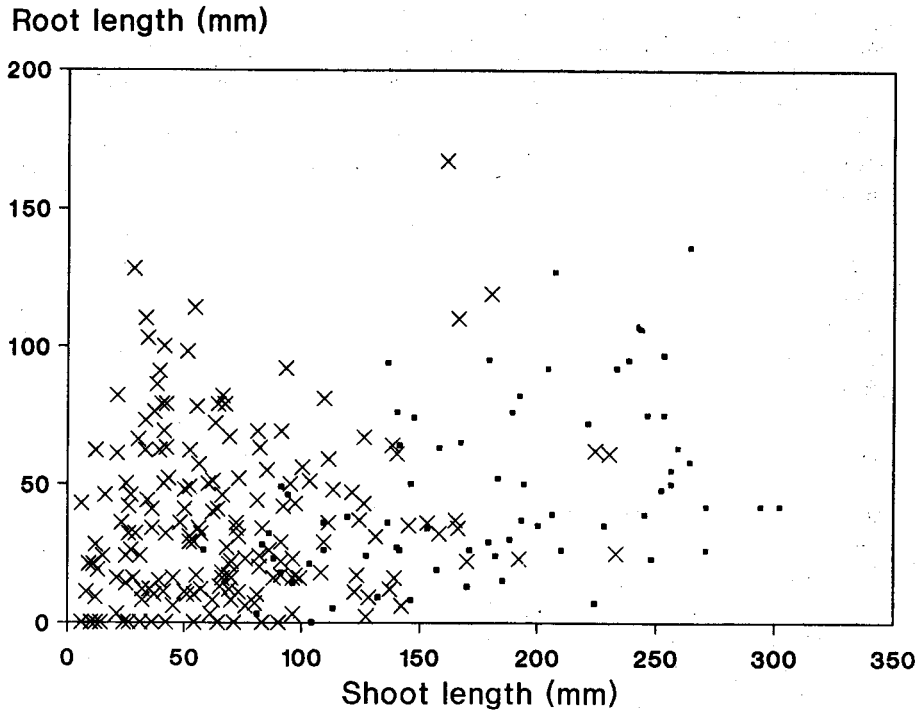

Fig. 7.2: Plantlet survival during acclimatisation in relation to initial shoot and root length. Results analysed by a generalised linear model using a logit link function.
The equation is:
$y = -4.659 + 0.03158\,x$
where y is logit (p) and p is the proportion of the total surviving plants and x is the shoot length.
x represents death during acclimatisation.
■ represents successful acclimatisation.

DISCUSSION

With the present system for the collection and importation of coconut embryos, it is possible to obtain embryos from remote locations throughout the world, and to grow them *in vitro* for disease indexing. Australia is playing a third-country quarantine role by screening for contamination and diseases. All material is indexed for coconut Cadang-Cadang viroid, coconut foliar decay virus and related organisms by molecular probe techniques developed at the Waite Agricultural Research Institute, University of Adelaide, Australia. Although field collection techniques for coconut embryos have been developed (Assy Bah *et al.*, 1987; Sossou *et al.*, 1987), modifications are being made that cater for international collection and transport, in particular, the method

is required to be simple, compact and inexpensive. As with most systems, there is room for improvement in collection and transport, and refinements are continually being made.

Acclimatisation is the ultimate goal in this embryo-culture work. Successful acclimatisation is possible if the plantlets have one true leaf and one or more roots of the 30 mm (Assy Bah *et al.,* 1989). Although our results generally agree with Assy Bah *et al.* (1989), further work should be conducted to determine why acclimatisation at an earlier stage is not possible, and how to optimise the acclimatisation procedure.

Given that large shoots are a prerequisite for acclimatisation, it is important that plantlets grow rapidly, and that manipulation of shoot size *in vitro* is possible. Large shoots are also essential to provide sufficient sample material for disease indexing using molecular probes. It has been shown that manipulation of root : shoot ratio is possible through the use of exogenous auxin (Assy Bah, 1986) and sugar concentration (Guzman *et al.,* 1971; Rosario and Guzman, 1976). Growth has been enhanced by correct basal medium selection (Rosario and Guzman, 1976) and the use of activated charcoal (Guzman and Manuel, 1977). We have shown that temperature and the form of sugar used as a carbon source also play a role in plantlet growth. The correct timing of the change from liquid to solid basal medium is important. Any prolongation of the liquid phase past the shoot optimum period has deleterious effects on shoot development being marked by a sharp drop in chlorophyll content. Using the germination event to time the transfer from liquid to solid medium gives results comparable to transfer at the shoot optimal period.

Other factors that should be considered in culturing coconut embryos are the pH fall of the medium and the ethylene accumulation during growth. Measurements of these variables have been made, but no obvious conclusions could be drawn.

In summation, it is possible to transfer germplasm by embryo culture techniques through a third-country quarantine and be confident that no known disease is present. Techniques for the collection and transport of embryos are established, and growth manipulation (*in vitro*) is possible for enhancing acclimatisation. Further research should be carried out in the area of acclimatisation and survival *in vitro.*

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DISCUSSIONS

J.J. Solomon: Why should there be indexing for viruses?

M.A. Foale: Foliar decay virus has been reported from Vanuatu. Hence collections made from healthy palms in that region are subjected to indexing for viruses in addition to viroids.

M.A. Foale (Comments): The coconut viroid is present in every country that has been sampled. The only countries for which there is no report of the viroid are those that have not been sampled. In Australia, it was found that more than 60 per cent of cultured embryos from South Pacific countries were positive for the viroid. We hope that future research on the nature and variation of the viroid will provide a better understanding of the risk involved in moving germplasm that contains the viroid.

8

VARIATION FOR LEAF POLYPHENOLS IN COCONUT CULTIVARS

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Leaf polyphenols were taken as a population parameter to describe the genetic variability observed in coconut cultivars based on earlier work in coconut (Jay *et al.*, 1989) and other seasonal crops (Jambunathan and Mertz, 1973; Eggum, 1977).

Thirty-six cultivars belonging to eight different geographical origins, namely, Africa, America, Pacific Ocean Islands, Malaysia, Indonesia, Philippines, India and Sri Lanka were included in the study. A minimum of seven palms per cultivar were sampled. Samples were taken from the 14th leaf and total phenols estimated using the method of Bray and Thorpe (1954).

The polyphenol levels showed significant differences among the varieties studied (Tables 8.1 and 8.2). Chowghat Green Dwarf and Kappadam, two cultivars from India had higher phenol levels than all the others. Maximum variability was also seen among the cultivars from India which ranged from 4.72 for Laccadive Ordinary to 10.82 for Chowghat Green Dwarf. The higher phenolic levels associated with Chowghat Green Dwarf can be correlated to its relatively better tolerance to root (wilt) disease.

The cultivars from Sri Lanka (Gonthembilli and Ceylon Tall), Laccadive Micro from Lakshadweep Islands and also those from Pacific Ocean Islands (Guam I, Guam II, Fiji Tall and British Solomon Islands) showed lower phenolic levels.

Significant variations are also seen based on different geographical origins especially with regard to cultivars belonging to Africa (Kenya Tall, Zanzibar and Seychelles) and Indonesia (Java Tall, St. Kudat and Borneo).

The dwarf cultivars invariably had higher phenolic levels as compared to the talls, irrespective of the geographical origin. This higher content found associated with the dwarf cultivars and the wider variation observed among the cultivars from India need to be studied in detail. In addition, more in-depth

studies based on the individual phenolic constituents are required to draw inferences as to the variability seen.

Table 8.1: Leaf polyphenols in exotic coconut cultivars

Origin	*Cultivar*	*Polyphenols (mg/g fresh weight)*
Africa	Kenya Tall	7.44
	Zanzibar	9.83
	Seychelles	6.31
North Central America	Jamaican San Blas	8.10
	St. Vincent	8.09
	Jamaican Tall	8.00
Pacific Ocean Islands	Fiji Tall	5.44
	Guam I	5.46
	Guam II	6.15
	British Solomon Islands	6.20
Philippines	Phil. Ordinary	7.56
	Phil. Laguna	7.69
	San Ramon	8.11
Indonesia	Java Tall	7.06
	St. Kudat	6.52
	Borneo	8.06
Sri Lanka	Gonthembilli	4.53
	Ceylon Tall	5.02
Malaysia	SS Green	6.85
	Klappawangi	8.05
	Federated Malay States	8.10
	Malayan Green Dwarf	9.23
	Malayan Yellow Dwarf	9.78
	Malayan Orange Dwarf	9.79

Table 8.2: Leaf polyphenol levels in indigenous cultivars

Cultivar	*Polyphenol levels (mg/g fresh weight)*
West Coast Tall	8.24
Laccadive Micro	7.98
Laccadive Ordinary	4.72
Andaman Ordinary	6.83
Kappadam	10.74
Gangabondam	8.53
Benaulim Tall	7.84
Chowghat Green Dwarf	10.82
Chowghat Orange Dwarf	8.26
Kulasekaram Green Dwarf	8.79
Kulasekaram Orange Dwarf	9.34
Kulasekaram Yellow Dwarf	9.02

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9

PRELIMINARY OBSERVATIONS ON A VARIANT FORM OF COCONUT CULTIVAR LAKSHADWEEP MICRO

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Lakshadweep Micro is a valuable genetic material because of its highest oil content of 75 per cent as against 65 to 72 per cent present in other tall cultivars and 60 to 65 per cent in dwarf cultivars. It has been the traditional source of good quality special grade ball copra which fetches a premium price. However, there has been a sharp decline in the L. Micro population in its place of origin. L. Micro palms are distributed among the dominant Lakshadweep Ordinary (Chandrakalpa) palms which allow free outcrossing resulting in intermediate forms. Low germination (49 per cent) under field conditions, the lack of interest by the islanders to propagate the L. Micro palms, discontinuation of the practice of ball copra production in the island etc. contribute to the gradual decline in its population. In the absence of any concerted efforts to conserve, maintain and multiply the L. Micro population (about 100 palms, Jacob and Krishnamoorthy, 1981), the search for an alternate and better source material for ball copra production assumes greater significance.

A survey undertaken (1979 to 1982) to locate the available L. Micro palms in Androth, Agatti, Kavaratti, Kalpeni and Minicoy Islands in Lakshadweep identified certain other palms, producing small ball-shaped nuts, distinct from L. Micro. The morphological and reproductive characters were recorded from 10 palms using the IBPGR descriptor for the cataloguing of coconut germplasm.

These variant palms are tall and resemble Lakshadweep Ordinary and L. Micro in gross morphology. Their distribution is highly scattered like that of L. Micro and maximum population was recorded in the Androth Island. The palm height varies from 4.5 to 12.5 m with a spherical to hemispherical canopy. The leaf production was comparatively higher (35 to 40) which is generally associated with the high yielders. The palm produces on an average 13 bunches

annually, yielding 195 nuts. The female flower production is in the range of 32 to 118 per inflorescence as against 400 to 500 in L. Micro (Table 9.1). The peduncle and the inflorescence length are relatively low resulting in the bunches being supported by the subtending petioles. There is a remarkable difference in the female flower distribution in the variant form where 50 per cent of the rachillae are having only one female flower each as against 5 to 10 per cent in L. Micro (Table 9.2). The palm bears regularly and produces only a very few barren nuts, unlike the L. Micro which has an irregular bearing habit combined with the tendency to produce barren nuts in large numbers.

The age of the palms (40 years approximately) suggests that this could be a variant form of L. Micro evolved in recent times probably due to introgression with L. Ordinary. The nuts of the variant are more or less uniform in size which is a preferred character in the production of better quality ball copra.

Table 9.1: Vegetative and reproductive characters of variant form of L. Micro

Character	*Mean*	*Range*
Height of the palm (m)	8.8	4.5–12.5
Crown shape	Spherical to hemispherical	—
Girth (cm)	93.7	72–108
No. of leaf scars in 1 m length	16.5	11–24
No. of leaves on the crown	37.4	30–45
Length of the inflorescence (cm)	83	58–99
Length of the peduncle (cm)	33	18–46
Length of the rachilla (cm)	38.6	33–49
No. of rachillae/inflorescence	39.7	32–44
No. of female flowers/inflorescence	57.9	32–118
Female flower distribution	1.3	0–4
Setting percentage	42	32–55
No. of bunches produced/year	13	12–16
No. of nuts/bunch	19.6	12–30
Annual yield of nuts/palm	195	128–290

Table 9.2: Pattern of female flower distribution in the variant form

Female flower distribution	*Mean*	*Range*	*%*
No. of rachillae with 0 button	7.4	0–15	18.7
No. of rachillae with 1 button	20	7–33	50.4
No. of rachillae with 2 buttons	6	1–12	15.1
No. of rachillae with 3 or more buttons	6.3	1–18	15.8

It is necessary that a detailed survey of the Lakshadweep Islands is undertaken to identify, conserve, catalogue and maintain the other probable variant forms that could be utilised in the crop improvement programme of coconut.

ACKNOWLEDGEMENT

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CROP IMPROVEMENT

CHAIRMAN	K.V.A. Bavappa
RAPPORTEURS	R.V. Pillai P.M. Jacob

10

BREEDING FOR HIGH YIELD IN COCONUT

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ABSTRACT

The Indian coconut population comprises enormous variability, accrued over the years of its cultivation in the country. Improvement in yield potential so far achieved in coconut has been through conventional breeding methods like selection and hybridisation. Mother palm selection based on the number of nuts and morphological characters genetically correlated with yield were found to improve the efficiency of selection. The concept of prepotency though proposed by Harland in the fifties did not receive attention from coconut breeders. Exploitation of hybrid vigour involving crosses between tall and dwarf has resulted so far in releasing nine hybrids with not only high yield but also precocity in bearing. Exploitation of prepotency, crosses between tall and dwarf possessing wider genetic diversity, utilising prepotent talls and homogeneous dwarfs in breeding for disease and drought tolerance, quality improvement with respect to oil content and evolving plant types suitable for coconut-based farming systems are the future strategies suggested.

INTRODUCTION

Coconut improvement is a difficult and time-consuming programme mainly because of the long gestation period, large area and resources required for experimentation, low seed multiplication ratio and lack of reproducible clonal propagation technique. Despite these limitations India was the first country in the world to report hybrid vigour in coconut involving a cross between tall and dwarf palms (Patel, 1937). Enormous variability has accrued in the Indian coconut population over the years of cultivation and this is represented in the 40 indigenous accessions among the world's largest germplasm holding of 126 accessions maintained at the Central Plantation Crops Research Institute, Kasaragod.

BREEDING STRATEGIES FOR COCONUT IMPROVEMENT

Cocos nucifera L. is a monotypic genus with a restricted genetic base. Two distinct cultivars identified in nature are *typica* or the Tall and *nana* or the Dwarf. Tall is a cross-pollinated palm population and the dwarf is comparatively having more homogeneous population with varying degrees of self-fertilisation. Improvement in yield potential in coconut so far achieved has been through conventional selection among the Tall population and hybridisation between Tall and Dwarf.

SELECTION

The earliest selection procedure adopted in coconut was upgrading the existing Tall population through the selection of consistently high-yielding individuals and marking these palms for collection of seed-nuts. Selection of mother palm is mainly based on annual yield (number of nuts/palm) and copra content/nut. An examination of the variability in yield of nuts showed that an improvement up to 20 per cent could be achieved by the mother palm selection alone. By convention, an average annual yield of more than 80 nuts/palm/year under rainfed condition is considered necessary for mother palm selection. The yield data of four different populations of West Coast Tall presented in Table 10.1 indicates that the percentage of high yielding palms (80 nuts/palm/year) varies from 5.9 to 16.7.

Table 10.1: Distribution of palms in various yield groups

Location	*No. of palms studied*	*Yield group*	*Percentage of palms in the group*	*Percentage contribution to yield*	*References*
Kasaragod Kerala	1400	Below 40	32.0	17.3	Menon and Pandalai (1958)
		40–80	59.4	66.9	
		Above 80	8.6	15.8	
Kasaragod Kerala	4347	Below 40	31.3	17.2	Jacob Mathew *et al.* (1979)
		40–80	60.3	67.6	
		Above 80	8.4	15.3	
Pilicode Kerala	150	Below 40	29.3		Kannan (1982)
		40–80	54.0		
		Above 80	16.7		
Veppankulam Tamil Nadu	1668	Below 40	66.9	34.1	Venkateswaran *et al.* (1975)
		40–80	27.2	47.4	
		Above 80	5.9	18.5	

Identification of many elite palms with annual yields of 200 nuts and in rare cases over 400 nuts (Table 10.2) by Iyer *et al.* (1979) indicates the gap between the yield realised and the available yield potential. The fact that some of these super palms are root (wilt) tolerant, adds to their importance as potential parental material in the breeding programme.

Mother palm selection aiming at retention of the desired genotypes and elimination of undesirable ones is recognised as an important method in coconut improvement. The process involved identification of potentially high yielders using some of the recognised morphological characters followed by progeny selection. Straight stout trunks with uniform trunk growth, spherical or semi-spherical crown, short and stout bunch stalks, number of leaves and inflorescences, high and consistent yield of nuts, high copra outturn and freedom from pests and diseases are the characters recommended for mother palm selection (Menon and Pandalai, 1958). It is clear that the selection emphasis is naturally for annual production of nuts since the market value still depends on the number of nuts produced.

Table 10.2: Characteristics of elite palms

Palm No. and location	*Age of palm in years*	*No. of leaves on crown*	*No. of spathes/year*	**Annual yield of nuts*
Root (wilt) disease free area				
SP-I Chengala (Cannanore Dt.)	40	35	22	200
SP-II Ezhom (Cannanore Dt.)	20	35	20	300
SP-II (a) Attaygoli (Cannanore Dt.)	16	43	24	250
Root (Wilt) disease prevalent area				
SP-III Ernakulam	16	46	24	300
SP-IV Kayangulam	12	43	19	200
SP-V Thazhava	20	35	24	471
SP-VI Krishnapuram	21	40	19	300
SP-VII Kalayoor	20	46	21	250
SP-VIII Champakulam	30	50	21	300

*Average yield for three years (Iyer *et al.*, 1979).

HERITABILITY/CORRELATION STUDIES

Heritability estimates for yield of nuts in coconut varied from 0.48 to 0.63 (Lakshmanachar, 1959; Nambiar *et al.*, 1970; Narasimhayya and Sukumaran, 1978) and its importance in selection based on yield alone is expected to be negligible. Some of the yield attributes such as copra/palm/year and weight per husked nut showed comparatively high heritability values of 0.67 and 0.97 respectively (Liyanage and Sakai, 1960). Usefulness of giving attention to yield related attributes such as number of leaves produced during the first 40 months (Liyanage, 1967), number of female flowers and percentage of nut set (Nambiar and Nambiar, 1970), high initial yield (Satyabalan *et al.*, 1972) and more number of spikes with one female flower (Nambiar and Ravindran, 1974) were indicated to improve the efficiency of mother palm selection.

Yield in coconut being a complex character controlled by a number of components and their interaction, path coefficient and regression analysis were attempted on coconut to identify the characters with direct influence on

cumulative and average yield (Sukumaran *et al.*, 1981). Their study showed that number of female flowers at 21 to 24 years, number of functional leaves in the nineteenth year, internodal distance at a fixed mark, total leaf production up to three years after sowing, and time taken for flowering, are the important components which have direct influence on the yield. While these characters can be used to a certain extent, the expected gains are not often realised mainly because of their high phenotypic correlation but low genetic correlation. Nampoothiri *et al.* (1975) therefore suggested giving importance to characters like girth at collar and leaf production in the nursery and spathe production in adult palms since these are generally correlated with yield.

SELECTION OF PREPOTENT PALMS

The concept of prepotency proposed by Harland (1957) was a significant step in mother palm selection. Based on the experience with open-pollinated cocoa progenies and drawing analogy with animal breeding he proposed that prepotent palms transmit to their progenies their high yield probably through the possession of a favourable combination of dominant genes even when they are subjected to random open mating. The concept further assumes that in a highly cross-pollinated and heterogeneous population of tall coconut, a small proportion of elite high yielding palms are maintained in nature, which exhibit a high rate of transmission of the parental traits to their progeny.

Identification of prepotent talls based on progeny performance would normally take several years and hence attempts were made by many workers to select palms at the nursery stage by correlating seedling characters with adult palms. Ninan and Pankajakshan (1961) showed that it is possible to distinguish high yielders which would give superior progenies from those giving inferior progenies on the basis of seedling performance in the nursery. The possibilities of locating prepotent palms on the basis of their progeny performance in the nursery was reported by Ninan *et al.* (1964) based on significant differences in vigour and growth rate of seedlings between families in comparison with variation within families. The report of Satyabalan *et al.* (1975) that seedling characters such as collar girth and leaf production are genetically correlated with the adult palm yield was subsequently confirmed by Nampoothiri *et al.* (1975). The possibilities of identifying palms of superior genetic value even at the first month based on collar girth and leaf production of high-yielding families was indicated by Satyabalan and Jacob Mathew (1983). In spite of these reports the concept of prepotency has not been put into practical utility by the coconut breeders perhaps due to the very low percentage of such palms and the time consuming and laborious procedure in the evaluation of performance of open-pollinated progenies.

EXPLOITATION OF HYBRID VIGOUR

Ever since the report of heterosis in Tall × Dwarf hybrids by Patel (1937), various hybrids involving Tall and Dwarf have been evaluated for their increased

productivity. In the immediate years following the discovery of hybrid vigour in coconut, the emphasis was on the production of Tall × Dwarf hybrids. These hybrids were precocious and high yielding compared to the local cultivar West Coast Tall, under irrigation and good management. Among the different dwarfs, Chowghat Orange Dwarf and Gangabondam were preferable as pollen parents over Chowghat Green Dwarf (Satyabalan *et al.,* 1970). Emphasis for specific combinations involving selected individual dwarfs and talls was stressed as the field performance of hybrids derived from different combinations were found to vary due to differential combining ability of individual palms.

So far nine hybrids have been recommended for release for large-scale cultivation to various parts of the country. The details are given in Table 10.3. It could be seen that the cross-combinations between Talls and Dwarfs are not only high yielding but also precocious. The yields of hybrids in terms of nut production were much higher (95 or more nuts/palm/year) compared to around 80 nuts produced by the Tall cultivar.

Table 10.3: Performance of released coconut hybrids

Hybrids	*Nut yield/ palm/year*	*Copra yield*		*Copra yield/ ha (t)*	*Oil content (%)*	*State for which recommended*
		Mean/ nut (g)	*Mean/ palm (kg)*			
Chandrasankara (COD × WCT)	116	215	25	4.4	68	Kerala Karnataka Tamil Nadu
Kerasankara (WCT × COD)	108	187	21	3.5	68	Kerala Karnataka
Chandralaksha (LO × COD)	109	195	21	3.7	69	Kerala Karnataka
Lakshaganga (LO × GB)	108	195	21	3.7	70	Kerala
Anandaganga (AO × GB)	95	216	21	3.6	68	Kerala
Keraganga (WCT × GB)	100	201	21	3.5	69	Kerala
VHC-1 (ECT × DG)	98	135	13	2.3	70	Tamil Nadu
VHC-2 (ECT × MYD)	107	152	16	2.9	69	Tamil Nadu
ECT × GB	140	150	21	3.7	68	Andhra Pradesh
WCT	80	176	14	2.5	68	Control

The difference in copra yield is more marked in Chowghat Orange Dwarf × West Coast Tall hybrid giving as much as 25 kg per palm per year in comparison with 14 kg from West Coast Tall. However judicious selection of parental lines and cultivars within the talls and dwarfs seems necessary since combination-wise differences are noticeable.

SEED DEMAND VERSUS SUPPLY

It is of interest to examine the extent of availability of improved/released hybrids *vis-a-vis* its requirements. The current annual demand for coconut

seedlings in the country is estimated at 15 million. The production of hybrids is to the tune of only one million and that of Talls is 2.2 million (Table 10.4). Thus there is a wide gap between demand and supply. This situation is being exploited by private nurseries which supply poor quality seedlings. It is, therefore, necessary to increase hybrid production capability of the existing 24 seed gardens covering an area of 1,258 ha and additional seed gardens need to be established in the major coconut growing states. These seed gardens should be planted with parental materials to produce hybrids recommended for the respective states.

Table 10.4: Production of planting materials (in millions)

Agency	*Present production (1991)*			
	Talls	*Dwarfs*	*T x D*	*D x T*
1. Dept. of Agric. Kerala	1.26	—	0.09	0.01
2. C.S.F., Aralam	0.04	—	0.007	0.01
3. Dept. of Agric. Tamil Nadu	0.70	—	0.35	0.35
4. Dept. of Agric. Lakshadweep	0.06	—	0.05	0.05
5. C.P.C.R.I., Kerala	0.11	0.02	0.003	0.01
TOTAL	2.17	0.02	0.50	0.43

FUTURE BREEDING STRATEGIES FOR YIELD IMPROVEMENT

From the foregoing review, it is evident that, if adequate planning is made to adopt viable strategies and their implementation, higher yield levels are attainable through use of quality planting material. Future strategies for increasing the productivity in coconut are indicated below:

1) *Prepotency*

Since the possibility of selecting prepotents has been adequately demonstrated, it now remains to identify and multiply a large number of such palms which could be directly used to improve the local talls and also as parents in breeding programmes.

2) *Crosses involving wider genetic diversity*

Most of the results so far obtained are through hybrids between local talls and dwarfs, the genetic diversity of which is narrow. We should make use of the available materials introduced from various countries and crosses between Talls and Dwarfs possessing as much wider diversity as possible which should be evaluated. Rennel Tall, for example, has been reported to be a good combiner in many of the countries. It will be rewarding to try cross-combinations involving Rennel Tall and Indian Dwarfs. Selfing of talls and testing the individual combining ability with Dwarfs could improve the efficiency.

3) *Tall x Tall crosses*

Although there are reports of high yielding Tall × Tall crosses elsewhere, the performance report of these hybrids in India has not been encouraging. It is likely that by a judicious choice of the parental talls better yielding Tall × Tall hybrids could be evolved.

4) *Homogeneous dwarfs*

In spite of the reported self-pollination in dwarfs variability is observed in the progenies of pure populations of dwarfs. It will be of advantage to employ more homogeneous dwarfs, which can be easily identified through simple field experimentation in crossing programmes.

5) *Breeding for disease and drought tolerance*

Breeding for adaptive traits like tolerance to diseases which has no control measure should receive priority attention.

Root (wilt) disease prevalent in Kerala is caused by MLOs and there is no specific control measure available. Though none of the varieties/hybrids tested so far is tolerant to the disease individual high yielding field tolerant palms have been identified in 'hot spot' areas. Selfed and *inter se* progenies of these field tolerant palms are now under field testing, and evolving a tolerant variety is the only hope to combat the disease.

Similar work is also to be taken up to locate tolerance to Thatipaka disease caused by mycoplasma like organisms.

More emphasis is required on breeding for drought tolerance since coconut is by and large grown under rainfed conditions and more and more non-traditional areas are being brought under this crop. Some of the comparatively tolerant hybrids, namely, Laccadive Ordinary (LO) × Chowghat Orange Dwarf (COD); LO × Gangabondam (GB); and West Coast Tall (WCT) × GB as well as WCT, Andaman Ordinary and FMS Tall are found to be more tolerant to stress (Rajagopal *et al.,* 1990). These materials could be advantageously used in breeding programmes to evolve stress-tolerant varieties.

6) *Quality improvement*

Though the variability in oil content is narrow, cultivars like Laccadive Ordinary are known to have an oil content of 72 per cent. Efforts have not been made for purposeful improvement in oil content perhaps because the market value is mostly dependent on the number of nuts. It is also necessary to breed for a low saturated : unsaturated oil ratio in view of the dietary consciousness of vegetable oil users.

7) *Establishment of seed gardens to meet the demand*

At present the country is not in a position to meet the increased demand for quality planting material. At the time of establishment of existing seed gardens, the various hybrids now recommended for cultivation were not released. The existing seed gardens will have to be redesigned to produce recommended hybrids and new seed gardens are to be established to meet the demands for hybrids.

8) *Comprehensive breeding strategy*

Though a breeding strategy was suggested by Bavappa and Nampoothiri (1974) most of the trials undertaken were on an *ad hoc* basis relating to one specific problem or the other. It is therefore felt necessary to adopt a comprehensive breeding strategy utilising all the available information and existing genotype resources, notwithstanding the large number of years required for the same.

9) *Breeding for genotypes suited for multiple cropping system*

With the declining trend of monoculture systems and adaptation of multiple cropping, there is anticipated demand for cultivars/hybrids suited to such situations. Continued work on ideotypes for various coconut-based farming systems will be required in the near future.

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DISCUSSION

Rupa Wickramaratne: Do you have location specific varieties for yield?

M.K. Nair: Yes. The varieties recommended for Kerala are West Coast Tall, WCT × COD, COD × WCT, LO × COD, LO × GB, AO × GB and WCT × GB. Laccadive Ordinary is recommended for the states of Kerala, Tamil Nadu, Andhra Pradesh and Maharashtra. Banawali Green Round is recommended for Maharashtra. For Tamil Nadu, two hybrids VHC-1 and VHC-2 are recommended.

A. Muralidharan: The variety Kappadam fulfils all the three essential criteria for mother palm selection. Why is it not finding a place in the breeding programmes?

M.K. Nair: CPCRI is using Kappadam as a parent in the current breeding programme.

11

SEEDLING SELECTION IN COCONUT BASED ON JUVENILE AND ADULT PALM CORRELATIONS

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ABSTRACT

Criteria for mother palm selection in Sri Lanka have been updated in keeping with research findings. Male and female transmitters have been identified and their best use has been derived through seed gardens. Significant yield increases have been achieved through the tall × tall (prepotent) and dwarf × tall hybrid seedlings. The available cultivars are being evaluated under local conditions, with particular interest in their ability to withstand the adverse effects of weather. Nursery techniques are being improved and emphasis is being placed on seedling selection. The improved material is being used for the expansion of seed gardens. The annual demand for seednuts has increased from about 100,000 in 1948 to 3 million in 1991. Currently the seed gardens only produce about 20 to 25 per cent of the national requirement.

INTRODUCTION

Early studies on methods of mass selection in coconut were carried out in Sri Lanka as far back as 1930 (Anonymous, 1932; Liyanage, 1955).

Two stages of selection were advocated, namely the seednut selection and the seedling selection. Seed-nuts were selected from either selected high-yielding blocks (block nuts) or from selected mother palms in these high-yielding blocks.

With respect to seed-nut selection, early studies (Liyanage, 1953; 1956) showed that in open-pollinated populations, whether seed-nuts were selected from identified mother palms or from high-yielding blocks, the total nut production and copra production were not significantly affected. However this finding was refuted by Liyanage and Sakai (1960), who showed that the populations of selected and unselected parents in the previous study came from two distinct populations and hence the conclusion drawn previously was incorrect.

Subsequently selection was based on the heritability of economic characters, such as time to first flowering, number of nuts produced/palm/year, the total copra production/palm/year and the weight of husked nuts (Liyanage and Sakai, 1960). The heritability for yield of copra and weight per husked nut were found to be high (0.67 and 0.95 respectively), for yield of nuts it was intermediate (0.48) and for the flowering period it was low (0.23). The genetic correlation between yield of nuts and copra was found to be high and positive, whereas that between yield of copra and the flowering period high and negative (Liyanage and Abeywardena, 1957). The genetic progress in the progeny was likely to be more when the seed parent was selected on high yield of copra and of nuts rather than on weight per husked nut and the flowering period.

CRITERIA FOR MOTHER PALM SELECTION

Criteria for the selection of mother palms had been outlined as far back as 1930 (Pieris, 1934). These criteria were improved based on the results of the correlation studies. The first 56 mother palms from Geneticists' block of 296 palms were selected in 1947 based on a yield record of 16 years. The selected high-yielding blocks, produced at least 10,000 nuts/ha under average environmental conditions. Each selected mother palm produced an average of 100 nuts with 220 g copra/nut (or 680 g husked nut weight), that is, a total of 22 kg of copra/palm/year. The selected palms had a stout straight stem; closely set leaf scars; short, well-oriented fronds; short bunch stalks, a fair number of female flowers on the inflorescence and a large number of inflorescences carried evenly around the crown. Palms were selected after recording two years yield prior to their selection as seed parents. Seedlings raised from selected mother palms and high-yielding blocks were issued for planting after very rigid selection, based on: (a) early sprouting, (b) vigour of seedling, and (c) resistance to pests and diseases.

Emphasis was placed on seedling selection during this early phase (Harland, 1957). Liyanage (1953) showed that the difference in favour of selected seedlings was about 12 per cent and on an average 50 per cent of seedlings were culled in the nursery.

As a result of increased activity in coconut cultivation from about 1950, the demand for seednuts increased reaching an average of about 2 million/year during the period 1971 to 1980. It was not possible to raise such a large quantity of seedlings due to lack of sufficient number of identified mother palms. The Isolated Seed Garden (ISG) at Ambakelle, the first of its kind in the world was set up in 1955 for the mass production of seed-nuts. The selection of mother palm for seed-nuts could not be dispensed with until the production from the seed garden was adequate to meet the increasing national demand.

THE FIRST SEED GARDEN

The study of progenies from selected palms showed that the best 5 per cent of the palms in the population gave rise to progenies which yielded 14 per cent

higher than the population mean. With the downward selection the worst 5 per cent of the palms gave progenies much inferior to those of the worst 15 per cent. The selection was based on weight of husked nuts and the response was positive (Liyanage, 1957). From progeny trials at Marandawila, (1934) and Walpita (1948) it was found that open-pollinated progenies of certain coconut palms were uniformly high yielding and they produced a mean copra yield of 35 to 40 per cent higher than the population mean. Identification of such 'prepotent' palms was laborious and time consuming and relatively few palms would be proved 'prepotent' from a large number tested. Thus the quantity of seed that could be collected from 'prepotent' palms would be negligible in relation to the 2 million seed-nuts required annually.

The progeny of 'paired-crosses' were used for planting a large area of the seed garden, and the progenies resulting from all *inter se* crosses were used as seed-nuts after weak palms were systematically replaced. In 1959, the seed garden was expanded for the production of Dwarf × Tall hybrids by planting of pure dwarfs and systematically emasculating them so that nuts harvested from all female dwarfs were D × T hybrid nuts.

DEVELOPMENT OF IMPROVED CULTIVARS

As a result of the hybridisation programme between selected mother palms and 'prepotents' and the mass production of seed through the seed gardens, two types of planting material, Tall × Tall ('prepotent') (CRIC 60) and Dwarf × Tall (CRIC 65) were issued to the industry in 1960 and 1965 respectively. They were studied under experimental conditions in the CRI research stations and were found to be superior to the tall (open pollinated) progenies. Tables 11.1, 11.2 and 11.3 summarise the results of early studies on these hybrids. There was evidence that T × T (prepotent) was superior to the T (OP) progeny in terms of total nut and copra production. The D × T hybrid was early flowering and performed better than both Tall × Tall and Tall (OP) in sandy and loamy soils and in the absence of prolonged rain-free periods and was therefore attractive to the farmer.

Table 11.1: Yield of typica × pumilla F1 hybrids (experiment 1), Rathmalagara†

Years after planting	*Nuts/palm*	*Nuts/ha*
5–10 (Cumulative)	44	6925 *
11	65	10270
12	75	11850
13	102	16116
14	116	18328
15	56	8848 **
19	117	18486

† (Manthiriratne, 1978)

*Average of 6 years **Result of adverse weather

Note: Planting system; Hedge 8 × 5.5 m
Initial density 229 palms/ha; final density 158 palm/ha

Table 11.2: Yield of *typica* × *pumilla* F_1 hybrids (experiment 2) Bandirippuwa planted in 1963*

Years after planting	*Nuts/palm*	*Nuts/ha*
9	91	14378
10	63(**)	9954
11	102	16116
12	104	16432

*(Manthiriratne, 1978)
**Yield affected by adverse weather conditions
Note: Planting system 7.3 m × 7.3 m; planted in 158 palm/ha.

Table 11.3: Comparative study of typica × pumilla, typica × typica and typica (OP) at the Poththukulama research station planted in 1963*

Planting material	*Nut/palm in 5th year*	*Yield/palm 10-year mean (1967–1976)*	*Yield/ha 10-year mean*
typica × pumilla	23	51	8043
typica × typica	11	45	7170
typica (OP)	7	42	6589

* (Manthiriratne, 1978).

Limitations in the use of Dwarf × Tall hybrid (CRIC 65) were recognised, as it was susceptible to soil water deficit and hence not recommended to agro-climatic regions where prolonged dry weather was of frequent occurrence (Manthiriratne, 1978). Dwarf × Tall hybrids with both green and the yellow forms of the dwarf as the female parent are proving to be superior to the other cultivars in the wet intermediate areas. In the 'drier' areas, it appears that 'plus' (the selected ordinary tall) show better adaptability than the 'improved' cultivars.

SEARCH FOR NEW MATERIAL

The overall low productivity of the coconut lands, aggravated by the rapidly changing weather pattern, brought to light the need for selection of plant material which could withstand the adverse effects of 'drought'. Wickramaratne (1987) has outlined the priorities in relation to breeding for drought resistance in coconut. The most appropriate population of palms which could be used for any selection programme was the population within the isolated seed garden. Genotype × environment studies were undertaken in 1982 to select parent material for genotypic adaptation, which show low variability in yield despite variation in weather. The study of yield and climate of 16 years led to the identification of 84 superior palms between 1982 and 1983 (Wickramaratne, 1983). These palms were further screened on the basis of husked nut weight and those producing higher than the mean (635.6 g/nut) of the block were selected as an elite set of palms. These were termed as

'Ambakelle Special' palms (Wickramaratne, 1982; 1983). The progeny of these palms was used for in-filling and for the expansion programme of the seed garden. The nursery performance of the Ambakelle special palms was studied and the early germinators were selected as pollen parents. Pollen parents and Ambakelle special palms have been crossed in different combinations and a progeny trial was planted within the ISG in 1988 (Wickramaratne, 1988) to test the efficiency of the selection criteria.

RECENT DEVELOPMENTS ON EFFICIENCY OF SELECTION

In standard nursery practice to raise seedlings for planting, about 20 to 30 per cent seed-nuts are rejected on size, shape and quantity of nut water prior to nursery laying. In the nursery, failures are removed at around 20 weeks after sowing and under optimum conditions, and 80 to 90 per cent sprouting can be obtained within this period (Wuidart, 1981). Late germinations and seedling rejections would amount to about 22 per cent. In the mid-eighties a study was undertaken to test the efficiency of the criterion used in seed-nut selection (Wickramaratne *et al.*, 1987). It was found that the criterion used for the selection of seed-nuts was not satisfactory and that seed-nuts should not be rejected on the basis of size, quantity of nut water or shape, since they did not show a strong enough relationship with germination to enable it to be used as a basis for more efficient seed-nut selection. The study recommended that seed-nut selection be dispensed with and that all seed-nuts harvested from selected palms be laid in the nursery and a rigorous seedling selection be carried out subsequently. This method of selection is currently being advocated.

FUTURE STRATEGIES

The studies or evaluation of cultivars in different agro-ecological regions would be used to identify morphological characters and palm responses to soil water deficit which would help in refining the selection criteria for drought-prone areas. This is considered very important in view of the emphasis placed in the selection of cultivars for drought tolerance.

Recurrent droughts have also been causing drastic reductions in the nut size in the seed gardens. A selection and hybridisation programme has been initiated towards improving the nut size of our local tall material.

Recent studies have shown that there has been a decline in the level of production in the replantings/underplantings during the last 10-year period. This could in part be attributed to the lack of judicious seedling selection at the nursery as shown by the poor early performance of these plantations. Research programmes will address this problem with particular emphasis on rigorous culling of seedlings in the nursery. Less effort would now be needed in seed-nut selection as research findings have shown no significance of rejecting seed-nuts on size, shape etc. More effort would be needed to ensure that the proper criteria are applied for seedling selection in the nursery and efficient culling is adopted on early seedling vigour to ensure a uniformly high-yielding plantation to the grower.

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DISCUSSION

M. Abdul Kalam: You have mentioned that there is no need for further selection of nuts from the mother palms. Have you made any study comparing the performance of nuts selected from mother palms on the basis of size, weight etc. and unselected ones?

R.R.A. Peries: Yes. The data are well documented (Wickramaratne *et al.,* 1987. *Cocos* 5: 01–07). A significant relationship could not be obtained to use the earlier criteria. Hence only misshaped or cracked nuts from the selected 'plus palms' are rejected.

R.D. Iyer: 1) How many prepotent mother palms have been identified in Sri Lanka based on progeny evaluation?

2) How large a population of prepotent progenies has been established in Sri Lanka?

3) How many of these prepotents have been used as parents in elite seed gardens in Sri Lanka?

R.R.A. Peries: 1) Only five proven prepotents have been identified.

2) About 15–20 ha of seed gardens have been established with the prepotents, but their progenies have been widely used in the second and third seed gardens.

3) Only three of the above five palms have been used as parents in the seed gardens.

12

COCONUT BREEDING AT IRHO AND ITS APPLICATION IN SEED PRODUCTION

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ABSTRACT

The coconut selection scheme used by IRHO involves two main procedures: Tall × Tall hybrid improvement and Dwarf × Tall hybrid improvement. In both cases, the method is based on reciprocal recurrent selection of half-sib families. The first stages of this scheme are split into three phases: building up a collection with broad variability, study of crosses between ecotypes, and improvement of crosses between ecotypes through individual combining ability tests. Comparative trials revealed hybrids producing twice as much as their parental ecotypes. The seed production method should enable immediate exploitation of the genetic progress achieved. The assisted pollination technique developed by IRHO enables seed production at moderate costs, with good legitimacy. Research is under way to optimise pollen use and concentrate seed production in the planting season. The recent success of *in vitro* vegetative propagation opens up new prospects for improvement programmes and for planting material production.

INTRODUCTION

Coconut research began in India in 1916 (Harries, 1978), but many programmes were disrupted, either by the two world wars or by the 1929 depression. Work was only seriously resumed in 1950 or thereabouts. Coconut genetic improvement is therefore a recent undertaking, which has been hindered by severe technical constraints linked to the biology of the plant: the long juvenile phase, the low multiplication coefficient, its bulk and the lack of a vegetative propagation method. Any coconut improvement programme calls for considerable resources over particularly long periods: an average genetic trial takes 8 ha and at least 12 years.

Despite these difficulties, the work carried out since 1950 has led to the creation of new varieties that considerably increase production potential.

Furthermore, this work has made it possible to collect considerable amount of data on the variability of the species and its genetic performance.

This paper gives a succinct account of Institut de Richerches de Huiles et Oleagineux (IRHO) contribution to coconut genetic improvement. Particular attention is paid to breeding methodologies and seed production methods that enable the extension of the varieties created. The data given below mainly come from the Marc Delorme Station in the Ivory Coast. However, the selection methodologies and schemes described are based on all the research work carried out in conjunction with IRHO, particularly at the coconut research stations in Vanuatu and Benin, and also in numerous other countries with which IRHO has cooperation agreements.

THE FIRST STAGES OF IMPROVEMENT

Mass Selection

All the research stations involved in coconut improvement have used mass selection. When a coconut breeding programme is launched, it is characterised by a period of at least 12 years during which no experimental results are obtained.

There was therefore no option but to extend the only material likely to offer a genetic advantage, that is, nuts harvested from high-yielding local varieties. This method was used in the Ivory Coast until 1960. Subsequent analysis has shown that the effectiveness of this first selection operation was limited. Furthermore, mass selection using open-pollination was unable to provide large quantities of top quality nuts. The strict selection procedure that had to be applied considerably limited the seed production potential (Bourdeix, 1988).

Once the first results had shown the superiority of crosses between ecotypes, mass selection was virtually abandoned in the Ivory Coast. It was continued for some time in Vanuatu, as the local ecotype was the only variety resistant to a lethal disease (Foliar Decay due to *Myndus taffini*). The recent discovery of tolerant hybrids means that this obstacle has now been overcome (Calvez *et al.,* 1985). Mass selection is currently only used in conjunction with progeny tests. However, it is worth remembering that the West African Tall that is used as a genetic control was obtained after two generations of mass selection (Bourdeix, 1988).

Ecotype Combining Ability Tests

Systematic crossing of introduced and indigenous ecotypes was undertaken at the Marc Delorme Station in 1965. The term 'hybrid' is used to describe these crosses between ecotypes.

In the trials laid out by IRHO 3 to 10 hybrid combinations are being evaluated. Dwarf × Dwarf, Dwarf × Tall and Tall × Tall hybrids are tested separately, due to differences in vertical growth. Each trial contains a control obtained by hand pollination. The Malayan Yellow Dwarf (MYD) is used in Dwarf hybrid tests and the West African Tall (WAT) in Tall hybrid tests in the

Ivory Coast. In the case of Dwarf × Tall hybrids the control was WAT until 1976, and then MYD × WAT. One hundred and ten hybrids have been produced by IRHO; 81 were planted in the Ivory Coast for evaluation.

Several trials have been assessed, and 35 hybrids involving 13 parent ecotypes can now be compared. The results show that only five of the 35 hybrids are not significantly superior (at the 5 per cent threshold) to a WAT control obtained after two generations of mass selection. On an average, the hybrids produced 65 per cent more than the control, and four produced more than twice (in terms of copra per ha). Characteristics of the best interecotype crosses identified at the Marc Delorme Station are given in Table 12.1.

These results have proved the merits of coconut hybridisation. The success of the programme is largely dependent on the use of appropriate experimental designs, comprising a sufficient number of replicates and trees per cross. The most frequently used design is a Fisher block with six replicates of 24 trees (four rows of six trees) that is, 144 trees for each cross tested.

Recent analyses have shown that certain ecotypes (Vanuatu, Rennell and West African Talls) always seem to perform better in crosses than others (Malaysia, Mozambique, Panama). This result has important implications for improvement methodologies. In particular, it is sufficient to cross each ecotype with one or two well-known testers to obtain an idea of its value in crosses. However, the most productive ecotypes do not necessarily lead to the best hybrids. It is therefore essential to carry out a progeny test to assess the value of an ecotype in crosses.

Improving the Best Crosses

The method consists in improving the best hybrids identified in ecotype combining ability tests. As far as we know, this method has only been used in the Ivory Coast and Vanuatu so far. Its main merit is that it leads to genetic progress that can rapidly be used for seed production. Trees from one of the ecotypes are individually crossed with a set of trees from the other ecotype used as a tester. The crosses studied are therefore families of half-sibs. At the same time, all the parents tested are multiplicated by selfing to give around 100 plants each. This enables the large-scale reproduction of the best crosses, using pollen taken from the selfs of the best parents (Fig. 12.1 illustrates this method).

The first results of these tests were discussed by Bourdeix *et al.* (1989). They show that genetic progress of 20 to 30 per cent is obtained by within-population selection. There is therefore a substantial amount of exploitable variability, even within ecotypes such as the West African Tall, traditionally considered homogeneous.

At the Marc Delorme Station, the same parents were crossed with different testers. Fifteen Rennell Talls were successively crossed with the West African Tall, Malayan Red Dwarf and Cameroon Red Dwarf; certain Polynesia Tall parents were crossed with the West African Tall and Malayan Yellow and Red Dwarfs. Table 12.2 gives a classification of these parents, depending on the different testers. Cross-checks between trials show that

Table 12.1: Production figures for the best hybrids identified in the Ivory Coast

	Characteristics of the WAT control				*Mean value of the hybrids in each trial*							
	PBGC 3 9–12 yrs	*PBGC 8 9–13 yrs*	*PBGC 5 9–15 yrs*	*PBGC 11 9–14 yrs*	*PBGC 3*		*PBGC 8*		*PBGC 5*		*PBGC 11*	
Flowering precocity (mths)	56	63	61	53	54	96%	62	98%	50	82%	42	79%
No. of bunches per tree	11.7	11.4	12.0	13.7	12.6	108%	12.2	107%	14.0	118%	15.7	115%
No. of nuts per tree	76	42	58	75	99	130%	78	186%	95	164%	112	149%
Copra/nut (g)	225	237	235	225	274	122%	263	111%	274	117%	274	122%
Copra/ha (tonne)	2.29	1.34	1.86	2.32	3.64	159%	2.21	165%	3.53	190%	4.15	179%

	Characteristics of the best hybrids (Production and percentage compared with control)													
	WAT x RLT PB 213		*WAT x VTT PB 214*		*MYD x WAT PB 121*		*MRD x PYT PB 132*		*MYD x PYT PB 122*		*MYD x RLT PB 123*		*CRD x WAT PB 111*	
Flowering precocity (mths)	51	91%	57	90%	51	84%	50	82%	52	85%	40	75%	44	83%
No. of bunches per tree	12.7	109%	13.5	118%	14.8	123%	14.2	118%	14.2	118%	16.5	120%	15.5	113%
No. of nuts per tree	102	134%	100	238%	109	188%	101	174%	110	190%	123	164%	132	176%
Copra/nut (g)	311	138%	212	89%	247	105%	282	120%	253	108%	289	128%	240	107%
Copra/ha (tonne)	4.26	186%	3.15	235%	3.67	197%	3.88	209%	3.80	204%	4.80	207%	4.35	188%

WAT: West African Tall
MRD: Malayan Red Dwarf
RLT: Rennell Tall
PYT: Polynesia/Tahiti Tall
VTT: Vanuatu Tall
CRD: Cameroon Red Dwarf
MYD: Malayan Yellow Dwarf
MLT: Malayan Tall

Table 12.2: Comparative classification of Rennell Tall and Polynesia Tall parents in crosses with different testers

Rennell Tall	*PBGC 16 Crosses with WAT*		*PBGC 20 Crosses with MRD*		*PBGC 25 Crosses with CRD*	
Parent No.	*Production copra/palm/year (kg)*	*Rank*	*Production copra/palm/year (kg)*	*Rank*	*Production copra/palm/year (kg)*	*Rank*
P 2664	25.348	1	24.416	2	26.969	1
P 2054	22.182	2	21.439	3	26.402	3
P 2556	22.577	6	25.109	1	25.259	6
P 1842	22.251	5	20.774	5	25.920	4
P 2654	23.752	4	18.189	11	26.626	2
P 2550	20.466	7	20.949	4	24.742	7
P 2665	19.010	3	18.162	12	25.296	5
P 1868	22.543	8	18.367	10	24.101	8
P 1867	20.801	10	19.712	7	23.273	10
P 2589	20.062	11	18.984	8	23.416	9
P 1846	16.801	9	15.963	14	22.498	11
P 2062	20.412	15	20.225	6	20.785	14
P 2078	23.243	13	17.863	13	22.487	12
P 2591	18.088	14	18.850	9	20.587	15
P 1854	18.135	12	15.110	15	22.042	13

Polynesia Tall	*PBGC 2-2 Crosses with WAT*		*PBGC 13 Crosses with WAT*		*PBGC 17 Crosses with MYD*		*PBGC 23 Crosses with MRD*	
Parent No.	*Production copra/palm/ year (kg)*	*Rank*	*Production copra/palm/ year (kg)*	*Rank*	*Production copra/palm/ year (kg)*	*Rank*	*Production copra/palm/ year (kg)*	*Rank*
P 167			19.141	1	18.854	1	18.994	2
P 306	17.865	1			16.356	6	20.042	1
P 594			13.492	2	17.037	4	17.437	3
P 600					17.772	3	15.556	5
P 608			12.858	3	18.543	2	15.457	6
P 318	14.902	3			14.767	9	15.794	4
P 607					16.829	5	15.360	8
P 1839					13.602	11	15.449	7
P 604	12.199	6			14.778	8	14.398	11
P 616	17.786	2			16.092	7	13.612	13
P 2499					13.915	10	13.662	12
P 641	13.845	5			12.520	14	15.033	9
P 606			11.275	4	12.622	13	14.443	10
P 316	14.619	4			13.035	12	12.714	14
P 315	11.591	7			11.704	15	10.809	15

Observation Periods

PBGC2-2 : mean copra/nut 8–11 yrs, mean number of nuts 6–12 yrs.
PBGC13 : mean copra/nut 6–9 yrs, mean number of nuts 5–12 yrs.
PBGC17 : mean copra/nut 5–8 yrs, mean number of nuts 4–11 yrs.
PBGC20 : mean copra/nut 4–8 yrs, mean number of nuts 4–9 yrs.
PBGC23 : mean copra/nut 5–8 yrs, mean number of nuts 5–11 yrs.
PBGC25 : mean copra/nut 5–7 yrs, mean number of nuts 5–7 yrs.

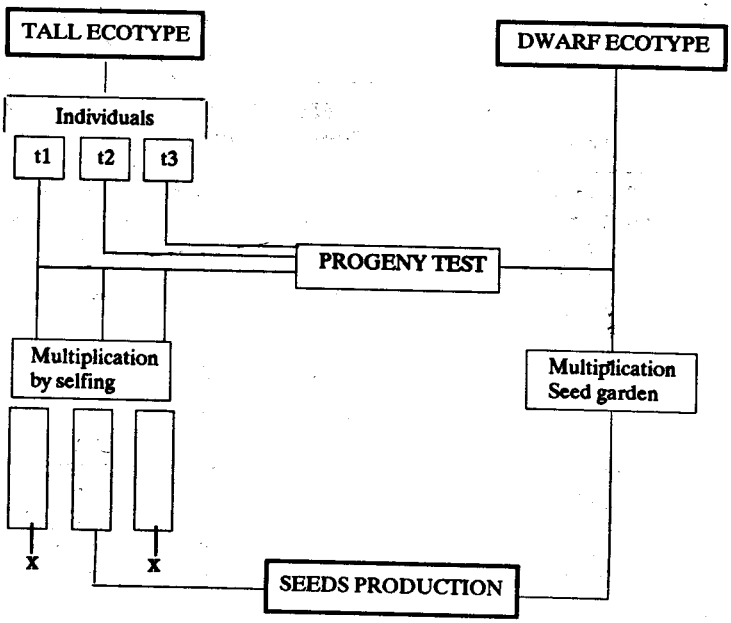

Fig. 12.1: The case of Dwarf x Tall hybrids unilateral individual combining ability tests.

certain parents come on top regardless of whether they are crossed with the West African Tall or various Dwarfs. This result, which has important implications for improvement, seems to suggest that parents with excellent general combining ability have been identified.

THE CURRENT SELECTION SCHEME

General Principles

Based on the results described above the following refinement in breeding methodologies is suggested:

a) The existence of a significant heterosis phenomenon in coconut prompts the continuation of hybrid selection. However, certain types of hybrids could be improved: Tall × Tall, Dwarf × Tall and Dwarf × Dwarf.

b) The low heritability of yield means that phenotypic selection is considerably less effective than the progeny test method. It is therefore essential to carry out progeny tests to estimate the value of an ecotype or tree in crosses.

c) The first breeding stage involves ecotypes. Once the "good ecotypes" are identified, the units selected are no longer populations but individuals.

The different improvement stages described above are part of a more general scheme, which proposes an overall approach to coconut breeding (Bourdeix *et al.*, 1990; 1991a; 1991b).

The scheme described was derived from a method initially developed on maize (Comstock *et al.*, 1949), which has since been widely extended to other plants. This consists in creating two populations that are kept in reproductive isolation and improved with respect to each other.

Two main breeding approaches will be described in succession, namely Tall × Tall hybrid improvement and Dwarf × Tall hybrid improvement. Fig. 12.2 gives a diagrammatical representation of the method.

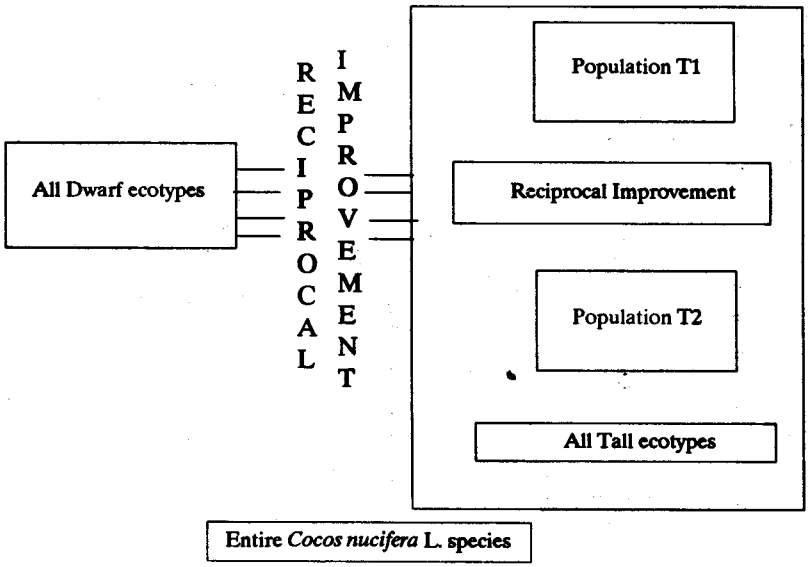

Fig. 12.2: Diagrammatical representation of two breeding approaches.

Tall x Tall Hybrid Improvement

Although most of the hybrids produced to date have been the Dwarf × Tall type, various factors suggest that the Tall × Tall type has higher improvement potential (de Nuce de Lamothe and Rognon, 1986).

The method described below consists in creating two complementary Tall populations using two specially chosen ecotypes. These two populations are then improved with respect to each other using recurrent reciprocal selection.

Choice of Basic Ecotypes

Basic ecotypes are used to split the tall ecotypes into two complementary groups. Two clearly different origins should therefore be chosen, with different (if possible complementary) characteristics and which produce an excellent hybrid when crossed.

In the Ivory Coast, an analysis of genetic trials led to the choice of the Rennell Tall (Pacific) and the West African Tall (Ivory Coast and Benin). Table 12.3 gives some results showing that these two ecotypes combine well, both with each other and with other Tall ecotypes.

The First Selection Cycle: Establishing Basic Populations

The method runs along the same lines as the recurrent reciprocal selection. There is a series of selection cycles, each comprising a test phase (enabling the detection of good genomes) and a recombination phase (which creates new genetic combinations).

Table 12.3: Characteristics of Rennell Tall and West African Tall ecotypes when hybridized

Hybrids and controls	*Young trees*					*Mature trees*			
	Prec. (month)	*Bunches*	*Nuts*	*Copra/tree/year (kg)*	*Copra/nut (g)*	*Bunches*	*Nuts*	*Copra/tree/year (kg)*	*Copra/tree/year (%)*
Trial PB-GC 3	*6–8 years*				*8–12 years*	*9–12 years*			
WAT × WAT (control)	60.3	9.5	56	12.6	225	11.7	77	16.9	100
WAT × RLT	55.2	11.8	89	27.6	312	12.8	102	31.4	186
PYT × RLT	59.5	10.1	65	20.4	316	12.2	86	27.1	160
Trial PB-GC 8	*6–8 years*				*7–10 years*	*9–14 years*			
WAT × WAT (control)	66.6	6.8	23	5.5	237	11.4	42	9.9	100
WAT × VTT	60.5	11.6	92	19.2	212	13.6	110	23.2	234
WAT × PYT	62.1	9.3	43	11.9	279	12.8	65	18.0	182
MLT × WAT	63.0	9.1	38	11.4	299	12.7	60	17.8	180

PB-GC 3 : mean of trials GC 3–1 and GC 3–2 planted in 1969 and 1970.
PB-GC 8 : mean of trials GC 8–1 and GC 8–2 planted in 1972 and 1973.
Prec. : time between planting and appearance of first spathe.
Bunches : mean of the annual number of bunches per tree.
Nuts : mean of the annual number of nuts per tree.

a) First generation: test phase

Each ecotype is crossed with the two testers: WAT and RLT in the Ivory Coast. This test makes it possible to split the ecotypes into two groups:

1) The ecotypes producing better hybrids with the WAT tester than with RLT are classed in the "RLT Group".

2) Those that combine better with the RLT tester are classed in the "WAT group".

b) Second generation: recombination phase

Once the ecotypes are split into two groups, the recombination phase consists in carrying out crosses, but only within groups. The two populations are made up of between ecotype crosses in which the testers are involved to varying degrees.

Figure 12.3 illustrates the whole of the first Tall × Tall selection cycle, which leads to the creation of two basic populations, one with good combining ability with Rennell Tall (population $G1_1$), and the other with good combining ability with West African Tall (population $G2_1$).

Subsequent Selection Cycles: Population Improvement

Once the basic populations are created, the breeding method used is recurrent reciprocal selection on half-sib families. The progeny tests used are similar to those described previously, used to improve the best hybrids. Each selection cycle covers two generations:

i) A test phase, making it possible to detect those individuals in population $G1_1$ with good combining ability with population $G2_1$ and *vice versa*. The parents tested are selfed at the same time, to ensure their preservation and multiplication (50 to 100 plants obtained by selfing for each parent).

ii) A genetic recombination phase, consists in crossing the various parents (or their selfs) separately for each population. The two improved populations, $G1_2$ and $G2_2$ obtained in this way make up the basis for the following selection cycle. Figure 12.4 illustrates a Tall × Tall recurrent reciprocal selection cycle.

Dwarf x Tall Hybrid Improvement

The method used to improve Dwarf × Tall hybrids is similar to that for Tall × Tall hybrids. The main difference lies in the fact that in this case, the two basic populations are defined in advance: there is true complementarity between Dwarfs and Talls, which warrants keeping the two groups in reproductive isolation and improving them with respect to each other.

In the first selection cycle, the Tall ecotypes are crossed with a Dwarf tester, and the Dwarf ecotypes are crossed with a Tall tester. The following phase consists in crossing the ecotypes that perform best when hybridised, Talls with each other and Dwarfs with each other. This leads to two complementary populations.

Subsequent selection cycles improve these two populations with respect to each other, using recurrent reciprocal selection on half-sib families.

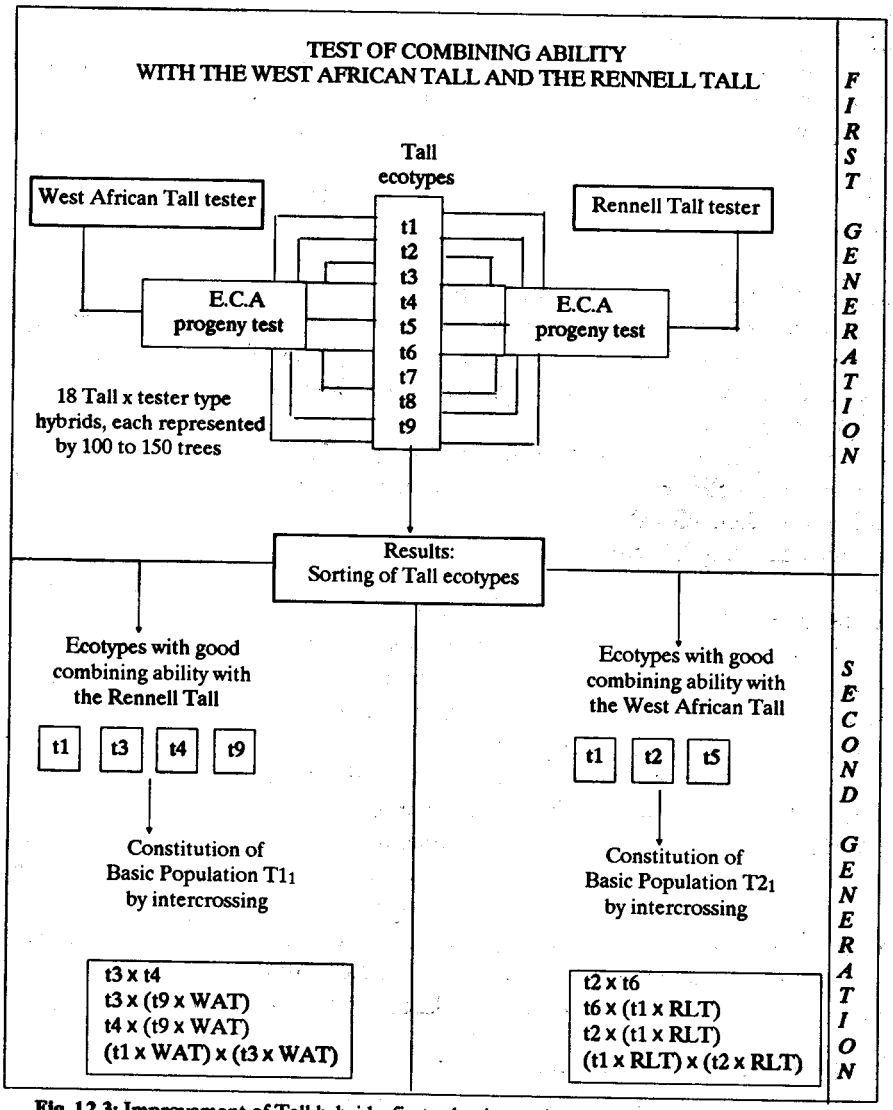

Fig. 12.3: Improvement of Tall hybrids: first selection cycle-theoretical example based on a study of nine tall ecotypes numbered from t1 to t9.

SEED PRODUCTION

Brief History

Although the first pollinations were carried out in India in 1920 or thereabouts, it is Marechal, who crossed the Malayan Red Dwarf with the Niu Leka Dwarf from Fiji, who is generally assumed to be the father of the first hybrids. Unfortunately, the pedigree of the hybrids was lost (Child, 1975). Patel (1938) carried out the first crosses between Talls and Dwarfs, with a view to combining the hardiness of the Talls with the precocity of the Dwarfs.

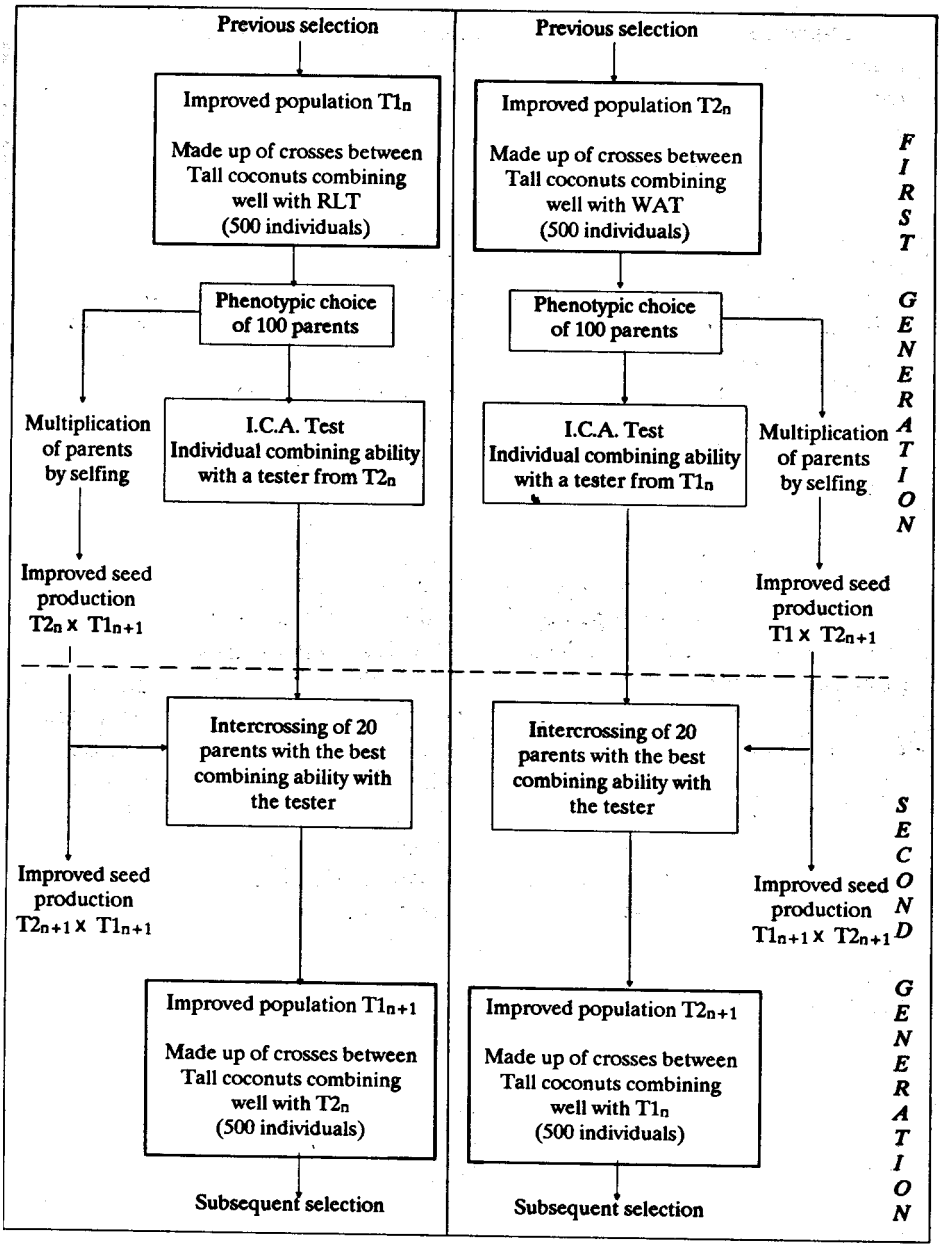

Fig. 12.4: Improvement of Tall × Tall hybrids. Description of a reciprocal recurrent selection cycle.

Although these hybrids were planted under poor conditions, they proved more precocious and more productive than their Tall parents. The years 1940 to 1960 saw the setting up of a certain number of hybrid tests (Anonymous, 1940 and Liyanage, 1958), which comprised crosses between local Dwarf × Tall and Tall × Tall ecotypes.

Thammes (1955) was the first to suggest applying the technique used on maize to coconut, consisting in interplanting two varieties to use one as the male and the other as the female. This method was adapted to coconut and used with success (de Nuce de Lamothe and Rognon, 1972a) under the title "directed open pollination".

The first hybrid popularised in the Ivory Coast was the cross between the Malayan Yellow Dwarf and the West African Tall. Several seed gardens were planted, with one Tall for five Dwarf mother-trees. The Talls were used only as a source of pollen. The Dwarf inflorescences were emasculated to prevent selfing. This method opened the way for hybrid extension, since it was possible to produce seeds cheaply with a good rate of legitimacy. However, it lacked flexibility, as it meant that only the type of hybrid chosen when the seed garden was set up could be produced. This method, which did not enable rapid exploitation of research results, was therefore gradually abandoned and replaced by a more flexible technique.

Assisted Pollination

Several articles published between 1972 and 1981 described the seed production method developed by IRHO (de Nuce de Lamothe and Rognon, 1972b and 1973; Wuidart and Rognon, 1981). This method, known as "assisted pollination" is still used in the Ivory Coast and in numerous other countries.

Seed gardens are planted with mother-trees only, isolated and separated from the male parents from which pollen is harvested. Pollen is dusted on to the inflorescences of the mother-trees, which have previously been emasculated. The method comprises four main stages: pollen harvesting and preparation, emasculation, pollination and checking.

Two studies carried out in the Ivory Coast provided information enabling improvement of the method. In 1975 a trial was set up to measure contamination in a seed garden in which assisted pollination was practised, depending on the distance from a major pollen source (de Nuce de Lamothe and Rognon, 1975). The results obtained led to the conclusion that a 300 m isolation area should be left around seed gardens (see Fig. 12.5). Another study carried out in 1981 showed that the female flowers on Yellow Dwarfs were preferentially pollinated by pollen from the same variety (Sangare, 1981). This result stresses the importance of good quality emasculation operations: even low pollen emission due to inadequate emasculation in the seed garden can lead to a high percentage of illegitimates. Assisted pollination calls for greater technical skills than directed open-pollination.

However, the advantage of assisted pollination lies in its greater flexibility. Pollen can be harvested thousands of kilometres from the seed production site, and can change in line with breeding results. Several types of crosses can be carried out successively using the same female parent in the same seed garden. Hence in the Ivory Coast, the first improved hybrids will be produced in the existing seed gardens: only the type of pollen will change.

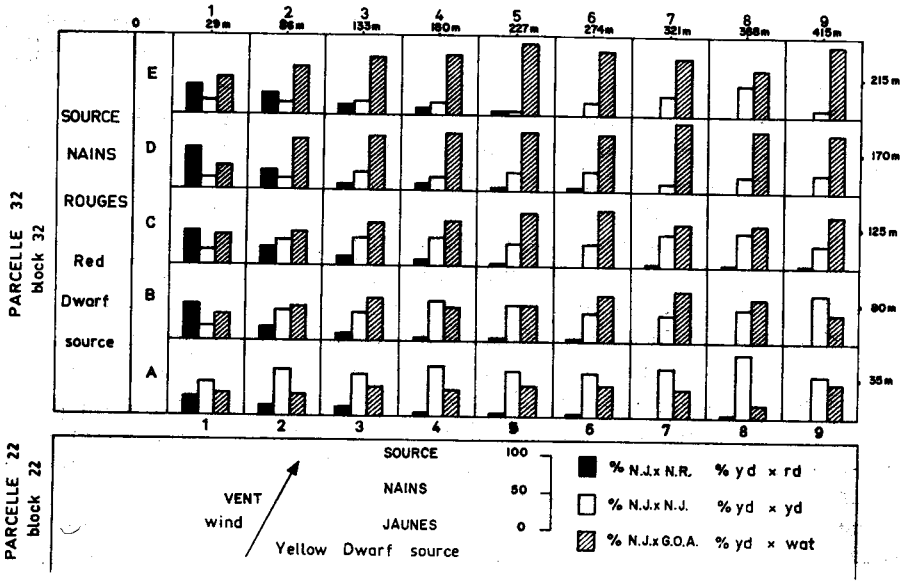

Fig. 12.5: Plan of the trial and repartition of the types of sprout in function of the distance from the contamination sources.

Questions Relating to Changes in Improvement Methods

Pollen as a Limiting Factor

To date, the hybrids produced have been crosses between two ecotypes. Pollen was rarely a limiting factor, as it could be harvested in sufficient quantities from a population of trees.

Changes in improvement methods will mean that crosses will have to be made between a specific parent and a population. In fact, the parents tested are selfed and the pollen taken from the selfs is used to reproduce the cross. The cross of a tree with a tester is generally equivalent to the cross of its selfs with the same tester. However, enough selfs must be used (theoretically 20) to prevent genetic drift phenomena.

In the Ivory Coast, 100 plants obtained by selfing were planted for each parent tested individually. This operation represents a very heavy workload, as selfing is difficult to carry out and takes up a considerable area of land. In addition, depression due to inbreeding is often seen in Talls. Selfs flower late and do not produce many flowers, which reduces pollen production. Pollen availability from improved parents may therefore become a limiting factor.

Under the conditions in the Ivory Coast, a 1 ha seed garden provides enough seednuts to plant around 60 ha of hybrid per year. This seed garden will utilise the pollen of around 15 trees obtained by selfing. Therefore pollen produced by a family of 100 selfs would only make it possible to plant 400 ha of improved hybrids per year.

In the Ivory Coast, there are now nine families suitable for use in improved hybrid production. However, in the case of very large development projects, the seednut production potential could prove inadequate. Two research approaches are therefore being considered, to make the best possible use of pollen from improved parents.

Reducing the pollen dose applied to each inflorescence enables certain savings to be made. However, an over-drastic reduction in the pollen dose leads to a drop in the percentage of set flowers.

Another study is attempting to determine whether regular removal of bunches in seed gardens makes it possible to concentrate seed production in a given period of the year and hence whether reducing removes the amount of pollen that is consumed. In fact, the given period is generally followed by a marked increase in the number of bunches of flowers per inflorescence. Pollen effectiveness (in terms of the number of seed per g) is therefore improved, since the amount of pollen dusted on to each inflorescence remains constant.

Figure 12.6 gives the results of an experiment conducted on a Cameroon Red Dwarf seed garden where bunches were completely removed over a total period of 18 months. If we look at a period of 18 months non-production and 18 months production, the seed deficit compared with a non-castrated control is 11 per cent. There is therefore clearly a "catching up" phenomenon. The trees that are castrated produce a good deal more flowers and nuts than usual. However, this over-production does not totally compensate for the losses caused by castration.

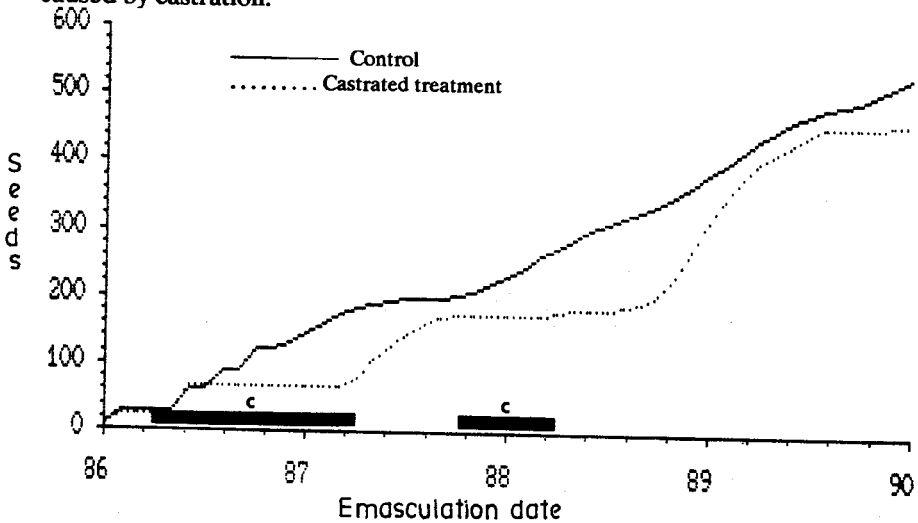

Fig. 12.6: Cumulated seed harvests per tree.

Before being applied on a large scale, this method should be confirmed by additional experiments. In particular, the seednuts produced by the castrated trees are often small and have a low free water content. They have to be placed in the seed-bed rapidly, or else their germination capacity can be affected. In addition, an experiment covering several castration-production cycles will make it possible to determine optimum-alternation patterns.

***In vitro* Vegetative Propagation**

A coconut genetic trial, from inception to the final results, takes around 15 years. Before then, *in vitro* vegetative propagation should be operational. It is therefore essential to prepare for this development.

This new way of multiplying varieties should enable a very significant genetic progress. In practice, however, the resources devoted to prepare for clonal selection will remain limited. Clonal selection will mainly be carried out in genetic trials designed for material produced from seed, which are well suited (high genetic variance both between and within progenies). The experience IRHO has acquired in the oil palm field could be transferred to coconut. The methodology will comprise two stages: cloning of the best trees chosen from the best progenies, and then clone comparison in field trials carried out simultaneously in several countries. The clones selected after these tests will be extended on a large scale.

With a view to clonal selection, it is also useful to create dwarfism segregation situations, for example by crossing Dwarf × Tall hybrids with each other. This type of cross was carried out in the Ivory Coast during the first selection cycle (Meunier *et al.,* 1984). It is hoped that highly variable progenies will be obtained, where some trees will have the precocity and slow vertical growth rate of the Dwarfs, coupled with excellent productivity. This method can be used systematically for every selection cycle, without taking too many resources. In view of the many phytopathological problems encountered with coconut, clonal selection will probably also be used to try and rapidly cumulate several sources of disease tolerance within a single genome.

CONCLUSION

The selection scheme developed by IRHO seems to be well adapted to coconut. It is based on rational management of variability, takes account of the constraints linked to the plant's biology and integrates recent selection achievements. It can be used to transfer the genetic progress made during previous improvement stages. Despite the low multiplication coefficient, high quality seeds can be produced on a large scale. Lastly, the fact that several types of hybrids can be improved will make it possible to satisfy the wide range of user requirements.

However, implementing such a programme requires considerable material and scientific resources, which may be beyond the reach of national research centres if the aim is to exploit the variability of the species as effectively as possible. Irrespective of the improvement schemes and ecotypes used, it seems obvious that the overall genetic progress will be faster the more the workload is spread. This implies at least a minimum of coordination and possibilities for comparison; joint use of certain very widespread basic ecotypes, such as Malayan Dwarfs, standard controls and choice of specific testers.

Planting material exchanges could be carried out, either in the form of pollen or in the form of zygotic embryos cultures *in vitro* (Assy Bah, 1986). In the absence of a quarantine centre—which is yet to be set up—this

technique could considerably reduce phytopathological risks. In addition, setting up an international test network would make it possible to quantify genotype-environment interactions — phenomena which have not as yet been studied in detail on coconut.

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CROP IMPROVEMENT PROGRAMMES IN SOUTH PACIFIC REGION

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ABSTRACT

Coconut is a very important crop for the South Pacific countries where it covers a total area of more than 600,000 ha and often the main source of income. A regional programme has been formulated by the government of the ACP countries to identify local varieties for evolving and testing of new hybrids to rejuvenate coconut groves. The implementation programme financed by EEC, has been entrusted by the RAB and the Government of Vanuatu to Saraoutou Research Station. Extension of the project to all SPC countries is sought. Development of networks, collection and duplication of germplasm collections and selection of improved varieties are the priority areas identified.

INTRODUCTION

Many countries of the South Pacific region regroup only tiny islands but they represent an aggregate area of more than 600,000 ha planted with coconut. They are the fourth largest producer and the second largest exporter of copra. In spite of the current slackness of the market, copra often represents almost 50 per cent of the export revenue of several countries and is the principal source of income for villagers. Besides copra production, coconut is a part of daily life and is a staple food. It is estimated that the national consumption accounts for between 25 and 45 per cent of the production.

Presently, due to several causes such as senility, typhoons and human destruction, the coconut is slowly disappearing and the time may soon come, when, paradoxically the Pacific countries would have to import coconut products to meet the needs of their fast-growing populations. To reverse the trend and to at least guarantee self-sufficiency, several programmes integrating "crop improvement" and "development" have been instituted during the last few decades.

Evolution of Programmes

Almost every country in the region has, at one time or another, launched a coconut replanting programme. Each programme has incorporated the idea of crop improvement through selection of parent material and/or through hybridisation.

The following impediments exist:

a) Smallness of the countries resulting in a lack of research structure and research resources.

b) Irregularity of funding.

c) Lack of perennation in the programmes, alternance of interest and sometimes short-term funding periods.

d) Pests, diseases and other related problems.

e) Lack of available land.

f) Sometimes also a lack of farmer supervision.

Not forgetting the decreasing prices of copra which have discouraged farmers from taking up new plantings, many of the programmes have not been very successful and some have even been halted before achieving their aim.

As a whole it can be said that these programmes have not had a great impact and have not resulted in true rejuvenation of the coconut groves. This has remained a great source of concern to the government leading them to establish a regional project for the production and dissemination of improved coconut cultivars.

The Project

This project "Production and Dissemination of Improved Coconut Cultivars" was requested for during the VIth Regional Conference on Coconut Growing at Saraoutou in August 1986. Its operating expenses are covered by the EEC while the coordinator from IRHO is funded by the French Budget; the Vanuatu government makes available the facilities at Saraoutou for the implementation of the work and the necessary land for field experiments and tests.

Objectives and Methods

The general objective of the project is to advise the countries on utilising the best varieties to plant or replant coconut by testing the varieties existing in the region so as to make maximum use of them and of their adaptation to the conditions in the country.

Hybridisation between dwarf and tall varieties is implemented in the first phase as it has often proved to be a faster way of improving production. The current hybridisation programme is based on pollen transfer. The pollen is collected either in the countries or from the Saraoutou Research Station collection. It is used to create hybrids with dwarf varieties by hand pollination.

These hybrids are compared with one another in field tests. The two Malayan varieties, Yellow and Red dwarfs are widespread in the region. As a result, they are included in all the crossing plans. Other varieties are selected, either for their good combining ability or because they are well established in the country from which the pollen is obtained.

For example, the Apa Yellow Dwarf (AYD) and the Niu Leka Dwarf (NLD) have been tested with the pollen from Tonga as the two dwarfs exist in this country. Two hybrids Red Malayan Dwarf × Rennell Tall (RMD × RLT) and Green Brazilian Dwarf × Polynesian Tall (GBD × GPY2) are known to perform well. As a result, they are included in the programmes specific to the countries: for example, when testing pollen for Kiribati the two hybrids GBD × GPY2 and (GBD × KIT) GBD × Kiribati Tall are included. The permanent control for all trials is the Red Vanuatu Dwarf × Vanuatu (RVD × VIT).

In this way each trial test compares five to six hybrids including Tall or Dwarf varieties already present in the countries and/or varieties that could be adapted to the specific country's conditions.

Description of Varieties

At the same time as the hybridisation programme progresses, the description of varieties is undertaken to ensure that the genetic variation of the coconuts of the region is properly recorded. This concerns both qualitative and quantitative characteristics, which are used to varying degrees by the planters in the region.

In order to ensure valid comparisons it is essential that sampling conditions, measuring criteria and measuring methods be standardised. This standard descriptive system will be implemented in all the countries, based on the model set up by the Saraoutou Research Station in collaboration with the IBPGR and which is already in use in several countries. To increase precision and in order to take into consideration some of the variations due to the environment, the same measure will be carried out on a sample of the varieties which will be introduced in one location.

All the data collected will be analysed in order to obtain a description and a classification of the ecotypes. The project programme comprises training of personnel from the various countries so that those involved in coconut improvement in each country are properly trained in sampling methods, observation and description of varieties, creation and development of seed gardens, production and selection of seedlings and other requirements of coconut cultivation.

It also comprises advising countries as to the steps to be taken to prepare for seed gardens or to manage the existing ones and as to the best crosses to make in accordance with their specific conditions.

Current Achievements of the Project

The project started in June 1989 with a meeting where the general programme was discussed and drawn up with the representatives (national coordinators) of the countries involved (the eight ACP countries).

Since then all the countries — except one — have been visited by the regional coordinator.

1) Seventeen hybrids have been developed involving pollens from Solomon Islands populations — Tonga and Kiribati.

2) Twenty-one agricultural officers attended a 10-day training course session in Saraoutou.

3) Technical advice has been given in Tonga for the creation of coconut collection and the establishment of a seed garden.

4) Technical advice and support on the management of seed gardens have been given in Western Samoa and Tuvalu.

5) Pollen production and dispatching has been implemented in collaboration with officers at Kiribati for the creation of Dwarf × Tall hybrids.

6) A consultancy by an entomologist has been organised in Vanuatu, the Solomon Islands and Papua New Guinea to investigate the significance of the pests: Oryctes, Scapanes, Rhynchophorus and Sexava in relation to coconuts and to recommend means of control.

7) Specific work programmes have been established with the officers in-charge of coconut in Kiribati, Western Samoa and Tonga.

Other Crop Improvement Programmes in the Region

At the same time as the regional programme of the PDICC develops, national programmes are also being implemented in the countries associated with the project:

In Western Samoa, a seed garden is producing hybrids of YMD and RMD × RLT to support a replanting programme: seeds are also collected from selected tall palms but the planters prefer the hybrids. A small collection of palms has been established and a trial aims to test locally produced hybrids. Identification and description of varieties are in progress.

In Tuvalu, a small seed garden is being operated to produce hybrids of YMD and RMD with RLT or with local coconuts.

In Tonga, steps are being taken to create a collection of palms with coconuts of the varieties available locally and also to plant a seed garden for production of hybrids. A previous programme, using local Talls as parent material has been discontinued.

In Fiji, a seed garden is now productive with the potential to produce hybrids between YMD or RMD and RLT or (Rotuma Tall) RTT.

In PNG, a very extensive survey of the coconut varieties existing in the country and their description has been implemented by national officers. An analysis of the data gathered will make it possible to programme new research work for crop improvement. Steps are being taken to organise control measures against: Oryctes, Scapanes, Rhynchophorus, Sexava and to reactivate the Small Holders Cocoa and Coconut Replanting Programme (SCCRP) that had been discontinued for a few years.

In the Solomon Islands, a replanting programme is being carried out based on the RMD × RLT hybrid whose good performance is well known.

In Vanuatu, work started in 1962 with the establishment of the Saraoutou Coconut Research Station managed by IRHO. The introduction of exotic materials then led to the discovery of the coconut foliar decay (CFD) disease to which local coconut varieties are tolerant while exotic ones are susceptible. Along with research work conducted on CFD, crop improvement programmes were oriented towards improvement of local varieties through selection of

parent materials and through hybridisation between local talls and local dwarfs.

The production of the improved local tall planted at 143 palms/ha and well maintained is about 2.5 t of copra/ha/year. In the same conditions, several Dwarf × Local Tall hybrids planted at 160 palms/ha are producing 3.5 to 4 t of copra/ha/year. Meanwhile, 37 hybrids between varieties are also being tested for both productivity and tolerance to CFD.

In line with these work programmes, a collection of coconut varieties has been planted and expanded over the years. Current holding consists of 35 ecotypes — 21 Tall and 16 Dwarf varieties, covering 23 ha. This collection is the largest in the Pacific region and is used as a source of germplasm for local programmes, for research work on CFD and for the regional collaboration programme with other organisations.

Future Priorities

Development of networks

Due to the place that coconut occupies in their economy and the over-ageing of the coconut groves, crop improvement is of paramount importance for the countries of the South Pacific region. Its requirements, however, in terms of staff, access to germplasm, availability of land or of infrastructure make it impossible to be implemented by a single country. It requires collaboration and exchanges between countries. The creation of the PDICC project launched this regional approach. To deal with a general improvement programme in the region, and all its various aspects in a comprehensive way from both the geographic and the scientific viewpoints, at the same time to reduce the cost by economies of scale, it would be advisable to extend the scope of the project from the eight ACP participating countries to all the SPC member countries.

Duplication of germplasm collections

The Saraoutou coconut collection is for the time being unique in the South Pacific Region. Like any collection of living plants anywhere, it is exposed to the hazards of natural elements: typhoons, diseases etc. It would be useful if, for safety, such a collection could be duplicated in another country with the means to accommodate it. This obviously implies that like the one at Saraoutou, the duplicate collection would be accessible to researchers from other countries as well as the host country. This condition reinforces the notion of a network suggested previously.

Germplasm collection in other forms than living trees

Coconuts, even of Dwarf varieties, cannot be planted above a relatively low density per ha (for example, 205 or 210 trees per ha for Dwarfs and 143 to 160 trees per ha for Talls). This means that a relatively large area of land is necessary to keep a collection of several varieties. In countries prone to

cyclones it may be useful to duplicate such a planting. In terms of land as well as in terms of upkeep, such collections become rather expensive.

It would be very useful if means of conservation other than living trees could be developed to preserve coconut germplasm either in the form of embryos or of living tissues that could be regenerated at will. This would also facilitate exchanges of material that are always difficult and expensive when implemented in the form of seed-nuts.

Means of identification of varieties

Discrimination of coconut varieties still depends on a description of phenotypic and vegetative characteristics although the coconut phenotype is very much influenced by the ecology.

Work has been started to distinguish between coconut varieties through analysis of cell-components (enzymatic systems, poly-phenols). Priority should be given to this field of research so as to be able to ascertain differences between varieties. The availability of such a discriminating tool would eliminate much guesswork in breeding programmes and would certainly enable faster progress in crop improvement, principally if at the same time studies on mitochondrial activity could enable an early assessment of the value and performance of the new varieties/hybrids developed.

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THE ISHS COCONUT REGISTRATION AUTHORITY

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ABSTRACT

The need for an International Registration Authority to maintain uniformity, accuracy and stability in the naming of coconut cultivars around the world is largely felt. The ISHS and IBPGR are doing significant work in this direction, helping to conserve coconut germplasm and encouraging national and international efforts for replanting with superior varieties etc. The ICCRA will compile and publish a check-list of coconut cultivars, regularly update it, and offer registration facilities to new cultivars and hybrids. Besides, ICCRA will concentrate on other equally important matters such as improving disease and drought tolerance and generally bringing coconut cultivation, processing and marketing into the twenty-first century. The ICCRA wishes to report its findings in scientific, technical or popular publications to bring about an awareness among the coconut workers.

Coconut palms are supposed to have a number of uses and almost as many names. Scientifically, there is only one species of coconut (*Cocos nucifera* L.) with two plant habits (Tall and Dwarf) and three basic colour forms (yellow, red and green). But the actual range of intermediate palm habits and colours, exhibit every possible combination. This is particularly so for the size, shape and appearance of the fruit (the hard-shelled, dry, brown nut enclosed in a thick, fibrous, smooth-skinned husk). Attributing the names and the descriptions to inherited genetic traits is extremely difficult. Even if the plant breeding work is done before the palms get too tall, the low number of fruit set per pollination, the 12 months taken before the seed is mature and the five or more years it then takes to bring the next generation into bearing, make it practically impossible to study coconut genetics.

All plants are essential to civilisation and none more than the coconut palm, which has had a long association with mankind. It is important that plants should be named according to a precise, stable and internationally

accepted system. The International Code of Botanical Nomenclature governs the use of botanical names in Latin for both wild and cultivated plants. There is also an International Code of Nomenclature for Cultivated Plants. This aims to promote uniformity, accuracy and stability in the naming of cultivars (varieties). This is done through the establishment of International Registration Authorities under the guidance of the International Society for Horticultural Science (ISHS). There are registration authorities for many ornamental plants and for fruit-tree crops, such as mango. Until now there has not been one for any palm genera.

The International Coconut Cultivar Registration Authority has been set up by the appointment of an international registrar and a work programme has been laid down. There are three stages: (a) to compile and publish a checklist of coconut cultivars; (b) to regularly add to, and amend the checklist; and (c) to offer registration facilities for new cultivars and hybrids.

The ISHS expressed an interest in making a checklist of coconut cultivars in 1973. At that time, when F_1 hybrid coconuts had begun to be produced in commercial quantities, it became important to know all about the hybrids and about their parentage. In 1968, the Coconut Breeders' Consultative Committee had been set up by the Food and Agriculture Organisation of the United Nations (FAO), through its technical working party on coconut production, protection and processing. This *ad hoc* committee proposed the establishment of a hybrid register using the recommendations of the international code of nomenclature for cultivated plants but the initiative did not survive the closure of the FAO technical working party in 1981.

The International Board for Plant Genetic Resources (IBPGR) began to take an interest in coconut germplasm in 1975 and there have been meetings (sponsored by IBPGR and FAO) in the Philippines (1987) and in Thailand (1988) which have included recommendations for cataloguing and characterising coconut germplasm collections. The IBPGR coordinator for South and Southeast Asia is presently planning to establish a coconut germplasm data-base. National organisations, such as the Philippine Coconut Authority and the Institut de Recherches de Huiles et Oleagineux also maintain coconut germplasm data-bases. It might be asked whether the new ICCRA is needed if it merely duplicates the other national and international efforts. That is not the intention.

National organisations that do research in coconuts need to keep detailed records of the varieties that grow in their countries and of any varieties that are introduced for research purposes. In the same countries there are likely to be variety release committees who have to pass judgement on whether new varieties and hybrids are suitable to be grown by farmers. Because of the long generation time and other delays to successful breeding programmes, the release of new coconut varieties tends to be a fairly rare event. The existence of coconut cultivar registration authorities will therefore, assist variety release panels to make judgements that are consistent with generally accepted standards. The ICCRA would not attempt to interfere in these national, statutory and governmental operations, but it would encourage the responsible

individuals from those national organisations to appoint one of their members to act as a national registrar, affiliated to the International Registration Committee.

The possibility of a regional or international coconut germplasm data-base, whether organised by the IBPGR or any other agency (for example BUROTROP or the organisation that may emerge if CGIAR responds favourably to the ACIAR initiative) does not conflict with the ICCRA. In addition to identifying germplasm resources wherever they occur the IBPGR has a major role to play in ensuring that these resources are available to future generations. The IBPGR is concerned with encouraging national and international efforts to conserve coconut germplasm that is under threat of extinction from replanting with superior coconut varieties, or other crops, or from removal by logging or from devastation by pests, diseases or from rises in sea level caused by global warming. The IBPGR data-base organisers might not need to be involved with ICCRA but a check-list of coconut cultivars and information on locations, origins, descriptions and so on, would greatly assist the further development of IBPGR coconut data-bases. Similarly, the other international organisations have many facets of research competing for first priority and germplasm will have to share attention with other subjects. The information that could be received from ICCRA will allow efforts to be concentrated on other equally important matters, such as improving disease and drought tolerance, and generally bringing coconut cultivation, processing and marketing into the twenty-first century.

The ICCRA approach takes these important criteria into account but also concerns itself with aspects such as the sources used by, and the stocks held in private and commercial seed gardens and nurseries; the interests of the palm society amateur gardener as well as the professional botanical garden superintendent; and the information needs of the high school teacher as well as those of the university taxonomist. By using commonly available computer hardware and software listings can be readily exchanged. Information will appear in scientific, technical or popular publications, as appropriate. Above all, by appointing voluntary registrars who will be bound only by their own interest and initiative, the ICCRA will be as useful as its contributors care to make it.

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MULTISTAGE SELECTION IN COCONUT PALM FOR GENETIC IMPROVEMENT

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Genetic improvement to increase the yield level of coconut palm is in progress in Tamil Nadu, India. The results of the investigations indicated that best performing populations have to be identified and mother palms with high level of bearing have to be selected. The seedlings raised with seed-nuts from mother palms from seven different source populations exhibited segregation of normal and defective seedlings. The defective types included chlorophyll deficient types, namely, *xantha* and *chlorina* and rarely *albina*. These types exhibited foliage syndrome with crumpled and crinkled small leaves, poorly developed stem and roots which occurred to the extent of 2 to 9 per cent. The mean percentage of defective seedlings was 5.9 in 0.12 million seedlings scored over eight years from seven different population sources. Besides, selection for seedling vigour further led to the rejection of 8 to 10 per cent of seedlings, and thus 75 to 80 per cent of seedlings only were selected for planting. Three parameters for minimum standards for seedlings vigour are: 6 cm girth at base, six numbers of well-developed leaves and at least one fully split leaf at 10 months after sowing. These parameters were highly and positively correlated with one another.

Heterozygosity *per se* for genes controlling normal and defective seedling phenotypes was evident from the segregation for seedling phenotype and vigour. Adult palms also exhibited variation for earliness, crown shape, fruit number and related traits. The genetic behaviour of coconut palms indicating heterozygosity is attributed to the highly cross pollinated nature owing to the differential maturity of male and female flowering on the same spadix in the 'Tall' form. In the 'Dwarf' form also, although the maturity of male and female flowering phases are overlapping, segregation for defective phenotype occurred to the extent of 10 per cent in a sample of 579 seedlings indicating outcrossing. In view of the perennial nature, long time life span, long pre-bearing

period of five to seven years, and highly heterozygous nature, the genetic improvement in coconut palm is slow. Nevertheless by multi-stage selection during seedling, pre-bearing and at stable bearing stage of adult palms substantial improvement could be achieved.

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COCONUT SELECTION AND BREEDING PROGRAMME IN VIETNAM

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ABSTRACT

Coconut plantations extending an area of 300,000 ha, constitute a primary source of income to millions of farmers in Vietnam. Research and development efforts on coconut are being intensified by government in order to increase the production and productivity. In the last 10 years the coconut germplasm collection with 20 local forms and 14 introduced varieties has been established and the characteristics of the major local varieties have been investigated. The coconut classification has been suggested together with the criteria of plus palm selection. More than 100,000 palms have been chosen, seed-nuts from them have been used to develop thousands of hectares of coconut plantations. Seven exotic and two indigenous hybrids have been planted simultaneously with the establishment of 120 ha isolated seed garden.

INTRODUCTION

Research on coconut was formally initiated from 1980 in Vietnam with the establishment of the Institute for Research on Oils and Oil Plants (IROOP). In its research activities, IROOP has cooperated with "Institut de Recherches pour les Huiles et Oleagineux" (IRHO), France, and has received considerable support from UNDP/FAO through project VIE/08/009 and has also received valuable assistance from APCC.

IROOP has launched a study programme on all aspects of coconut in order to improve the coconut yield which at present is evaluated to be low. The programmes of coconut selection and breeding, including collection of local germplasm, introduction of varieties and hybrids, crop improvement and planting material production have been undertaken. This paper presents a general view about these aspects and some preliminary results received during the last 10 years.

LOCAL GERMPLASM

Collection from local sources has been carried out in almost all areas of Mekong Delta and in the central region where coconuts are planted. Till now 20 populations (15 Talls and 5 Dwarfs) were gathered in collection gardens in Dong Go Station (Ben Tre Province) and Trang Bang Station (Tay Ninh Province). These types are suited well to local conditions and some of them are high yielding with more than 2 t of copra/ha/yr under normal management conditions. Ta, Dau, Giay are good for tendernut water with the high content of sugar in water (9.8 per cent). Besides, the presence of special types of coconuts has also been noticed — 41 Sap: having the Makapuno type of kernel in the Philippines; 41 Ngot: with husk that is sweet and edible when the nut is tender; 41 Dua: having an aromatic flavour in its water and meat; and 41 Soc: having brown stripes on exocarp like water-melon.

These indigeneous materials will be a "gene bank" for the breeding programme. Three talls Ta, Dau and Giay are commercial varieties, but Eo, Xiem and Tam Quan are in limited cultivation.

At present Ta is the most widely cultivated variety in the country (79.2 per cent). Ta is considered as a traditional coconut variety due to its presence from the very early time in different localities characterised by its large nuts and average number of nuts per bunch.

Dau, the second popular variety under cultivation (14.4 per cent) has good characteristics such as a high number of nuts/bunch, good fruit components (Q value: 23.5) with medium size. There has been an opinion made that Dau to be a natural hybrid due to its pollination habit and its characteristics has been stable through generations.

Giay is popular in the central area especially in the coastal areas with big nuts and good fruit components.

Bung is the largest size nut variety (2.78 kg per nut) but with low number of nuts/bunch.

There are some other coconut forms which may be of different types, such as, Ta, Dau, Giay in different regions. Except Dau, most of Talls exhibit cross pollination. As for Dwarfs, Xiem belongs to type 3, Eo and Tam Quan belong to type 4 (they resemble Catigan and Tagcunan of the Philippines).

The yield and other characteristics of some major Talls and Dwarfs observed in their natural habits are presented in Table 16.1.

In Vietnam, coconut varieties are generally divided into two varieties: Tall and Dwarf with seven major groups. The details of these seven groups are shown in Table 16.2 and Fig. 16.1.

INTRODUCED VARIETIES AND HYBRIDS

Vietnam introduced coconut seeds for further breeding as well as hybrids for evaluation since 1984. Seed-nuts of 14 introduced varieties and seven hybrids from the Ivory Coast, the Philippines, Sri Lanka and Fiji were sown and planted in the fields, together with the indigenous germplasm collection (Tables 16.3 and 16.4).

Table 16.1: Characteristics of some major coconut varieties in Vietnam

Coconut variety	*Female flower/ bunch*	*Fruiting set (%)*	*Nuts/ bunch*	*Nuts/ tree*	*Weight of nut (g)*	*Weight of copra/nut (g)*	*Weight of copra/tree (kg)*	*Oil content (%)*	*Overlapping of male and female phases*	
									same inflorescence (%)	*successive inflorescence (%)*
TALLS										
1. Ta	18.9	24.2	4.6	50.2	2390	320	18.6	63.70	0	36.8
2. Dau	21.9	23.3	5.1	69.2	1340	274.8	19.0	64.10	37.3	43.5
3. Giay	26.7	18.4	4.9	62.0	2395	411	25.5	63.50	0	0
4. Bung	14.8	22.3	3.3	41.2	2790	362	15	61.94	7.5	0
DWARFS										
1. Eo	57.0	37.8	21.6	285.1	295	59.6	16.9	63.40	76.9	52.3
2. Xiem	21.8	35.3	7.7	110.1	621	103.2	11.3	63.15	100.0	39.4
3. Tam Quan	26.3	20.2	5.3	76.3	972	156.5	11.9	61.50	93.9	35.5

Table 16.2: Classification of coconut varieties

Character	*Dwarf*	*Tall*
Stem	Thin base, slow growth, 10 m high	Thick base, rapid growth, 18 to 20 m high
Leaf	Short, evenly distributed	Long, distributed in spherical, semi-spherical shape and erect
Initial flowering	Three to four years	Five to seven years
Inflorescence production	Discontinuous	Continuous
Pollination	Mostly autogamous	Mainly heterogamous
Nut	Small, thin husk, thin meat	Large, thick husk, thick meat
Copra/nut	65–170 g	270–420 g
Taste of water while tender	Sweet	Insipid
Germination time	Seven to nine weeks	Eight to 12 weeks
Nuts/bunch	High	Low to medium
Yield/year	More than 75	About 55
Economic life	Thirty-five to 40 years	Fifty to 60 years
Adaptability	Poorly adapted to saline, acid sulphate and drought	Can stand diverse soil conditions and tolerant to drought
Nut use	For drinking	For copra and other culinary purposes

Character	*Dwarf*		
	I	*II*	*III*
Whole nut	Very small, oblong 12 × 6 cm pointed end, thin husk about 250 nuts/tree	Small, ovoid 14 × 11 cm, thin husk, about 110 nuts/tree	Medium ovoid 17 × 11 cm, thin husk, about 75 nuts/tree
Husked nut	Round, thin meat	Round to ovoid, thin meat	Round to ovoid, meat medium thick
Colour	Brown/green	Green/brown	Yellow
Variety	Eo	Xiem	Tam Quan
Other types/ Synonyms		Dua: meat and water have special aroma SOC: Brown and green striped husk	

	Tall		
I	*II*	*III*	*IV*
Whole nut			
Very big Round with ridges 29 × 25 cm, thick husk, about 40 nuts/tree	Big, ovoid with ridges 24 × 20 cm, medium thick husk about 58 nuts/tree	Big, round 23 × 21 cm, medium thin husk, about 60 nuts/tree	Large, ovoid 21 × 17 cm thin husk, about 69 nuts/tree
Husked nut			
Round, small compared to whole nut, thick meat	Large, flat bottomed shell, thick meat	Large and round thick meat	Large compared to nut size, medium thick meat
Colour			
Green	Green/yellow/red	Green	Green/yellow/red
Synonyms			
Bung	Ta Sap: Soft meat (Makapuno type) Ngot: Sweet edible husk	Giay Synonym: Vang Yellow†	Dau Hon: medium, round green* Nhim: Oblong** Vu Bo: round, pointed end†

*Pham Thiet Province; **Mekong Delta; †Central Provinces.
Source: IRVAC Breeding Department, 1989

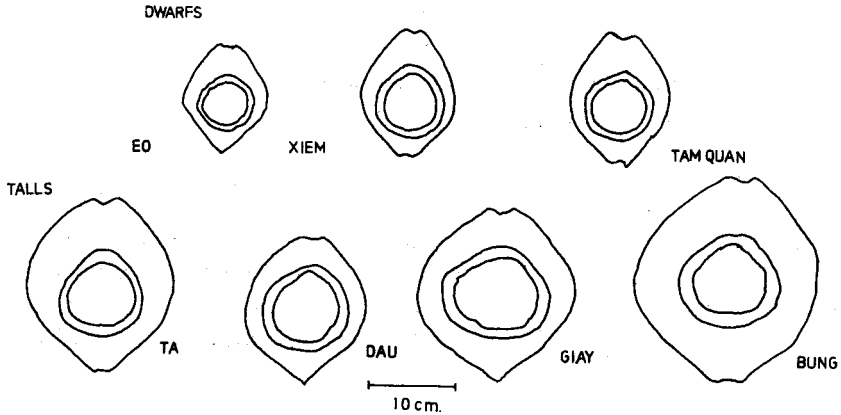

Fig. 16.1: Major coconut varieties of Vietnam.

Source: IRVAC Breeding Department, 1990.

Table 16.3: Exotic varieties introduced to Vietnam

	Variety	*Source*	*Year of planting*	*No. of trees*
1.	West African Tall	Ivory Coast	1987	44
2.	Hijo Tall	Philippines	1987	44
3.	San Ramon Tall	Philippines	1987	44
4.	Fiji Tall	Fiji	1989	20
5.	Niu Leka Dwarf	Fiji	1989	14
6.	Orange Dwarf	Philippines	1987	74
7.	Ghana Yellow Dwarf	Ivory Coast	1987	37
8.	Equatorial Guinea Green Dwarf	Ivory Coast	1987	50
9.	Malayan Yellow Dwarf	Ivory Coast	1987	50
10.	Malayan Red Dwarf	Fiji	1989	50
11.	Catigan Dwarf	Philippines	1987	23
12.	Sri Lanka Yellow Dwarf	Sri Lanka	1987	47
13.	Sri Lanka Red Dwarf	Sri Lanka	1987	19
14.	Sri Lanka Green Dwarf	Sri Lanka	1987	54

Table 16.4: Performance of imported hybrids
(Adaptability experiment at Dong Go station, Ben Tre Province)

	Hybrid	*Parents*	*Year of planting*	*No. of plants*	*Flowering percentage 1989*	*1990*
1.	PB121	MYD × WAT	1985	100	82.97	100
2.	PB111	CRD × WAT	1985	100	59.57	98.88
3.	PB132	MRD × Polynesian Tall	1985	100	58.88	95.49
4.	PB141	EGGD × WAT	1985	100	48.21	76.37
5.	JVA1	MYD × Hijo Tall	1987	162	—	—
6.	JVA2	MRD × Hijo Tall	1987	162	—	—
7.	C65	Green Dwarf × Sri Lanka Tall	1977	162	—	—
8.	Ta (open-pollinated local tall as control)		1985	100	13.41	37.12

Among the dwarfs, Sri Lanka's Green Dwarf and Orange Dwarf have grown better than the others with the most vigorous girth and high leaf production. Among hybrids, PB 121 has flowered earliest with the highest flowering percentage as compared to the other six hybrids.

CROP IMPROVEMENT

A selection programme has been initiated from very early times in order to increase the production on a large scale. Besides palm selection, seed-nut and seedling selection the programme included the selection of local cultivars which give high production of copra and are suited for various ecological areas. Through this programme, Ta, Dau and Giay are considered the three good varieties to be recommended for planting (new planting and replanting) while waiting for improved varieties produced inside the country in the coming years. The criteria for mother palms, seed-nuts and seedling selection, and nursery techniques had been standardised and popularised among farmers.

CRITERIA FOR MOTHER SELECTION IN VIETNAM

- 10 to 45 years old.
- Well distributed crown with thick leaf scars.
- Far from sources of excrement of cow, pig, goat.
- Nuts/tree/year.
  - For Ta cultivar : 60 nuts
  - For Dau cultivar : 80 nuts
- Weight of meat/nut:
  - For Ta cultivar : 500 gr.
  - For Dau cultivar : 400 gr.

So far more than 100,000 plus palms of Ta, Dau and some other cultivars were selected and seed-nuts from these palms supplied to coconut growers.

Dwarf cultivar, Tam Quan possesses homogeneous fruit quality value (F.Q.V.) = 0.43, high weight of copra/tree and nuts having yellow colour and resemble Malayan Yellow Dwarf. Eo has been chosen due to the high number of nuts/bunch. The seed-nuts of the combinations of Tam Quan × Ta and Eo × Ta have been produced and their performance is being observed in the field.

Some progress was made in an attempt to update the pollen processing techniques. Using a fluid bed drier has decreased the drying time of coconut pollen from 48 hours by the traditional method at 40°C to less than two hours with a higher viability of pollen.

PLANTING MATERIAL PRODUCTION

Up to now, the seed-nuts used for the new planting are mainly supplied from selected mother palms. This method has limitations as the percentage of outstanding palms is only 1 per cent and is widely distributed.

In order to meet the farmers requirement to plant improved planting materials, a seed garden of 120 ha has been established at Trang Bang, Tay Ninh Province. In this garden the following parents have been planted:

Malayan Yellow Dwarf	:	43.7 ha
Malayan Red Dwarf	:	1.7 ha
West African Tall	:	11.7 ha
San Ramon, Hijo Tall and Fiji Tall	:	1.5 ha
Local Talls : Ta and Dau	:	50.0 ha
Tam Quan Dwarf	:	6.5 ha
Eo Dwarf	:	2.0 ha
Xiem Dwarf	:	2.2 ha

In this seed garden, parent palms have been planted separately and there is an isolation band between the cultivars. Once the best hybrid has been evaluated, it will be produced immediately in this garden.

CONCLUSION

The coconut selection and breeding programmes in Vietnam are long-term research programmes in an attempt to produce the improved coconut varieties and to increase gradually the production and productivity of coconut in the whole country. Up to now, IROOP has selected Ta, Dau and Giay as the three good local talls for copra making and the characteristics of some major varieties have been investigated. The germplasm collection has been built up. This will be a valuable "gene bank" for geneticists and breeders to use. Of the nine hybrids under observation, preliminary data showed that the PB 121 exhibited better performance than others.

DISCUSSION

R.V. Pillai: What is the copra content of the hybrid produced?

V.V. Long: The copra content is yet to be assessed. Since the hybrid nuts are intermediate, the copra per nut will be lower than that of the female parent.

E.V.V. Bhaskara Rao (Comments): As the copra content of 'Ta' cultivar is very high, priority should be to select with high oil content rather than attempting for production of D × T and T × D hybrids. Hybridisation may be successful only if we have dwarfs with high oil content.

R. Bourdeix: How many hybrid seedlings/seed-nuts do you produce every year?

V.V. Long: Malayan Yellow Dwarf palms in a 50 ha seed garden have started flowering. We will start seed production of PB 121 by 1992.

THE QUEST FOR THE IDEAL PALM

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ABSTRACT

The causes for poor yield in coconut are many and varied. Stabilisation of yield required careful consideration of both genetic and agro-ecological conditions. The performance of certain hybrids have suggested positive effects of favourable environment on growth and yield. Besides, clear evidence for the presence of genotype environment interactions also exists. Based on the findings, it can be suggested that the cross of RMD × WAT is the nearest to a universal variety which performs equally well under diverse conditions while GDE × WAT seems to be more stable, specifically adapted to poor environments and RCD × WAT is suited to high yielding environments. Coordinated efforts among the coconut growing countries to obtain valuable information on some of these promising varieties are suggested.

Throughout the ages, coconut growers the world over have been seeking the ideal palm. Since the thirties this search has been formalised with methods such as mass selection and hybridisation being put to use. The main objective of the quest was to identify or produce palms with higher yield. However, in his preface to Sumith de Silva's presentation (1989) of results of a regional study of high-yielding coconut varieties undertaken by the Asian and Pacific Coconut Community (APCC) P.G. Punchihewa, Executive Director of APCC says: "In spite of research and development and extension work carried out in the area of improved varieties the impact they had on increasing production and thereby improving the living conditions of the coconut farmers was not apparent." This is borne out by the individual country studies in which many cases of dissatisfaction with the improved varieties and preference for the old varieties are reported. Amongst the many reasons for dissatisfaction are yield not reaching expected levels or uncertainty of yield performance, high costs of inputs, vulnerability to pests, diseases and drought, small size of nuts, high variability, seasonal bearing habit, and immature nut fall due to buckling of bunches.

Different approaches are available to the plant breeder. One must consider whether there is likely to be an ideal or "universal variety" or rather, whether there are several desirable types adapted to different situations. A universal variety would necessarily be one which continues to yield above average in all situations. It would be desirable for it to give optimum yields with low levels of management and minimum inputs. Production should be steady and predictable with minimal yield fluctuations. Other favourable features would be early bearing, palms not too tall, nuts not too small and tolerance to unfavourable conditions such as pests, diseases and drought.

If we consider the conditions under which this palm is to be grown, we will find they are many and varied. The general environmental requirements for coconut cultivation have been listed in order of priority in Table 17.1. Here the "length of growing period" refers to the period of time during the year in which the crop requires adequate moisture for growth and its determination is based mainly on requirements of rainfall distribution, humidity and sunshine hours. In Sri Lanka which is a small island, the palm grows in a wide range of habitats with a variety of soil, rainfall and topographic conditions. When one considers the other coconut growing countries of the region, the environmental range is even wider, with certain countries encountering specific problems while others are at an advantage. For example, typhoons pose a problem in the Philippines, soil types in Papua New Guinea range from coralline clays, loamy and coral sands to fertile volcanic ash soils, Indonesia has tidal swampy areas with problems of water logging and peaty soils and so on. It seems unlikely that a single variety or type of palm could excel in this range of environmental conditions. The alternative would, of course, be to develop a range of palms with specific adaptation to different types of environment.

Table 17.1: General environmental requirements for coconut cultivation

Land characteristic (in order of priority)	*Highly suitable*	*Moderately suitable*	*Marginally suitable*	*Not suitable*
1. Length of growing period (days)	≥ 300	≥ 270	≥ 240	Others
2. Soil depth (cm)	≥ 150	≥ 100	≥ 75	Others
3. Soil drainage	Well drained to moderately well drained	Somewhat excessively drained	Imperfectly drained	Excessively drained, poorly drained and very poorly drained
4. Soil texture	Fine sand, loam and clay loam	Coarse or medium sand	Gravel	Silty clay and finer clays
5. Mean annual temperature (°C)	≥ 25	≥ 23	≥ 21	Others
6. Dominant slope range	0–2%, 2–8%, 8–16%	16–30%	30–60%	60–90% and ≥ 90%
7. Soil reaction (pH)	4.5–6.5	4.0–7.0	3.5–8.0	Others
8. 75% confidence mean annual rainfall (mm)	≥ 1500	≥ 1200	≥ 1000	Others

Source: Land Use Policy Planning Division, Ministry of Lands and Land Development and FAO. (unpublished)

Available information on the performance of different coconut varieties under different conditions of soil, management and climate are very limited. Santos *et al.* (1986) have published some interesting data on growth performance of different coconut varieties in relation to crop production and area classification in the Philippines. They concluded that hybrids proved superior to talls in that they were more precocious and higher yielding in terms of the number of nuts and total copra; however, results regarding yield potential are perhaps inconclusive as the talls had not yet attained full bearing. The varying performance of hybrids at different locations was used as an environmental index to rank the locations. They reported that the performance of hybrids in pilot farms suggested positive effects of favourable environmental conditions on yield and growth. This is not unexpected; all varieties of coconut, have been found to respond positively to favourable environmental conditions although perhaps some more than others. Most interesting in this study is the fact that certain varieties were superior to others in some locations but not in others and that differences between some hybrids became evident only in certain locations, which implies the presence of genotype environment interactions. Re-examination of these data from a different angle reveals some interesting features regarding the likely responses of different coconut genotypes to changes in environmental conditions. Considering each year at each location as a set of separate environmental conditions, it is possible to extract 12 sets of environmental conditions from their data. The data set for 1981 are discontinued as palms have not attained the regular bearing age. The data from tall palms have been excluded for the same reason. The data can then be set out in a two-way table to give the performance of four different hybrids across 12 different types of environment (Table 17.2).

An analysis of variance was not possible as there was no access to the original data. In the absence of an analysis of variance and a joint regression analysis, the existence of significant genotype-environment interactions cannot be clearly established. However, there are indications of their existence which may be worth pursuing.

The method used was similar to that of Finlay and Wilkinson (1963). The mean yield of all hybrids for each environment (environmental mean yield) was used as a measure of the environment. Environmental conditions were graded quantitatively according to productivity. While Albay was generally the least favourable environment and Davao the best, there were exceptions in certain years. For instance, yields in Davao for 1984 were exceptionally low and may even distort the picture somewhat. Although 1984 was the worst year in the data set production-wise for Davao and Zamboanga, this was not so for Albay. The best year at all locations was 1985. Thus, it is not always possible to identify specific years or locations as being best or worst, considering each year at each location as a separate set of environmental conditions is hence justifiable.

A plot of the population mean yields against the environmental index has a regression coefficient of unity and is a measure of the average response of all the genotypes to changes in environment due to year and location. It is clear

Table 17.2: Number of nuts per palm per year for four hybrid varieties at three locations (extracted from Santos *et al.*, 1986)

Site	*A*				*B*				*C*					
Variety	*1982*	*1983*	*1984*	*1985*	*1982*	*1983*	*1984*	*1985*	*1982*	*1983*	*1984*	*1985*	*Total*	*Variety mean yield*
YMD x WAT	30	39	34	61	51	72	10	72	41	52	22	104	588	49
RCD x WAT	34	35	43	88	73	61	13	81	39	48	22	92	629	52
RMD x WAT	32	40	43	81	52	63	9	78	56	77	34	103	668	56
GDE x WAT	36	44	40	88	51	51	5	60	36	48	24	95	578	48
Total	132	158	160	318	227	247	37	291	172	225	102	394	Grand mean yield is 51	
Mean	33	40	40	80	57	62	9	73	43	56	26	99		
Rank	**3**	**4**	**5**	**11**	**8**	**9**	**1**	**10**	**6**	**7**	**2**	**12**		

A = Albay Research Centre B = Davao Research Centre C = Zamboanga Research Centre

YMD x WAT : Yellow Malayan dwarf x West African Tall
RMD x WAT : Red Malayan dwarf x West African Tall
RCD x WAT : Red Cameroon dwarf x West African Tall
GDE x WAT : Green Dwarf Equatorial x West African Tall

that ranking of the different hybrids changes across different types of environment. This is generally accepted as an indication of genotype environment interaction. The performance of each hybrid can be evaluated by considering the variety mean yield (the mean yield of a variety over all the environmental types) in combination with the variation due to response of the genotype to change in the environment as measured by the slope of the regression line (regression coefficient). The grand mean yield or the mean yield of all varieties over all types of environment was 51 nuts per palm. Although the three hybrids YMD × WAT, RCD × WAT and GDE × WAT had similar mean yields there is clear evidence of different responses to environmental change. The performance of YMD × WAT was below average and remained more or less consistently so over nearly all environmental conditions. Although GDE × WAT had a similar variety mean yield, it was less responsive than the average in that while its yield in the poorest environment equalled or even exceeded the population mean yield it was unable to exploit the improved conditions of the higher yielding environmental conditions. Thus, although it often outyielded the others at Albay, it was not even able to reach levels similar to the others in Davao and Zamboanga. This hybrid seems to perform better, relative to others in poor environmental conditions, and may be described as being specifically adapted to low yielding types of environment. RCD × WAT was generally about average or slightly below in the poorer conditions but its performance improved enormously in response to favourable conditions where it often moved to first or second place. It seems sensitive to environmental change and better adapted to high yielding environmental conditions. RMD × WAT was the best overall performer with a variety mean yield of 56, well over the population average. It seemed to have above average performance in nearly all types of environment indicating general adaptation.

To summarise the findings of the above analysis, RMD × WAT has a high mean yield and possesses general adaptation. It is the nearest to a "universal variety". GDE × WAT seems to be more stable and specifically adapted to poor yielding types of environment. Such a variety would be desirable for areas prone to fluctuations of weather as yield would not be drastically reduced due to, for instance, unexpected long dry spells. It would also be of interest to determine whether this type of palm also shows less yield within year fluctuations in yield. RCD × WAT, on the other hand, seems better adapted to high yielding environmental conditions and is suited for planting in ideal conditions. YMD × WAT seems generally a poor performer. The study, therefore, reveals differences in adaptation and stability and the extent of the genetic basis of this can only be assessed by further study which seems merited by the present findings.

The data presently available in Sri Lanka are insufficient for such a study. Multi-locational trials for evaluation of cultivars have been established there since the mid-eighties but have not yet come into full bearing. However, I feel the time is now ripe for setting up a series of coordinated regional trials to test all promising varieties/cultivars available in the region. The quest for the ideal palm or range of palms adapted to various conditions now requires an

interregional and interdisciplinary flavour. Of course necessary precautions would have to be taken against transmission of diseases across countries. Forward planning considerations for research are essential. Such a study must necessarily be well planned in consultation with all concerned, and statistically designed and coordinated, so that results from different countries are comparable and can be analysed jointly to yield the required information.

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DISCUSSION

E.V.V. Bhaskara Rao: Even if the overall performance of a cultivar is best in a multi-location trial, I feel the performance in a specific location is more important. Therefore testing in a large number of locations for identifying region specific varieties is necessary.

M.R.T. Wickramaratne: I agree entirely. Multi-location trials will help to identify the cultivars which may perform relatively well in 'low yielding' types of environment even though they may be poor in a 'favourable' environment. If the trials were only located in favourable areas, these cultivars would be rejected and hence lost.

PATH ANALYSIS IN COCONUT PALM

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The cause and effect relationship of the contributory factors with copra weight per nut was assessed. Among the five characters significantly correlating with copra weight, kernel weight, length of the petiole, and thickness of the shell had positive direct effects. Negative direct effects on copra weight were observed with the pre-flowering period, and thickness of the kernel. Highest direct and positive effects on copra were observed by the kernel weight per nut, followed by leaflets and the number of leaves produced in a year. The thickness of the shell had the least direct positive effect on copra.

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EVALUATION OF TENDERNUT WATER IN COCONUT CULTIVARS

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ABSTRACT

The tendernut water of 12 coconut cultivars was evaluated biochemically to find out a suitable tendernut cultivar. Biochemical evaluation indicated that Chowghat Orange Dwarf (COD) had the maximum amount of total sugars (7.0 g/100 ml) and reducing sugars (4.7g/100 ml) and low sodium and potassium content (20 and 2003 ppm respectively). Scores and weightage were given for tendernut characters following Anderson's method and a maximum index score of 73 was given to COD. Four cultivars selected based on biochemical evaluation were subjected to organoleptic test by seven tasters following a non-parametric statistical method. This study also confirmed the superior tendernut quality of COD.

INTRODUCTION

The annual production of coconut in India is estimated to be around 9,283 million nuts, out of which 60 per cent is consumed as fresh nuts (Thampan, 1988). Consumption in the form of tendernuts in earlier years was estimated to be about 4 per cent of the total production (Muliyar and Mathew, 1976). Tender coconut water has a caloric value of 17.4 per 100 g of water (Shivandiah, 1970). When the nut is seven to eight months old, the nut water has the maximum concentration of sugars and a large nut at this stage may contain about 30 g of sugar in solution and 2 g of potassium (Jayalakshmi *et al.*, 1988) besides organic and inorganic compounds including vitamins (Vitamin C and B group vitamins like nicotinic acid, pantothenic acid, riboflavin and biotin), and minerals such as potassium, sodium, calcium, magnesium and iron. The pleasant taste of tender coconut water is attributed mainly to the sugars and mineral matter (Chikkasubbanna *et al.*, 1990). Although several studies have been made to estimate the changes in the chemical composition of nut

water in relation to maturity (Nathaniel, 1952; Kamala Devi and Velayutham, 1978; Jayalakshmi *et al.,* 1988 and Chikkasubbanna *et al.,* 1990), no systematic study has been made to identify the best cultivar for tendernut purposes. The present study was aimed at identifying the best coconut cultivar suitable for tendernut purposes on the basis of biochemical and organoleptic analyses.

MATERIALS AND METHODS

Forty-six cultivars belonging to both exotic and indigenous types were subjected to a preliminary organoleptic screening for the quality of tendernut water. Of these, 12 cultivars were selected for a detailed biochemical analysis. Seven-month old nuts at the rate of one nut/palm were used for biochemical analysis and the sample size was four nuts/cultivar. The study was carried out for a period of four years (1988 to 1991) during April–May.

Chemical Analysis

The total volume of nut water was recorded for all the selected cultivars. Total sugars were estimated following the phenol-sulphuric acid method of Dubois *et al.* (1951). Reducing sugars were estimated by the copper reagent—ammonium molybdate method (Somogyi, 1952) and free amino-acids by the method developed by Yapinlee and Tunekazu Takahashi (1966). Sodium and potassium were estimated using a flame photometer (Jackson, 1973).

Scoring Method

Anderson's method (1936) was used for assigning weightage and scores for each character depending upon their relative importance in contributing to sweetness, consumer acceptability and cultivator preference (yield). The range of values for each character was divided into five class intervals and were considered as score values (1 to 5). The scores and weightages given to each character are presented in Table 19.1. A maximum score of five was given in the ascending order of increasing volume/quantity of nut water, total sugars, reducing sugars, free amino-acids and nut yield, and in the descending order for decreasing quantity of sodium and potassium. The consumer's preference for a tendernut cultivar with fairly high volume of nut water, maximum sugar content and low sodium and potassium contents, and cultivator's preference for high nut yield is assumed. An index score for each cultivar was worked out by adding individual score values. A total weightage of 20 was given for all the characters. A weightage of six was given for total sugars and nut yield assuming cultivator/consumer's first preference for these two characters. Since reducing sugar content is also important, a weightage of three was given for this character. Next to sweetness, a consumer looks for a tendernut cultivar with fairly high volume of nut water. Hence a weightage of two was given for this character, while for free amino-acids, sodium and potassium, a weightage of one each was given.

Table 19.1: Weightage and scores

	Volume of water (ml)	*Sugars (g/100 ml)*		*Free amino-acids (mg/100 ml)*	*Na (ppm)*	*K (ppm)*	*Annual nut yield per palm (Nos.)*
		Total	*Reducing*				
Weightage	*2*	*6*	*3*	*1*	*1*	*1*	*6*
Scores							
1	200–250	4.6–5.0	3.0–3.3	1.2–1.3	36–39	> 2630	50–70
2	251–300	5.1–5.5	3.4–3.7	1.4–1.5	32–35	2471–2630	71–90
3	301–350	5.6–6.0	3.8–4.1	1.6–1.7	28–31	2311–2470	91–110
4	351–400	6.1–6.5	4.2–4.5	1.8–1.9	24–27	2151–2310	111–130
5	> 400	6.6–7.0	> 4.5	> 1.9	20–23	1990–2150	131–150

Organoleptic Test

Based on the biochemical parameters, four cultivars were selected for organoleptic evaluation, following a non-parametric statistical method (Siegel and Castellan, 1988) with the help of seven independent tasters. The nut water sample of each cultivar (treatment) was replicated 10 times and randomly placed. The tasters were asked to taste the nut water and rank them as follows:

Rank 1 for the best preferred
Rank 2 for the next preferred
Rank 3 for the third preferred
Rank 4 for the last preferred

The total score for each cultivar was worked out by adding individual score values of the tasters and Klendall's coefficient of concordance (w) was worked out.

RESULTS AND DISCUSSION

The mean values for four years (1988 to 1991) for the different biochemical parameters of nut water and annual nut yield are given in Table 19.2. The total volume of nut water showed significant differences among the cultivars. The minimum volume was recorded in Malayan Yellow Dwarf (MYD) (238 ml) and the maximum in Philippines Ordinary (PO) (451 ml). Significant cultivar differences were also seen in the case of total sugars, with Chowghat Orange Dwarf (COD) recording the maximum of 7.0 g/100 ml followed by Malayan Orange Dwarf (MOD) 6.7 g/100 ml. Fiji Longtongwan recorded the least total sugar content of 4.9 g/100 ml. The reducing sugar content also varied from 3.0 g/100 ml to 4.7 g/100 ml. Here also, COD recorded the maximum reducing sugar content of 4.7 g/100 ml. In the case of free amino-acids, Andaman Ordinary (AO) showed the highest content of 2.1 mg/100 ml of nut water followed by Guam III (2.0 mg/100 ml). Significant differences were also observed between cultivars in respect of sodium and potassium levels. The potassium levels ranged from 1,998 ppm in Malayan Yellow Dwarf to 2,797 in

WCT. Lower K levels were recorded in MYD and COD. The lowest level of sodium was recorded by COD (20 ppm). The mean annual yield of nuts ranged from 53 to 149 nuts/palm with COD recording 67 nuts/palm/year. Though the yield of COD is comparatively low, the yield could be improved by harvesting only the tender coconuts. A recent study by Chatterjee and Ghose (1990) on the comparative economics of harvesting tender and mature coconuts showed that the gross return from the harvesting of tender nuts comes to Rs 92 per palm compared to Rs 80 per palm by harvesting only mature nuts. The individual scores obtained in the 12 coconut cultivars for the different tendernut characters and nut yield and their index scores are given in Table 19.3. It is seen that the COD registered the maximum index score of 73 followed by MOD (68) and PO (67). This shows that COD with maximum index score of 73 was preferred as a cultivar for tendernut purpose on the basis of nutritional parameters. The fact that COD is having higher contents of total and reducing sugars, accounts for its sweetness and pleasant taste as also reported by Jayalakshmi *et al.* (1988). The lower content of sodium, potassium is also another factor which enhanced the consumer acceptability to a greater extent. This coupled with an appreciable nut water volume (351 ml) favours the choice of COD for the tender nut purpose.

Table 19.2: Biochemical constituents of tendernut water and nut yield in 12 coconut cultivars (Mean values for 1988 to 1991)

	Volume of water (ml)	*Total sugars (g/100 ml)*	*Reducing sugars (g/100 ml)*	*Free amino-acids (mg/100 ml)*	*K (ppm)*	*Na (ppm)*	*Mean annual yield (nuts/ palm)*
New Guinea	358	5.8	3.0	1.4	2258	21	73
Phil. Ordy.	451	5.8	3.7	1.3	2273	24	113
Fiji Longtongwan	390	4.9	3.6	1.4	2641	29	105
Spikeless	275	5.3	3.2	1.7	2617	38	149
WCT	240	5.6	3.2	1.3	2797	37	92
Andaman Ordy.	274	5.3	3.3	2.1	2272	27	94
Jamaica Sanblas	263	6.0	3.4	1.7	2703	28	65
MYD	238	6.2	3.8	1.7	1998	36	53
MOD	303	6.7	4.1	1.8	2142	35	75
GB	267	5.6	3.5	1.7	2125	28	68
COD	351	7.0	4.7	1.8	2003	20	67
Guam III	278	6.0	3.7	2.0	2434	34	96
Gen. Mean	307	5.9	3.6	1.7	2355	30	
SE/Plot	101.7	1.2	0.79	0.51	258.0	9.0	
CD	73.0	0.89	0.56	0.36	185.1	6.4	

The sum of scores of organoleptic evaluations of the four selected cultivars namely COD, PO, MOD and Gangabondam (GB) indicated that COD had the least score of 73 followed by MOD (150), GB (228) and PO (248). To know

whether the random arrangement of the different types of treatment has any influence on the taster's ability to rank them in the order of preference, Klendall's coefficient of concordance (w) for the different random arrangements of the treatment was worked out. Based on the critical value it was concluded that the tasters essentially applied the same standard in ranking the cultivars irrespective of the random arrangements of the treatment. Thus organoleptic evaluation also confirmed that the COD will be highly acceptable to the consumers and can be taken as the best cultivar for tendernut purpose. Even though the yield is relatively low, the acceptability and economic returns from the tendernuts are factors which justify the choice of COD as the best tendernut cultivar.

Table 19.3: Individual score and index score for 12 coconut cultivars

	Individual scores for							*Index score*	
	Vol. of water	*TS*	*RS*	*FAA*	*K*	*Na*	*Nut yield*		
New Guinea	8	18	3	2	4	5	12	52	
Phil. Ordy	10	18	6	1	4	4	24	67	
Fiji Longtongwan	8	6	3	2	1	3	18	41	
Spikeless	4	12	3	3	2	1	30	55	
WCT	2	18	3	1	1	1	18	44	
And. Ordy	4	12	3	2	4	4	18	47	
Jamaica Sanblas	4	18	6	4	1	3	6	42	
MYD	2	24	9	3	5	1	6	50	
MOD	6	30	9	4	5	2	12	68	II
GB	4	18	6	3	5	3	6	45	
COD	8	30	15	4	5	5	6	73	I
Guam III	4	18	6	5	3	2	18	56	

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DISCUSSION

T. Ovasuru: What is your sample size? Have you tested individual palms in each population? Individual palms do have high sugar content.

S. Dhamodaran: The sample size was four palms per cultivar and one nut per palm. Variation within cultivar in respect of total sugar was found to be of smaller magnitude than that between cultivars.

Gaya Prasad: Can you explain the environmental effects on sugar content in coconut?

R.V. Pillai: The sugar content varied significantly from year to year; however, variety × year interaction was not found significant.

20

SELECTION CRITERIA OF HYBRID COCONUT SEEDLINGS

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Selection index to select the genetically superior seedlings from four ecotypes of Tall and Dwarf varieties and a hybrid VHC 1 was formulated with observations made on 13 characters including one embryonic leaf attribute. The investigation indicated the genetic superiority of the hybrid VHC 1 (East Coast Tall × Adhirampattinam Dwarf) followed by various ecotypes of Tall and Dwarf. The characters which contributed for high index score were duration taken for germination, length and width of the embryonic leaves, along with collar girth and height of seedlings at the fourth month. The use of index selection as calibrating variate to identify the superior planting material during their fourth month of growth is recommended.

UTILISATION OF COCONUT GERMPLASM IN THE BREEDING PROGRAMME IN PAPUA NEW GUINEA

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INTRODUCTION

The coconut palm (*Cocos nucifera* L.) is cultivated extensively, throughout the coastal mainland areas and on many islands in Papua New Guinea (PNG). The total area planted with coconuts in PNG has been estimated at 250,000 ha of which an insignificant proportion derives from selected planting material (Douglas, 1965). About 50 per cent of commercial plantings were considered to be approaching senility (Sackett and Williamson, 1973) and yields have further declined since then. Depending largely on age, copra yield per ha was estimated to vary from 0.5 to 1.0 ton/ha (Shepherd, 1981).

It has generally been recognised in the seventies that revival of the coconut industry required extensive replanting. To this end, the department of agriculture and livestock initiated, a hybrid coconut breeding programme during 1978 involving a number of Dwarf × Tall crosses. The Malayan Red Dwarf × Renell Island Tall (MRD × RIT) cross (in which both parents are exotic) was chosen for seed production and distribution to growers. Over wide areas this material proved commercially unsuccessful due to a devastating attack by the Dynastids *Scapanes* spp. and *Oryctes rhinoceros* followed by *Rhyncophorous* spp. The responsibility for continuation of coconut breeding work is now vested in the PNG Cocoa and Coconut Research Institute (PNG CCRI) but progress is not sufficiently advanced for presentation of performance data. The purpose here is to outline the criteria for the collection of germplasm within PNG and methods proposed for the most advantageous employment of the best of the available genetic resources in the breeding programme.

RESULTS

Data on fruit and nut characters, percentage of fruit and nut components, nut production and number of female flowers per spadix are given in Tables 6.1, 6.2 and 6.3. Other characters are not presented in this paper.

Karkar Tall

This is a well-known population which has been distributed widely throughout the world. The Karkar population originates from Karkar Island in the Madang province growing on soils dominated by recent volcanic ash deposits, and usually with high base and organic matter status. The ecotype has spread to other areas. This study revealed that many of the best Karkar populations are to be found among small-holder plantings.

West New Britain Tall

This ecotype is found in West New Britain province and is also notable for palms with large fruit and good endosperm content.

East Sepik Tall

The East Sepik Tall is found in the East Sepik province. The province includes a great deal of swampy land where the sago palm (*Metroxylon* spp.) provides a staple dietary item for much of the population. The sago palm is an alternate host for the palm weevil, *Rhynchophorus bilineatus*. This pest is fairly well controlled by human population because it forms part of their diet. The Sepik Tall population may have some resistance due to its long association with *R. bilineatus* and *Scapanes australis*.

Markham Tall

The Markham Tall cultivar is grown extensively along the Markham valley in the Morobe province. This ecotype is known for its large fruit weight and endosperm content. From the several sites measured in the valley, Markham Farm and Riara village appear to have superior cultivars. Both sites experience a marked dry season. Soil consists of black silty loam deposited by the Markham river and its tributaries. In Markham farm the palms are underplanted with cocoa which check the vigorous weed growth. Fruit weights are exceptionally high (3,669 g per nut) ranging from 2,850 to 4,575 g with very low variability (CV = 9). Nut weights are also high with an average of 2,444 g per nut, ranging from 2,050 to 3,000 g. The palms produce on an average 791 g endosperm per nut, ranging from 660 to 1,012 g. Water percentage of 49.9 is the highest recorded in PNG as would be expected in such a large-fruited type. Like the fruit weight the nut weight and the endosperm weights are less variable. This also applies to endosperm, husk and water percentage. However, the nut number and the number of female flowers per spadix are highly variable characters. The average nut count is 77 nuts per palm from observations made so far.

Individual and Population Selection

A considerable number of regional populations have been studied in the process of germplasm collection. The mean values and variation ranges for important characters for these populations have been determined from 20 to 30 trees taken at random. Individual palms have been selected on the basis of their phenotypic values.

In the selection process, the following practical guide-lines have been adopted:

a) Several localised 'tall' coconut populations in PNG are characterised by an obvious genetic uniqueness. In other cases, important differences have emerged only as a result of comprehensive measurements.

b) Weaknesses in selections based on phenotype are effectively reduced by confining such work to areas which are relatively uniform with respect to age, spacing, drainage and soil homogeneity.

c) Emphasis in selection work in tall populations is placed on those characters of economic importance which are also highly heritable.

Progeny Testing

Since individual trees of a particular ecotype from population selection are selected on the basis of their phenotypic values, superior genotypes for breeding purposes can only be identified through progeny testing. The following crossing programmes are being carried out in an attempt to capture both additive (GCA) genetic effects and non-additive genetic effects (SCA).

A) *Dwarf* × *Tall*

Currently, hybrids between Dwarf and Tall are recognised as the most productive planting material in many coconut growing countries. The North Carolina Model II (Comstock and Robinson, 1948) (NCMII) provides the best mating design suited for the Dwarf × Tall progeny trials. Dwarf ecotypes are used as female parents because of their homozygosity, their low stature which greatly simplifies problems in artificial pollination and because colour marker genes (in most cases), permit ready identification of accidental 'selfs' in sprouted seedling progenies. Tall ecotypes mainly from local selections, are used as male parents (Table 21.1).

In the PNG programme, more than 50 trees from each of the four dwarf ecotypes (Malayan Red Dwarf, Malayan Yellow Dwarf, Nias Yellow and PNG Brown) have been used. Each female ecotype is to be crossed with five tall ecotypes to be chosen (Table 21.1). The pollen representing each tall ecotype was collected from 10 individual tree selections. Performance of individual crosses will be separable from compound results for Dwarf × Tall ecotypes. The parents included in the crossing programme are considered as fixed effects, and GCA and SCA of both the parental ecotypes and individual tall can be estimated according to the method described by Gerhold and Park (1986).

Table 21.1: Nut characters of some 'tall' ecotypes from germplasm collection

Location	*Fruit wt. (g)*	*Nut wt. (g)*	*Endosperm wt. (g)*	*Endosperm thickness (mm)*	*Endosperm/ nut (%)*
East New Britain					
Raulawat	2157	1300	567	13.2	43.5
Natava	1955	1196	496	12.3	41.6
Pellavarus	2400	1414	587	13.0	41.9
Ultava	2356	1499	620	13.2	41.8
West New Britain					
Gaungo	1948	1383	625	13.7	46.2
Naviro	2431	1737	686	12.6	39.7
Morobe Province					
Riala	3321	2171	805	12.9	37.5
Markham	3824	2643	871	12.5	33.1
Madang Province					
Kaul	2654	1664	675	14.3	40.7
Kinim	2157	1517	632	13.1	42.0
Mangar	2622	1632	646	13.7	39.7
Katom	2372	1530	636	13.0	41.7
North Solomon Islands					
Thomas Farm	2760	1714	680	—	42.0
East Sepik Province					
Wamain	2209	1654	630	12.6	38.9
Kwakie	2633	1917	707	10.6	37.5
Gwelikum	2357	1642	610	11.9	37.4
Anglangir	3132	2165	779	12.3	36.2
Yangouru	2845	1860	668	11.5	35.9

B) *Tall* × *Tall*

In T × T crosses, those ecotypes with a high number of nuts per bunch will be used as female parents whereas male parental lines will comprise selected ecotypes in which endosperm weight per fruit is particularly high. Suitable material is available from the wide genetic range of locally adapted tall ecotypes from several districts in PNG. Ecotypes characterised by high endosperm weight per nut are Markham, North Solomon, West New Britain and Sepic Talls, whereas Raulawat, Natawa and Karkar Talls are characterised by a higher number of nuts per bunch.

C) *Dwarf* × *Dwarf*

A diallel design crossing programme (Griffing, 1956) to combine a wide range of dwarf ecotypes including both local and exotic varieties is in progress with the objective of creating new types of dwarf coconut (Table 21.2). Large differences are expected from these interecotypes crosses which should provide genetically diverse dwarf material for a future breeding programme.

Table 21.2: Mean values of female flowers number/spadix, fruit and nut character of coconut Dwarf ecotypes

Dwarf ecotypes	*No. of observations*	*Female flowers per spadix (no.)*	*Fruit wt. (g)*	*Nut wt. (g)*	*Endo-sperm wt. (g)*	*Endo-sperm thick-ness (mm)*	*Husk/ fruit (%)*	*Nut component*		
								Water (%)	*Shell (%)*	*Endo-sperm (%)*
Malayan Red Dwarf	50	44.8	945	564	255	11.0	40.0	30.6	24.0	45.2
Malayan Yellow Dwarf	50	63.6	829	558	260	10.6	32.5	33.4	19.8	45.6
Nias Red Dwarf	8	37.6	785	519	248	10.9	33.6	30.2	21.9	45.9
Nias Yellow Dwarf	50	48.2	688	474	224	10.4	32.5	32.5	20.1	45.4
Nias Green Dwarf	41	57.1	785	519	248	10.9	33.6	30.2	21.9	45.9
PNG Brown Dwarf	50	217.3	1377	910	429	11.4	32.4	34.8	18.1	45.1
PNG Red Dwarf	33	128.0	558	354	164	9.6	35.8	25.0	28.2	45.8
Iokea Red Dwarf	3	96.5	1340	1006	309	9.2	47.5	47.5	20.9	33.6

Multi-locational Trials

Since coconuts are grown over a very wide range of environmental conditions in this country, genotype-environmental interaction is an important factor to be considered in the coconut breeding programmes. Therefore, it is considered that at least the most important progeny trials should be tested in several locations. There is little information in the literature about G × E studies in coconut.

New Cultivars

Since our coconut breeding programme is intended to develop planting material which will adapt to a wide range of growing conditions, the development of multi-line or mixed cultivars seems to be the most appropriate approach. This multi-line cultivar will be a mixture of different hybrids which are similar agronomically but different in their genetic constitution. The mixture can also be a combination of selections which will benefit from their mutually complementary characters in a compensatory manner.

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22

SELECTION INDICES IN COCONUT

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A study was carried out at the Regional Agricultural Research Station, Pilicode during the year 1990 with the objective of selecting the promising seed material in coconut by using the discriminant function analysis suggested by Fisher (1936). Eighty palms belonging to 15 hybrid combinations and WCT planted in 1973 (Table 22.1) were selected for the study.

Observations on the following quantitative characters were recorded.

1) Number of leaves produced in 1989.
2) Total number of leaves produced from 1973 to 1989.
3) Number of nuts produced in 1989.
4) Cumulative production of nuts since first flowering.

Significant differences among the hybrid combinations were observed for all the four characters studied. The hybrid Andaman Ordinary × COD produced the maximum number of leaves in 1989 while the total production of leaves was maximum in hybrid WCT × GB (Table 22.1). These two characters showed low heritability and genetic advance (Table 22.2). Among the hybrid combinations WCT × MYD and WCT × CGD emerged as the two most promising hybrids based on the nut production during the year of study and the total nuts produced till date.

Discriminant Function

The discriminant function is represented by the relation

$I = b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$

where I is the selection index

b_1, b_2, b_3, b_4 are the relative weights assigned denoting their genotypic contribution to yield.

x_1, x_2, x_3 and x_4 are the overall mean of the hybrid 1, 2 etc. in each character.

For the hybrid studies the I value = $-0.722011\,\bar{x}_1 + (-0.358693\,\bar{x}_2) + 0.028268\,\bar{x}_3 + 1.21201\bar{x}_4$. The value of I is found to range from 329.00 (WCT) to 1007.18 (WCT x MYD) as presented in Table 22.3.

Table 22.1: Leaf production and yield in hybrid combinations and WCT

S. No.	Hybrids/Cultivar	No. of leaves produced in 1989 ($\bar{x}_1$)	Total number of leaves produced till date ($\bar{x}_2$)	No. of nuts produced in 1989 ($\bar{x}_3$)	Total number of nuts produced till date ($\bar{x}_4$)
1.	West Coast Tall × COD	14.0	187.2	163.8	750.8
2.	Cochin China × COD	13.4	181.2	117.0	483.6
3.	Andaman Ordinary × COD	15.0	185.2	149.8	574.8
4.	Laccadive Ordinary × COD	13.2	175.4	114.6	529.4
5.	Fiji × COD	12.6	184.6	142.8	682.2
6.	Fiji × GB	14.4	186.4	94.6	453.2
7.	West Coast Tall × MYD	13.8	185.0	*204.6*	*889.2*
8.	West Coast Tall × TBL	14.4	185.8	191.2	629.8
9.	West Coast Tall × SS	13.8	189.0	148.4	687.0
10.	West Coast Tall × COD	12.8	189.0	*184.4*	*876.6*
11.	West Coast Tall	13.8	174.0	75.6	329.4
12.	Chowghat Orange Dwarf × WCT	13.2	176.8	123.8	470.4
13.	Chowghat Orange Dwarf × LO	12.6	169.4	94.4	330.2
14.	Gangabondam × LO	14.6	183.2	115.4	411.4
15.	West Coast Tall × LD	12.8	174.8	163.0	656.6
16.	West Coast Tall × GB	14.4	*190.6*	124.6	567.6
	Grand Mean ($\bar{x}$)	13.7	182.4	138.0	582.64
	CD	1.44	12.54	62.1	231.50

COD : Chowghat Orange Dwarf
SS : Strait Settlement
GB : Gangabondam.
LO : Laccadive Ordinary
LD : Laccadive Dwarf

Table 22.2: Genetic parameters of the characters studied

	Character	Phenotypic variance	Genotypic variance	Heritability (%)	Genetic advance	Mean	Genetic advance as percentage of means
x_1	No. of leaves produced in 1989	1.342	0.389	28.99	0.692	13.68	5.06
x_2	Total number of leaves produced till date	112.99	22.10	19.56	4.28	182.35	2.34
x_3	No. of nuts produced in 1989	3,151.99	923.55	29.30	33.89	138.00	14.56
x_4	Total number of nuts produced till date	53,883.44	22,914.95	42.53	203.37	582.64	34.91

Table 22.3: Ranking of hybrids/cultivars based on the index value

Rank No.	*Hybrid/cultivar*	*Index value*
1.	WCT × MYD	1007.81
2.	WCT × CGD	990.63
3.	WCT × COD	879.03
4.	WCT × SS	759.09
5.	Fiji × COD	755.56
6.	WCT × LD	728.47
7.	WCT × TBL	691.69
8.	AO × COD	634.47
9.	WCT × GB	612.70
10.	LO × COD	572.43
11.	CC × COD	514.04
12.	COD × WCT	500.68
13.	Fiji × GB	474.70
14.	GB × LO	425.63
15.	COD × LO	333.01
16.	WCT	329.00

WCT :West Coast Tall
MYD : Malayan Yellow Dwarf
CGD : Chowghat Green Dwarf
CC : Cochin China
TBL : Tembili.

Selection of coconut hybrids by considering all the characters simultaneously can be done by using the discriminant function analysis. The mean values of four characters studied showed significant differences among the hybrids, indicating existence of variability. Cumulative nut production in early years will be the best yardstick to select a hybrid rather than the other characters studied.

Based on the selection indices worked out in the present study WCT × MYD and WCT × CGD emerged as the best hybrids with index values of 1007.81 and 990.63 respectively. Those two hybrids performed better than the popular WCT × COD hybrid.

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BIOTECHNOLOGY AND PHYSIOLOGY

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CURRENT STATUS OF COCONUT TISSUE CULTURE IN THE UNITED KINGDOM

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ABSTRACT

Vegetative propagation of coconut has been achieved through a somatic embryogenesis system, but the yield of plantlets is low. Inflorescence explants are cultured to give a calloid which produces somatic embryos, but the majority are not normal. A few clonal plants have been produced over several years from more than 20 mother palms, but it is not yet possible to produce large numbers. The somatic embryos often produce haustorial type tissues and calloid can be regenerated from this using a high auxin treatment.

INTRODUCTION

Tissue culture of coconut has been carried out in the UK at several centres during the last 20 years, but Wye College is the only laboratory to have maintained a continuous programme. In 1970 the British Government's Overseas Development Administration (ODA) started a project at Wye to develop a method of clonal propagation for coconut, but this funding ceased in 1980 and the German Development Agency, GTZ, have since provided support as part of their aid programmes, initially to Tanzania and latterly to the Philippines.

Additional support at the Wye has recently been received from ODA, and a joint programme with Mexico, funded by the European Commission, has just started. Thus, Wye is now in the fortunate position of having joint programmes with the Philippines and with Mexico, a situation which facilitates rapid exchange of information.

CLONAL PROPAGATION

Clonal propagation has been the main aim of the programme at Wye, and the research until 1988 has been reviewed by Blake (1990). The early work at Wye

resulted in the formulation of the Y3 medium (Eeuwens, 1976). This medium was based on that of Murashige and Skoog (1962) (MS) but with considerable alteration to the microelements. The medium now used at Wye combines MS macroelements with Y3 microelements. Explant material is normally immature inflorescence (variety Malayan Dwarf) sent by air from the Coconut Industry Board in Jamaica. Recently, material has also been received from the Philippines and Mexico.

Explants of immature inflorescence tissue are initially cultured on a high 2,4-D medium (10^{-4} M) in the presence of activated charcoal (0.25 per cent). Calloid development occurs from the floral meristems on a proportion of the explants, but the success rate is very variable. Despite extensive trials it has not been possible to develop calloid on a medium from which charcoal is omitted. However, once a good calloid is developed, it can be cultured on a lower level of 2,4-D without charcoal. Although cytokinin appears to be necessary in the production and subculture of calloid, it has not been possible to determine an optimal level.

Further development of a good calloid has proved erratic. Some embryoids have been obtained after lowering the 2,4-D concentration and clonal plants have been developed from over 20 different mother palms, but they have only been obtained in small numbers. The calloid produces a range of developments such as roots, abnormal leafy structures or haustorial-type tissue. The production of haustorial tissue indicates that the calloid has gone through an embryogenic process, since the haustorium is a cotyledonary structure in the zygotic embryo. However, the culture conditions have not yet been optimised to obtain normal and balanced development of shoot, root and haustorial meristems. Current work is being directed to understanding the controlling factors in the process of coconut somatic embryogenesis.

Haustorial-type tissue which is obtained at low auxin concentrations can be re-cultured on to a high 2,4-D medium (4×10^{-4} M) when new calloid is initiated. This will go through the same sequence as the calloid developed directly on inflorescence explants and has yielded a plantlet. If subcultured for long periods of time on low levels of 2,4-D, this calloid becomes habituated. However, it is a tissue which is very easily multiplied and is being used to investigate the changes taking place during the transition from calloid to embryoidal structures.

FUNDAMENTAL STUDIES

It is clear from the lack of success in consistently obtaining clonal plants, that there is a need for much more understanding of the process of somatic embryogenesis. Although the addition of activated charcoal to the initiating medium seems to be essential, there is no clear understanding of its function or its effect on the availability of other media components. The elimination of this substance would allow determination of the effective levels of growth regulators in the culture medium, and thus enable more effective control of the system.

Tracer studies at Wye have shown that activated charcoal rapidly adsorbs a major portion of the 2,4-D from gelled medium and that this adsorption continues for several days. A relatively constant situation is attained about a week after the medium has been prepared (Ebert and Taylor, 1990). The concentration of available 2,4-D has then been reduced to approximately one-hundredth of the original value. This information may be employed to obtain a more accurate control of regulator level in culture media, by preparing them, for example, seven days before use. It seems that the nature of the gel affects the time taken to achieve such an equilibrium, the rate of diffusion being a major factor. This concept is supported by the rapid adsorption in liquid media where diffusion is not a constraint.

The introduction of plant tissue is an added complication to the system and such experiments are currently being carried out at Wye (Oropeza, unpublished). The results of these investigations with coconut tissue will give valuable information concerning the depletion of regulator levels in media and indicate how frequently transfers to fresh media should be performed. Equally important are observations on the formation of metabolites, their accumulation and their physiological effects on tissue explants.

Whilst the research at Wye has been concerned primarily with carbon-14 2,4-D and its interaction with activated charcoal, Jones (unpublished) has used media without charcoal and studied the metabolism of cytokinins.

After a 24-hour incubation of coconut callus, about 70 per cent of exogenously applied benzyladenine had been taken up and metabolised into the riboside and the ribotide. Such studies concerning the availability, uptake and metabolism of synthetic auxins and cytokinins must be seen as an essential component of research towards the successful tissue culture of coconut.

ZYGOTIC EMBRYO CULTURE

Zygotic embryos have been transported successfully for culture in the UK. They can be excised aseptically from the nut and placed in a sucrose-coconut water medium for transport. Germination can occur after more than two weeks in transit at ambient temperatures, but it is somewhat slower than when embryos are cultured immediately. This may be partly a reflection of their increased age as coconut embryos are recalcitrant and germination is reduced with increasing time after maturity. Embryos have also been successfully transported within copra cores by the method of Rillo (1990).

Successful germination in a liquid medium is followed by culture on a gelled medium. Both media are basic Y3 or MS/Y3 with activated charcoal but without growth regulators (Rillo, 1990). A good root system is not always developed without a rooting treatment, but once good primary and secondary roots are formed, establishment into a coir/grit mixture or into a Nutrient Film Technique (NFT) system has been satisfactory.

Plants from cultured zygotic embryos have been maintained satisfactorily in an NFT system for two years at Wye and have produced a new leaf each month, which is comparable with the development observed in the field. This

suggests that the availability of ample moisture and nutrients around the root system more than compensates for the low light intensity experienced in the winter in the UK.

Zygotic embryos of 10 coconut varieties have been brought in from the Solomons and Indonesia and successfully cultured by Unifield TC Ltd (Lord and Eeuwens, personal communication). Over 5,000 embryos were cultured initially and, overall, well over half were potted and established (Table 23.1). Just under half of the original total were successfully established in the field in Colombia, Zaire and South Africa.

Table 23.1: Coconut embryo culture: performance in culture and establishment in the field (Data from Lord and Eeuwens)

Variety	*Number cultured*	*Plants potted*		*Plants surviving in field*	
		number	*%*	*number*	*%*
Nias Yellow Dwarf × Bali Tall	657	485	74	447	68
Kima Atas	130	48	37	39	30
Nias Yellow Dwarf	387	221	57	215	55
Mapanget Tall	221	84	38	72	32
Bali Tall	359	197	55	150	42
Tenga Tall	42	18	43	4	10
Malaysian Red Dwarf × Rennell Tall	2000	1443	72	1267	63
Malaysian Red Dwarf	476	182	38	115	24
Rennell Tall	520	224	43	110	21
Solomon Tall	447	97	21	71	16
Total	**5239**	**2999**	**57**	**2550**	**49**

Results at Unifield and at Wye indicate that although embryos may be transported over extended periods of time, they will still give a reasonable percentage germination. Repetition of these early trials would undoubtedly result in overall improvements. The results of shipment of plants from Unifield suggest that once clonal plants are developed, there should not be too much difficulty in their transport and establishment in the field.

RESEARCH IN GERMANY

Coconut tissue culture research has been carried out in Gottingen between 1986 and 1991. Hagedorn (1990) cultured coconut tissue and obtained callus and somatic embryogenesis. The explants were apical and sub-apical stem tissues from two-year old seedlings. The main work investigated the influence of different media and media additives, including auxins, cytokinins, vitamins and organic nitrogen compounds. Hornung (unpublished) studied the effects of various sugars and 2,4-D concentrations on callus proliferation.

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DISCUSSION

R.D. Iyer: Have you noticed any direct transformation of floral meristems into vegetative shoots as it happens in bulbil production in coconut?

J. Blake: We have obtained only partial reversion of floral meristems to the vegetative stage with the production of a continuing series of bracts but at no time leaf formation was seen.

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COCONUT TISSUE CULTURE IN INDIA: STATUS AND PROSPECTS

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ABSTRACT

The first report of successful induction of somatic embryoids and their subsequent organisation into clonal plantlets was from CPCRI in 1984. Using tender leaf segments from one to two-year old WCT seedlings, somatic embryoids were induced in 16 weeks on a modified Y-3 medium supplemented with high levels of auxin (NAA), inositol and casein hydrolysate. After a process of hardening, four of these plantlets have been successfully field planted in January 1989 and are growing well. More recently, with a view to reproducing the above success with mature palm tissues, a non-destructive method of tissue extraction has been standardised. Rachilla explants have so far given only shoot-like outgrowths, but no true leaves yet, whereas anther culture gave only multi-celled pollen embryoids.

INTRODUCTION

A survey conducted by CPCRI scientists has brought to light several elite disease-free coconut palms showing unusually high yields (over 470 nuts/year), although many of these are growing in root (wilt) disease-affected 'hot spots' of Kerala (Iyer *et al.,* 1979). If such rare single super palms could be propagated clonally through *in vitro* approaches, this would certainly open up tremendous possibilities of breaking the yield barrier in coconut. With this objective in view, attempts have been made in different laboratories to establish *in vitro* cultures of vegetative explants from seedling as well as adult palm tissues, including floral tissues.

Besides clonal propagation, work has also been done on standardising an embryo-culture technique with twin objectives: (i) to obtain viable rooted plants which could be used for further experiments on clonal multiplication using these aseptically produced seedlings, and (ii) to collect embryos and retrieve coconut germplasm in field expeditions, so as to obviate the need for

whole nut collection now becoming problematic in view of the bulky nature of seed which restricts the size of each accession, quarantine difficulties, and the high cost of air transportation of whole nuts.

Work Done in Different Laboratories in India

A survey of published literature on coconut tissue culture has revealed that nine centres have been engaged in this work, in different university as well as national laboratories. These are dealt with here in chronological order of their reporting in publications.

1. Department of Botany, Kerala University, Trivandrum

Abraham and Thomas (1962) have the credit of publishing the earliest paper on coconut embryo-culture. They scooped out the embryo along with surrounding endosperm, from the large eye of a ripe coconut, and the embryo measuring 7.5 to 10 mm long and 5 mm wide was then separated and transferred to a modified White's medium (White, 1943), supplemented with Nitsch's minor elements (Nitsch, 1951), cobalt chloride (25 ppm), White's vitamins (two and a half times that of White, 1954) and 50 ppm Ca-pantothenate, ferric citrate (10 mg/l), 3-IAA (2 mg/l), casein hydrolysate (200 mg/l), agar (0.8 per cent) and sucrose (20 g/l). Coconut water extracted from tender nut by sterile syringe was added to autoclaved medium cooled to 40°C, in 2 : 1 ratio. The cultures were kept at room temperature (15° to 28°C). In two months, the coleoptile emerged at the blunt end of the embryo, the first leaf appeared in four months, and was completely developed in six months. However, the root growth was rudimentary. No further progress was reported by these authors.

2. Central Plantation Crops Research Institute, Kasaragod

As a sequel to the recommendations arising out of the First International Symposium on Coconut Research and Development (ISOCRAD-I) and the special study groups held in December, 1976 at CPCRI, Kasaragod (Iyer *et al.*, 1977), a tissue culture facility was established by the author in 1977.

Work on Rachilla Tissues

Coconut rachillae explants were cultured *in vitro* to explore the possibility of converting the floral primordia into vegetative shoots as indicated in the paper presented by Prof. Schwabe (1983) at the ISOCRAD-I. Although bulbil formation is a known phenomenon in certain freak mutants of coconut (Iyengar, 1922; Davis, 1948), these bulbils do not strike roots in nature. However, Davis *et al.* (1981) have succeeded in air layering these bulbils, and raised these clonal palms in soil, but they again produced only bulbils instead of normal flowers. Nevertheless, this was the first demonstration of clonal propagation of coconut *via* the naturally occurring bulbils (Sudasrip *et al.*, 1978).

Our attempts at CPCRI to culture immature rachillae explants excised from the first to the third leaf axil after the unopen spindle, resulted in formation of shoot-like structures, some of which turned green and even

formed roots on Y3 medium (Eeuwens, 1978) supplemented with cytokinins 6-BAP and 2-ip (2 mg/l each). This transformation was noticed in over 50 per cent of the floral primordia. It was possible to excise a responding spadix without damaging the shoot meristem of the palm. Browning of explants was severe in older spathes, and addition of 5 of 10 g/l activated charcoal reduced this considerably. However, so far no viable plantlet could be obtained from floral primordia *in vitro* (Kuruvinashetti and Iyer, 1980; Iyer, 1982).

Leaf Tissue Culture

Work on tender leaf tissue culture was initiated in 1982 using one to two-year old WCT seedlings from the nursery. Seedling tissues from apices, tender leaves, leaf bases and leaf sheath were cultured initially on Y3 basal medium supplemented with various combinations of auxins (NAA and 2,4-D) and cytokinins (Kinetin, BAP and 2-ip). The cut surfaces of tender leaf bases of one-year-old seedlings showed profuse callusing on 2,4-D (10 mg/l) and Kinetin (0.5 mg/l) media whereas tender leaf lamina segments showed only limited callusing (Raju *et al.,* 1982). Subsequently, these leaf cultures produced rooting profusely. In order to induce somatic embryogenesis these leaf cultures were subjected to a wide range modified Y3 media (Anon. 1985) in a broad spectrum experiment running into 2,430 combinations involving varying concentrations of the components. This resulted in the induction of somatic embryoids after 16 weeks in 12 per cent of the explants, which could be shortened to three weeks by adjusting Mg : K ratio, and optimising the hormone level, avoiding the use of 2,4-D. A single leaf explant could give up to 48 somatic embryoids which after 45 to 60 days of maturation became detached from parent leaf tissue. Anatomical studies indicated that these somatic embryoids probably arose from the phloem cells of the vascular bundles of leaf vein. The individual embryoid had a tripolar structure with root and shoot poles and an incipient haustorial bulge. Initially, the shoot growth was promoted by cutting away the root pole and part of the haustorium. However, in subsequent experiments, reducing auxin to 75 per cent and increasing cytokinin 125 per cent has resulted in successful sprouting of the embryoids to give a normal green shoot with scale leaves and sheathing leaf base, a primary root with root cap, and an incipient haustorium (Raju *et al.,* 1984).

A technique for the extraction of the tender spindle tissues without damaging the single meristem of the mature palm, has been standardised. The central column of the spindle is exposed by removing two whorls of leaves outside the spindle, and cutting away the spindle 15 to 20 cm above the shoot meristem. The exposed tissues of the palm are then treated with insecticide (endosulfan) and fungicide (Bavistin), and covered by polybag to prevent infection. The severed spindle column is then brought to the laboratory in a polybag, the outer sheaths removed and swabbed with alcohol for surface sterilisation. The tender leaf tissues are then quickly dissected and bulk-inoculated into liquid media initially. Subsequently, each of these bulk-inoculated tissues are further subcultured as 1 cm segments containing a minimum of

three folds of the unopen leaf. In this manner, from each palm nearly 2000 to 2,500 cultures could be established.

Constraints Experienced in Achieving Repeatable Results

One of the constraints in working with coconut seedlings or mature palms is the plant to plant differences in genotypic response, since each time we sample a different seedling or adult palm. Apart from this, there is also the possible variation in physiological maturity of different regions of the spindle leaf tissues. There is seasonal variation also in response of tissues *in vitro*. Those sampled in June, July and August gave a higher rate of somatic embryoids than those sampled at other times.

Browning of tissues is another constraint which has been tackled by: (a) incorporating activated carbon in the medium (1 g to 3 g/l) to absorb the polyphenolic exudates, (b) the use of antioxidants such as ascorbic acid (100 to 300 ppm) and cystein-HCl both in the medium and for dipping the explant prior to transfer to medium, (c) using liquid medium with filter paper bridges, and frequent transfers to fresh medium in the induction phase of culture, and (d) avoiding the use of phenolic auxins such as 2,4-D or to use them in very low concentrations, and reducing the duration and concentration in each passage.

Preponderance of root formation at the cost of shoot was seen in leaf tissue cultures. This could be overcome by aseptically severing off the root pole along with a portion of the haustorial bulge of the tripolar somatic embryoid.

Embryo Culture for Germplasm Collection, Transport and Conservation

The collection of coconut germplasm and their transport to one's own country has now become not only too expensive but is wrought with quarantine risks.

Hence, techniques for aseptic collection of embryos under the palm itself, their storage, transport and retrieval had to be standardised (Raju and Bavappa, 1987). Using a simple portable equipment weighing about 4 kg and measuring 40 × 30 × 8 cm, up to 100 embryos could be collected in the field aseptically in a culture tube measuring 25 × 150 mm, and on subsequent transfer to fresh media gave 95 per cent germination (Anon. 1990). In an earlier trial zygotic embryos excised from immature coconuts and cultured in January, 1987 were found to remain viable even after two years of storage without any environmental control and periodic transfers (Anon. 1989). Presently, a systematic trial is underway using embryos extracted in the field from eight, 10, 11 and 12 months old nuts and brought to culture, to see the relative recovery percentage of viable plants.

Field Planting of Clonal and Embryo Culture Derived Plants

During January 1989, four tissue culture raised clonal plants, derived from tender leaf explants of one year old WCT seedlings, and two embryo culture derived seedlings of WCT cultivar which had been maintained in pot culture in a green house, were transplanted in the field. The pit for planting was filled

with a mixture of coir dust + farmyard manure + sand. All these plants have established and are growing vigorously (Anon. 1989).

Endosperm Culture

A fast growing friable callus was obtained from coconut endosperm which was in contact with zygotic embryo, and maintained by repeated subcultures on Eeuwens Y-3 medium containing 2,4-D (50 mg/l) Kinetin (2 mg/l) and 1 g/l activated charcoal and with lowered auxin levels. Callus showed high aneuploidy and abundant oil globules when maintained for over eight weeks without subculturing. Hence, this system could be used for extraction of edible oil and other metabolites like cytokinins and amino-acids which are known to occur in the coconut endosperm tissue (Prakash Kumar *et al.,* 1985).

Future Thrust

a) While future emphasis will be on the use of mature palm tissues for clonal propagation, seedling tissues would also be used in a limited way for maximising response of somatic embryogenesis, their maturation and sprouting to give viable clonal plantlets. Clonal plantlets, if any, derived from adult palm tissues could also be subjected to further subculturing to produce somatic embryoids from juvenile leaf tissues.

b) The use of lower concentration of auxins, avoiding 2,4-D, and also of conjugated auxins like IAA-aspartate, IAA-alanine etc. would be emphasised especially when activated charcoal is being used in media, so as to ensure that the auxins are available in a stable form for the cultured tissues to respond at the induction phase of somatic embryogenesis (Neera *et al.,* 1986; Neera and Bagga, 1988).

c) High CO_2 concentration of the order of 20,000 ppm in the culture environment is reported to enhance sprouting of somatic embryos in cacao as well as oil palm (Figueira *et al.,* 1991). Hence, suitable chambers would be devised for subjecting the coconut leaf tissue cultures to high levels of CO_2 to achieve higher frequency of response.

d) Partial dehydration and water stress induced by osmo-regulants like PEG, is also reported to favour sprouting of somatic embryoids and their encapsulation. This method would also be tried on coconut somatic embryoids.

e) Use of translation inhibitors and antiauxins for temporary arrest of root growth in somatic embryos and to promote shoot elongation at a predictable frequency would be worth attempting (Sethi and Guha-Mukherjee, 1990).

f) Immature floral tissues will continue to be used to realise the transformation of the floral primordia into vegetative shoots and their subsequent rooting.

g) Induction of androgenic haploids through anther culture would also be tried more vigorously in view of some preliminary success obtained in inducing multi-celled pollen and early stages of embryogenesis (Iyer, 1982; Thanh-Tuyen and Guzman, 1983; Thanh-Tuyen, 1985).

h) Another area which has potential and deserves future attention is the isolation and culture of protoplasts in coconut as a tool for clonal propagation and genetic engineering studies. Haibou and Kovoor (1982) have reported the

successful isolation and culture of protoplasts from tender tissues of rachilla extracted without any damage to the palm. Raphide damage to protoplasts was reduced to a minimum by avoiding agitation in enzyme mixture and prompt removal of raphides upon centrifugation in a percoll gradient. These protoplasts regenerated cell walls within 24 hours, and cell division has led to the formation of micro-calli on agar media although at a low frequency.

3. Plant Research Laboratory, School of Life Sciences, Jawaharlal Nehru University, New Delhi

Under a five-year cess fund supported scheme financed by ICAR, entitled "Vegetative propagation of coconut palm through tissue culture", work was carried out by a 10-member team under Prof. Sipra Guha-Mukherjee, as Principal Investigator, during 1979–84 (Guha-Mukherjee, 1984). Much of the work was done on zygotic embryo cultures raised from seed-nuts sent from CPCRI. The major findings of this project are summarised below:

a) Callus was raised from various explants such as young (eight to 10-month old) zygotic embryos, on B5 medium with IAA-amino-acid conjugates (IAA-aspartate and IAA-alanine 2 mg/l).

b) Shoots and roots differentiated by transferring calli to B-5 + IAA-asp (2 mg/l) + Kinetin (2 mg/l) or NAA (2 mg/l).

c) Embryoids were formed on roots originating from callus as well as from sections of an embryo.

d) Complete plantlets were obtained on B-5 medium + NAA (0.5 mg/l) + BAP (2 mg/l) + PVP (1.0 mg/l). Three plantlets were obtained which could not grow further for transfer to soil due to poor root growth (Neera Bhalla-Sarin *et al.,* 1986).

e) Callus initiated from leaves, leaf bases, and apical meristems could not be subcultured or regenerated.

f) Other tissues tested, such as, endosperm (semi-solid and solid), apical meristem, leaf and leaf base, male flowers, anthers and rachilla, did not give repeatable response on the media tested (Neera Bhalla-Sarin and Suman Bagga, 1988).

g) Viable protoplasts were isolated after plasmolysing young leaves in 0.6 M mannitol, cutting into small bits and incubating in enzyme mixture of 1.5 per cent cellulase + 1 per cent macerozyme + 0.6 M mannitol at 5.8 pH for 16 hours followed by washing in B-5 + 0.6 M mannitol. Few divisions occurred on B5 with conjugated auxins.

4. Laboratory of Applied Biology, St. Aloysius College, Mangalore

Mature embryos of 'Tiptur Tall' and 'West Coast Tall' cultivars were cultured on modified Y3 medium (Eeuwens, 1976), to study the effect of sugar, coconut water, N and Cl levels on germination and growth of embryos — NH_4Cl was used at 803 mg/l, with sucrose (68.4 g/l) myo-inositol (102 mg/l), Thiamine (10 mg/l) and CW (120 ml/l). Cultures were kept at 26° ± 2°C under 14 hours illumination (D'Souza, 1980).

On basal medium without NAA, embryos germinated to produce coleoptile and roots. On transfer to NAA-medium before the onset of differentiation,

growth was stunted at lower NAA-levels (1 to 3 mg/l) whereas at higher levels (5 to 7.5 mg/l) and low chloride and high N-levels the cotyledonary sheath enlarged to form a callus consisting of 'protocorm' and bud-like structures, which on subculture to low (1 to 2 mg/l) NAA medium, produced roots with pneumatophores. The embryos developed better in liquid rather than on semi-solid media. Rooting was inhibited without high sugar levels. Haustorium was underdeveloped and darkened (D'Souza, 1980; 1982; D'Souza *et al.,* 1988).

The seedlings were first transferred to a sand-vermiculite mixture and kept under a plastic hood in a culture room. Roots did not develop further and the haustorium started decaying causing infection to the plant. If the haustorium was cut away the cut surface became infected. The above work was carried out by Dr. Leo D'Souza, Principal Investigator and his assistants under an ICAR Cess Fund Scheme during 1980 to 1983.

5. Department of Plant Morphogenesis, School of Biological Sciences, Madurai Kamaraj University, Madurai

Embryo-culture work was carried out under a C.S.I.R. financed scheme on "Experimental cloning of palms", using mature nuts of the West Coast Tall cultivar. Embryos isolated from mature seed-nuts after surface sterilization with 50 per cent alcohol, were planted on Eeuwens (1976) agar medium containing BAP, auxins (NAA) and GA_3, with ascorbic acid (AA) as antioxidant, and cultures were kept at 85 to 90 per cent RH, 30° ± 2°C in diffuse light. A balanced growth of root and shoot was achieved on a new medium named YNBG (Padmanabhan, 1982) consisting of Y-3 basic + NAA (1 mg/l) + BAP (0.5 mg/l) + GA_3 (0.5 mg/l) + AA (100 mg/l), which totally suppressed the release of polyphenols into the medium. Three types of roots were observed—the primary root, shoot and brownish adventitious roots induced in three weeks, and the ageing adventitious roots, white, wiry and pale ones formed in large numbers. The shoots formed eophylls in the order seen in germinating nuts. The culture-raised embryos were hardy and took five to seven weeks to form seedlings that could withstand transplantation to soil whereas in nature they took 12 weeks (Jagadeesan and Padmanabhan, 1982b).

In another experiment, Jagadeesan and Padmanabhan (1982a) dissected out explants of 10 × 5 mm size from cotyledonary, radicle and plumule regions of 20-day old WCT seedlings from aseptic embryo-cultures, and planted them on MS (Murashige and Skoog, 1962), SH (Schenk and Hildebrandt, 1972), and Y-3 (Eeuwens, 1976) basal media supplemented with NAA (0.5 mg/l) + BAP (1 mg/l).

The haustorial tissue showed more rapid callus formation and regeneration after initial enlargement, utilising the fatty acids. Being rich in nutrients and edible, haustorial culture might become a means of food production (Padmanabhan, 1988).

6. Tissue Culture Laboratory, Hindustan Lever Research Centre, Bombay

Work on tissue culture of coconut was initiated in 1977 using immature leaf explants for induction of callus and somatic embryogenesis (Bhaskaran,

1985). By modifying culture media it was possible to get somatic embryos both from induced callus and also directly from mid-rib region of leaf explant. Calli were induced from immature leaves obtained from coconut seedlings of five varieties and hybrids on media containing high auxin and low cytokinin. Somatic embryogenesis could be induced in calli by lowering the auxin level gradually.

Direct embryogenesis from the mid-rib region of leaf explants was also observed, the number of embryoids per 1 cm explant varying from 10 to 40. Histological studies showed that the embryoids originated from the phloem cells surrounding the vascular bundle without undergoing dedifferentiation to form a callus. Both direct and indirect (via callus) somatic embryogenesis occurred in similar culture conditions. However, the embryos arising from callus showed shoot and root apices as well as a well-developed haustorium like that in zygotic embryo, but those arising directly from leaf explant bypassing callus phase, were bipolar with shoot and root apices, with little evidence of the presence of a haustorium.

The somatic embryos arising *via* callus, on transfer to high-cytokinin media, germinated to give plantlets, whereas the bipolar are yet to be stimulated to give rise to clonal plantlets (Bhaskaran, 1985). According to Bhaskaran and Prabhudesai (1986), the propagules should be produced from a wide range of mother palm selections to avoid risk of monoculture, and to ensure interpopulation variation.

7. Division of Plant Tissue Culture, National Chemical Laboratory, Pune

Initial studies on WCT embryos of 5 to 10 mm size grown on Y-3 medium (Eeuwens, 1978) supplemented with auxins, cytokinins and activated charcoal, gave rise to whole plants, but attempts to transplant these to the field were unsuccessful (Mascarenhas *et al.,* 1988). In a detailed study, Gupta *et al.* (1984), showed that neither MS (liquid or solid) nor Y3 agar media supported growth of coconut embryos, but only Y3 liquid medium + CW (10 per cent) + BA (4.44 mg/l) + NAA (0.27 mg/l) gave plantlets in two to three weeks, without any antioxidant use. However, the initial size of embryo at culture was seen to be important, the larger sized ones (7 × 4 mm) being more suitable for getting complete plantlets. The cultures were kept at 27°C under 16 hours light regime of 1500 lux, and at 25°C in darkness for eight hours. Plantlets were transferred to polybags containing a 3 : 3 : 1 mixture of soil : sand : compost, and kept at 25°C for four weeks in 16-hour photoperiod. When transferred to a glasshouse after emergence of new leaves, the plants survived for four weeks and later withered and died. From mature trees, explants taken from young stem, leaf and rachilla tissues of young inflorescence, were cultured on Y3 liquid media without success. Best response was obtained on Y3 + 2,4-D (4.52×10^2 μM) + Ca pantothenate (2.1 μM) + biotin (4.10 μM) and activated charcoal (0.25 per cent), in which all tissues swelled and turned green in four to five weeks. Stem explants gave globular callus in 10 weeks but no organogenesis occurred even after subculture to fresh medium.

8. Tissue Culture Laboratory, Punjab Agricultural University, Ludhiana

Bajaj (1984) has studied the survival of frozen WCT zygotic embryos of 1 to 1.5 cm size. Following storage for one month, the embryos were partially dehydrated and then cut into two transverse halves. After pretreatment with cryoprotectant (7 per cent DMSO + 7 per cent sugar in MS liquid), the embryos were blotted dry, wrapped in sterile aluminium foils, and frozen by gradually lowering into liquid nitrogen for five minutes. They were thawed in warm water (35° to 40°C), washed, and cultured on MS + 2,4-D (0.2 mg/l) + NAA (0.5 mg/l) + Kinetin (0.1 mg/l).

The retrieved coconut embryos and their segments showed a lag period of four months without any sign of growth. This indicated the possibility of long-term conservation of coconut germplasm.

9. Biotechnology Unit, School of Genetics, Tamil Nadu Agricultural University, Coimbatore

Four different media (White's, Nitsch's, MS and Y3) were tried for coconut embryo culture using mature seednuts of Tall × Gangabondam hybrid, of which Y3 proved better than others. Frequent subculturing in differential medium promoted high shoot differentiation and leaf formation. These on transfer to Y3 + NAA (1.5 mg/l) and charcoal (0.1 per cent) produced roots (Kalamani and Sree Rangaswamy, 1990).

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DISCUSSION

I.S. Dua: Have you tried different ratios of cytokinins/auxins in the media and which cytokinins have you used?

R.D. Iyer: Auxin-cytokinin ratios were tried at several thousand combinations and at different intervals. The cytokinins tried were Kinetin, BAP, 2ip and zeatin riboside in various ratios with auxins, NAA, 2,4-D and IAA.

CURRENT STATUS OF COCONUT EMBRYO AND TISSUE CULTURE IN THE PHILIPPINES

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ABSTRACT

Coconut embryo and tissue culture researches in the Philippines started with the desire to mass propagate the Makapuno coconut, an economically important coconut mutant that does not germinate *in situ*. The late Emerita V. de Guzman of U.P.L.B showed in 1964 that embryo culture to rescue Makapuno embryo is possible. Through the years embryo culture has been greatly improved and is now routinely used to mass propagate Makapuno coconuts and transport embryos within the country for research and germplasm exchange. Very limited tissue culture work towards cloning the coconut is going on in the country mainly due to lack of financial resources to support a long-term research necessary for a crop such as coconut. The Philippine Coconut Authority is conjointly implementing with Deutsche Gesellschaft fuer Technische Zusammenarbeit (GTZ) GmbH, a tissue culture project to develop the coconut cloning technology up to a commercially viable level.

INTRODUCTION

Compared to an increasing world market demand for coconut and its by-products precipitated by a ballooning world population, coconut production does not seem to have improved satisfactorily. The Philippines, although still the world's biggest exporter of oil is no longer the world's biggest producer of copra (Coconut Statistics, 1989). The industry is assailed by many problems: the unstable copra market, inferior copra quality, poor domestic marketing system, low production, ravages of diseases like the *cadang-cadang* and *Phytophthora* bud rot and destruction brought about by natural calamities like strong typhoons and prolonged drought conditions.

Embryo Culture

Embryo culture of coconut in the Philippines is very safely claimed to have started with the desire to mass propagate the Makapuno, a high value coconut,

due to its relative rarity and its importance in the food industries. The Makapuno coconut is borne by Laguna Tall coconuts concentrated in the Southern Luzon area of the Philippines. Very sporadic occurrence is reported in various other provinces as well. The nut is filled with a jelly-like endosperm unlike the normal nut. The jelly-like endosperm is in great demand in the ice cream and pastry industries. The phenomenon is governed by a single recessive gene which explains its relative rarity (Zuniga, 1953). The tree is propagated by planting the normal nut from the Makapuno-bearing tree resulting in about 2 to 25 per cent Makapuno yield. The embryo does not germinate due to the abnormal surroundings it is in. However, it is normal in all aspects so that when it is excised and grown *in vitro* with the proper nutrients it develops into a normal tree. The yield of *in vitro* grown Makapuno palms goes up to 75 per cent Makapuno nuts. If assisted pollination is done on the tree, 100 per cent Makapuno yield could be attained.

A small Makapuno mass propagation facility was established at the UPLB in 1982 with Philippine Coconut Research and Development Foundation (PCRDF) funding to supply *in vitro* grown Makapuno palms to interested clients. It is run by two technicians with a 10 per cent success rate. A great improvement that shortens to almost half the culture time has been reported (Rillo and Paloma, 1990) with a transplanting success rate of 70 per cent. *In vitro* culture is now being routinely used to transport embryos within the country.

The Albay Research Centre of the Philippine Coconut Authority at Banao, Guinobatan, Albay, has for the past six years already been doing embryo culture of coconut in connection with studies on the dreaded coconut *cadang-cadang* disease. A technique to inoculate *in vitro* grown coconut varieties has been developed as an aid in screening coconut varieties against the disease (Rillo and Paloma, 1989). However, an overall standardisation of the procedure has yet to be achieved.

A hectare planted to *in vitro* grown Makapuno palms has just been established at the PCA-Albay Research Centre early this year to augment production of this economically important coconut mutant. The plantation is envisioned to supply materials for mass propagation and further research on this particular palm.

Tissue Culture

For more than a decade, work on coconut tissue culture had been conducted in various laboratories using different tissue explants such as zygotic embryos (de Guzman *et al.,* 1978; Gupta *et al.,* 1984; Bhalla-Sarin *et al.,* 1986; Thanh-Tuyen and Dionzon, 1986), roots (Fulford *et al.,* 1981), leaf explants (Raju *et al.,* 1984; Pannetier and Buffard-Morel, 1986), and inflorescence explants (Eeuwens, 1976; Branton and Blake, 1984). Coconut, however, proved to be a resistive crop to the oil or date palm tissue culture technologies. Nevertheless, sporadic and hardly any repeatable success has been reported (Branton and Blake, 1983; Raju *et al.,* 1984; Verdeil *et al.,* 1989) which shows that coconuts will lend to asexual propagation by tissue culture.

In the Philippines, the Philipinas-Kao Incorporated (PKI), a Filipino-Japanese Corporation based in Cagayan de Oro, the Visayas State College of Agriculture (ViSCA) in Baybay, Leyte, and the University of the Philippines in Los Banos are doing very limited off and on research work on coconut tissue culture.

Very limited sporadic publications came out through the years since de Guzman started the embryo culture of Makapuno coconut. Very recently, results of their attempts to asexually propagate the coconut palm have been presented by Rosario *et al.* (1989). They claimed to have regenerated plantlets from immature coconut embryo calluses. Unfortunately, these did not survive.

Sugimura and Salvana (1989) of the Philipinas-Kao, also reported some early successes towards coconut cloning using immature inflorescence tissues. Recently, Ceniza and Ueda (personal communication) claimed complete plantlet regeneration from inflorescence tissues both in Kao Corporation, Japan and Philipinas Kao, Inc. Philippines, laboratories. However, the problem of contamination and slow growth persist. The recent claim of Poonsapaya (1989) that geographical location can affect results of tissue culture researches could explain the isolated, hardly repeatable success claimed by cooperating groups working on the same crops and aspects of research.

Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH agreed to collaborate with the Philippine Coconut Authority to jointly implement the Philippine-German Coconut Tissue Culture Project to develop a vegetative means of propagating coconut to a commercially viable level and the project, which has a project horizon of 20 years, started in February 1989.

The first phase of three years will end in January 1992. The project has been reviewed and favourably endorsed to continue. A Memorandum of Agreement has been signed by PCA-GTZ for a second phase of another three years to commence in February 1992.

It is envisioned that, depending on the results obtained, satellite laboratories will be built in strategic places in the Philippines to disseminate the technology to provide a homogeneous, high-yielding coconut population to improve coconut production in the country.

It is a well-known fact that tissue culture is very effective in cloning a number of economically and commercially important plant species (Murashige, 1974), including oil and date palms (Corley *et al.,* 1977; Tisserat, 1981). However, due to the vast commercial implications of the coconut tissue culture technology, the cloud of secrecy of any progress in coconut cloning is increasing as the method is nearing perfection.

It should be pointed out, however, that the outlook is bright, though it will be years before vegetatively propagated coconut palms could be authenticated to be true-to-type due to its long juvenile period.

Anther Culture

Anther culture in many herbaceous plant species had been initiated following the success of Guha and Maheshwari (1964) on *Datura*. Anther

culture greatly helps crop improvement as inbreeding could be shortened to produce inbred lines.

The occurrence of a naturally occurring haploid coconut embryo (Thanh-Tuyen and de Guzman, 1983a) suggested that haploid coconut could be produced *in vitro*. However, no successful attempt in this regard has been documented in coconut.

Very little research has been reported on coconut anther culture. In the Philippines, there are only the works of Thanh-Tuyen and de Guzman (1983 a, b). In France, Monfort (1985) studied coconut androgenesis and successfully initiated embryos from anther culture. However, these promising early results have not been pursued to obtain plantlets. Currently, there is no work on anther culture in the Philippines.

APPLICATION OF TISSUE CULTURE TECHNOLOGY TO COCONUT

A. Breeding/Plant Improvement

For coconut, crop improvement is beset by a number of problems: its inability to be asexually propagated, long juvenile period, long life cycle, high heterozygosity, and its bulky nature as a crop.

Tissue culture technology could provide solution to some of these problems. Obtaining homogeneous material or cloning high yielding individuals could bring about a significant increase in the productivity as well as homogeneity of the plantation.

However, the application of tissue culture technologies for the development of asexual means of propagation of coconut is still at its developmental stage.

B. Germplasm Storage/Exchange

Germplasm conservation in palms is expensive, labour intensive and often impractical due to the lack of vegetative propagation system.

Coconut germplasm exchange in particular is again hindered by the size of the nut and the absence of dormancy resulting in quick germination *in situ*. The transport of the large nuts would be costly, especially if international exchange is envisaged.

In vitro culture of embryos would reduce the costs for transportation and would meet phytosanitary regulations. Micro-propagation may be coupled with cryopreservation to preserve rare and endangered species for further breeding and genetic studies (Anonymous, 1987).

C. Disease Screening/ Elimination

A working clonal propagation system for coconut could also be used to produce disease-free coconut palms as well as to provide the ideal homogeneous test plants to screen for resistance against dreaded diseases such as *cadang-cadang*.

D. Micro-propagation

The ultimate objective of the use of tissue culture in coconut is micro-propagation. With the available technology, clonal plantlets of elite

palms developed by breeding could now be mass produced in programmed time for massive replanting and planting programmes greatly saving on time, space and resources.

RESEARCHABLE GAPS

A. Explant and Nutrient Factors

Earlier workers hoped that the protocol for clonal propagation of oil palm, being a member of the same family, would also work for coconut. However, coconut proved to be a recalcitrant crop to work with after almost three decades of tissue culture work.

It seems that no single optimum nutrient medium exists or has been developed to allow growth and maintenance of the various explants from the various types at various times. Various factors influencing callus initiation, multiplication, development, and regeneration under controlled conditions have to be standardized yet.

B. Transplanting to Free-living Conditions

Coconut cloning would only be beneficial if plantlets are easily transplanted from the bottle to the soil with high percentage of success of survival. *In vitro* grown plants adapt to their culture environment very differently from those growing in free-living conditions, making it very difficult for them to acclimatize, once outside of *in vitro* conditions. Plantlets obtained by *in vitro* methods are initially small. In order to survive, the small plantlets have to undergo a critical transition period before they are capable of independent growth.

Considerable success in the culture of zygotic embryos has been reported (Assy Bah, 1986; Rillo and Paloma, 1990). The technique, however, to successfully wean plantlets to free-living conditions could still be greatly improved.

C. Quality Control Tests

In vitro culture of coconuts, in spite of the many advantages, runs the risk of somaclonal variation, particularly prominent in prolonged *in vitro* callus stage. The risk of finding clonal plantlets which are not true-to-type is one great apprehension which will take years to ascertain. But this should not deter us from pursuing taking the risk as the benefits from clonal propagation far outweigh such risk.

CONSTRAINTS IN THE ADOPTION OF TISSUE CULTURE METHOD OF PROPAGATION

Although many plant species can be multiplied economically very rapidly by *in vitro* micro-propagation methods (George and Sherrington, 1984), this is not the case with coconuts, which up to now are only propagated by seed. Since it is generally a cross-pollinated and highly heterozygous crop, a high seedling variation results which is a serious problem for a perennial crop with a life span

of 30 years or more. Low productivity in such crops could be due to a genetically variable population so that planting high-yielding clones could increase yield many fold.

Since the protocol for coconut cloning has not been perfected yet, establishing a tissue culture facility to study all the factors affecting the development of the technology will undoubtedly be tremendous. This is not to say more about the time, money and personnel required.

The Philippine Coconut Authority is mandated to undertake all research and development activities pertinent to the coconut industry. As such it has recently, under the auspices of the Secretary of Agriculture, created the National Committee on Coconut Tissue Culture to review all R and D activities of both government and non-government organisations undertaking coconut tissue culture. It will also help to raise funds to accelerate development of the technology and organise a technical working group to plan for a well-coordinated and directed coconut tissue culture research in the country.

CONSTRAINTS IN THE ADOPTION OF CLONAL COCONUTS

Early research work towards developing a technique to asexually propagate the coconut palm were done in developed countries like France and England, and not in the coconut-producing countries. The obvious reasons for this are the dearth of trained personnel and of the necessary equipment which are hard to come by in coconut-producing countries.

However, due to the global importance of the coconut palm, coconut-producing countries such as the Philippines, Thailand, Indonesia, India, and Sri Lanka have started researches towards cloning the coconut palm.

The possibility of cloning the coconut palm is real. But since it is foreseen that clonal coconut will be greatly different from the true seed, agricultural and economic constraints will be felt in its adoption. By its very nature and its limited root development, clonal coconuts will require considerable extra care and attention before being transplanted. The absence of the nut which provides nourishment through the haustorium during its juvenile stage necessarily requires extra care (Harris, 1989) than *in vivo* grown coconut seedlings and will need additional costs.

Another agricultural constraint is the yield potential of the clonal coconuts. Will the increase in yield expected of the clones be realised? The possibility of a negative answer is there and should not be ignored. It should be emphasised, therefore, that superior planting material will not perform any better than the standard material without giving them the utmost conditions.

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CURRENT STATUS OF EMBRYO AND TISSUE CULTURE IN COCONUT IN SRI LANKA

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ABSTRACT

Attempts were made to develop *in vitro* techniques for cloning coconut for germplasm collection, exchange and selection for stress. The immature embryo was found to be the best material for propagation research. Somatic embryogenesis from leaf tissues was direct but time consuming. Morphogenesis from leaf tissues is strongly determined by the physiological maturity of the palm as well as the leaf.

Embryo culture technology has been developed successfully for use in coconut germplasm collection and exchange programmes. Two packages, one for the laboratory and the other for field collection of explants are offered.

Feasibility of employing embryo culture technology in screening stress-tolerant coconut germplasm has also been investigated. Under water-deficit conditions, a comparatively higher survival rate was observed from putative drought-tolerant cultivars and heavy losses from drought-susceptible cultivars, even under moderate stress conditions.

INTRODUCTION

Coconut is still the number one commercial source of vegetable oil in Sri Lanka. In addition, desiccated coconut, shell charcoal and fibre are other products of considerable economic importance. Improvement of coconut production is thus of paramount importance and it has become necessary to harness modern technologies to produce high quality planting materials. With this objective in mind, development of *in vitro* technologies for use in crop improvement programmes was undertaken in the eighties. This paper briefly summarises the current developments in this field, their potential and future programmes.

Embryo Culture Research

One major objective of embryo culture research is to develop an *in vitro*-based technique for collecting germplasm from distant locations where

materials have to be retained until the expedition is over. Investigations were channelled along two directions in developing this technology:

1) Slow-growth method (Karunaratne, 1988).

2) Direct *in vitro* explanting in the field (Sossou *et al.*, 1987).

Preliminary investigations which consisted of successful germination of zygotic embryos *in vitro* and establishment of resulting seedlings in the soil were accomplished using a variety of cultivars available in Sri Lanka (Karunaratne *et al.*, 1985). The seedling survival in soil was found to be about 43 per cent and further experiments are in progress to enhance this.

In the slow-growth method, materials to be collected are delivered to the nearest tissue culture laboratory for aseptic manipulation. Embryos are dissected and cultured in a special agar-based medium which suppresses further growth and development of embryos without affecting their viability. Cultured embryos are transferred to the normal germination-medium for resumption of growth, on return to the base. Two and three month preservation give 53 and 32 per cent germination respectively in the growth-suppressed medium (Karunaratne, 1988). By this method a large number of embryos can be transported and physically separated from each other, in very small containers. In the field explanting method, culture techniques are essentially similar to the normal laboratory embryo-germination technique except that a compact inflatable glove box is taken to the field for aseptic explanting and culturing in the site. Furthermore, materials are cultured directly in the germination medium placed in the vessel, called the Sossou flask which is specially devised for long collecting expeditions (Sossou *et al.*, 1987). The flask holds about five germinating coconut embryos and the chance of embryos outgrowing the flask volume (until the next medium transfer) is minimal. The flask design prevents spilling of the liquid medium thus facilitating transport. A case measuring 70 × 45 × 15 cm, which a traveller can carry by hand, will hold 100 flasks. In practice, the techniques may be used separately or in suitably modified combinations depending on the facilities available at various collecting sites.

Research for Clonal Propagation

Development of tissue culture techniques aimed at rapid multiplication of planting materials was attempted using explants from the leaf, shoot apex, root, inflorescence and the immature zygotic embryo. Young leaf tissues underwent direct somatic embryogenesis but further development of somatic embryos was erratic and inconsistent. Palm maturity and the physiological maturity of the leaf explant were found to be critical factors determining embryogenesis. From our investigations we found that crucial factor determining embryogenesis is elaborated at a certain physiological stage of maturity of one particular leaf in the crown of a young palm. Furthermore, only a portion of this leaf yields embryogenic explants and its competence is of short duration. This situation not only limits the availability of leaf materials for research but prevents reproducing results of previous work also, if the same developmental stage is not chosen for explanting.

The response from immature embryo explants has been uniform and reproducible. Embryo explants produced a highly embryogenic, subculturable callus which in turn produced somatic embryos (Karunaratne and Periyapperuma, 1989). Germination of somatic embryos lead to the production of a few plantlets but it is too premature to comment on the consistency of plant development. Direct somatic embryogenesis was rare. Here again, the developmental stage of the embryo and orientation of the explant in culture were found to be critical.

Clearly, the immature embryo is not the explant to be used for propagating elite or superior plants. However, the technique, if successfully developed will be very useful in making replicas of improved seed materials.

Screening for Drought-Tolerant Coconut Germplasm by *In vitro* Techniques

With the current global weather pattern changing, it is becoming increasingly important to introduce drought-tolerant planting materials to the grower. Attempts were made to develop an *in vitro* method, for screening large numbers of plants for water stress, under precisely controlled laboratory conditions (Karunaratne *et al.*, 1991). Zygotic embryos derived from mature nuts of Sri Lanka Tall coconut were used in this investigation. Water stress conditions were simulated during *in vitro* germination and subsequent plant development using NaCl, PEG and mannitol. NaCl was proved to be the best. In NaCl-stressed media, about 22 per cent of embryos died before reaching the 170 mM NaCl. About 78 per cent survived 170 mM NaCl and only 12.6 per cent were able to resist the 320 mM NaCl. When zygotic embryos derived from two known drought susceptible cultivars of coconut, CRIC-65 and Dwarf (Pumila) were tested using the same technique, 29 and 73 per cent died respectively due to stress damage caused by 170 mM NaCl and none survived a salt concentration higher than 230 mM. However, embryos originated from two putative drought-tolerant cultivars, showed a higher survival rate when subjected to salt stress. At 170 mM salt, all embryos had developed into seedlings and there were no casualties due to stress caused by 170 mM NaCl. In fact, per cent germination of embryos at 170 mM NaCl was better than in the control which was devoid of NaCl. However, per cent survivors gradually dropped with increase in salt concentration and about 18 per cent survived the 330 mM NaCl. In this investigation, the total solute concentration in the medium at 330 mM NaCl is very close to that of sea water and unlike the sea-shore coconut palms, these plants have no access to fresh water at all. An important step in this investigation is appraisal of seedlings showing severe drought symptoms. Experiments are in progress to reach this goal.

Concluding Remarks and Future Programmes

Experiments with leaf and immature embryo culture have shown that the developmental stage of the explant is an extremely important factor determining somatic embryogenesis. Somatic embryogenesis is highest when mitotic activity of the explant is at its peak. Unfortunately, in the case of coconut leaf and embryo this lasts only a few days and it again appears a month after, in the

next younger leaf and the bunch of nuts, respectively. In other words 'material' available for experimentation is scarce. This point should be taken into serious consideration in planning coconut tissue culture research programmes.

We believe that a propagation system for coconut using immature embryo explant is feasible. Perhaps an in-depth study on this system, backed by basic research might generate information which will be useful in understanding regeneration problems associated with vegetative tissues.

A few problems likely to crop up in developing a consistent plant regeneration technique from immature embryo explants are foreseen. Our future programmes are targeted at these points.

a) Mass production of embryogenic callus tissues from a single explant: Callus seems to undergo embryogenesis much earlier than expected or rather, before large quantities of embryogenic callus tissues are proliferated. Attempts to obtain embryogenic cell suspension cultures have so far failed.

b) High per cent germination from somatic embryos: Not all embryos germinate in culture under present culture conditions. Culture conditions have to be improved.

c) Profuse rooting from germinating embryos: Plantlets from some embryos were observed to have poor rooting capacity during the early stages in culture.

Our experiments on *in vitro* assay for drought-tolerant germplasm have already produced some encouraging results. We hope to strengthen our findings by looking into plausible biochemical markers of water stress, using the survivors of drought. The selected material will also be tested in the field to evaluate their performance under different water deficit conditions.

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COCONUT CLONES THROUGH SOMATIC EMBRYOGENESIS

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ABSTRACT

An important stage has been reached in the mastery of coconut *in vitro* vegetative propagation: reproducible formation of ramets from five clones belonging to different genotypes. Two sources of tissue taken from selected adult individuals were used: leaf explant and inflorescence explant. The procedure developed comprises the following steps: callogenesis induction on primary explants, embryogenesis induction on the calli obtained, embryo maturation and ramet production.

The final stage had not been mastered until now. The embryos obtained were incomplete and showed no stem meristem, which was the major obstacle in developing a coconut cloning procedure.

An analytical approach provided a better understanding of the causes behind embryogenesis obstruction. These new data led to the consistent production of complete embryos, described for the first time on a histological basis.

Work is now being directed towards the search for a culture medium that favours intense embryo proliferation for mass ramet production.

INTRODUCTION

Productivity in coconut plantations could be significantly improved if uniform planting materials are obtained by cloning high-yielding individuals. Vegetative propagation of tolerant or resistant individuals could also be an effective way of controlling some diseases, such as lethal yellowing or *cadang-cadang*, which threaten coconut groves in South America and South-East Asia, respectively.

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Unfortunately, the coconut palm, which is usually allogamous, is only multiplied by seed at the moment. The only hope of asexual propagation, lies in *in vitro* culture techniques and, more particularly, in somatic embryogenesis.

Whilst the initial results of somatic embryogenesis research were promising (rapid growth of embryo-type formations in calluses), only three teams have so far reported complete regeneration of plants from somatic tissues (Raju *et al.*, 1984; Branton and Blake, 1984; Buffard-Morel *et al.*, 1988). Apparently, the ramets obtained came from a limited number of cultures. As far as we know, coconut cloning has still to be completely mastered.

An important stage was reached at the beginning of 1991 by the ORSTOM/IRHO-CIRAD team, who obtained reproducible ramets from five different clones. The experimental procedure followed was as follows:

1) Callogenesis from leaf or inflorescence fragments, leading to the formation of non-organized tissues (calluses).

2) Callus subculturing and embryogenesis induction.

3) Embryo maturation and conversion leading to ramet production.

These encouraging results (reproducible formation of complete embryos) were obtained through an analytical approach designed to provide a better understanding of the causes behind halts or deviation in somatic embryogenesis, which are often seen with coconut.

In this paper, we shall be describing this approach and giving the main results of:

i) Histological studies (description of embryogenic calluses and for the first time on coconut, complete somatic embryos).

ii) Nutritional studies (analysis of medium composition and determination of specific nutritional requirements in the initial phases of embryogenesis on calluses).

MATERIALS AND METHODS

The planting material was supplied to us by the Marc Delorme Station in the Ivory Coast. It was taken from adult individuals (20 to 25 years) primarily the Malayan Yellow Dwarf variety and the Malayan Yellow Dwarf × West African Tall hybrid (PB 121 created by IRHO); a few trials were conducted with another hybrid (PB 111) and other dwarf varieties.

Samples can be taken without wounding the apex; growth resumption is therefore, possible and has actually been observed. The leaf explants used were fragments (1 cm long) of young non-chlorophyllous leaves surrounded by the petiole bases of older leaves.

The inflorescence explants used were fragments of rachilla (1 to 1.5 mm thick) from young inflorescences with an internal spathe length of between 15 to 40 cm. For each individual tested, 1,200 to 2,000 leaf explants, and as many inflorescence explants, were cultured.

The standard medium consisted of: Eeuwens mineral solution, Morel and Wetmore vitamins, sucrose (40 g/l) and agar-agar at 7.5 g/l, to which

2,4 dichlorophenoxyacetic acid (2,4-D) was added (30 to 80 mg/l), along with activated charcoal (2 or 3 g/l), in order to limit tissue browning.

The range of 2,4-D and activated charcoal quantities mentioned takes into account reactivity differences between individuals of the same genetic origin or different origins. The test tubes containing the cultured explants were placed in the dark at 27°C ± 1°C.

RESULTS

a) Callogenesis from Leaf and Inflorescence Explants

This stage has now been well mastered on the two explant sources worked on by the ORSTOM-IRHO team.

The first calluses appeared after four months' culturing (Figs. 27.3-1 and 27.3-2), and optimum callogenesis occurred around the ninth month (on an average, 35 to 40 per cent of leaf or inflorescence explants gave calluses). The callus production varied significantly according to the physiological age of the explant and the auxin concentration in the culture medium.

Histological studies showed that there were two possible origins for the newly formed tissues:

i) An internal origin observed for calluses derived from leaf explants and for those formed on the rachis cross-section of inflorescence fragments.

In both cases, they appeared in the fourth month of culturing, on the perivascular cells. This origin is identical to that described for oil palm.

ii) An external origin observed for calluses forming on floral sites. These calluses appeared later (after the fifth month of culturing). They were derived from pre-existing floral meristems and were similar to the calloids described by Branton and Blake (1984).

Whatever their tissue origin, callus growth and multiplication are ensured by the establishment of a peripheral meristematic zone organized all the way through as a cambial type meristematic zone.

b) Embryogenesis Induction

Calluses were isolated from the sixth month of culturing onwards. They were placed on media containing activated charcoal and enriched with 2,4-D (compared to the callogenesis media).

Under these culturing conditions, the callus growth and multiplication ensured by the peripheral meristematic zone can continue for months, with no notable change. It can lead to secondary callus growth. These calluses were used to make up homogeneous tissue strains on which a large number of embryogenesis induction trials were conducted.

1) Histological Description of Embryogenic Calluses

Two types of embryogenesis processes were observed:

a) One from organogenetic type of epidermal complex meristematic structures which can lead to embryogenesis of multicellular origin. This process leads to embryo type structures that are usually incomplete (haustorium with or without root pole, embryos with a leaf-like appearance).

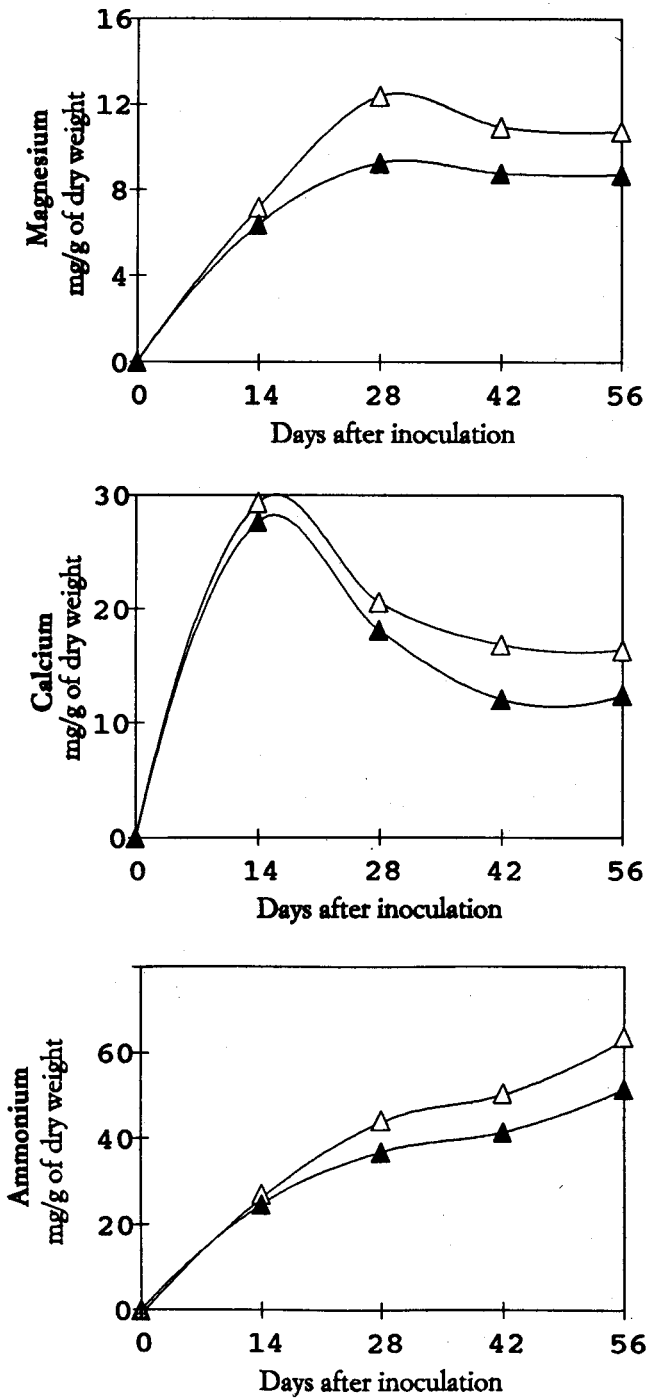

Fig. 27.1: Coconut somatic embryogenesis. Evolution of magnesium, calcium and ammonium during callus multiplication (▲) and embryogenesis initiation (Δ).

b) The other of unicellular origin, with individualization of typical embryogenic cells, similar to those described for oil palm (Schwendimann *et al.*, 1990). These cells have a large, very active nucleus, dense cytoplasm rich in soluble proteins and numerous small vacuoles. They are isolated from the rest of the callus by a thick wall.

The second process led to the formation of typical pro-embryos with all the characteristics of the first stages of zygotic embryos as described by Haccius (1978).

2) Determining the Specific Nutritional Requirements for Embryogenesis

A kinetics study conducted on two strains of homogeneous calluses revealed the specific mineral nutrient requirements during induction and during the initial phases of somatic embryogenesis.

The cations NH_4^+, K^+, Ca^{++}, Mg^{++} and the anions NO_3^-, Cl^-, $H_2PO_4^-$ and SO_4^- were titrated in the culture media using HPLC (DIONEX ionic chromatograph). For the same tissue strain, a comparison of callus nutrient requirements on multiplication media and on the embryogenesis medium revealed greater ammonium, calcium and magnesium absorption per g of dry matter for embryogenesis (Fig. 27.1).

These specific nutritional requirements are accompanied by an increase in protein synthesis (Fig. 27.2) reflected in an accumulation of proteins in the embryogenic cells (see results of the histological approach). This study has largely contributed to better knowledge of somatic embryogenesis factors in coconut. It therefore, provides the opportunity of controlling it better by acting upon medium composition and culture transfer frequency.

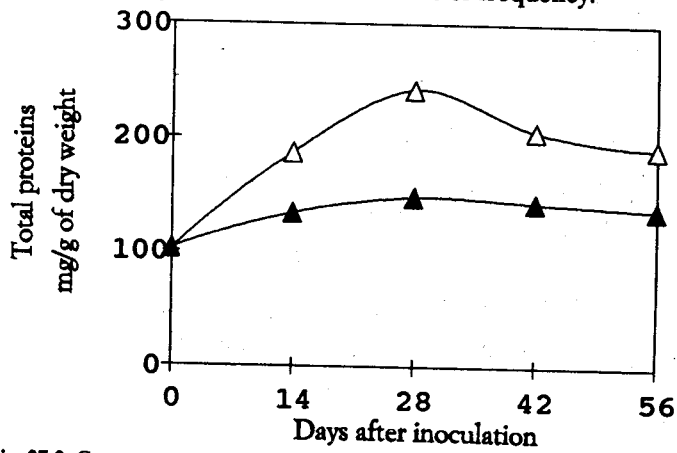

Fig. 27.2: Coconut somatic embryogenesis. Evaluation of total protein content in callus during multiplication (▲) and embryogenesis initiation (Δ).

3) Embryo Maturation/Conversion and Shoot Development

Somatic embryo maturation was obtained by gradually reducing the 2,4-D concentration compared to the auxin level enabling embryogenesis induction (Fig. 27.3-3). After elongation of the haustorium, a cotyledonary notch appears at the base of the embryo; this immediately precedes root-pole differentiation.

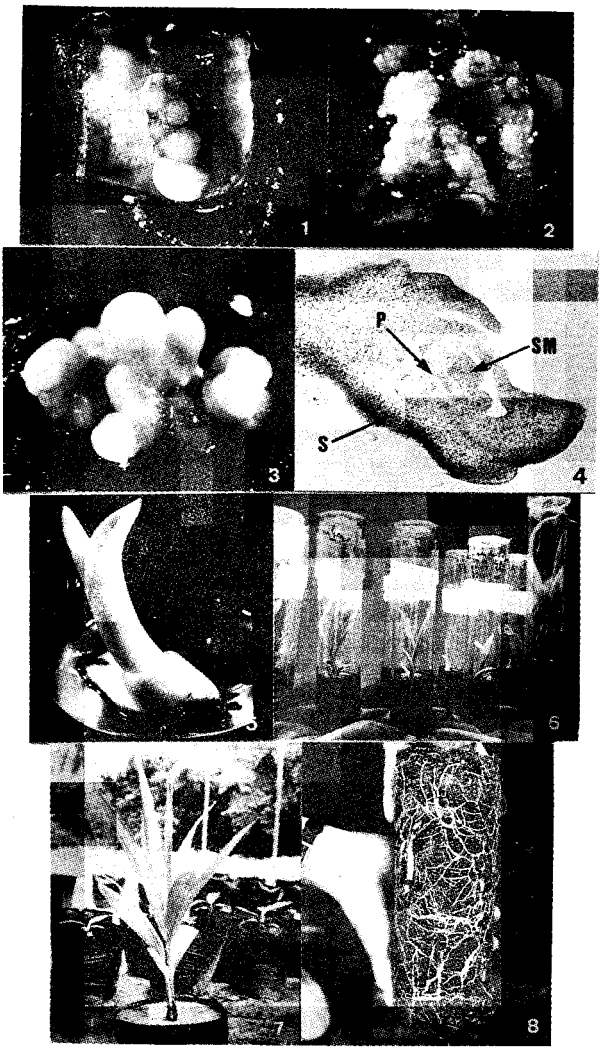

Fig. 27.3: Somatic embryogenesis from leaf and inflorescence tissue of coconut.
Fig. 27.3-1: Callogenesis from leaf explants: nodular calluses after around four months' culturing.
Fig. 27.3-2: Callogenesis from inflorescence explants: globular white calluses arising from floral areas.
Fig. 27.3-3: Clump of somatic embryos at the beginning of the 'maturation' phase.
Fig. 27.3-4: Histological cross-section (just below the notch) of a somatic embryo. SM = domed shoot meristem, P = provascular strands, S = starch grains.
Fig. 27.3-5: Isolated somatic embryo, emission of first two leaf sheaths.
Fig. 27.3-6: Overall view of some ramets arising from somatic embryos.
Fig. 27.3-7: Ramet after weaning, in pre-nursery (Côte d'Ivoire).
Fig. 27.3-8: Root system of the same weaned ramet.

For the first time in coconut, histological cross-sections, made at the cotyledonary notch, revealed somatic embryos with perfectly structured stem meristem, consisting of a protruding meristematic dome (Fig. 27.3-4) surrounded by leaf primordia.

The haustorial tissue located opposite the shoot meristem contains starch reserves. The positioning of starch grains, which is a good indication of embryo polarity, is identical to that found in zygotic embryos.

Shoot development (Figs. 27.3-5 and 27.3-6) from isolated embryos takes place in the light, on a hormone-free medium with activated charcoal.

Once the first leaf sheaths have emerged, the embryo root can develop spontaneously (without hormone treatment) which indicates the existence of a functional bipolar axis within the embryonal structures.

However, in the majority of cases, rooting requires treatment with an auxin namely, naphthalene acetic acid (NAA) (Figs. 27.3-7 and 27.3-8).

CONCLUSION

The results recently obtained by the ORSTOM/IRHO-CIRAD team have led to a procedure for reproducible development of complete somatic embryos.

Twenty or so ramets from five different clones of Malayan Yellow Dwarf and PB 121 have been obtained in this way. They were obtained from leaf or inflorescence explants taken from adult trees. Other cultures are currently making good headway.

However, the number of ramets regenerated per clone remains low, due to absence of an embryo multiplication phase, as research has so far concentrated on achieving complete embryogenesis.

The main purpose of our future work will be to determine the conditions required for achieving adventive embryogenesis. Successful multiplication of the somatic embryos obtained should make it possible to satisfy ramet mass production requirements.

We hope these promising results will pave the way for the application of recent plant biotechnology techniques to coconut genetic improvement in the near future.

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PHYSIOLOGICAL BASIS FOR YIELD IN COCONUT

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ABSTRACT

The long association of coconut with man has led to a wide range of fruit composition and other plant characters that contribute to yield improvement. The coconut palm develops a large and highly productive canopy when nutrients are non-limiting. It is capable of an estimated 51 t/ha/year total dry matter production if all incoming light (at an average of 20.5 MJ/sq m/day) were intercepted and growth conditions were non-limiting. The proportion of dry matter partitioned to the fruit can be as high as 62 per cent within which there is a maximum of 26 per cent dried kernel, giving a potential copra yield of 13 t/ha/year. The highest reported yield is 6.3 t/ha/year of copra. In reality, low light intensity, low interception, reduced light use efficiency due to nutrient deficiency and periodic water deficit and a low proportion of kernel in the nut, will all combine to give a very much lower yield. A 30 per cent increase in the proportion of kernel has led to at least a 30 per cent yield increase, and a copra yield level up to 5 t/ha/year.

Future improvement will rely on combining favourable growth form and fruit composition, present in an exotic dwarf or tall cultivar, with a locally-adapted tall population. Further advance could be made by selection within the adapted tall population to provide an elite F_1 hybrid.

INTRODUCTION

There is continuing demand for coconut as a source of vegetable oil for the food and chemical industries of the western countries. It retains a high potential as an export cash crop in many countries, while its local importance as a source of food, fibre and fuel continues to rise.

Coconut oil is subject to direct competition from other vegetable oils such as soybean, sunflower, rape-seed and palm kernel oil. It is therefore important, for the sake of competitiveness with other crops, that productivity and the economic efficiency of production be raised to the highest possible level. This paper explores the possible role of coconut physiology in helping to achieve an increase in yield through greater biological efficiency.

Historical Perspective

Seeds from the ancient wild coconut palm had the capacity to disperse widely by floating on the ocean, thanks to a thick layer of highly buoyant husk, long angular fruit shape and slow germination. Very isolated and long uninhabited islands such as Palmyra (Lat. 5.52° N Long. 162.05° W) in the Pacific, and the Seychelles (Lat. 4.40° S Long. 55.30° E) in the Indian ocean, appear to have retained such a 'wild' coconut type up to the present (Harries, 1978; 1990).

It is likely that the coconut grew wild on the coast of large and small islands and land masses of South-east Asia, Indonesia, The Philippines, Melanesia, and the western Pacific region for many thousands of years before the arrival of man took place in the period between −120 kyr and −50 kyr. Glaciation has led to great fluctuation in the global sea level, and in as recently as −15 kyr, it was 140 m below the present level (Chappell, 1978). During one millenium around −9 kyr (Chappell and Polach, 1991) the sea level on the north coast of New Guinea rose faster than 1 m/100 years. The consequent rapid drowning of coastal groves of coconut could have allowed rapid change in the genetic composition of coconut populations as man 'rescued' seeds for planting further inland.

The coconut is vital to the survival of many people who inhabit small islands and the coastal zone of large islands and continental Asia. It appears to have been selected by them for convenient traits like large nut size which provides a convenient and portable source of pure drinking water (Harries, 1979; Foale, 1987). Large internal volume is generally associated with reduced thickness of husk (Harries, 1978), while it was the greater ease of extraction of the kernel that led the coconut planters of the nineteenth and the twentieth centuries to prefer large nuts.

Scope for Research on Yield

Early efforts to improve the yield of coconut using mass selection were fraught with confusion about the effectiveness of the method (Charles, 1961). When confidence was restored, selection still offered only a slow rate of progress due to the natural heterozygosity of tall populations and to the lack of a suitable technique for controlled pollination. Meanwhile, some Tall × Dwarf hybrids were found to achieve a large increase in yield through the very favourable combining ability of certain Tall populations with Red and Yellow Dwarfs.

The empirical yield performance of some hybrids has been reported in detail (Sangare and Rognon, 1980; Ooi and Chew, 1985) but the only reports on the physiological processes that contribute to yield were presented by Corley (1983; 1985). The present review builds further on Corley's work to assist plant breeders to focus on specific traits in carrying out selection both within and between populations. The importance of adaptation to ensure the success of improved material in a specific environment is also underlined.

DISCUSSION

The Physiology of Yield

The yield level of a crop plant is the result of the combination of its genetic potential and the climate, soil and biotic factors that influence the expression

of that potential. It has been demonstrated in many crops that productivity can be raised by genetic improvement, often by a factor of two or more, as in the case of wheat and rice during the sixties and the seventies. Genetic improvement also has a role in increasing the security of production in the presence of potential pest or disease problems, or under the influence of unfavourable natural conditions.

The following analysis deals with the basic plant processes that affect growth and yield, namely, the interception of light and its use to fix carbon, and the partitioning of dry matter between vegetative growth and the economic end product.

The Photosynthetic System and Light Interception

The general form of the palm crown is familiar enough, but the effect of variation in the disposition of fronds within the crown on light interception is not well understood. The extreme forms are hemispherical, with most fronds erectophile and spherical, with half or more of the fronds in a lax down-pointing position. There is a gradient of light intensity from the upper to the lower level within the assembly of coconut crowns that make up a plantation canopy. The change in the intensity of photosynthetically active radiation (PAR), known as the rate of light extinction ('k'), is a useful measure to define the effect of different canopy structure. Physiologists would need to provide data to show the effect of different crown type on 'k', before the breeder could make use of this parameter.

The value of 'k' was calculated at 0.65 by Corley (1985) from data generated in Solomon Islands, but the line fitted to his leaf area index (LAI)/light interception data did not pass through the origin. This procedure was intended to make an allowance for the highly clumped nature of a coconut canopy, but it does not fit the true definition of extinction coefficient. Perhaps measurement of light interception over a complete range of solar altitude would overcome the problem. Corley's data showed that 95 per cent of incoming radiation was intercepted by an LAI of 5, and 50 per cent at an LAI of 2.5.

The rate of frond production and the amount of leaf area per palm are not much affected by plant density, as palms are highly determinate with respect to leaf production. An increase in density can therefore lead to greatly increased LAI (Barrant, 1977). The maximum functional leaf area in a plantation, is strongly influenced by the intensity and duration of seasonal soil water deficit. Thus the optimum density of palms is primarily a function of available soil water (Coomans, 1974).

Efficiency of Light Use in Photosynthesis

Light use efficiency (LUE) is a measure of the amount of dry matter produced per unit of PAR intercepted. It was noted by Corley (1985) that as coconut has a C3 photosynthetic system, a leaf will become light saturated at a value less than half the intensity of direct solar radiation. Interception by leaf surfaces oblique to direct-beam radiation therefore, favours an increase in LUE and allows a large leaf area to be illuminated.

Adequate mineral nutrition and supply of water ensure that light use efficiency (LUE) of individual leaves is maintained close to the maximum potential value. Nutrient deficiency is frequently brought about by competition between fruit growth and leaf maintenance.

The only reported values for LUE in coconut (Corley, 1985) show an increase of 14 per cent up to 1.2 g/MJ of PAR in response to improved mineral nutrition in a thinning trial in Solomon Islands.

Achieving Maximum Dry Matter Production

It was estimated by Corley (1983) that if a coconut canopy intercepted all the incoming radiation and the canopy was operating at maximum light use efficiency with 75 TJ/ha/year of global solar radiation (equivalent to 20.5 MJ/sq m/day) it would yield 51 t/ha/year of dry matter. He noted that the highest value recorded was 31 t/ha/year, and attributed the shortfall to lower values for solar radiation, interception and LUE.

The coconut palm undergoes a marked reduction in canopy size with age which is reflected in measured light interception values which in a typical case actually 'peak' at around 50 per cent (Nair and Balakrishnan, 1976; Wilson and Ludlow, 1991). There is scope to improve light interception by increasing density but only within the constraint of water supply on leaf area referred to above. Even so, high density is effective for only a limited part of the life of a plantation as the individual crown size becomes smaller with advancing age beyond 20 to 30 years.

This highlights a major problem in achieving high production from the long-lived coconut in monoculture. There must be a trade-off between the maximum allowable density in young palms which is set by the constraints of water supply and harvest index (see below) and the density required to achieve a reasonable yield beyond the age of 40 years.

Partitioning of Dry Matter

The amount of harvestable product that accumulates depends on the proportions of the total dry matter that are partitioned to the various plant parts. The harvest index of coconut is the amount of copra dry matter as a proportion of the total vegetative dry matter. Alternatively, allowance can be made for the carbohydrate equivalent or the energy equivalent of the oil.

It is quite difficult to estimate all of the non-yield dry matter because a substantial fraction of it goes into the trunk, and in coconut the rate of production of root dry matter is as yet unknown. The method described by Corley *et al.* (1971) for growth analysis of oil-palm was used on coconut by Corley and Friend (personal communication) in Solomon Islands. Relationships were established between linear measurements on the leaves and stem and their dry matter content. They measured the yield of copra and estimated the harvest index of five populations in two separate trials (Table 28.1).

Corley (1983) calculated maximum values for the partitioning of dry matter into the whole nut and into endosperm (copra). He showed that 62 per cent of dry matter could be partitioned to the nut and 26 per cent to copra. The

copra contained 38 per cent of the total energy fixed. These data were derived from outstanding hybrid coconuts in Ivory Coast, Solomon Islands and Malaysia. The highest harvest index reported is 0.16 (Table 28.1). Thus, the value of 0.26 proposed by Corley (1983) would require a very much increased partitioning to the nut than what has so far been achieved.

Increasing plant density increases leaf area progressively to a point where partitioning to yield begins to decrease. It was pointed out by Corley (1985) that the density giving maximum yield in crops like coconut and oil-palm is usually below that giving maximum light interception.

Table 28.1: Yield and harvest index (copra dry matter as a fraction of vegetative dry matter) of five coconut populations in two trials in Solomon Islands (Friend and Corley, in preparation)

Population Name	*Copra yield (t/ha)*		*Harvest index*	
	Trial 1	*Trial 2*	*Trial 1*	*Trial 2*
Rennell (RLT)	2.58	1.95	.16	.13
Sol. Is. (SIT)	2.45	1.43	.12	.08
Red Dwarf (MRD)	2.15	–	.12	–
RLT × MRD-F1	3.82	2.61	.15	.15
SIT × MRD-F1	2.79	1.91	.11	.11

The Physiology of Nut Retention

An extremely high nut set is sometimes observed on palms that have undergone a strong disturbance in their productivity such as when tapped for toddy. When tapping ceases, the common response is to produce many female flowers most of which successfully form nuts. More than 100 nuts may be seen on each of the six or more successive bunches. This appears to be a response to the accumulation of 'surplus' assimilate when the rapid removal of assimilate by tapping was stopped. Sometimes dwarf palms carry a huge load of nuts when they first come into production, presumably because there are no older nuts growing, and surplus assimilate is available (Harries, personal communication). The frequent occurrence of biennial bearing reflects fluctuation in the demand for assimilate that controls nut setting.

Raising Yield Through Selection and Hybridisation

The greatest scope for improvement in yield appears to lie in selection for improved partitioning of dry matter. A shorter, thinner petiole on the frond, a thinner trunk, and a lower rate of trunk extension are traits that demand less assimilate and should therefore be conducive to higher yield. As a high proportion of total dry matter can be found in the nut (Corley 1983), increased partitioning to the endosperm at the expense of other nut components offers greatest scope for yield improvement.

A thin trunk with a low extension rate is characteristic of a group of dwarfs. These have not been adopted widely for copra production because of unfavourable fruit composition and poor adaptation, small nut size, and poor quality in the copra. Some dwarf populations combine well with tall

populations that possess superior adaptation and copra quality, resulting in some very successful hybrid progeny.

The Performance of Hybrids

Two examples of successful hybrids between dwarf and tall coconut cultivars are the Mawa (Malayan Yellow Dwarf crossed with the West African Tall in Ivory coast by IRHO) and the Maren (Malayan Red Dwarf crossed with Rennell Tall developed by the JCRS in Solomon Islands). These hybrids produce around 5 t/ha of copra under favourable conditions (de Nuce, 1990). It was reported that the Mawa achieved this by producing an increased number of nuts compared to the tall parent (Bourdeix *et al.,* 1990). The performance of three hybrids: Mawa, Malayan Yellow Dwarf × Rennell (called Maren in error, as it differs from the Maren above); and of Mamat hybrid (Malayan Yellow Dwarf × Malayan Tall) was reported by Ooi and Chew (1985). They found that Mawa did best, Mamat was second and the Rennell hybrid third, in an environment where there was a severe annual water deficit.

Data for fresh fruit composition, including water, of two hybrid and three tall populations are presented in Table 28.2. There was a close similarity between the two hybrids, and wide variation in components between the diverse tall populations.

Table 28.2: Comparison of the fresh fruit composition of two hybrid and three tall populations. Weight in g; per cent values are for kernel in the whole fruit (Sangare and Rognon, 1980; Foale 1964; 1987, Whitehead, 1966)

Population	*Fruit*	*Husk*	*Shell*	*Water*	*Kernel*	*(%)*
Mawa	1109	408	158	185	358	32
Maren	1160	300	190	290	380	33
Rennell	2209	673	311	563	662	30
Sol. Is.	1196	543	175	178	300	25
Sri Lanka	1460	670	200	190	400	27

A superficial comparison between the Maren hybrid and the Solomon Islands population is instructive. While they have a similar fruit weight there is 32 per cent more kernel in the hybrid, which corresponds to the estimated difference in yield capacity of the two populations. The estimate is based on observed plantation yield of 5 t/ha in the hybrid and an extrapolation of data for the Solomon Islands population of Faiami estate to an expected yield peak of 3.75 t/ha (Green and Foale, 1961). This yield improvement could therefore, be attributed solely to change in fruit composition.

Potential for Further Improvement in Yield

The current dearth of knowledge of photosynthetic rate and of light distribution within the canopy precludes any immediate progress using these traits. Likewise there is no information about the relative size and level of activity of the root system of different cultivars. There is an obvious need for research on these topics.

Better partitioning of assimilate therefore still offers the best opportunity for yield improvement, especially where introduced hybrids are not suitable due to lack of appropriate adaptation. It may be essential to use a local tall population which has poor fruit composition as a parent to combine with an exotic dwarf or tall in hybrid seed production. The resultant hybrid should achieve both improved yield and security of production.

The Physiology of Adaptation

The importance of suitability of a variety or hybrid for a particular environment was referred to above. For example, populations from Papua New Guinea and Solomon Islands show a high level of resistance to the attack of *Brontispa* spp. a leaf-eating Hispid beetle, while the introduced Malayan Tall suffered severe damage from the beetle in the Solomon Islands. West African and Malayan Tall populations appear to have good tolerance to seasonal water deficit, whereas Polynesian and Rennell Tall populations do not. The indigenous tall and dwarf in Vanuatu both tolerate the Foliar Decay virus which is fatal to all introduced germplasm (Calvez *et al.,* 1985).

It is clear that the coconut has adapted itself to pest, disease and climatic factors associated with particular locations. The consequences of failure to retain local adaptation in breeding for higher yield were demonstrated when Maren was introduced to regions of Papua New Guinea which had the twin pests *Scapanes* (a local form of Rhinoceros beetle) and *Rhyncophorous* sp. (the red palm weevil). The hybrid suffered a much higher rate of fatal damage than the local tall population (Brook, 1982).

An understanding of the physiology and inheritance of particular adaptations, to assist in their incorporation into high-yielding cultivars, is a worthwhile research objective.

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DISCUSSION

C. Jayasekara: Net assimilation of the lower leaves in the canopy is only about 1 to 5 per cent compared to upper leaves. Therefore, they make very little contribution to the dry matter production.

M.A. Foale: I agree with the comment. The lower leaves are overshaded by the upper canopy and by the crowns of neighbouring palms. They achieve sufficient assimilation only for maintenance of green condition, but contribute little to the growth of the palm. Their water use may be a liability.

G. Dev: Yield is a function of many factors affecting plant growth. In the model presented emphasis has been given to light and LUE only. How about fertilizer use efficiency?

M.A. Foale: Fertilizer use efficiency is expressed via the pathway of light use efficiency. Ultimately good nutrition results in the maximum photosynthetic capacity of the coconut leaves; thus, fertilizer contributes to the operation of this basic process. Therefore fertilizer use efficiency is a secondary index of coconut performance.

M.R.T. Wickremaratne: In view of your findings do you think a palm with 'v' shaped crown with upward looking leaves would be higher yielding than one with spherical crown?

M.A. Foale: A 'v' shaped crown is present on young palms of five to 10 years age. Total dry matter production at that age is very high but a large proportion of it goes into trunk growth. If a 'v' shape is present in an older palm, it will be due to high density which causes trunk extension to remain high. Production of nuts will be poor because much dry matter continues to be allocated to trunk extension. The ideal crown is probably hemispherical as this implies reduced growth of the trunk but still a high level of light interception.

CHARACTERISATION OF DROUGHT TOLERANCE IN COCONUT

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ABSTRACT

Coconut palms experience moisture stress of different magnitudes depending upon the extent of dry spell. Investigations on drought tolerance centred around the morphological observations on leaf and inflorescence characters, the physiological parameters like stomatal regulation and water potential components and biochemical aspects such as epicuticular wax and assay of certain sensitive enzymes.

Out of the 23 genotypes screened, ten were found to possess desirable traits to withstand moisture stress. These included high stomatal resistance with low transpiration rate, high leaf water potential, high leaf-wax content, and relatively stable enzyme activities during moisture stress. Based on the above features, the released hybrids like LO × GB, LO × COD, WCT × COD are classified as drought tolerant. A rapid screening method has been developed to evaluate a large number of samples.

Occurrence of Drought

Kerala accounts for 58.8 per cent of the total area of 1.47 M ha under coconut in India. Coconut is generally cultivated under rainfed conditions. Despite a mean annual rainfall of 3000 mm or more there is frequent occurrence of drought in Kerala. High evaporative demand between January and May leads to both soil and atmospheric droughts. When exposed to such severe moisture stress, coconut palms exhibit adverse effects like dry and broken leaves, poor spathe development, empty spikes in some bunches and heavy shedding of buttons (Ramadasan *et al.,* 1991). The investigations at CPCRI were concerned with the impact of weather variables, critical soil moisture level for the stress, the response of genotypes to soil types and the biochemical changes during stress development in coconut (Kasturi Bai *et al.,* 1988; Rajagopal *et al.,* 1989; Voleti *et al.,* 1990; Shivashankar *et al.,* 1991). The extent of damage to coconut palms by drought was assessed on the basis of aridity index (Rao, 1985). The occurrence of drought and its impact on

morphological and yield characters have also been reported in Sri Lanka (Abeyawardena, 1968) and Ivory Coast (Ollagnier *et al.,* 1983).

Drought-Tolerant Characters

A survey of literature indicates that the essential features of drought resistance/tolerance in crop plants are attributed to morphological, anatomical, physiological or biochemical adaptations (Kramer, 1983). At morphological level, the rooting pattern, leaf area development and reproductive structures like awns, and at anatomical level the cuticular thickness and epidermal/guard cells, assume importance in withstanding drought (Parsons, 1979). The physiological attributes in drought studies include the stomatal regulation and leaf water potential components (Milburn and Zimmermann, 1977), whereas the changes in the activities of certain important enzymes (Shivashankar, 1990), accumulation of proline (Sinha and Rajagopal, 1978) and abscisic acid (Alvim *et al.,* 1979) are some of the characteristic features from the biochemical viewpoint. There is genetic variability in the above characters among different crop species (Keim and Kronstad, 1979), the degree of variation thus reflecting on the extent of drought resistance/tolerance. The work on drought research in annual crops has been well documented (Hall and Jones, 1961) while there are limited reports on tree crops (Raghavendra *et al.,* 1984; Balasimha *et al.,* 1988; Rajagopal *et al.,* 1990 a).

Screening Methods and Identification

i) *Morphological characters*: The drooping and drying of leaves are generally noticed in coconut palms during severe summer months in rainfed plots. Pomier and de Taffin (1982) used the drought tolerance index, expressed as the percentage of dry leaves compared to the number of living or functional leaves, to screen five coconut hybrids. Accordingly, the hybrid PB 121 (MYD × WAT) was reported to be most tolerant, while the hybrid RT × WAT the most sensitive to drought. A similar approach was made by Ramadasan *et al.* (1991) which revealed the relative tolerance of WCT × COD and LO × COD to drought. The genotype Tiptur Tall had more dry or dropping leaves with less functional leaves as compared to WCT and WCT × COD during the unprecedented drought of 1982 (Rajagopal *et al.,* 1990 a). Recent studies showed that among the three hybrids, MYD × WCT had more functional leaves than either MOD × WCT or COD × WCT, during the stress period (unpublished). These findings thus indicate that the counts recorded on the dry over functional leaves may be simple but a useful method of screening for drought tolerance in coconut. An indirect approach on root characteristic was made by determining the soil moisture depletion pattern in coconut genotypes between non-stress and stress periods, which revealed the proper water balance in tolerant genotypes (Rajagopal *et al.,* 1991).

ii) *Physiological characters*: The basic physiological principle in drought studies is to look for the genotype which can conserve water and maintain leaf turgidity during adverse conditions. This can be assessed through the

determination of leaf diffusive (stomatal) resistance, reflecting on the degree of transpiration rate and leaf water potential or the relative water content. Based on this principle, Rajagopal *et al.* (1990 b) screened 23 coconut genotypes both during non-stress and stress periods (1987–88). It is evident that genotypes like WCT × WCT, FMS, Java Giant, Andaman Giant, LO × GB, LO × COD, WCT × COD and WCT had higher stomatal resistance with lower rate of transpiration (lower right quadrant in Fig. 29.1), a desirable character, than the other genotypes (upper left quadrant). This indicates the effective control of stomata on the water balance of palms, as reported earlier (Milburn and Zimmermann, 1977). Balasimha *et al.* (1988) found a similar influence of stomata in checking transpirational loss of water in cocoa. There are a number of reports on the stomatal regulation in annual crops. Jones (1979) had viewed the relevance of stomatal studies on breeding for drought tolerance in crop plants.

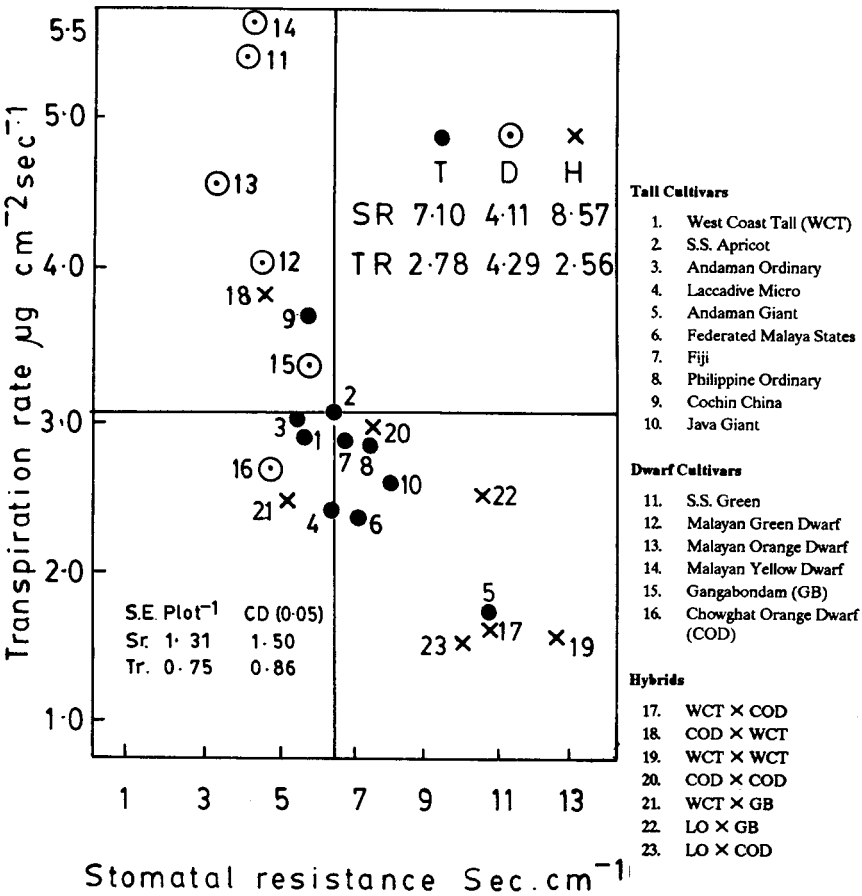

Fig. 29.1: Relationship between stomatal resistance and transpiration rate in talls '●', dwarfs '⊙' and hybrids 'X' during stress period.

Determination of relative water content—RWC and leaf water potential components are the widely used techniques in screening for stress tolerance. These methods were applied to coconut to assess the drought tolerance among the genotypes. The RWC was reduced, to different degrees among the genotypes when subjected to osmotic stress with polyethyleneglycol (Voleti *et al.*, 1990). The RWC was higher in LO × GB, LO × COD and WCT than other genotypes with GB recording the lowest (Table 29.1). Using the Scholander's pressure bomb technique, the leaf water potential (ψ) was measured during stress period in coconut genotypes (Rajagopal *et al.*, 1990 b). The ψ ranged from -1.19 to -1.57 MPa among the genotypes, the ones, with higher ψ (LO × GB and LO × COD) proving to be drought tolerant. The significance of leaf water potential determinations in drought stress has been emphasised by Turner (1979).

As an adaptive mechanism to combat water stress, the epicuticular wax on the leaf surface plays a major role by checking transpiration rate (Svenningsson and Liljenberg, 1986). Using the colorimetric method of Ebercon *et al.* (1977), Rajagopal *et al.* (1990 b) estimated the wax content in coconut genotypes. The drought tolerant LO × COD and LO × GB exhibited higher wax content than the susceptible ones like COD and GB (Table 29.1). This is in agreement with the findings on cocoa (Balasimha *et al.*, 1988) and rubber (Gururaja Rao *et al.*, 1988). Rajagopal *et al.* (1991) had shown the relationship between the wax content and transpiration rate in coconut genotypes. There was no qualitative change in the composition of wax, but quantitatively there were differences among the genotypes. Drought tolerant genotypes were also found to possess high photosynthetic rate and instantaneous water use efficiency as compared to susceptible ones.

Table 29.1: Relative water content (during osmotic stress), leaf water potential and cuticular wax content in coconut genotypes

Genotype	*Relative water content (%) after 24 hours*			*Leaf water potential (– MPa)*	*Cuticular wax content*
	Initial	*Control*	*Osmotic stress*		$\mu g \cdot cm^{-2}$
WCT	90.8	90.4	81.5	1.27	108.6
LO	91.1	91.1	79.8	1.21	–
GB	93.9	88.5	67.8	1.32	90.3
COD	90.4	91.5	78.3	1.56	87.6
LO × GB	91.0	87.1	80.7	1.23	132.6
LO × COD	91.6	89.4	80.5	1.20	120.7
WCT × COD	91.6	92.6	78.6	1.24	111.4
COD × WCT	91.9	88.9	75.4	1.19	124.2

iii) *Biochemical characters*: Among the biochemical changes during stress period, the stability in the activity of certain key enzymes assumes significance in view of their role in assimilatory processes (Levitt, 1980). Nitrate reductase activity was extensively studied in annual crops, while other enzymes like PEP

carboxylase, polyphenol oxidase, peroxidase, acid phosphatase also received attention. In coconut, the activity of acid phosphatase and L-aspartate 2-oxo-glutarate amino-transferase enzymes were greatly enhanced with the onset of drought stress in the field and increased exponentially with further increase in the degree of stress during rainless months (Shivashankar *et al.,* 1991). These enzymes also showed statistically significant differences between tolerant and susceptible types under conditions of soil water deficits (Shivashankar, 1990). Based on the threshold leaf water potential to trigger the enzyme activity the Aph was found to be highly sensitive to moisture stress in coconut.

Besides the activity, the isozyme profile of certain enzymes also have a direct bearing on stress tolerance in crop species (Vieira de Silva, 1970). An attempt in this direction on polyphenol oxidase in coconut revealed that under osmotic stress, induced with PEG, the two hybrid genotypes exhibited two additional fast moving bands, unlike the non-stressed ones (Fig. 29.2) (Shivashankar, 1988). Shivashankar (1990) studied the enzyme kinetics of Aph and also the response of genotypes to temperature in terms of NR activity. From the foregoing, it is evident that measurement of Aph activity under water deficit conditions could serve as a sensitive indicator of the degree of stress suffered by coconut palms.

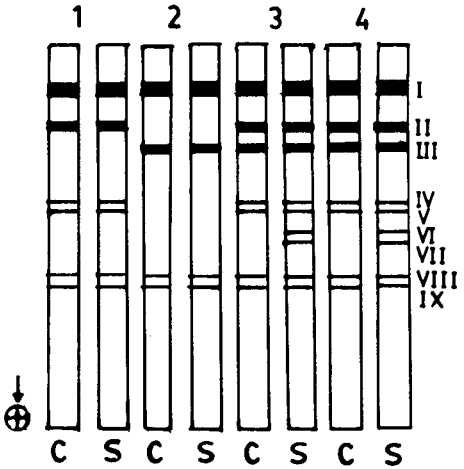

Fig. 29.2: Pattern of polyphenol oxidase isozymes in coconut genotypes before and after induction of stress. C: Control; S: Stressed. 1. WCT; 2. COD; 3. WCT x COD; 4. COD x WCT.

Although proline accumulation was reported to be the most sensitive indicator in annual crops (Singh *et al.,* 1973) in coconut it did not accumulate at the level of stress recorded under field conditions. However, stimulation of stress with PEG enhanced proline level to different degrees among the genotypes (Voleti *et al.,* 1990). Interestingly, the drought tolerant types failed to accumulate proline, contrary to the earlier reports on barley (Stewart and Hanson, 1980) and other crops, but in support of the findings on crops like soybean and wheat (Guo *et al.,* 1988; Sinha and Rajagopal, 1978). Thus proline accumulation does not appear to help in screening methods for coconut.

iv) *Rapid screening method*: Large-scale screening necessitates a rapid method to handle more samples within a reasonable time limit. Among the methods described above, the method involving the changes in leaf water potential and activity of Aph in coconut leaves subjected to air desiccation was found to be rapid and reproducible. When the known genotypes were subjected to this method, the confirmation was obtained on the drought-tolerant nature of LO × COD and LO × GB, as much as the drought susceptible characteristics of COD and GB (Rajagopal *et al.*, 1988). Thus it is possible in coconut to adopt the determination of leaf water potential and assay of Aph activity as rapid screening methods for drought tolerance.

Yield Evaluation

The relationship, if any, between the stress parameters and the nut yield for four years, representing both the normal and drought years, has been recently examined (Rajagopal *et al.*, 1990 c). It is clear that the drought-tolerant types LO × COD, LO × GB and WCT × COD, which had desirable traits to withstand drought, also had a high yield potential (Fig. 29.3). Bavappa (1986) had earlier reported the high yield performance of LO × GB and LO × COD over the years under rainfed conditions. Conversely, the relatively poor nut yield in rainfed COD × WCT palms especially under sandy loam indicates the sensitivity of the hybrid to drought, as also corroborated by the low diffusive resistance with high transpiration rate, low leaf water potential and low wax content. Thus, the yield evaluation studies lend support to the usefulness and validity of the screening methods for drought tolerance in coconut.

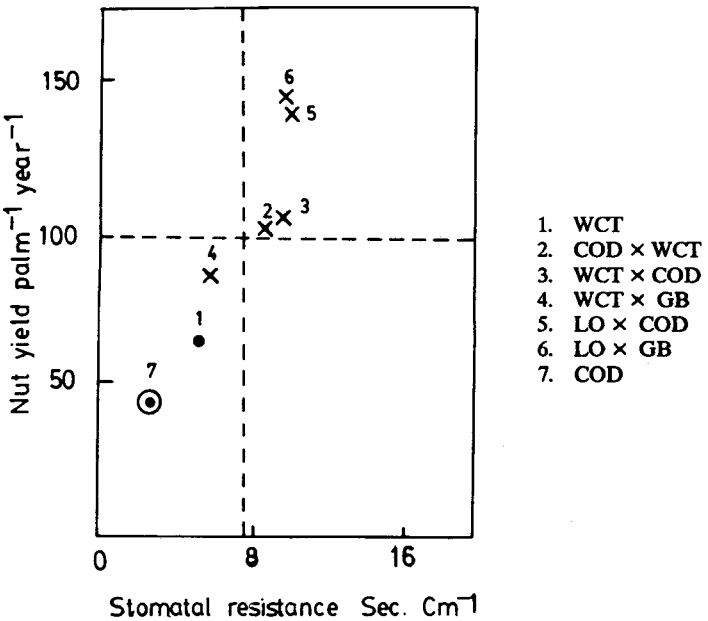

Fig. 29.3: Relationship between stomatal resistance and nut yield in talls '●', dwarfs '⊙' and hybrids 'X'.

Approaches for Drought Management

One of the practical problems often reported by the farmers, is the abnormal shedding of buttons, leading to heavy loss in nut production. The major cause for this is reported to be drought, the other reasons being water logging, nutritional and/or hormonal imbalances, pest infestation and genetical make up, that is, heavy female flower production. Summer irrigation has definitely been shown to enhance button retention (Nelliat and Padmaja, 1978). Hormonal treatment also improved the palms by way of reducing the button shedding (Vijayaraghavan *et al.*, 1989).

An integrated approach, encompassing soil moisture conservation methods, effective drainage system, balanced fertiliser application, prophylactic measures against pests and raising the drought tolerant genotypes, is called for drought management in coconut.

Future Thrust

The following areas of research are identified for future investigations:

i) *Screening of remaining genotypes*: At present only about 30 genotypes were screened for drought tolerance, while there are approximately 90 genotypes to be still screened. This needs to be taken up in a phased manner.

ii) *Drought tolerance at seedling stage*: The work done so far was confined to adult palms and there is urgent need to find out whether the seedlings of the identified palms maintain the same character. This is of practical significance inasmuch as the screening could be undertaken at the earlier stages and selection for breeding initiated at the bearing stage.

iii) *Breeding strategy*: The selection criteria may be developed to aid in breeding for drought tolerance, based on the weightage given to the characters and yield performance.

iv) *Biochemical marker*: While the present data revealed unequivocally the sensitive nature of certain biochemical parameters, it needs to be taken to a logical conclusion through efforts at molecular level.

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DISCUSSION

TSG Peiris: How do you define 'drought index'? Don't you think you have to consider the daily measurements rather than averages over the periods?

V. Rajagopal: Drought index is defined as the ratio between functional leaves and dry leaves, as proposed by Pomier and de Taffin (1983). Daily measurements were taken on physiological parameters during the given season.

SELECTION OF COCONUT SEEDLINGS THROUGH PHYSIOLOGICAL AND BIOCHEMICAL CRITERIA

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ABSTRACT

In the adult West Coast Tall palms, the rate of photosynthesis, number of leaves, chlorophyll content, nitrate reductase activity and relative assimilation rate are significantly and positively correlated with mean annual yield of nuts. The efficiency of dry matter production and chlorophyll content are heritable. In the evaluation of hybrids, the results suggest that physiological and biochemical characters can be used to identify potential high-yielding hybrids in the one-year-old nursery.

INTRODUCTION

The West Coast Tall (WCT) coconut palms exhibit wide variability in the annual yield of nuts, ranging from 30 to 400. Normally, more than 15 years after planting is required to evaluate the potential yield of a variety or hybrid. If the potential yield could be predicted at the nursery stage itself, coconut plantation with uniformly high yield could be established. A study was therefore conducted to characterise the high yield in the adult palms and to relate the same with the vigour of the one-year-old seedlings which are usually used for planting.

MATERIALS AND METHODS

One hundred West Coast Tall palms (age: 35–40 years) growing in the CPCRI Research Farm were selected for the study. The rate of apparent photosynthesis was studied following the method of Forsyth and Hall (1965).

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The youngest fully unfolded leaf was found to be the most suitable leaf for sampling (Mathew and Ramadasan, 1974). The chlorophyll content was determined following the method described in AOAC (1966). For this purpose N/2 + 1th leaf was sampled as this leaf was found to be the most suitable tissue for sampling (Mathew and Ramadasan, 1973).

In an attempt to apply the growth analytical approach in adult palms, a method for determining the relative assimilation rate (RAR), instead of NAR (Watson, 1952) was standardized. Following this method, the RAR was determined in 40 adult WCT palms (Ramadasan *et al.,* 1984).

The nitrate reductase activity (NR) was determined following the method of Ferrari and Varner (1971). In the adult crown the activity was found increasing with maturity up to the fourteenth leaf, thereafter falling. Hence the fourteenth leaf was sampled. The enzyme activity was studied in 50 adult palms belonging to low and high yield groups.

Ten to 20 one-year-old seedlings were raised from each of a batch of 40 adult WCT palms consisting of low, medium and high yielders. Each of these 40 palms together with 10 to 20 seedlings from each palm formed one family unit. The RAR and chlorophyll contents in these 'families' were determined; in the seedlings the NAR was determined instead of RAR. The total shoot dry weight of one-year-old seedlings was determined non-destructively by the method of Satheesan *et al.* (1983). The morphological characters such as, annual yield and the number of leaves in the palms, the girth at collar, the total leaf area and height of the one-year-old progeny seedlings were also recorded.

In the hybrids, 1000 seedlings of five cross-combinations namely, Malayan Yellow Dwarf (MYD) × West Coast Tall (WCT), MYD × Kenyan Tall (KT), MYD × Zanzibar Tall (ZT), Malayan Orange Dwarf (MOD) × WCT and Chowghat Orange Dwarf (COD) × WCT were selected for the study. Besides recording the girth at collar, the number of leaves, the leaf area and shoot dry weight, the NR activity and the efficiency of accumulation of nitrate in the seedlings were also studied.

RESULTS

In the adult WCT palms a significant positive correlation has been found between the annual yield and (i) the rate of apparent photosynthesis, (ii) the number of leaves on the crown, (iii) the RAR, (iv) the NR activity, (v) total chlorophyll content, and (vi) the leaf area index (LAI) (Table 30.1).

In the one-year-old progeny seedlings of WCT palms, significant positive correlation has been noticed between the shoot dry weight and (i) the total leaf area, (ii) girth at collar, (iii) NR activity, and (iv) NAR with girth at collar (Table 30.2).

The relationship of the height of seedling, the number of leaves and the girth at collar with the total leaf area and shoot dry weight was studied using the path coefficient analysis (Table 30.3). It was found that the height of the seedling had a negative effect on the shoot dry weight. The number of leaves also showed a negative effect on the shoot dry weight.

Table 30.1: Physiological/biochemical parameters related to annual yield of nuts in adult WCT and hybrid coconut palms

	Parameters	*'r' value*
1.	Rate of photosynthesis	0.6137*
2.	No. of leaves on the crown	0.7028***
3.	Relative assimilation rate (RAR)	0.5800*
4.	Nitrate reductase activity	0.6855*
5.	Total chlorophyll content	0.2735**
6.	Leaf area index (LAI)	0.5167*

Table 30.2: Physiological/biochemical and morphological characters related to vigour (shoot dry weight) of one-year old tall and hybrid seedlings

	Parameters	*'r' value*
1.	Leaf area	0.9557**
2.	Girth at collar	0.7730*
3.	NR activity	0.4896**
4.	NAR with girth at collar	0.2016***

Table 30.3: Relative contribution of seedling characters to shoot weight in coconut

	Shoot dry weight versus			
	Girth	*Height*	*No. of leaves*	*Leaf area*
Correlation coefficient	0.9690	0.8822	0.7439	0.9695
Direct effect	0.4171	0.0953	–0.0862	0.5711
Indirect effect via				
Girth	–	0.3411	0.3293	0.3812
No. of leaves	–0.0681	–0.0681	–	–0.0664
Leaf area	0.5230	0.5007	0.4400	–
Residual effect = 0.0306				

In the preliminary screening of the 1000 hybrid seedlings of the five cross-combinations, namely MYD × WCT, MOD × WCT, COD × WCT, KT × WCT and ZT × WCT, based on the leaf area and shoot dry weights (Table 30.4) three hybrid combinations namely COD × WCT, MOD × WCT and MYD × WCT were selected for further studies. The characters further studied were LAI, LAR and the nitrate reductase activity, nitrogen uptake efficiency as well as nitrogen accumulation (Shivashankar and Kasturi Bai, 1988). The results are presented in Tables 30.5 and 30.6.

The rate of leaf area development and dry matter accumulation in MYD × WCT were significantly higher than those in MOD × WCT and COD × WCT. Such trends are noticed in the case of LAI and LAR also.

The inducible NR activity, nitrate uptake and nitrogen accumulation are also significantly higher in MYD × WCT than in COD × WCT and MOD × WCT. The rate of nitrogen accumulation was significantly and positively correlated with dry matter production ($r = 0.5782^{**}$).

Table 30.4: Leaf area and dry matter accumulation in coconut genotypes

Hybrids	*6th month*		*8th month*	
	**LA (m^2)*	**DM (g)*	*LA (m^2)*	*DM (g)*
MYD × WCT	4.57	100.40	7.50	176.50
MYD × KT	3.84	77.80	7.40	172.50
MYD × ZT	2.90	62.00	6.39	127.70
MOD × WCT	4.10	79.96	7.10	136.60
COD × WCT	2.50	44.00	5.20	90.00

*LA = Leaf area; DM = Dry matter

Table 30.5: Growth parameters of hybrid seedlings

Hybrid	*Girth (cm)*	*Leaf area (m^2)*	*Shoot dry wt. (g)*	*LAI*	*LAR (cm^2/g)*
COD × WCT	13.4 (0.15)	0.619 (0.003)	130.67 (10.225)	6.97 (0.28)	45.2 (0.46)
MOD × WCT	16.0 (0.63)	0.822 (0.005)	154.08 (10.659)	9.14 (0.55)	49.7 (2.69)
MYD × WCT	17.8 (0.63)	1.011 (0.119)	197.90 (15.128)	11.51 (1.39)	52.4 (2.45)
C.D. (P = 0.05)	1.6**	0.23**	–	2.60**	5.40**

Values are mean of 10 replicates
Figures in parentheses are SE of mean
** Significant at 1% level

Table 30.6: Total nitrate reduced and N accumulated after 1 month of N application (50 g N/seedling)*

Hybrid	*% increase in shoot dry wt*	*Total shoot N (g)*	*Total nitrate reduced by shoot (millimoles)*	*% N contributed by shoot*
COD × WCT	22.1	0.698 ±0.036	3.29 ±0.34	6.13
MOD × WCT	23.8	1.240 ±0.075	8.81 ±2.35	10.00
MYD × WCT	24.9	1.901 ±0.068	27.08 ±4.32	19.99
C.D. (P=0.05)	–	0.190	–	–

*N rate recommended at six months after field planting.

DISCUSSION

In adult WCT palms the photosynthesis, the chlorophyll content and the efficiency of dry matter production are positively and significantly correlated with the mean annual yield of nuts. The heritability of the chlorophyll content and efficiency of dry matter production (RAR) were further tested in the progeny seedlings of WCT. A relatively high heritability has been noticed for these characters in the one-year-old progenies. This indicates that in the WCT palms, the efficiency of dry matter production together with the chlorophyll content are heritable (Table 30.7) (Ramadasan *et al.,* 1985).

Table 30.7: Mother palm and progeny characters and their heritability

Characters	*Mean*		*Heritability*
	Mother palm	*Progenies*	
NAR (g/m^2/week)	4.07*	6.73	0.64
Total chlorophyll content (mg/g fresh weight)	1.83	1.90	0.81
Shoot dry weight (g)	4.07*	118.37	0.74

*RAR of adult palm (g/m^2/week)

In WCT palms nursery the method presently followed for selection of seedlings for planting is based on (i) the height, (ii) the number of leaves, and (iii) early splitting of leaves. The path coefficient analysis showed that the first two characters, namely, the height and number of leaves do not significantly contribute to the leaf area and shoot dry weight characters which denote the index of vigour in the seedlings.

Among the morphological characters, only the leaf area and the girth at collar contribute significantly to the shoot dry weight and hence the girth at collar alone is found to be the most suitable character (Ramadasan *et al.,* 1980) (Table 30.3) that indicates the vigour of the seedling. Since the efficiency of dry matter production in adult palm is positively and significantly correlated with high yield, the selection of one-year-old planting material based on girth at collar alone will be highly beneficial. Based on the management adopted in the coconut nursery, all seedlings having a girth at collar of 10 cm and above would be potential high yielders, and the early leaf splitting ones would also be included among those having more than 10 cm as the girth at collar.

Presently the breeders conduct field evaluation for the performance of hybrids they produce. This is obviously a time-consuming procedure as the coconut hybrids stabilise the yield only after 15 years. However, the present results show that the hybrid vigour is indicated very early in the sixth month to one-year-old seedling. The characters associated with the hybrid vigour are the efficiency of dry matter accumulation and nitrogen use. Based on these results the hybrid MYD × WCT was selected and planted in the field along with MOD × WCT and COD × WCT. Three years after planting, the MYD × WCT hybrid continued to show the vigorous growth (Table 30.8). In all the

Table 30.8: Leaf area, leaf dry weight, rate of leaf production and NR activity in the three hybrid cultivars — three years old

	MOD x WCT	*MYD x WCT*	*COD x WCT*
1. Rate of leaf production (No./year)	5.70	7.86	6.16
2. Leaf dry weight (g)	163.54	206.11	191.50
3. Leaf area (x $10^3 cm^2$)	31.27	44.32	39.00
4. NR activity (n. moles)	22.47	36.24	33.05

characters studied, namely (i) rate of leaf production, (ii) leaf dry weight, (iii) leaf area, and (iv) NR activity, the MYD × WCT is superior to the other two hybrids including the presently released hybrid, namely, COD × WCT. At the age of six years in the field, the data reveal the same trend (Table 30.9). In the canopy area, dry weight of the crown, the number of functional leaves and in the age of commencement of first flowering, the MYD × WCT continues to show superiority over the other two hybrids.

Table 30.9: Growth and flowering characters of six-year-old hybrids

Hybrid	*Age at first flowering (months)*	*Canopy area (m^2)*	*Dry weight of crown (kg)*	*Mean No. of functional leaves*
MYD × WCT	52	129.9	47.5	23.8
MOD × WCT	64	112.9	41.1	21.6
COD × WCT	73	107.8	42.9	18.8

Although the utility of the selection criteria of hybrids based on the physiological/biochemical methods adopted is to be finally established after relating the seedling characters to the yielding efficiency, the usefulness of the methods adopted is already established from the present studies.

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SCREENING FOR HIGH YIELD AND DROUGHT TOLERANCE IN COCONUT

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ABSTRACT

Putative drought-tolerant palms were initially selected from a 32-year old plantation grown in the isolated seed garden (Ambakelle) of Sri Lanka, on the basis of their relative stability of yield under changing weather conditions over a period of 16 years. The transpiration rate and leaf water potential measured over a two-year period, showed wide variation of these parameters with the weather conditions. Regression coefficients for these physiological parameters were further computed in order to develop a screening procedure based on the genotypic stability for the studied physiological parameters under fluctuating weather conditions.

Based on the screening procedure, three physiological parameters, namely, transpiration rate, leaf water potential and stomatal diffusive resistance, were measured, for another 43 putative drought-tolerant palms selected on the basis of their yield stability over the years. Sensitivity analysis for individual parameters carried out for all the genotypes showed high stability for two parameters. The genotypes showing above-average stability for three or two parameters were identified as drought-tolerant palms and others were rejected.

The biochemical parameters, namely, leaf sugar and starch did not show much variation between the groups. However, proline showed an increased accumulation rate for the selected palms during the dry period.

INTRODUCTION

The total land area under coconut in Sri Lanka is 416,260 ha. About 20 per cent of the coconut lands are in the dry zone and the balance is equally distributed in intermediate and wet zones. In the intermediate dry and dry zones annual rainfall is 1000–1500 mm and 1000 mm or less, respectively with four to seven months long dry periods and one monsoon rainy period. Scarcity of available soil water and high temperature are the main 'stress' factors experienced by plants growing in these regions. Wide fluctuations in the national coconut production between 300 million and 1,800 million nuts/annum has been reported during the last three decades primarily due to recurrent droughts and

fertiliser usage. Poor setting of female flowers, immature nutfall, drooping of fronds and bunches, scorching and death of palms are common end results of the prolonged droughts.

Problems Associated with Crop Improvement for Drought Tolerance

Perennial tree crops have to experience varying environmental conditions throughout their vegetative and reproductive life cycles. The plants growing in dry and semi-dry zones are compelled to experience extreme conditions where the amount of available water is very little, drought period over the year is long, rainfall is unpredictable, solar radiation and temperature are high and relative humidity is low.

Perennial tree crops are organised to maintain low maintenance respiration, storage of organic metabolites and plant nutrients in the foliage and trunk and the ability of the plants to explore large volume of soil for water. Also unlike other improvement strategies improvement for drought tolerance is not associated with any single character or gene.

Therefore, any crop improvement strategy for drought tolerance, environmental complexities and complex nature of plant processes in perennial tree crops and their adaptive mechanisms have to be taken into consideration.

Past Efforts for Drought Screening

During the last two decades many physiologists have proposed traits that can be used to improve the performance of drought-affected crops (Seetharama *et al.,* 1983; Turner, 1986; Rosenow and Clark, 1981). Peacock and Sivakumar (1986) proposed some of the physiological measurements including visual assessment of drought effects at various growth stages and quantitative assessment of physiological parameters. Campbell and Díaz (1988) proposed detailed water balance model which provides sufficient details about the environment but specific investigations are needed to determine the functional relationships of crops grown in drought-affected areas.

Finlay and Wilkinson (1963) developed a statistical technique and considered the linear regression slope as a measure of stability of the maize genotypes. Eberhart and Russel (1966) emphasised the importance of considering both slope and deviation from regression to express the stability of genotypes to environment. To describe the adaptabilities, a regression coefficient of 1.0 is taken as having an average stability. A genotype which has a coefficient less than 1 or greater than 1 indicated the above average and below average stability, respectively. Breese (1969) using this technique to analyse the performance of herbage plants under diverse soil, climatic and management systems reported that the same technique could be effectively used to describe relative performance of plant populations over seasons, localities and years.

In this study we have chosen several physiological and biochemical traits namely transpiration rate, stomatal diffusive resistance, leaf water potential, sugar, starch and proline concentration in leaves to identify desirable phenotypes depending on the relative stability of more than two physiological parameters to fluctuating environmental conditions.

MATERIALS AND METHODS

The initial drought screening studies were carried out on a 32-year old coconut plantation grown in the isolated seed garden (Ambakelle) of the Coconut Research Institute of Sri Lanka. Putative drought-tolerant Tall × Tall coconut palms were first selected on the basis of mean yield and genotypic adaptation to changes in weather over a 15-year period (Wickremaratne, 1984). The mean yield of these selected putative drought-tolerant palms was 80 nuts/palm/year and regression coefficient (b values) evaluated (Finlay and Wilkinson, 1963) were closer to 1. All the selected putative drought-tolerant palms received the same dosage of fertiliser and cultural practices as the rest of the palms. Weather parameters in the seed garden were routinely measured and soil water availability and extraction pattern up to a depth of 2 m were measured at monthly intervals using a neutron probe for individual palms. Canopy water relation parameters, namely, transpiration rate and leaf water potential were measured for individual palms at monthly intervals using LI-COR steady state porometer and the pressure bomb. The ninth leaf was used as the standard leaf for all the measurements. Leaf samples were collected from the same leaf, at monthly intervals and total sugars (Dubois *et al.,* 1956) reducing sugars (Sumner, 1924), starch and proline (Troll and Lindsley, 1955) content were assayed using oven dried, powdered leaf samples extracted in 50 per cent ethanol.

Stability of selected putative drought-tolerant genotypes to the studied physiological parameters over the changing seasonal weather conditions were further analysed by the method of Finlay and Wilkinson (Jayasekara, 1990). Regression coefficients (b values) evaluated for these parameters were again closer to 1. The palms selected at the second screening were considered as "drought tolerant". Visual observations of these selected palms were made at the end of a drought period.

Based on the above screening procedure another 43 putative drought-tolerant palms were used for drought screening. As in the earlier study three physiological parameters, namely, transpiration rate, leaf water potential and stomatal diffusive resistance were measured for 35-year old putative drought-tolerant palms at monthly intervals over a period of one year. Sugar, starch and proline content in leaves were analysed as described earlier. Stability of phenotypes to studied physiological parameters under fluctuating environmental conditions were determined by b value analysis.

RESULTS

The changes in weather parameters over a four-year period from 1987 to 1990 are given in Figs. 31.1 and 31.2. The transpiration rate, leaf water potential and stomatal diffusive resistance were measured for 10 putative drought-tolerant palms over a period of 10 years in the preliminary study. It was observed that during the monsoon period of 1987 (April/May and October/November) most of the palms used in this study showed a two-fold increase in transpiration rate and wide variation in leaf water potential during wet and dry months (Figs. 31.3 and 31.4). Few palms have shown a slightly high transpiration rate during wet

months, but maintained a steady transpiration rate throughout this two-year period (Palm numbers 12, 14 and 20). Similarly few palms were able to maintain fairly steady leaf water potential regardless of the environmental conditions. When the sensitivity coefficient (b value) of individual palms for transpiration rate and leaf water potential were computed, palm numbers 12, 14 and 19 had fallen into the high stability group to the fluctuating

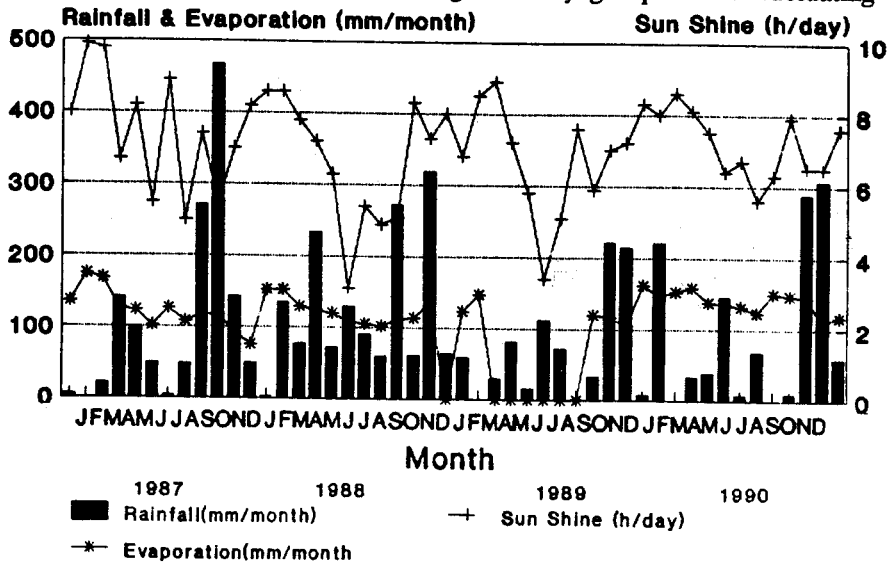

Fig. 31.1: Rainfall, pan evaporation and daily sunshine at isolated seed garden (Ambakelle) during 1987–1990.

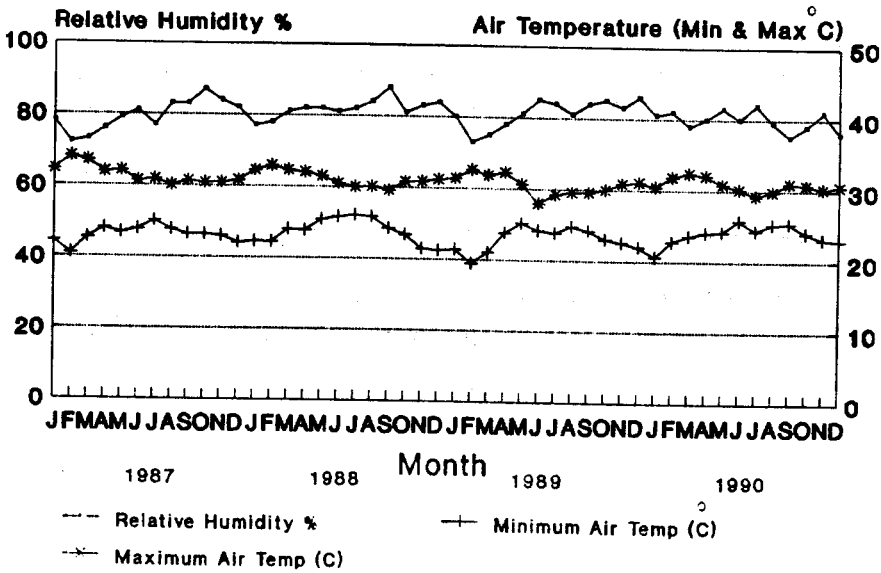

Fig. 31.2: Average relative humidity and air temperature at isolated seed garden (Ambakelle) during 1987–1990.

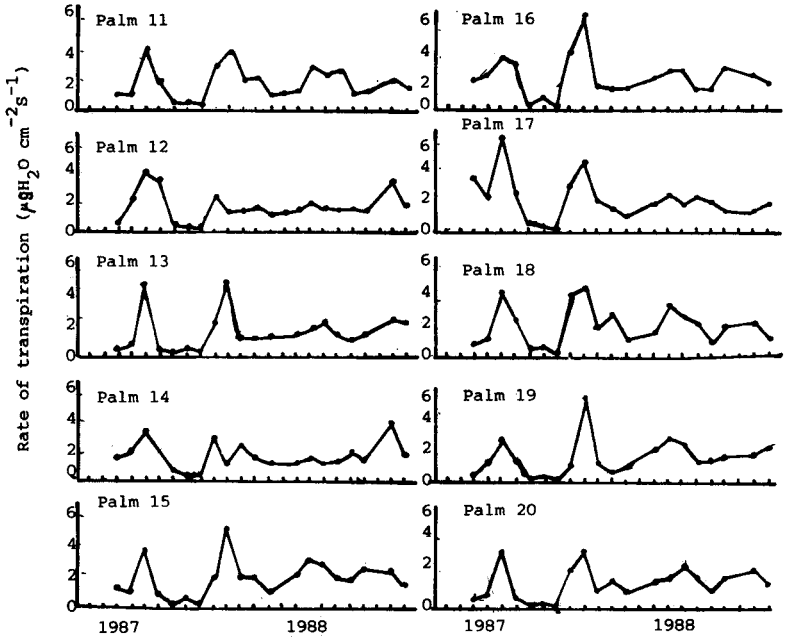

Fig. 31.3: Transpiration pattern of putative drought-resistant palms during a two-year period from 1987 to 1988.

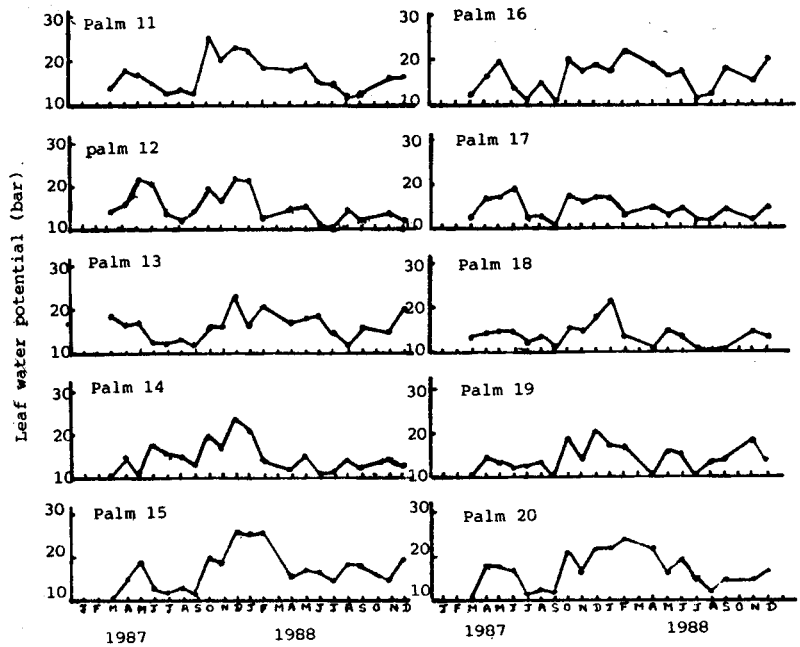

Fig. 31.4: Leaf water potential (ψ) of putative drought-resistant palms during a two-year period from 1987 to 1988.

environmental conditions, whereas palm number 16 had an average stability (Fig. 31.5). These four palms showed low response to fluctuating environmental conditions and maintained a steady transpiration rate and high leaf water potential whilst giving high yields throughout the year. When visual observations were made at the end of seven months long drought period that existed last year, it was found that the palms selected as phenotypically superior for drought tolerance based on this procedure were able to stand drought without drooping the fronds and bunches in the lowest whorl and with substantial nut setting in the developing bunches. Based on this screening procedure physiological parameters, namely, rate of transpiration, stomatal diffusive resistance and leaf water potential were studied for another 43 putative drought-tolerant palms over one-year period. In this approach the regression coefficient (b value) measures the response of phenotypes to studied parameters under fluctuating environmental conditions at the location where these measurements were taken. The phenotypes with b values greater than unity would have adapted to favourable weather conditions, whereas those phenotypes with b values less than 1 would have adapted to less favourable weather conditions. The relationship between the rate of transpiration and b values for 43 putative drought-tolerant phenotypes is shown in Fig. 31.6, in which all the phenotypes were grouped into four compartments. The four compartments were identified by drawing the broken line at b = 1 and at the grand mean of the physiological parameters measured. There were 21 phenotypes with an above-average stability to rate of transpiration under fluctuating environmental conditions and above average yields. Relationship between regression coefficient and leaf water potential as well as stomatal resistance are given in Figs. 31.7 and 31.8. Sixteen phenotypes have shown the above average stability for those parameters under fluctuating environmental conditions.

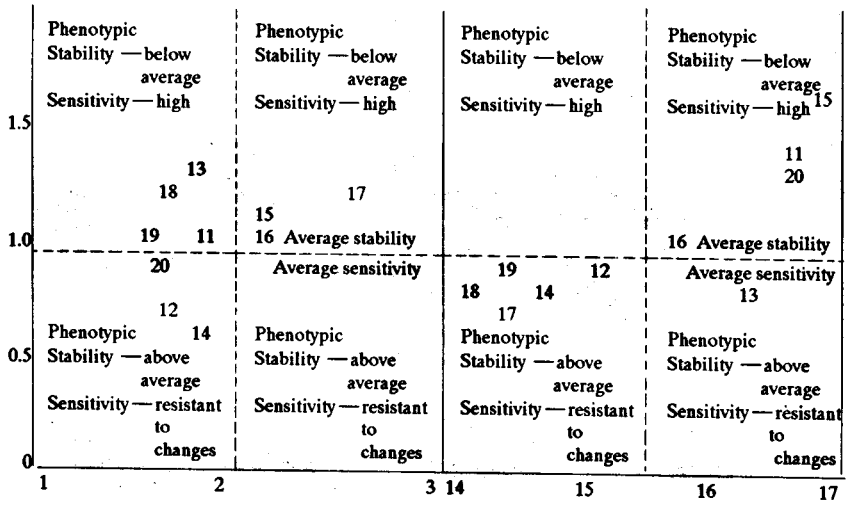

Fig. 31.5: Distribution of the palms according to phenotypic stability and sensitivity.

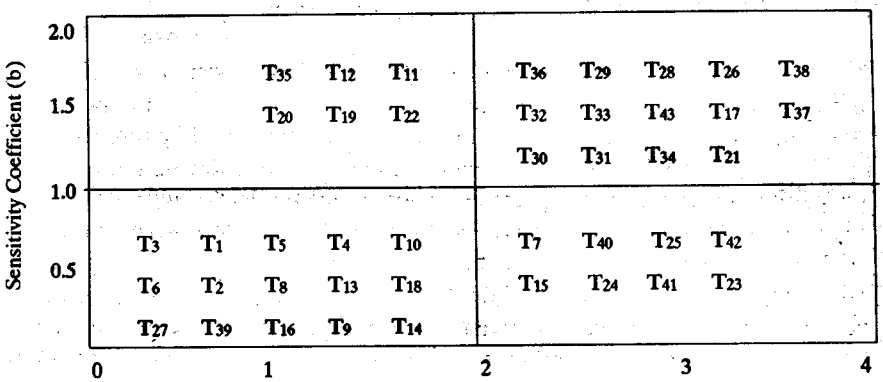

Fig. 31.6: The relationship of rate of transpiration ($\mu g\ cm^{-2}\ s^{-1}$) and relative stability of studied coconut palms.

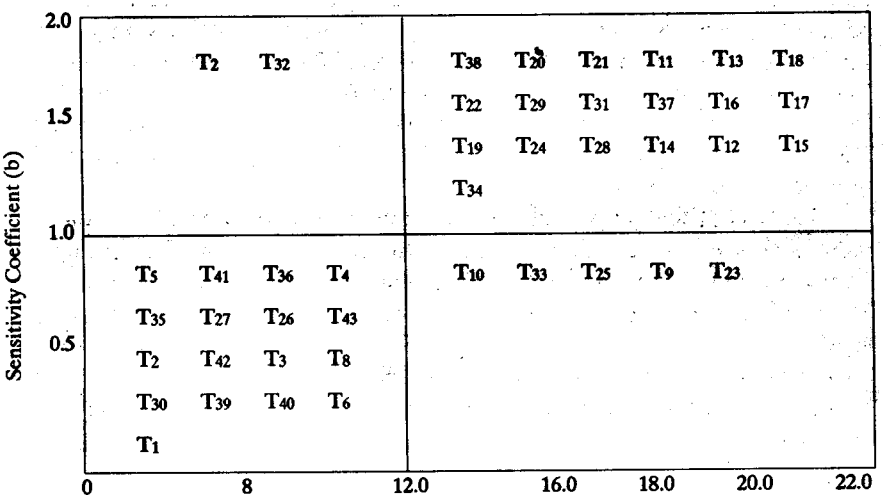

Fig. 31.7: The relationship of leaf water potential (bars) and relative stability of studied coconut palms.

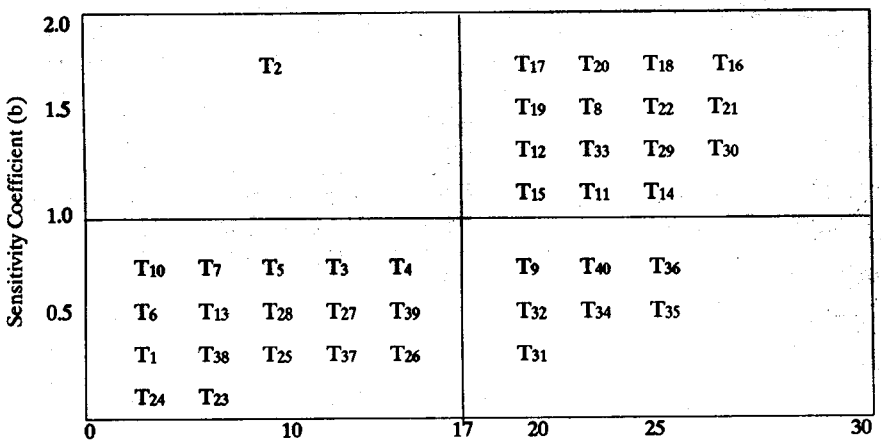

Fig. 31.8: The relationship of stomatal diffusive resistance ($s\ cm^{-1}$) and relative stability of studied coconut palms.

Out of those 43 putative drought-tolerant palms, seven palms showed above-average stability for all three physiological parameters studied. Five palms showed above-average stability for two parameters and 16 palms showed above-average stability for one parameter studied. Palms showing above-average stability for three or two parameters were selected as "drought-tolerant" palms and others were not considered suitable. These palms were stable for three or two physiological parameters and were able to maintain moderate transpiration rates (2.5 — 1.5 $\mu g\ H_2O\ cm^{-2}\ s^{-1}$), whereas the other two groups showed a wide fluctuation and higher transpiration rate during some months. Palms stable for all three parameters maintained the leaf water potential between 10 and 12 bar during the year except on one occasion when low leaf water potential was recorded. A similar trend was observed with palms selected for the stability for two characters. Among the two palms stable for one parameter, palm No. 43 behaved exceptionally well maintaining higher and stable leaf water potential throughout the year. Palms in the sensitive group showed wide fluctuations in leaf water potential throughout the year. Thus, from this study it was possible to select 12 palms (28 per cent) as "drought-tolerant" palms or palms with high stability for physiological parameters under fluctuating environmental conditions.

Analysis of leaf sugars and starch content in leaves during wet and dry months showed no variation in these parameters among the four groups of palms selected on the basis of their physiological stability and sensitivity (Table 31.1). All the palms selected in this study have been initially selected for their yield stability over the years. Perhaps this may be a reason to have similar concentrations of sugars in leaves. However, accumulation of slightly higher concentration of proline during dry months was observed in palms selected as drought-tolerant.

Table 31.1: Leaf sugar and proline concentration in 'drought-tolerant' and susceptible palms during wet and dry periods of the year

Selection criteria		*Average concentration*					
		Total sugars		*Starch*		*Proline*	
		Wet	*Dry*	*Wet*	*Dry*	*Wet*	*Dry*
Genotypes stable for	3 parameters	32.5	32.8	19.1	19.9	611.6	702.6
	2 parameters	34.3	34.8	19.7	20.7	647.0	686.7
	1 parameter	31.7	34.8	17.6	20.5	695.9	672.7
	none	32.9	36.5	17.8	20.7	661.4	681.7
Significance		NS	NS	NS	NS	NS	NS

DISCUSSION

Survival of palms under stress conditions is determined by the plant's ability to maintain an internal water status which allows it to sustain essential metabolic

processes such as photosynthesis, respiration, translocation and uptake of water and nutrients. The measured physiological parameters provide the information about the response of plants under drought-affected conditions. The usefulness of these physiological traits for systematic screening of germplasm for drought tolerance have been described in detail by several researchers (Morgan, 1983; Bidinger *et al.,* 1982; Peacock and Sivakumar, 1986; Seetharama *et al.,* 1983).

The regression approach was used in this study to determine the adaptability of individual genotypes to environmental changes. Considering that high genotypic variations exist in individual coconut palms, each palm was treated as one variety and with no replicates. Once they are selected on the basis of physiological parameters, their relative stability to the environment could be assessed by osmotic adjustment (Ludlow, 1980) and visual observations. Osmotic adjustments contribute to plant yield in water limited conditions by increasing the amount of water transpired and by maintaining harvest index (Wright *et al.,* 1983; Hsiao *et al.,* 1984). Further osmotic adjustment appears to be the main mechanism of stomatal control under low leaf water potential conditions as drought increases (Ludlow, 1980).

Drought is one of the major limiting factors that considerably reduce productivity of coconut palms. However, severity of drought and the response of plants to drought are highly location specific. Therefore, once suitable physiological traits are identified, selection of most appropriate genotypes should be based on environmental, genotypic characters, economic and social factors that exist in different agro-climatic regions. For successful crop improvement programmes, integration of breeding and physiological research is vitally important. Once suitable physiological traits are identified, hybridisation, selection and assessment of inheritance and heritability of the selected characters could help to develop efficient screening techniques.

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THE IDENTIFICATION AND ISOLATION OF PLANT GROWTH REGULATING SUBSTANCES FROM THE LIQUID ENDOSPERM OF *COCOS NUCIFERA*

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ABSTRACT

The identification and isolation of various endogenous cytokinins from the liquid endosperm of *Cocos nucifera,* with their subsequent quantitative estimations, revealed the presence of zeatin, zeatin riboside and 2iP, whereas zeatin ribotide eluded the experimental material. Further appraisal of liquid endosperm concomitantly also showed the presence of indole-3-acetic acid (IAA) and two gibberellins (GA_3 and GA_7). The activity of cytokinin oxidase augmented as the liquid endosperm aged both *in vivo* as well as *in vitro* conditions. However, the activity of IAA oxidase remained static *in vivo* ambient while it increased under *in vitro* conditions. The data showed that the activity of cytokinin oxidase can be regulated through specific transcriptional inhibitors (cycloheximide/actinomycin D) both *in vivo* and *in vitro* conditions.

INTRODUCTION

The coconut water is a liquid endosperm and has the potentiality of enhancing the growth of cells, tissues, or organs under *in vitro* conditions. The fable of coconut water getting into the world of tissue culture dates back to the forties when Prof. Van Overbeek and his co-workers (Van Overbeek *et al.,* 1941) demonstrated that embryos of *Datura* plant required a factor for growth which was present in coconut water. Later on, in an appraisal of the promotory factors present in coconut water Miller resolved that a number of nucleic acid preparations could substitute for coconut water. To his surprise he found that herring sperm DNA supported optimally the growth of tobacco stem callus. Perhaps the unique observation of Miller (1956) which deserves an adulation forever, was that the tissues responded to the exogenous supply of DNA preparations only when it was old and the same lacked in response when the

fresh sources of nucleic acids were incorporated into the system. Since these discoveries and observations (Mauney *et al.,* 1952; Shantz and Steward, 1952; Pollard *et al.,* 1961; Shantz and Steward, 1964; Kovoor, 1964; Loeffler and Van Overbeek, 1964; Zwar *et al.,* 1964; Shaw and Srivastava, 1964) innumerable experiments have been planned and executed with the sole aim of identifying the growth promoting substances which must be constituting this mysterious liquid endosperm. The in-depth appraisal of the liquid water *vis-a-vis* the identification of the relative levels of different growth regulating substances might prove a boon to the tissue culturist for quick clonal propagation, as a research tool and as a basis for the development of future of tissue culture programme which is still considered to be a highly dexterous pursuit. It is with these objectives that the present work, which deals with the aim of looking at the composition of coconut water and to know in more detail the growth regulating substances present *per se* is reported.

MATERIALS AND METHODS

Bioassays and chromatographic methods: Estimates of auxin activity were carried out on the basis of growth test of oat (Kent) (*Avena sativa* Linn.) celeoptiles as described by Mer *et al.* (1962), gibberellin by the modified technique of Ogawa (1963) using 'Tainan-3' rice (*Oryza sativa* Linn.) and cytokinins by *Xanthium* leaf disc senescence method of Osborne and McCalla (1961). Standard series of cytokinins (zeatin, 2ip, zeatin riboside, zeatin ribotide), gibberellins (GA3, GA4, GA5, and GA7) and auxins (IAA, IAN) were run separately for their Rf values. Scheicher and Schull 598L paper was used for all paper chromatography. Zones of preparative paper chromatograms were eluted with 0.3 N acetic acid and the elutes evaporated in vacuum. N-Butanol-acetic acid-water (12 : 3 : 5 v/v) as solvents were used for chromatographs.

Coconut water (3L) obtained from tender coconut fruits (nine months old) was adjusted to pH 10.8 with NaOH solution and then clarified by filteration. Ammonia solution (60 ml, 14N) was then added and the water was (final pH 10.9) percolated through a column of De-Acidite FF. The column was washed with water 45L, pH 10.9 with ammonia and then eluted with 1.5 N acetic acid. The elute was evaporated at 20°C in an evaporator. The subsequent extraction procedure was basically the one as described by Nitsch (1956) for auxin, by Murakami (1966) for gibberellins and by Dua and Jandaik (1979) and by Letham (1974) for cytokinins. The samples were either taken from intact coconut fruits at different stages of storage which was done at 5°C (*in vivo* samples) or the liquid endosperm after extraction was kept in improvised sample bottles under the same conditions. The data were analysed statistically according to the variance method. The different inhibitors used under various studies were morphactin (methyl-2-chloro-9-hydroxy-fluorene-(9)-carboxylate chloro-fluornol-methyl ester-II-3456), DPX-1840 (3, 3a-dihydro-2-(p-methoxyphenyl) 8H-pyrazolo-(5,7)-a-isoindol-8-one and AMO-1618 (ammonium (5-hydroxy carvac. yl) trimethyl chloride piperdine carboxylate).

RESULTS

A) Cytokinins

The scrutiny of the data, available from the bioassays of the different extracts of liquid endosperm of tender coconuts, deciphered the presence of three different cytokinins namely zeatin (Rf 0.2–0.3), zeatin riboside (Rf 0.4–0.5) and 2ip (0.6–0.7). The activity of each one of the cytokinins, available in the liquid endosperm, declined as the samples passed from the first stage to the sixth stage of incubation (total 60 days). As indicative from Fig. 32.1 an approximate 53 per cent depreciation in the level of total cytokinins was apparent in a total span of 60 days of storage. A look into the behaviour of these substances from the samples stored for 24 hours after extraction (Stage 1 *in vitro* samples) projected a sudden disappearance in the levels of all the cytokinins almost instantaneously. The most interesting revelation was from the *in vitro* samples which had the presence of morphactin for at least 24 hours in the coconut fruit (injected through a specially improvised injection syringe) and then stored under *in vitro* conditions for different periods (stages). Herein, the scenario with regard to cytokinin distribution, was almost alike to that of *in*

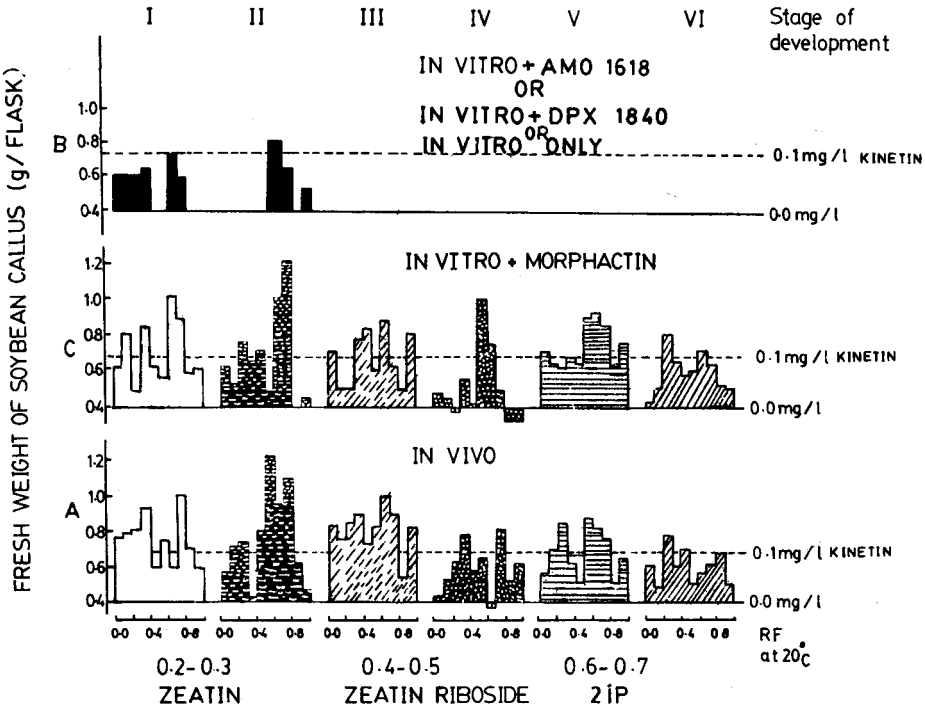

Fig. 32.1: Distribution of cytokinins under different conditions and the effect of different growth inhibitors on their levels under *in vitro* conditions in the liquid endosperm of coconut (*Cocos nucifera* L.). The values are expressed on per unit (1L) basis and are the averages of five replications.

vivo distribution and there was almost no difference with regard to total cytokinin contents whether they had been extracted from tender fruits or whether the samples had been stored under controlled conditions for different intervals of time. In fact at three stages (fourth, fifth and sixth) the cytokinins contents from this treatment were significantly more than from the samples procured from *in vivo* conditions. The presence of other inhibitors did not alter the levels of endogenous cytokinins.

B) Auxins

A look into the levels of auxin like substances from liquid endosperm, revealed the presence of an active principle at a broad Rf which spanned from 0.5 to 0.8 both under *in vitro* and *in vivo* conditions. The levels of auxin group decreased under both the conditions of storage and by the onset of the sixth stage there was a depreciation of 72 per cent in the level of auxins on absolute terms. The whole segment appeared to be occupied by a group of substances since indole-3-acetic acid appeared to occupy Rf 0.5 to 0.6. A noticeable observation was the appearance of a biologically active auxin at Rf 0.3–0.4 during the later stages of liquid endosperm under *in vivo* conditions. This newly formed auxin quantitatively was significantly more than the group of auxin isolatable during the early stages (13 per cent more). It appeared to be an enzymatic degradative product of an earlier biological non-auxin substance or newly synthesised auxin which did not appear to be IAN or 2-IAN or indole acetyldehyde.

C) Gibberellins

The analysis of liquid endosperm, with regard to gibberellin like substances, revealed the presence of two substances at Rfs 0.0–0.2 and 0.6–0.7. The

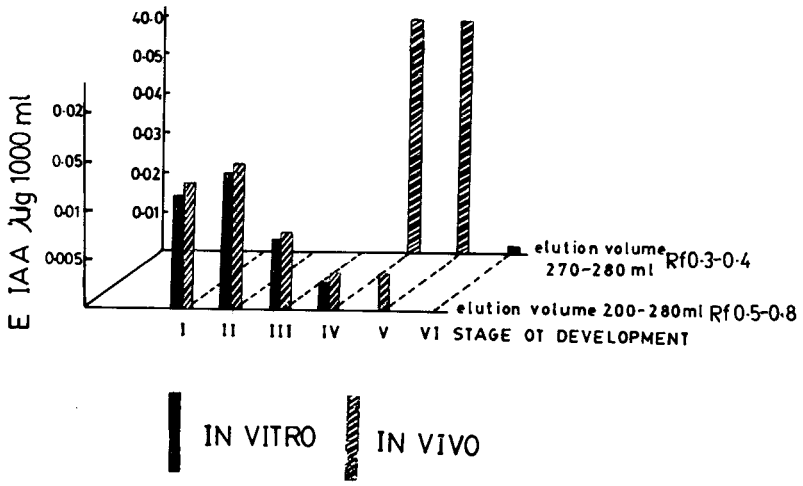

Fig. 32.2: Distribution of auxin in the liquid endosperm of coconut (*Cocos nucifera* L.) at different stages of incubation under *in vitro* and *in vivo* conditions (values expressed on per unit basis (1L) and are the averages of five replications).

Rf 0.1–0.2 corresponded with the synthetic gibberellic acid (GA3) while 0.6–0.7 Rf did not match with the available GAs (GA5, GA7, GA9 or GA4). The level of gibberellin declined as the liquid endosperm matured both under *in vitro* or *in vivo* conditions and by the end of the sixth stage there was a reduction of 160 per cent in the level of total gibberellins. A noticeable feature was the instant jump in the level of gibberellin at the second stage (20 days old) and the real decline started from that stage only, or to put it in other words, the fruit supported the maximum level of gibberellins at 20 days stage after harvest. The presence of specific inhibitors namely DPX-1840, AMO-1618 or morphactin under *in vitro* condition did not alter the behaviour of these two substances unlike cytokinins which retained their *in vivo* levels once morphactin was *in situ* for 24 hours (see under cytokinins). Fig. 32.4 depicts the pattern of endogenous hormones in the liquid endosperm in the presence of specific inhibitors under *in vivo* conditions. A perusal of data reveals that with a simple presence of morphactin the total level of cytokinins increased by 37 per cent whereas with the presence of other substances namely AMO-1618/DPX-1840 did not alter the levels of cytokinins in the liquid endosperm. On the other hand, the presence of AMO significantly decreased the level of GA3 and DPX-1840 decreased the level of auxins and as these were the specific synthetic inhibitors of their respective endogenous hormones it appeared that the synthetic activity continued in the post-harvest stage under *in vivo* conditions only. Since the absolute quantities depreciated, it appeared that the breakdown also continued simultaneously under both *in vitro* or *in vivo* conditions. In the samples which had different permutations and combinations of inhibitors the rule appeared that wherever morphactin was present the levels of endogenous CKs decreased whereas other inhibitors checked Au or GAs levels.

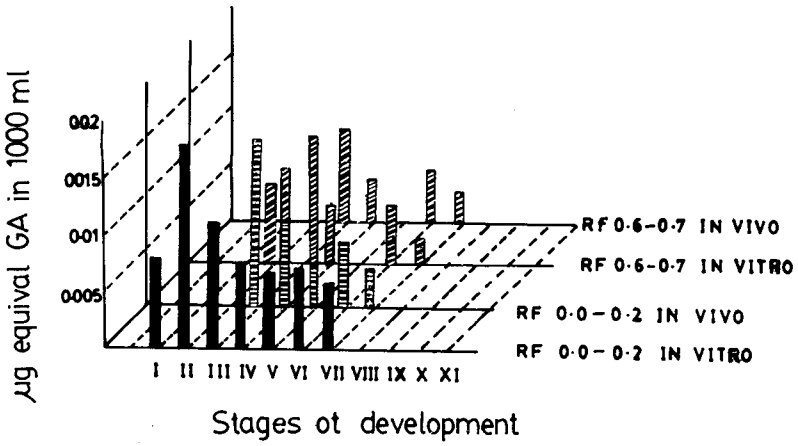

Fig. 32.3: Distribution of gibberellins in the liquid endosperm of coconut (*Cocos nucifera* L.) at different stages of incubation under *in vitro* and *in vivo* conditions (values expressed on per unit basis (1L) and are the averages of five replications).

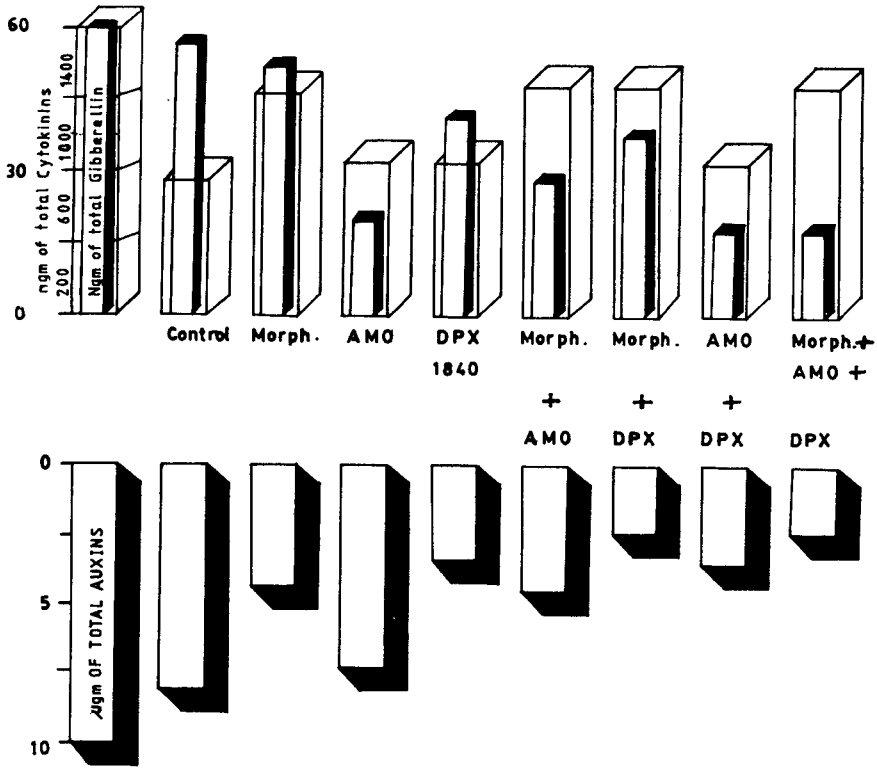

Fig. 32.4: Effect of morphactin, AMO-1618 and DPX-1840 on the endogenous levels of total cytokinins (small shaded blocks inside the bigger blocks) in n grams and auxins (in μg) per 1L of liquid endosperm of *Cocos nucifera* L. under *in vivo* conditions (average of five replications).

DISCUSSION

The use of coconut water as a moderator for plant growth regulation took birth in coincidental circumstances mainly on the work on tissue culture experiments conceived and carried out by Van Overbeek and his group in the forties. In the subsequent tissue culture experiments, performed in the next decade or so, a number of substances like malt extract or liquid endosperm of *Aesculus hippocastanum* were used as additives in the basic medium (Fonneshbeck, 1972) but ultimately it was coconut water which could stand the test of time and was acquiescenced almost as an integral part of the growing media in tissue culture experiments.

Many diverse substances have been envisaged to be the part of this multiple component system, and people like Miller *et al.* (1955), Letham (1974) and Vanstanden and Drews (1975) thought these to be cytokinins while earlier workers like Steward (1968) considered inositol, also known as myoinositol, meso-inositol or inositol, as an important component of the neutral fraction of coconut water. Somehow Arditti (1977) advocated that inositol's presence for

tissue culture propagation in a number of orchid plants was not mandatory. Fonnesbech (1972) reported that even coconut water may be inhibitory or without any significant effect for some of the tissue culture experiments.

The present findings unequivocally reveal the presence of three cytokinins namely zeatin, zeatin riboside and zeatin ribotide from the liquid endosperm of tender coconuts. Letham (1974) had mooted that zeatin riboside is the translocational form of zeatin and this premise was based on the work of Gorden *et al.,* (1974) who had confirmed the presence of zeatin riboside in a number of tender seedlings. Further the dominant cytokinin in the xylem sap of *Populus robusta, Salix viminalis* and *Acer pseudoplatanus* intervened to be zeatin riboside. Since during the development of the coconut seedling, the cotyledon enlarges inside the cavity of a nut and absorbs nutrient from the milk to nourish the seedling, zeatin riboside may be getting translocated without modification to regions of the developing seedling where it is required. The very fact that their level dwindled, as the liquid endosperm aged under *in vitro* or *in vivo* conditions, revealed the fragility of the system. Somehow the observation of many tissue culturists that the fresh coconut water invariably proved to be an effective promoter of growth and development and the stale one drew a blank adduce support from the present work. Their depreciation may have something to do with the appearance of few degradative enzymes and in fact our preliminary experiments (Dua *et al.,* unpublished) have shown instant upgradation in the quantity of a few catabolic enzymes during storage, under *in vitro* or *in vivo* conditions. A salient component of the present investigations appears to be the phenomenon that the decrement in the levels of endogenous hormones like cytokinins could be checked through the use of specific growth regulators like morphactin. The presence of gibberellin and auxin like substances at the particular stages may have a bearing with the peculiar stage of development of coconut fruit and may find relevance as per the requirement of tissue culturist especially once we have acquired a proficiency in their manoeuvrability through the use of specific inhibitors as in the current probe. The appearance of auxin-like substances during the later stages of storage appeared to be a bio-transformation of a precursor of auxin since the same appeared exclusively under *in vivo* conditions. As apparent from the different line drawings the result depicts, without any unequivocation, that the levels of cytokinins *per se* could be augmented by the use of morphactin. The upgradation in the levels of CKs through this compound also draws its support from the work of Bednar and Linsmaier-Bednar (1971); Dua *et al.* (1978); Dua and Dhuria (1980) and Dua *et al.* (1982) as well as the work of Ruddat and Pharis (1966) and Baldev *et al.* (1965) on AMO-1618 and the work of Morey and Dahl (1975) and Morey (1974) on DPX-1840 where the two inhibitors abated the levels of these two hormones respectively.

ACKNOWLEDGEMENTS

The authors are thankful to Prof S.P. Vij, Professor of Botany, Panjab University for suggesting key points and for innumerable discussions during

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DISCUSSION

H.C. Harries: Please explain the differences between coconut water and coconut milk?

I.S. Dua: They are one and the same. In an earlier work, coconut liquid endosperm has been referred to as the coconut milk and only in recent literature the usage of coconut water is preferred to coconut milk.

PHILIPPINE-GERMAN COCONUT TISSUE CULTURE PROJECT—FIRST RESULTS

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ABSTRACT

The Philippine-German coconut tissue culture project focusing on technology development and transfer of an asexual propagation system for coconut started in February 1989. Immature embryos, leaves and inflorescence are used as explant sources. Predictable callus formation is being obtained with immature embryos and inflorescence explants. For leaf explants the composition of the basic medium as well as the concentrations of the growth regulators still need to be defined. Experiments on anther culture have been initiated. The type of cytokinin added to the medium affected the browning incidence of inflorescence explants. While 6-benzylamino-purine (BAP) alone resulted in the highest percentage of browning, combined BAP and N^6-isopentenyladenine (2-ip) on the other hand showed the lowest browning incidence.

INTRODUCTION

Conventional propagation of coconut palm is at present carried out entirely by the use of seednuts. This induces a high degree of variation of yield in the plantations. Therefore, vegetative propagation by means of tissue culture techniques is highly desirable allowing significant yield increases by propagation of high-yielding individuals. In the same way, individuals presenting resistance to certain diseases and tolerance to adverse growing conditions could be propagated. Moreover, clonal propagation would mean a more rapid availability of breeding results to the farmers.

After having gained experience with embryo culture as an experimental tool in relation to *cadang-cadang* disease researches (Rillo and Paloma, 1989), the idea for a comprehensive project on tissue culture of coconut palm in the Philippines was born. It was suggested that the Philippine Coconut Authority

(PCA) should take the lead within the Philippines to develop a technique for asexual propagation of coconut. An international review mission selected the Albay Research Centre of PCA as the project site and Ms. Erlinda P. Rillo was designated as project leader.

In September 1988 the Governments of the Federal Republic of Germany and the Republic of the Philippines formally agreed upon a technical cooperation concerning the project "Tissue Culture of Coconut Palms". The Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, a German Agency for Technical Cooperation, was commissioned by the German Federal Government with the technical planning and implementation of this project.

The first implementation phase of the project with a duration of three years effectively started in February 1989.

This project entails collaborative efforts not only with the Federal Republic of Germany, but also maintains a close cooperation link with Wye College, University of London, UK. In this paper the first results obtained by the tissue culture team at Albay Research Centre are reported.

TYPES OF EXPLANTS UNDER INVESTIGATION

Immature Embryos

The production of callus on embryo tissue could yield plants through somatic embryogenesis. De Guzman *et al.* (1978) obtained nodular callus, root-like structures and spongy haustorial-type tissue from the cotyledonary sheath tissue of mature zygotic embryos. Slicing of embryos encouraged calloid development, especially on 11-month old embryos as compared with 12-month old embryos (Blake, 1990).

A more novel approach is the use of immature embryos from very tender nuts. Karunaratne and Periyapperuma (1989) obtained embryogenic callus tissues from the culture of six to seven months old embryos in the presence of 1.2 to 2×10^{-5} M 2, 4-D. Part of these callus tissues produced globular embryos which germinated and produced shoots. However, regeneration of plantlets has not yet been achieved.

In our laboratory, immature embryos are also being used as explants for the clonal propagation of coconut palm. Embryos excised from about seven-month-old 'Catigan' nuts cultured on the medium used by Karunaratne and Periyapperuma (1989) showed quick expansion, but no calli were formed. The culture of embryos of the same age using a medium formulation which has been elaborated at Wye College, UK (in this paper referred to as Blake's medium; see Ebert and Taylor, 1990 for details) supplemented with high 2,4-D levels resulted in predictable callus formation. Further refinement of the media composition is under way to optimise the production of embryogenic callus. It is felt that only marked nuts, the age of which is being precisely determined by close monitoring while still in the pre-anthesis stage, should be used. This procedure could eliminate one source of variability in response to the cultured explants arising from differences in the age of the nuts.

The culture of zygotic embryos is being further intensified with the objective of optimising the factors for successful growth *in vitro* and the subsequent transfer to *ex vitro* conditions. In this respect progress has been reported recently from our laboratory (Rillo and Paloma, 1990). The results obtained with zygotic embryos could prove very useful for the successful establishment of clonal plantlets.

Immature Leaves

Leaf explants comprise fragments of juvenile, non-chlorophyllous leaves, still surrounded by the petiole bases of the older leaves. Although reported possible (Verdeil *et al.,* 1989), the sampling of immature leaf tissues without wounding the apex does not always result in continued growth of the selected donor palm. At the Albay Research Centre in the Philippines continued growth of the donor palm was only observed when sampling was done during the rainy season. The extreme heat during dry season collections caused cracks in the exposed apex leading to the death of the palms.

Two groups reported successful regeneration of coconut palm from leaf explants. Raju *et al.* (1984) suggested that a callus stage may not be necessary for regeneration in coconut, but that direct embryogenesis in cultured leaf tissue could lead to the formation of clonal plantlets. Direct embryogenesis from leaf explants, but without successful regeneration, has also been reported by Gupta *et al.* (1984). In contrast, Verdeil *et al.* (1989) obtained their first clonal plantlet from leaf explants after undergoing callogenesis and embryogenesis.

In our laboratory, experiments for calloid initiation are underway using leaf tissues from *in vitro* maintained plantlets at the two-leaf stage and from greenhouse maintained seedlings at the stage of five expanded leaves. The basic medium as well as the levels of the added growth regulators still need to be defined.

Immature Inflorescences

The non-destructive collection of immature inflorescences has been successfully demonstrated (Rillo, 1991). After collection from the donor palms the inflorescences with outer spathe lengths of 70 to 150 mm are dissected under aseptic conditions and the central part of the rachillae cut transversely into 1 to 2 mm thick segments. For calloid induction, the establishment of the explants on a medium with high 2, 4-D levels and activated charcoal has proved successful (Blake, 1990). The gradual lowering of the 2, 4-D concentration in the medium is associated with embryoid production and plantlet development. The first clonal plantlets were obtained at Wye College (Branton and Blake, 1983), but none has been successfully established. The only successful establishment of one clonal plantlet derived from inflorescence explants appears to be that produced at the laboratory of Unilever in the U.K. (Smith, 1986) and now established in the Solomon Islands.

At Albay Research Centre immature inflorescences from three types of palms — 'Catigan' (Dwarf); 'Catigan' × 'Laguna' (hybrid) and 'Laguna' (Tall)

—are being cultured on Blake's callus initiation medium. Calloid is being regularly obtained arising from the flower meristems. After about four months in culture, nodules are observed, which may be considered as pre-embryogenic tissue. Upon gradual reduction of the 2, 4-D level in the medium some of the calloid nodules developed into embryoidal structures as described by Blake (1990). However, plantlet regeneration has not yet been obtained.

Anther Culture

The *in vitro* production of haploids is of great interest for coconut, since the length of its cycle and its heterogeneity make the production of inbred lines difficult and expensive. Reports by Thanh-Tuyen and de Guzman (1983) and Monfort (1985) indicate the eventual possibility of the regeneration of coconut haploid plants. Direct embryogenesis seems to be the principal pathway of haploid formation in coconut (Thanh-Tuyen, 1990).

In our laboratory, initial experiments with anther culture were discouraging. Flower buds from both close and open spathes were collected from 'Catigan' trees for cytological analysis and anther culture. Extracted anthers were inoculated onto B5 medium (Gamborg *et al.,* 1968). After two weeks from initial culture most anthers turned brown.

SOME FACTORS AFFECTING THE GROWTH RESPONSE OF THE EXPLANTS

The sporadic and unrepeatable results obtained in the field of clonal propagation of coconut by various research teams all over the world are clear indications that culture conditions are not yet sufficiently defined and standardized. Most research teams use activated charcoal (AC) as additive to the medium, at least during the early stages of culture. Radio-tracer experiments by Ebert and Taylor (1990) showed that the rate of adsorption of 2, 4-D by activated charcoal is influenced by several factors. Low pH levels and the maintenance of the medium at higher temperatures accelerated the adsorption of 2, 4-D by AC. Higher 2, 4-D levels or reduced AC concentrations increased the level of available 2, 4-D in the medium and extended the period necessary for the stabilization of the same in the medium. In semi-solid medium the rate of adsorption of 2, 4-D by AC was considerably reduced in comparison with liquid medium. A stable ratio of gel/2, 4-D:AC/2, 4-D was only reached after 10 to 20 days, depending on the 2, 4-D concentration used. The importance of these findings was demonstrated with the culture of immature inflorescence explants of coconut palm. While most explants on one day old medium had died, a slightly better response was observed with the five-day old medium. The best results, however, were obtained with the nine-day old medium. Excessive levels of 2, 4-D are known to cause browning and growth inhibition of tissues in culture. The progressive adsorption of 2, 4-D by AC explains the better growth response of inflorescence tissue on older media. If the age of the medium used is not standardized, this will definitely induce variable growth response of the cultures.

For 6-benzylamino-purine (BAP), a fairly constant ratio of free BAP : AC-bound BAP was reached for both liquid and semi-solid medium between five and 10 days after preparation of the media (Ebert and Taylor, 1991). While BAP at 10^{-5} M did not alter the availability of unadsorbed 2, 4-D in the medium, high BAP concentrations of 5×10^{-4} M resulted in pronounced increases in the level of available 2, 4-D.

Not only the level of 2, 4-D used in the callus initiation medium for coconut, but also the type of cytokinin added is of importance to the growth response of inflorescence explants. With 2, 4-D at 10^{-4} M the browning incidence of the tissues varied according to the type and/or combination of cytokinin used (Ebert, unpubl.). The lowest incidence of browning was obtained with Cytomix (equal volumes of 10^{-6} M BAP and N^6-isopentenyladenine [2-iP]), followed by Thidiazuron (TDZ) at 10^{-7} M, TDZ at 10^{-6} M, 2-iP at 10^{-6} M, cytokinins omitted and BAP at 10^{-6} M. While BAP alone resulted in the highest incidence of browning — higher than with cytokinins omitted — the lowest incidence of browning was observed when BAP and 2-iP were combined.

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34

REGENERATION IN COCONUT TISSUE CULTURE

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Coconut being a highly cross-pollinated and exclusively seed propagated crop, shows a high degree of heterogeneity in progenies with respect to yield, regularity of cropping, disease resistance, etc. Vegetative propagation of high yielding, disease resistant 'super palms' is of prime importance. Tissue culture can play an important role in the cloning of these 'plus palms'. Several laboratories have been actively engaged in tissue culture studies of coconut palm with varying degrees of success (Pannetier and Buffard-Morel, 1982; Gupta *et al.,* 1984; Raju *et al.,* 1984; Blake, 1990).

An overview of the regeneration in coconut (*Cocos nucifera* L.) using various explants from mature trees is presented.

Leaf and rachillae explants from mature trees (40 to 80 years old) of West Coast Tall variety have been used. Collection of leaf explants (40 cm above the apical meristem) was done without disturbing the apical meristem. Rachillae tissue was obtained from spathes 4 to 20 cm in size. Explants were surface sterilized by the method described earlier (Gupta *et al.,* 1984) and inoculated on Y_3 medium with hormones and activated charcoal.

Leaf explants developed meristematic nodular structures initially (Kendurkar *et al.,* 1989) which multiplied slowly but profusely during subsequent transfer on different media (Fig. 34.1). The induction of globular structures on leaf explants from mature trees of West Coast Tall and Hawaiian Supreme varieties is being constantly obtained. These globular structures proliferated on subculture, developed into green protuberances and roots, depending upon culture conditions.

Anatomical sections of the leaf explants, show the initiation of globular structures (Fig. 34.2). These structures arise from the perivascular tissue, usually the phloem parenchyma. Dividing cells form layers, which gradually

develop globular structures consisting of small densely stained, meristematic cells.

Fig. 34.1: Nodular structures on leaf explants.

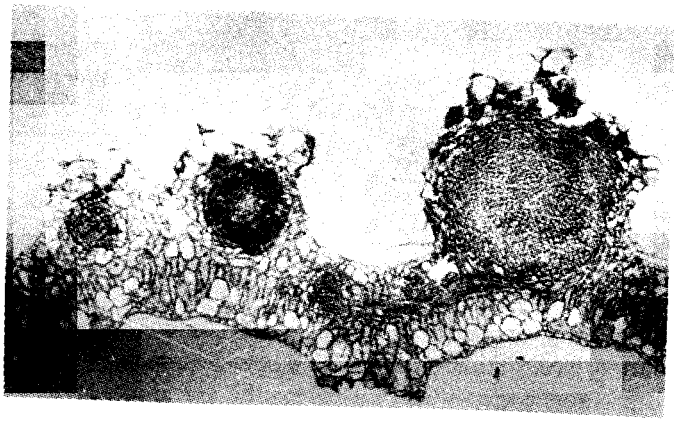

Fig. 34.2: T.S. of nodular structures showing highly meristematic cells.

Repetitive embryogenesis has also been obtained from rachillae tissue. The explants initially swelled and formed ivory white, glistening, globular, embryogenic masses (Fig. 34.3). Individual embryo-like structures isolated from these masses when transferred to fresh media, resembled embryos at various stages of development (Fig. 34.4). These structures can be multiplied and turn green in light.

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Fig. 34.3: Regeneration of embryogenic mass.

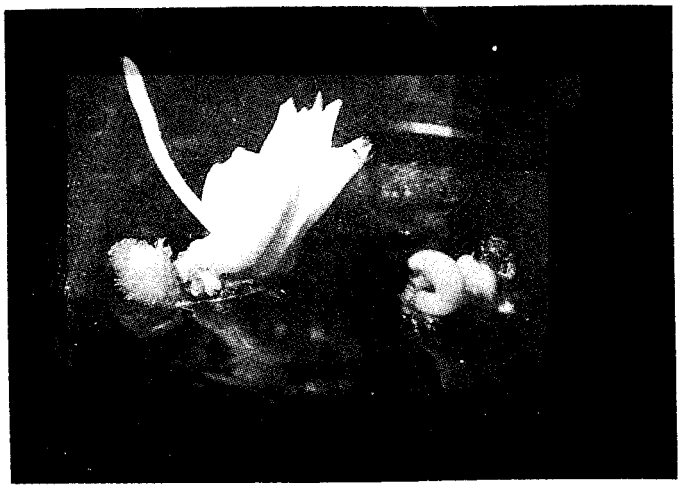

Fig. 34.4: Isolated embryos giving rise to shoot and root.

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EFFECT OF AGE AND CULTURE CONDITIONS OF DONOR PALMS ON COCONUT ANTHERS CULTURED *IN VITRO*

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Coconut being heterozygous and highly cross-pollinated, it is not possible to apply conventional methods to get homozygous lines needed for breeding programmes. Anther culture has been a valuable tool in getting homozygous lines in case of many herbaceous plants. However in case of trees, limited success has been obtained due to several factors which include physiological and development states of the donor tree (Radojevic and Kovoor, 1985). In coconut, attempts have been made to induce pollen embryoids by Haibou (1981); Iyer (1982); Thanh-Tuyen and Guzman (1983); and Monfort (1985). The present paper is an attempt to study some of the factors of the donor palms which possibly play a role in inducing pollen embryoids in coconut.

Coconut palms growing under three different irrigation patterns were used for the experiments. Group A: Dry unirrigated soil. Group B: Irrigated with well water. Group C: Irrigated with farm yard effluents. The palms were of two age groups — mature palms 15 to 20 years old, and young palms which had just begun to flower.

Male flowers were collected from inflorescences when the spathe had completely emerged out but had not yet opened. They were surface sterilised using mercuric chloride 0.1 per cent and sodium lauryl sulphate 0.1 per cent followed by several washes with sterile tap water. The anthers were dissected out aseptically and placed in the culture medium. The basal medium had the salts of Murashige and Skoog (1962) supplemented with sucrose 5g/l, myo-inositol 100 mg/l, thiamine 10 mg/l, pyridoxine and nicotinic acid each 1 mg/l. Variations were prepared by addition of 2,4-dichlorophenoxyacetic acid (2, 4-D), naphthalene acetic acid (NAA) and glutamine in various concentrations. Both solid and liquid media were used, the former having 8 g/l agar. The pH was adjusted to 5.6 before autoclaving. The incubation was done in

50 cm diameter petri dishes at 26 ± 2°C in permanent darkness or under a 16-hour photo-period with a photon-flux density of 10 to 15 $\mu E/m^2/s$ provided by cool day light fluorescent tubes. The cultured anthers were squashed, stained in acetocarmine and observed under the microscope at a two-day interval.

On solid media the anthers from all palms turned brown and gradually dried up. In liquid media they remained fresh and white for prolonged periods of culture (Table 35.1). The pollen grains of young palms from all the three groups and mature palms from group A did not show any response. The anthers from mature palms of groups A and B enlarged and about 0.2 per cent of the pollen grains of the former and about 3.6 per cent of the pollen grains of the latter showed multi-cellular globular pro-embryos on media having 500 mg/l glutamine and either 2, 4-D or NAA 1 mg/l (Table 35.1). In some cases the pro-embryos emerged out of the pollen wall. The results were similar whether or not the cultures received a photoperiod.

Table 35.1: Response on solid and liquid media of anthers of young and mature coconut palms from different culture conditions

Palms		*Response of anthers*		*Pro-embryos (%)*
Culture conditions	*Age*	*Solid medium*	*Liquid medium*	
Unirrigated	Young	Brown	Fresh unenlarged	–
	Mature	Brown	Fresh unenlarged	–
Irrigated with well water	Young	Brown	Fresh unenlarged	–
	Mature	Brown	Fresh enlarged	0.2
Irrigated with farmyard effluent	Young	Brown	Fresh enlarged	–
	Mature	Brown	Fresh enlarged	3.6

Besides genotype, age and nutritional status of the donor plants have been shown to play an important role in inducing division of pollen and formation of embryoids (Heberle-Bors and Reinert, 1977; Keller and Stringam, 1978). The present study indicates that donor coconut palms for anther culture have to be mature and well irrigated. The better response obtained from palms irrigated with farmyard effluents could be an indication of higher nitrogen requirement of the donor palms.

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36

WATER POTENTIAL IN THE LEAVES OF COCONUT (*COCOS NUCIFERA* L.) UNDER RAINFED AND IRRIGATED CONDITIONS

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Water potential (ψ leaf) in a plant, which is the energy level of water, is controlled by the availability of water from the soil, the demand for water imposed by the atmosphere and the resistance to water movement within the plant (Dee Roo, 1969). The changes in water status of plants depend on the evaporative demand in the atmosphere. In the present paper an attempt has been made to study the ψ leaf gradient between leaves of different physiological maturity over a period of time with the objective of identifying the critical leaf and time for ψ leaf determinations in the screening of coconut genotypes for drought tolerance.

Twenty-two-year-old West Coast Tall cultivar grown both under rainfed and irrigated conditions with normal fertiliser level was the material for the study. Leaf water potential was determined from five leaf positions, namely, spindle, first, sixth, fourteenth and twentieth, using a Scholander pressure chamber, plant water console (model 3000, Soil Moisture Co., USA) according to the method of Milburn and Zimmermann (1977) and modified by Rajagopal *et al.* (1987). The measurements were made at three-hour intervals starting from 0700 hours to 1600 hours.

The results are presented in Table 36.1. Vertical profile in ψ leaf has been observed from middle leaf upwards, the magnitude being higher under rainfed condition. Irrespective of rainfed or irrigated condition the spindle leaf maintained significantly higher ψ leaf throughout the day. During the early hours (0700 hours) the ψ leaf difference between the spindle leaf and the twentieth leaf was nearly –0.38 and –0.26 MPa respectively under rainfed and irrigated conditions, while within the spindle leaf the difference was negligible. Under rainfed condition there was 58 per cent reduction in the ψ leaf from the spindle leaf to the first leaf.

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Soon after sunrise the ψ leaf began to decrease in all the leaf positions, particularly in the spindle leaf. Leaf ψ declined rapidly up to mid-day and then rose beyond noon. The results clearly indicated significant differences between hours of sampling, leaf positions, rainfed versus irrigated condition and all their interactions, except hours of sampling versus different leaf positions (Table 36.1).

Table 36.1: Leaf ψ (−MPa) in different leaf positions over a period of time

Treatment/time (hours)	*Leaf position*				
	Spindle	*1st*	*6th*	*14th*	*20th*
Rainfed					
7	−4.1	−6.7	−7.7	−8.7	−8.0
10	−8.5	−10.4	−13.5	−12.8	−13.2
13	−10.3	−10.5	−12.5	−13.7	−13.5
16	−9.5	−10.1	−12.2	−13.9	−11.4
Irrigated					
7	−3.5	−4.6	−4.9	−4.7	−5.8
10	−8.8	−9.9	−11.4	−11.2	−10.1
13	−10.8	−14.2	−14.0	−13.2	−11.2
16	−10.5	−12.9	−13.8	−13.4	−13.8

SE/plot −1.302 G. Mean −10.279 CV 12.564 CD for I −0.474
CD for L −0.749 CD for R vs I x L −1.059 CD for R vs I x H × L −2.118
CD for H −0.67 CD for R vs I × H −0.245

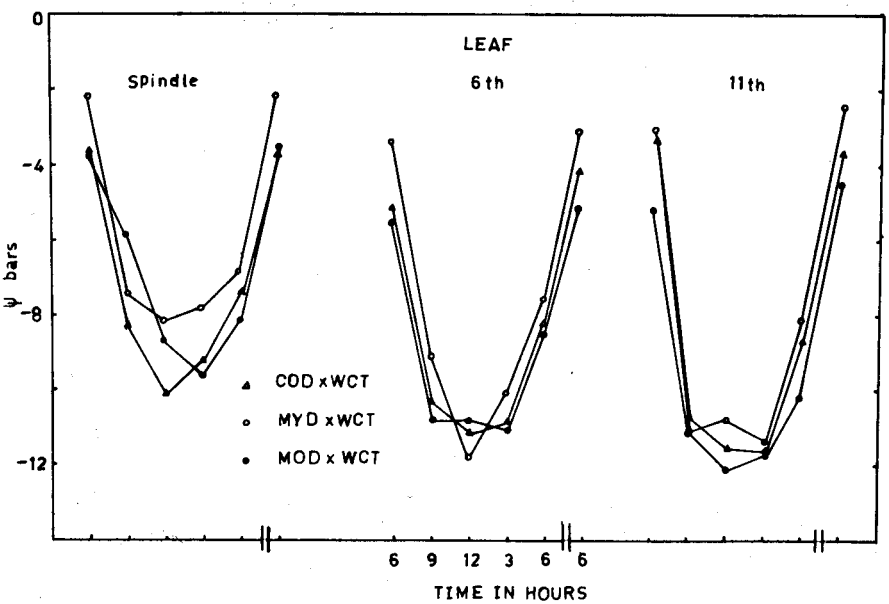

Fig. 36.1: Gradient in the leaf water potential (ψ) in the three hybrids.

Although the overall differences in ψ leaf were the same between the rainfed and irrigated conditions by 1000 hours and 1300 hours the gradient was much steeper in the irrigated condition, presumably because of the very high ψ leaf during the early hours in the irrigated palms. Characteristic mid-day depression in ψ leaf was evident in both the spindle and the first leaf and beyond this ψ leaf remained constant up to 1600 hours as compared to the first leaf. Similar observations have been recorded in the three year old hybrids of Malayan Yellow Dwarf (MYD) × WCT, Malayan Orange Dwarf (MOD) × WCT and Chowghat Orange Dwarf (COD) × WCT. In general, spindle leaf maintained higher ψ leaf than the 6th and 11th leaf throughout the day. Among the hybrids MYD × WCT had relatively high ψ leaf (Fig. 36.1).

The present study reveals the existence of vertical profile in ψ leaf over a period of time, and also confirms the importance of fixing the spindle leaf as the index leaf, as well as optimum time for leaf water potential measurements (between 1000 hours and 1200 hours) in coconut palms.

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THE EFFECT OF EXPOSING THE GERMPORE ON GERMINATION OF COCONUT

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INTRODUCTION

Agronomists and plantation managers attach great importance to the germination behaviour of coconut. It is well accepted that earliness of germination within a population is linked with high seedling vigour, precocity and eventual high productivity. Germination is defined by coconut growers as the emergence of the sprout through the husk.

The husk of the coconut fruit protects the brittle inner nut from exposure and damage as well as imparting buoyancy, which allows dispersal by floating. Kenman (1973) showed that seedling growth was improved by the partial removal of the husk. This procedure permitted the sprout and the root system to grow more freely, as entanglement in the tough fibres of the husk was avoided. It was noted by Harries (1981) that a change in nut orientation may trap the sprout before it can emerge from the husk. These observations led to the proposition that the husk might actually impair the growth of coconut seedlings.

Foale (1968) was able, by removal of the husk, to observe precisely the time of true germination, defined as the opening of the germ-pore or 'soft eye' due to expansion of the embryo. He reported that there was no loss or damage to seedlings grown from dehusked nuts, provided that they were adequately protected. These observations stimulated further investigation of the germination behaviour of dehusked coconut seeds, which is the subject of the study reported here.

MATERIALS AND METHODS

Nuts at the stage of 'fresh' maturity, with the drying husk just beginning to show browning of the surface, were harvested from mother palms and left in the field

for one week. There were three populations, all of the tall type, Solomon Islands (SIT), Malayan (MLT) — a population with a significant proportion of hybrids with SIT, and Rennell (RLT) — progeny from an isolated small population on the remote island of Rennell (Lat. 12° S, Long. 160° E), in Solomon Islands.

Two hundred nuts of each population were fully dehusked and placed as four replicates in an enclosed store room spread out in a single layer on the concrete floor. The temperature varied diurnally between 26°C and 30°C, and the relative humidity varied between 65 per cent and almost 100 per cent. The store was kept free of insect pests and vermin.

A further 100 dehusked nuts of each population were placed on day one into closed, opaque, airtight, germination sacks containing a vapour-saturated atmosphere. One hundred of the nuts of each population were transferred into the germination sacks at two weeks, and the remainder were transferred at four weeks.

A nut was recorded as germinated when the germ-pore had opened. Observations were made once weekly for 10 weeks from placement in the sack, by which time germination had ceased.

RESULTS

Accumulated germination for SIT population is plotted against time in Figs. 37.1A and 37.1B. The time scale in 1A is set at '0' on the day dehusking was done. Two weeks prior exposure raised germination in the first week to 30 per cent, which was the level that unexposed nuts reached after three weeks. Two more weeks exposure raised germination to 60 per cent in the first week. By week five all treatments had reached about the same level. It is clear that the germination behaviour compensated within a very short time for the delay involved in prior exposure. It also appears that two weeks prior exposure gave more than a cumulative "readiness to germinate". There is evidence of a stimulus to germinate more quickly, since in Fig. 37.1A at week three and week four, germination of exposed nuts exceeded unexposed nuts.

In Fig. 37.1B the time scale is set at '0' on the day nuts were placed in the germination sacks. This shows the strongly enhanced rate of germination due to exposure, and also shows that the rate was higher after longer exposure. Following four weeks prior exposure the seed batch attained almost maximum germination within three weeks. Nuts exposed for two weeks required four weeks, and non-exposed nuts required seven weeks to reach that level of germination.

The three populations appeared to differ in both their 'unexposed' germination rate (Fig. 37.2A) and in their response to exposure (Fig. 37.2B). The lack of statistical analysis, however, prevents the application of any firm conclusions. When unexposed, MLT showed more rapid early germination, followed by RLT and then SIT. By week five however, SIT caught up to MLT, which attained 83 per cent germination, while RLT fell behind, showing a final

level of 72 per cent germination. All three cultivars responded strongly to four weeks prior exposure by showing 60 to 70 per cent germination in two weeks.

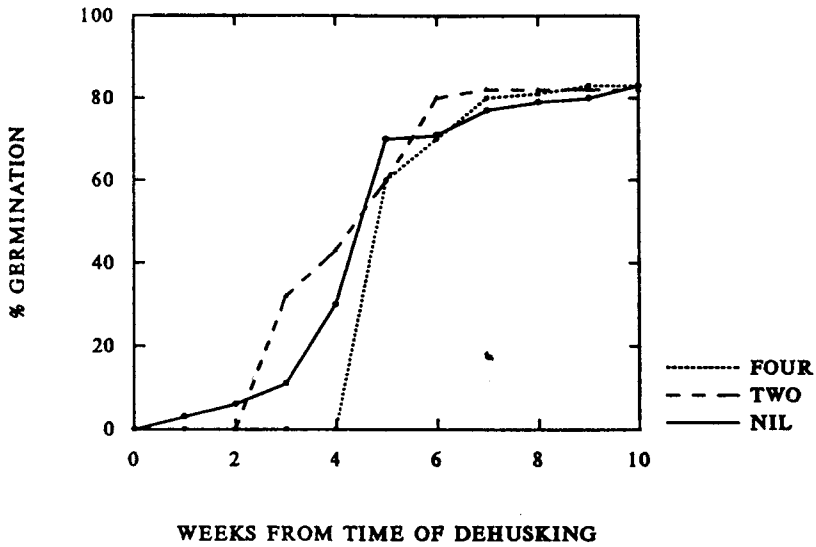

Fig. 37.1A: Germination of Solomon Islands' coconuts after three different durations of prior exposure to the atmosphere.

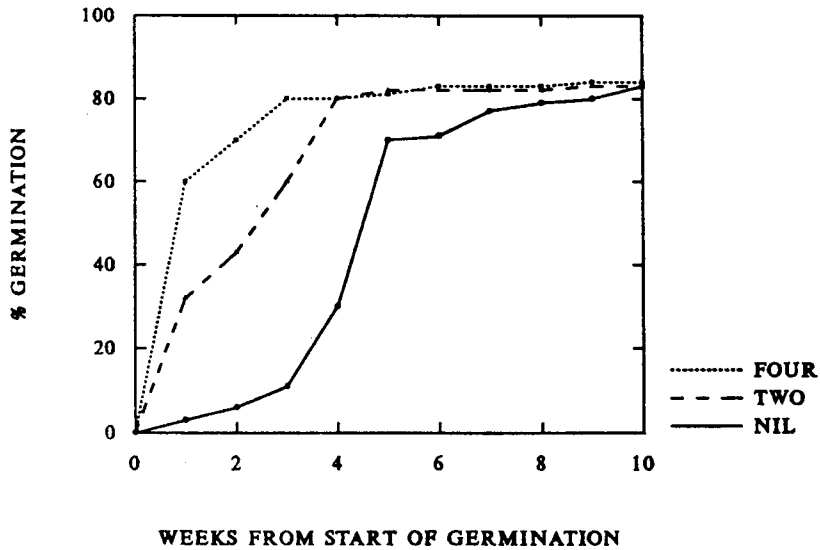

Fig. 37.1B: Comparison of the germination of a population of SIT seednuts following exposure for different periods.

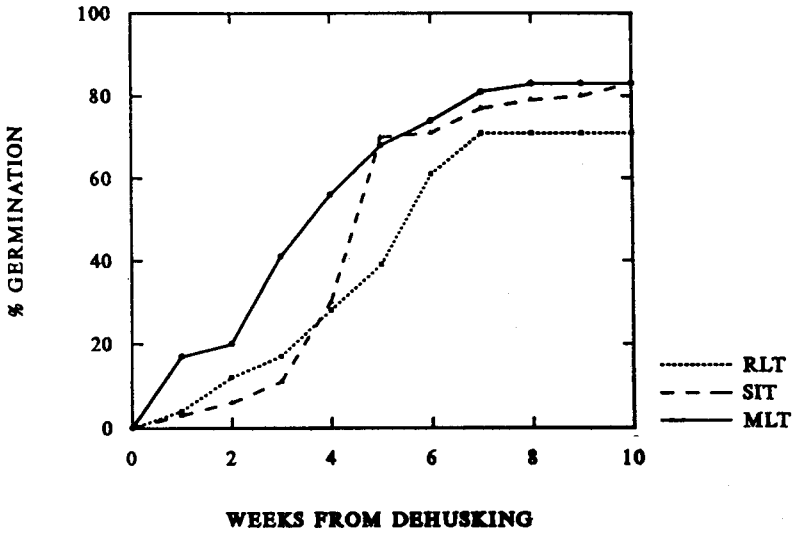

Fig. 37.2A: The germination of unexposed nuts from three tall coconut populations: MLT—Malayan; SIT—Solomon Islands; and RLT—Rennell.

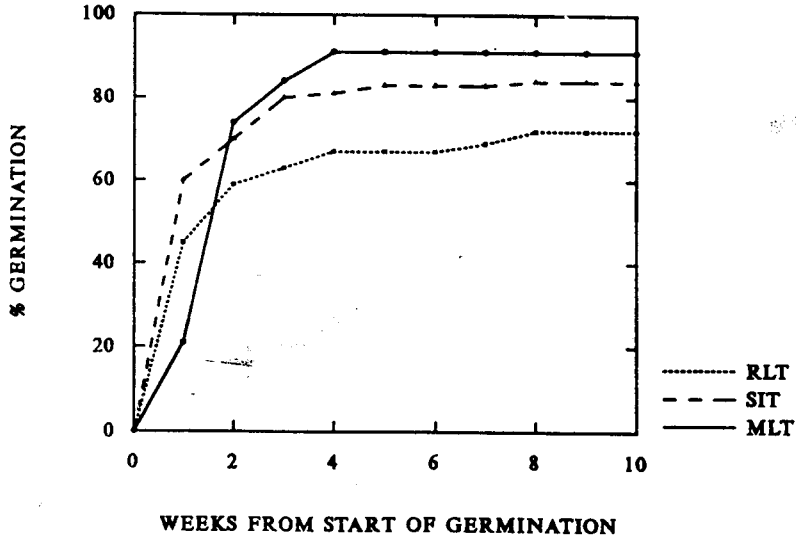

Fig. 37.2B: The effect of four weeks prior exposure on the rate of germination of three coconut populations. Identity as shown in Fig. 2A.

DISCUSSION

Exposing the germ-pore has the indirect benefit that germ-pore opening is easily observed. This contrasts with the entire nuts where the first sign of germination is the emergence of the sprout through the husk, many weeks after germ-pore opening. There is such variation in thickness of husk (Foale, 1987) and in its strength, due to variation in water content, that true germination performance is masked by sprout performance. Equally, when the husk is

intact, true growth performance of the sprout is masked as germ-pore opening is not observed.

Exposure of the germ-pore of these coconut populations to a vapour-unsaturated atmosphere prevented germination. Meanwhile all the embryos apparently progressed towards a state of readiness to germinate. This was shown by the shortening of the germination period of the exposed treatments once they were placed in the saturated atmosphere.

When the exposure period was limited to four weeks, the total germination achieved was similar to that of unexposed nuts (Fig. 37.1A). Longer exposure might be harmful, however, as a small batch of nuts that was exposed for six weeks (RLT population, data not shown) reached only 45 per cent sprouting compared to 70 per cent for unexposed nuts (Fig. 37.2A). Perhaps with longer exposure there was damage by desiccation to the embryo, through the germ-pore cover. The condition of the non-germinated embryos was not assessed. Nuts that float on the sea remain dormant, as sea water has a water potential of −2.3 MPa (Harries, 1981). This contrasts with a much lower water potential in the unsaturated atmosphere which not only induced dormancy in this experiment, but apparently harmed some embryos after six weeks.

Shortening the period required for the germination of a batch of seednuts has possible practical value. Any reduction in the duration of germination of a batch of seeds reduces the risk that temporal variability in the nursery environment would confound observation of intrinsic growth performance of the seedlings.

In practical nursery management, any procedure that shortens the period of germination allows a more accurate comparison of subsequent growth. Selection of seedlings for planting in the field, based on their growth vigour, is widely recognized as a requirement for establishing a potentially high-yielding plantation (Child, 1964). Earliness of germination of nuts with the husk intact represents a combination of early opening of the germ-pore and rapid sprout elongation.

A nursery that uses exposed nuts would require four stages: the prior storage area; the pre-nursery where the ungerminated nuts are held in sacks; a well-protected intermediate nursery, kept free of insects, rats and other pests; and the main nursery that contains seedlings robust enough to withstand such pests.

A polybag or other planting bag nursery is ideal for dehusked nuts that have germinated rapidly. Planting bags offer a high degree of uniformity of soil and water supply. The effectiveness of the final selection for seedling vigour is therefore enhanced.

The populations used in this study fit into the Niu Vai category described by Harries (1981). It is possible that populations of the Niu Kafa type, which show an intrinsic period of dormancy following maturity, would respond differently. A further study that includes Niu Kafa populations is therefore indicated.

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BIOCHEMICAL CHANGES AND LEAF WATER STATUS OF COCONUT GENOTYPES DIFFERING IN DROUGHT TOLERANCE

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The coconut palm possesses certain physiological features which makes it particularly susceptible to drought. Depending on the intensity and duration of drought the adverse effects can persist for up to two and a half years (Murray, 1977) leading to yield reductions. Among the commonly cultivated varieties and hybrids of coconut, variations appear to exist in their ability to withstand drought as evidenced by the differences in yield of palms between normal (non-drought) and drought years (Jacob Mathew *et al.*, 1988). The biochemical changes occurring as a result of the development of stress have been compared between the tolerant and susceptible genotypes in the present investigation.

The study was conducted on 20-year old palms of West Coast Tall (WCT), West Coast Tall × Chowghat Orange Dwarf (WCT × COD) and Chowghat Orange Dwarf × West Coast Tall (COD × WCT) maintained in the Institute farm under irrigated and rainfed conditions. The palms were grown in a strip plot design and supplied with 500 g N, 500 g P_2O_5 and 1000 g K_2O/palm/year. During the rainless period, the irrigated palms received 20 mm water at weekly intervals.

The depletion of soil moisture during the summer months associated with a concomitant rise in air temperature resulted in the development of drought stress. Under such conditions, the leaf water status of coconut varieties showed a gradual reduction. The WCT variety maintained the highest relative water content (RWC) under drought.

Changes in leaf water status of varieties was reflected in changes in the levels of chlorophylls, free amino nitrogen, epicuticular wax and total soluble sugars. In general, the irrigated palms had higher chlorophyll a and b than the rainfed palms while the levels of free amino acids, epicuticular wax and total

soluble sugars were higher in rainfed palms as compared to irrigated palms (Table 38.1).

Table 38.1: Changes in relative water content and related factors during stress

Variety	*RWC (%)*		*Chlorophyll a ($mg \cdot g^{-1}$ f.wt.)*		*Chlorophyll b ($mg \cdot g^{-1}$ f.wt.)*		*Epicuticular wax ($\mu g \cdot dm^{-2}$)*	
	Pre-stress	*Stress*	*Pre-stress*	*Stress*	*Pre-stress*	*Stress*	*Pre-stress*	*Stress*
WCT	93.8	88.0	6.51	4.84	2.75	1.95	9.18	13.15
WCT × COD	94.4	87.0	5.69	4.50	2.33	1.80	9.06	12.29
COD × WCT	94.4	86.1	5.71	4.41	2.44	1.80	9.45	11.50

The rainfed palms of COD × WCT recorded significantly higher levels of free amino acids than WCT and WCT × COD during the peak stress period. Significant differences in epicuticular wax and total soluble sugars were also found.

The studies clearly showed that the biochemical changes occurring during water stress are directly related to the leaf water status. The data presented show that WCT is able to conserve leaf water under drought better than the two hybrids and therefore, the biochemical changes during stress development could be used as sensitive indicators of water stress.

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CROP MANAGEMENT AND FARMING SYSTEM

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NUTRITIONAL REQUIREMENT OF COCONUT AND COCONUT BASED FARMING SYSTEMS IN INDIA

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ABSTRACT

The growth of young palms is influenced maximum by N, followed by K. While the effect of P has been marginal, it shows favourable interactions with N and K on growth and nut yield. Nutrient removal studies indicate that K is the dominant requirement for increasing the productivity of the palm. Increased rates of N had an adverse effect on copra content while K showed beneficial effect on all production factors. The hybrids (COD × WCT and its reciprocal cross) did not show response to levels beyond 500 g N + 500 g P_2O_5 + 1000 g K_2O/palm/year under rainfed conditions while high yielding West Coast Tall showed response to 1000 g N + 1000 g P_2O_5 + 2000 g K_2O/palm/year.

Magnesium has been a limiting nutrient in coastal sandy and laterite soils and the correction of Mg deficiency leads to 30–35 per cent increase in yield. Recycling long-term resources of soil P has been suggested and 10 to 12 ppm soil available P was found to sustain adequate P supply to palms. Boron is found to be a limiting element, particularly in the north-eastern region, leading to "Crown Choke" disorder in the palm which is corrected by judicious application of boron. The growth of young palms and yields of bearing palms were not affected when 50 per cent of K requirement was replaced by sodium chloride (common salt).

Limited organic farming with leguminous green manure crop in the coconut manuring circle is an encouraging practice for improving the fertility and nitrogen use efficiency. Coconut based high density cropping systems are found to require proportionately lower quantities of mineral fertilisers.

INTRODUCTION

The coconut palm, a tree crop of the humid tropics, is versatile in its adaptability to a wide range of soil and climatic conditions. Currently it is grown in an area of about 1.51 million ha in the country confined mainly to the states encompassed by the west and east coasts of which the west coast accounts for

nearly 85 per cent (Table 39.1). The major area under the crop (91.45 per cent) is concentrated in the four southern states namely, Kerala (50.07 per cent), Karnataka (15.38 per cent), Tamil Nadu (14.95 per cent) and Andhra Pradesh (4.04 per cent).

Table 39.1: Area and production statistics in India 1989–90

Sl. No.	*State/U.T.*	*Area ('000 ha)*	*Production (M. nuts)*	*Yield of nuts/ha*
1.	Kerala	864.1	4527	5239
2.	Karnataka	232.9	1202	5159
3.	Tamil Nadu	226.4	2358	10415
4.	Andhra Pradesh	61.2	731	11938
	Total	1384.6 (91.45%)	8818	—
5.	Others (Orissa; Goa; Andaman and Nicobar Islands; West Bengal; Assam; Maharashtra; Tripura; Lakshadweep and Pondicherry)	129.3 (8.55%)	882	—
	Total	1513.9	9700	—

Figures in parentheses indicate percentage of total area
Source: Coconut Development Board, Kochi, Kerala.

Soils, Fertility and Production Constraints and their Management

A broad account of different soils under coconut in the country has been reported by Sankaranarayanan and Velayutham (1976 a; 1976 b). The morphological and the physico-chemical characteristics of typical soils from different agro-climatic regions of the country were studied by Khan *et al.* (1978). The soils were broadly classified under the four orders, namely, Alfisols, Entisols, Ultisols and Vertisols, and their classification up to sub-group level was also attempted. The major coconut growing soils of different states of the country are given below:

KERALA

Kerala is the premier coconut growing state in the country. It has three physiographic regions running parallel to each other from north to south namely the highlands in the east, the lowland in the west and the midland in between. Coconut cultivation is mainly confined to the lowland regions bordering the west coast with level topography and the midland with an undulating terrain and elevation up to 100 m. The major area is under rainfed culture.

Laterite Soil

This soil type occupies the major portion of the coconut area of the state and is found in all the 14 districts. Its fertility is medium in N, low in available P

and K, poor in exchangeable cations with low CEC, high in free oxides of iron and aluminium, and acidic in reaction. Proper soil conservation measures to check erosion and run off on slopes are needed. A typical laterite soil of the Nenmanda series in Kozhikode district is classified as Oxic haplustult (Khan *et al.,* 1978).

Coastal Sandy Soil

This is the second major soil group found along the narrow coastal strip on the west. This soil is very poor in organic matter and nutrients and slightly acidic to neutral in reaction. Inadequate nutrient status and drought in summer months are the major production constraints. Judicious application of organic manures combined with inorganic fertilisers and summer irrigation are needed to improve the soil physical properties and fertility status of these soils. A typical coastal sandy soil of the Onattukara series in Kollam district is classified as Ustoxic quartzipsamment (Khan *et al.,* 1978).

Red Sandy Loam

This soil occurs largely in the three northern districts namely, Kozhikode, Kannur and Kasaragod, and in parts of Thiruvananthapuram district in the south and it occupies an area next to coastal sandy soil. These soils are reported to be of transported nature and had undergone a process of imperfect laterisation (Koshy and Varghese, 1972). It is medium in fertility status and acidic in reaction. As this soil has the desirable physical properties it supports good plantations wherever adequate management practices are followed. A typical red sandy loam soil of the Vellayani series in Thiruvananthapuram district is classified as Vermic ustorthent (Khan *et al.,* 1978).

Alluvial Soil

This soil is largely in parts of Kannur, Kozhikode, Thrissur, Ernakulam and Alappuzha districts of the state. The physical and chemical characteristics vary widely from place to place.

Reclaimed Marshy Soil

These soils are formed through the reclamation of the low-lying swampy and marshy lands adjoining backwaters and are locally termed as *Kari, Kaipad* and *Pokali* soils. They are subject to seasonal flooding and to the ebb and flow of tidal actions. They are found in isolated pockets of Kannur, Thrissur, Ernakulam, Alappuzha and Kottayam districts. The reclamation process consists of forming mounds by heaping up layers of soil, sand and organic wastes to a height of 1 m above the ground level/water table and then coconut seedlings are planted. In course of time the gaps between the mounds are filled using sand and organic wastes and are provided with drainage channels in between the rows of palms. Lack of adequate soil mineral mass and high acidity/salinity are the major production constraints of these soils. The reclamation and subsequent management of such gardens are generally expensive. However, under regular reclamation/management practices, the

palms perform well on these soils. These reclaimed soils are invariably black in colour, rich in organic matter and nitrogen, and low to medium in P and K. They are extremely acidic with a fair amount of soluble salts. Correction of acidity and elimination of Al toxicity can be achieved to a certain extent by the use of magnesium silicate.

KARNATAKA

The major coconut growing soils of Karnataka state are the coastal alluviums, laterite soils and red soils of *maidan* area. The laterite and red soils are subject to severe moisture stress in summer and respond well to irrigation and manuring.

TAMIL NADU

The major coconut growing soils of Tamil Nadu are the coastal alluviums, river alluviums and red and black soils. In general, coconut is cultivated under irrigated conditions in these soils.

ANDHRA PRADESH

Coconut cultivation is confined to the deltaic alluvium (Udic chromustert, Khan *et al.,* 1978) and coastal alluvial soils.

ASSAM

Alluvial soils of the deltaic regions of Brahmaputra and its tributaries.

ANDAMAN AND NICOBAR ISLANDS

(i) Coastal alluvium, and (ii) forest loams.

GOA

(i) Laterite, (ii) coastal alluvium, and (iii) river alluvium.

GUJARAT

(i) Coastal alluvium, (ii) river alluvium, and (iii) medium black soils.

LAKSHADWEEP ISLANDS

Coral soils, which are sandy in texture, excessively drained, low in organic matter, N and K, and high in available P. The soils are highly calcareous (93 per cent $CaCO_3$) with pH ranging from 7.5 to 8.9. Large applications of organic matter to soil are much needed and the palms respond well to nitrogen and potash application.

MAHARASHTRA

(i) Laterite soil, and (ii) coastal alluvium.

ORISSA

Coastal and deltaic alluviums.

PONDICHERRY

(i) Coastal alluvium, (ii) deltaic alluvium, and (iii) laterite.

WEST BENGAL

Coastal and deltaic alluviums. They need improvement in drainage and amelioration through gypsum application.

Nutritional Requirements and Nutrient Dynamics/Response in Relation to Productivity

The coconut palm is a heavy consumer of nutrients, particularly K, Cl and N for its growth and productivity.

Nutrient Export

Nutrient exhaust values usually provide useful guidelines for approximating the quantity of nutrients and their proportion in which they are to be applied. The nutrient exhaust studies conducted in India by Pillai and Davis (1963) and Ramadasan and Lal (1966) show that the proportionate requirement of NPK of the palm in terms of $N:P_2O_5:K_2O$ is 2:1:3 and the quantitative order of requirement of major nutrients for adult bearing palm is K > N > Ca > Mg > P which suggests that K is the dominant requirement of the palm while P requirement is the least. The quantity of major nutrients removed annually by a single palm (West Coast Tall) yielding an average of 40 nuts and producing 13 fronds per year as well as the quantity immobilised by the growing stem is estimated to be 321 g N, 69 g P, 406 g K, 196 g Ca and 72 g Mg (Pillai and Davis, 1963).

Table 39.2: Percentage removal of nutrients for the yield of nuts and for the growth of stem and leaves by West Coast Tall palm (Pillai and Davis, 1963)

Plant parts	*N*	*P*	*K*	*Ca*	*Mg*
Stem + leaves	49	50	22	77	59
Yield of nuts	51	50	78	23	41

It is seen that N and P are utilised more or less equally for the growth of stem and leaves and for the production of nuts. The proportion of K exhausted through the harvest of bunches is 78 per cent and that for the growth of stem and leaves is only 22 per cent. The data also suggest that increased productivity would eventually be accompanied by a proportional increase in the uptake of nutrients, particularly K.

Fertiliser Requirement of Nursery Seedlings

Nelliat (1972) was of the view that young seedlings are in short supply of nutrients for a major part of their one year growth in the nursery. He recommended the application of NPK fertilisers in the months of December, February and April to supply 40 kg N, 20 kg P_2O_5 and 40 kg K_2O per application per ha in nurseries where seednuts are planted in the month of May-June. This may ensure production of seedlings with favourable nutrient status so as to facilitate better establishment, faster growth and early bearing in the main field.

Fertiliser Requirement of Young Palms

Systematic fertilisation of young palms helps faster and vigorous growth and reduce the pre-bearing age. At Veppankulam (Tamil Nadu), application of NPK at the adult palm dosage of 340 g N, 230 g P_2O_5 and 450 g K_2O/palm/year helped the palms to flower one year ahead of the control (no fertiliser) palms. When double the above dosage was applied, the pre-bearing age was further reduced by four months (Varisai Mohammad *et al.,* 1969). Further trials on littoral sand (Anon., 1971) and sandy loam soil (Anon., 1972) showed that regular NPK fertilisation was essential for the satisfactory growth of young palms. Application of NPK fertiliser to young palms of COD × WCT and WCT × COD hybrids and high yielding talls resulted in highly significant increase in all growth characters and helped early flowering (Nelliat and Muliyar, 1971) and significantly influenced the leaf nutrient levels (Kamaladevi *et al.,* 1972) (Table 39.3).

Table 39.3: Foliar nutrient levels averaged over genotypes under different fertiliser levels at the fifth year of planting (Kamaladevi *et al.,* 1972)

Fertiliser levels	*Nutrient status (%) (Frond, 9)*				
	N	*P*	*K*	*Ca*	*Mg*
M_0	1.40	0.12	0.46	0.30	0.18
M_1	1.50	0.13	0.82	0.29	0.19
M_2	1.55	0.12	0.92	0.30	0.16
CD (5%)	0.095	NS	0.075	NS	0.03

M_0: (Control); M_1: 500 g N + 500 g P_2O_5 + 1000 g K_2O/palm/year.
M_2: 1000 g N + 1000 g P_2O_5 + 2000 g K_2O/palm/year.

In general the effect of N on vegetative growth of young palms was maximum followed by K while P showed favourable interaction with N and K. Nelliat (1972) recommended the application of one-tenth of the adult palm dose of fertilisers about three months after planting in the main field, one-third in the second year, two-thirds in the third year and the full dose in the fourth year onwards.

Fertiliser Requirement of Adult Palms

Large-scale fertiliser demonstration trials conducted all over the west coast of India showed that application of 340 g N, 340 g P_2O_5 and 680 g K_2O/palm/year had resulted in an increase of 35 per cent in yield of nuts and 44 per cent in copra outturn over the cultivators' practice. In certain locations where the above fertiliser dose was not responsive, significant increase in yield was obtained when the K_2O level was raised to 900 g/palm/year (John and Jacob, 1959).

In a 3^3 NPK factorial experiment on sandy loam soil at CPCRI, Kasaragod, higher level of N had an adverse effect on copra content while K levels showed positive response (Muliyar and Nelliat, 1971). They also reported that for palms yielding less than 60 nuts annually, the optimum dose of N ranged

between 400 and 650 g and that of potash (K_2O) between 890 and 1210 g/palm/year.

Wahid *et al.* (1988) have concluded from a 3^3 NPK factorial experiment the need to supply N and K in augmenting coconut yield particularly K at increased rates (Table 39.4). They observed that the main effect of P was marginal. Further the importance of balanced application of N, P and K was evident from the significant NP, NK and PK interactions.

Table 39.4: Effect of nutrient interaction on the cumulative nut yield per palm (1976 to 1985) (Wahid *et al.*, 1988)

N × P	*Yield*	*N × K*	*Yield*	*P × K*	*Yield*
N_0P_0	139.33	N_0K_0	36.87	P_0K_0	46.91
N_0P_1	133.96	N_0K_1	179.33	P_0K_1	267.00
N_0P_2	138.42	N_0K_2	194.21	P_0K_2	264.67
N_1P_0	160.50	N_1K_0	22.00	P_1K_0	23.63
N_1P_1	357.21	N_1K_1	323.96	P_1K_1	383.75
N_1P_2	226.92	N_1K_2	398.67	P_1K_2	362.92
N_2P_0	278.54	N_2K_0	24.75	P_2K_0	12.58
N_2P_1	281.13	N_2K_1	451.40	P_2K_1	303.94
N_2P_2	414.76	N_2K_2	498.27	P_2K_2	463.56
C.D. (0.05)	125.95		125.95		125.95

Exptl. site: CRS, Balarampuram, Red sandy loam soil.

The foliar N levels were increased as a consequence of N fertilisation. However, the values even at the N_2 level of treatment (680 g N/palm/year) were below the suggested critical level of 1.8 per cent for nitrogen. Whether further addition of N would increase yield as well as leaf N content and reasons for low N content of palms is an aspect worthy of investigation. The absorption of K was increased and Mg decreased with increased rate of KCl application while P fertiliser levels did not show any improvement in the foliar P status (Table 39.5).

It was further observed that (Wahid *et al.*, 1988) muriate of potash proved superior to sulphate of potash for coconut manuring and phosphatic fertilisation did not show significant response in nut yield in many of the field trials. The fertiliser requirement of coconut in laterite soils was found to be 500 g N, 250 g P_2O_5 and 1250 g K_2O/palm/year and that of the reclaimed marshy soils of the backwater regions of Kerala (Thomas, 1968) was found to be 250 g N, 340 g P_2O_5 and 680 g K_2O/palm/year.

The general recommendation from C.P.C.R.I. for fertilising the adult bearing palms is to apply 500 g N, 320 g P_2O_5 and 1200 g K_2O/palm/year in two split doses namely, one-third of the above dosage during May–June (pre-monsoon) and two-third during September–October (after the cessation of rains) (Nelliat, 1972). Under average management of coconut gardens, a minimum of 340 g N, 170 g P_2O_5 and 680 g K_2O/palm/year may be applied in two splits as above (Anon., 1989).

Table 39.5: Effect of inorganic fertilisation on major nutrient composition of palms at Balaramapuram (Wahid *et al.*, 1988)

Treatment	*Nutrient level (%) (Frond, 14)*						
	N	*P*	*K*	*Ca*	*Mg*	*S*	*Cl*
N_0	0.91	0.11	1.48	0.28	0.33	0.10	0.61
N_1	1.07	0.12	1.39	0.26	0.35	0.11	0.70
N_2	1.03	0.12	1.19	0.34	0.34	0.10	0.73
P_0	1.04	0.11	1.31	0.26	0.33	0.11	0.66
P_1	1.01	0.12	1.33	0.28	0.34	0.10	0.72
P_2	0.96	0.12	1.42	0.33	0.35	0.11	0.67
K_0	0.99	0.11	0.54	0.31	0.40	0.10	0.66
K_1	0.99	0.12	1.37	0.30	0.32	0.10	0.69
K_2	1.03	0.11	2.15	0.27	0.30	0.11	0.70
C.D. (0.05)	0.09	NS	0.31	0.07	0.06	NS	NS

Effect of Long-term NPK Fertilisation on the Mineral Nutrition and Yield of Three High-Yielding Genotypes

The effect of long-term NPK fertilisation on soil, leaf nutrient concentrations and yield of three high-yielding genotypes was studied after 18 years of planting (Khan *et al.*, 1986). The improvement in N nutrition of the palm due to fertilisation was reflected on the foliar N levels (Table 39.6). However, no marked improvement was seen in the soil mineralisable nitrogen contents. Higher dose of fertilisers (M_2) had apparently no effect on the N content of the leaves over the lower level (M_1). Even after the continuous fertilisation for 18 years, leaf P levels were not raised to the suggested critical level of 0.12 per cent for phosphorus. The available soil P (Bray I) of the M_0 plots ranged between 9 and 20 ppm and around 10 ppm was found to be sufficient for maintaining adequate plant P levels (Table 39.7). As in the case of N, the K content of all the three genotypes was raised to the sufficiency level by M_1 level of fertilisation while M_2 level had no additional effect in improving the leaf K status.

Table 39.6. Soil nutrient status (ppm) under different levels of NPK fertilisation (Samples from 0 to 100 cm depth averaged over genotypes). (Khan *et al.*, 1986)

*Fertiliser level**	*pH*	*Available nutrients*			*Available micronutrients (DTPA extract)*			
		N	*P*	*K*	*Zn*	*Cu*	*Fe*	*Mn*
M_0	5.1	75	15	18	0.21	0.20	10	30
M_1	4.7	80	63	55	0.28	0.55	14	41
M_2	4.7	86	93	70	0.36	0.50	17	44

*Same as under Table 39.3.

Table 39.7: Effect of different levels of fertilisers on plant nutrient levels (Frond 14) of three coconut genotypes

*Genotypes/ Fertiliser level**	(%)						(ppm)			
	N	*P*	*K*	*Ca*	*Mg*	*Na*	*Cu*	*Zn*	*Fe*	*Mn*
WCT										
M_0	1.4	0.11	0.7	0.23	0.17	0.25	6	20	93	593
M_1	1.7	0.11	1.0	0.33	0.17	0.14	6	18	96	711
M_2	1.7	0.11	1.1	0.27	0.15	0.13	7	17	90	648
COD×WCT										
M_0	1.4	0.11	0.6	0.26	0.23	0.24	6	19	99	599
M_1	1.6	0.11	1.0	0.26	0.18	0.11	8	18	108	585
M_2	1.7	0.11	1.1	0.27	0.11	0.10	9	15	108	620
WCT×COD										
M_0	1.4	0.10	0.6	0.25	0.26	0.27	10	24	96	521
M_1	1.6	0.11	1.1	0.26	0.16	0.14	8	18	86	615
M_2	1.6	0.11	1.1	0.30	0.15	0.11	8	16	73	678
CD (0.05) Fertiliser	0.09	NS	0.12	0.03	0.03	0.03	—	—	—	—

*Same as under Table 39.3.

While the high-yielding WCT palms continue to respond to fertilisers beyond the M_1 level, the COD × WCT hybrid showed maximum response to M_1 level and the WCT × COD hybrid showed only marginal increase in yield beyond M_1 (Table 39.8). The COD × WCT hybrid outyielded the other two genotypes. The data suggest that on red sandy loam soil the palms respond more to N and K fertilisers for satisfactory growth and yield.

Table 39.8: Nut yield of three coconut genotypes under different fertiliser levels

*Genotypes/ Fertiliser levels**	*Yield of nuts/palm/year (July 1982–June 1983)*			*Cumulative yield (1972–1983)*		
	M_0	M_1	M_2	M_0	M_1	M_2
WCT	33.7	66.9	84.4	131	435	578
COD×WCT	45.9	92.2	94.7	293	936	737
WCT×COD	26.4	79.2	80.4	87	473	503

*Same as under Table 39.3.

Monitoring the residual effect of long-term phosphorus application (22 years) Khan *et al.* (1990) observed that withholding application of phosphatic fertilisers for 14 years did not affect the yield and nutrition of adult coconut palms (Tables 39.9 and 39.10).

Interestingly VA mycorrhizal infection was more (79 per cent) in the root zone of palms where P application was withheld compared to palms receiving 50 per cent of recommended dose (52.1 per cent) and full dose (47.9 per cent). Population of P solubilising bacteria was also higher in the plots where P application was withheld. This suggested the beneficial association of micro-organisms in supplying phosphorus from accumulated soil reserves.

Table 39.9: Effect of phosphorus skipping on available P status in coconut basin. (Khan *et al.*, 1990)

Treatment	*Soil available P (ppm)*							
	1975				*1990*			
	0–30	*30–60*	*60–90*	*Mean*	*0–30*	*30–60*	*60–90*	*Mean*
P_0	84.00	24.00	23.66	43.85	20.64	9.81	7.83	12.72
P_1	88.42	24.20	12.00	41.54	67.95	12.06	11.29	30.43
P_2	84.25	34.15	12.75	43.72	120.75	26.95	12.66	53.29
SE/plot	—	—	—	—	20.60	9.85	3.14	—
C.D.	—	—	—	—	16.01	7.66	2.44	—

P_0 — control; P_1 — 160 g P_2O_5/palm/year; P_2 — 320 g P_2O_5/palm/year; N and K applied at recommended dose.

Table 39.10: Effect of phosphorus skipping on leaf P (Frond 14) content and yield of palm

Treatment	*1975*		*1989*	
	Leaf % P	*Yield*	*Leaf % P*	*Yield*
P_0	0.093	103.2	0.119	109.07
P_1	0.092	101.1	0.120	102.36
P_2	0.096	99.6	0.114	108.71

Khan *et al.* (1985) while evaluating the comparative efficiency of four phosphate carriers, namely, superphosphate, ammonium phosphate, nitro-phosphate and rock phosphate, recommended rock phosphate as the ideal carrier of P for coconut as the soil content receiving rock phosphate gave the best reflect on plant P and enriched all P fractions in the soil and influenced the overall yield.

Root CEC and Coconut Nutrition

The relationship among cation exchange capacity (CEC) of roots, yield and cationic concentrations in soil and plant of different yield groups of West Coast Tall palms (Wahid *et al.*, 1974) showed that K contents of both soil and plant were positively correlated with yield while root CEC was negatively correlated with yield as well as leaf K content emphasising the importance of K in increasing nut yields. The study also suggested a critical level of 0.8 to 1 per cent for potassium (Frond 14) for coconut. The CEC of coconut roots ranged from 12.1 to 23.0 m.e./100 g.

Ca, Mg and S Nutrition

Crop removal studies (Pillai and Davis, 1963) suggest that the requirement of Ca and Mg are higher than that of P for coconut. Specific instances of Ca deficiency conditions or the direct effect of Ca on yield of the palm was not reported in India. However, liming of acid soils was found to favour the uptake of N, P and Mg by the palm. For acid soils, one kg of slaked lime or dolomite per palm per year is recommended. A critical level of 0.3 per cent Ca (Frond 14) has been suggested (Cecil, 1991).

Magnesium has been observed to be one of the most limiting nutrients for young palms. Magnesium deficiency has been more common on acid sandy and laterite soils with low Mg content and is also induced by imbalance of nutrients like high K/Mg or Ca/Mg ratios in soils and leaf tissues (Pandalai *et al.*, 1957; Pandalai, 1959; Cecil, 1975). Higher dose of K fertilisers was found to depress foliar Mg content and induce Mg deficiency in the palm (Khan *et al.*, 1986). Regular application of magnesium sulphate (hydrated) at the rate of 500 g MgO/palm/year from the time of field planting on a Mg-deficient sandy soil in the west coast of Kerala (India) had increased the growth parameters at a highly significant level, reduced the pre-bearing age by 9.1 months, increased the initial yield up to the fourteenth year by 34 per cent (Table 39.11), and maintained Mg content of soil and leaf to desired levels (Cecil, 1981).

Table 39.11: Main effect of Mg on growth, flowering and initial yield of WCT palms planted in 1970

Treatment	*Girth at collar (cm)*	*Height (cm) (36 months)*	*Fronds produced up to Dec. '80 (No.)*	*Proportion of palms (%) in flower at 74 months*	*Pre-bearing age (months)*	*Yield of nuts/ palm up to Dec. '84*
Mg_0	63.5	325.4	96.9	31.4	78.4	313.4
Mg_1	72.8	356.1	105.0	59.7	69.3	419.4
C.D. (0.05)	4.5	14.7	—	10.2	2.4	—
Per cent increase	14.6	9.4	8.4	90.1	−11.6	33.8

Mg_0 — Control; Mg_1 — 500 g MgO/palm/year.

Kamalakshi Amma *et al.* (1982) observed that application of 500 g MgO/ palm/year gave a significant increase in growth and yield and 1000 g MgO/ palm/year did not show any superiority. The addition of Mg may be regulated up to a maximum dose of 3 kg magnesium sulphate ($MgSO_4 \cdot 7H_2O$) per palm per year based on the extent of limitation of Mg and the exchangeable Mg/K ratio values of soil. An exchangeable Mg/K ratio of 2.0 in the soil (0 to 50 cm depth) and the foliar content of 0.2 per cent Mg in frond 14 are considered as critical for regulating the Mg requirement of the palm (Cecil, 1988).

Critical studies on sulphur nutrition of the palm were not attempted. A survey of coconut growing tracts of Kerala (Pillai, 1975) indicated that sulphur

content (Frond 14) ranged from 0.10 to 0.16 per cent. Cecil (1981) observed improvement in plant S levels due to regular application of sulphur bearing fertilisers like ammonium phosphate (15 % S) and magnesium sulphate (13 % S) and the foliar levels were maintained at 0.20 to 0.23 per cent S in frond 14, suggesting that inclusion of any one of the S-bearing fertilisers like ammonium sulphate, superphosphate, ammonium phosphate, magnesium sulphate or sulphate of potash will avoid sulphur deficiency conditions (Cecil and Pillai, 1976).

Sodium Chloride Nutrition

Field fertility studies involving application of 50 per cent of K requirement as sodium chloride and the rest as muriate of potash did not show any difference in the growth of young palms or on the productivity of bearing palms (Table 39.12). The early flowering index of NaCl-treated palms was higher than that of KCl-treated palms (Wahid *et al.,* 1988). Further studies are in progress at CPCRI, Kasaragod.

Table 39.12: Effect of NaCl on growth and flowering of D × T hybrids (planted in 1976) and on yield of bearing West Coast Tall palms (Wahid *et al.,* 1988)

Treatment (g/palm/year)	*D × T hybrids*		*West Coast Tall*
K_2O + Na_2O	*No. of fronds produced (1976 to 1985)*	*Early flowering index*	*Mean post-treatment yield (nut/palm/year) (adjusted)*
0 + 0	73.9	1.0	69.7
1000 + 0	73.3	1.9	86.8
750 + 250	78.3	2.6	73.8
500 + 500	79.2	2.4	84.8
250 + 750	72.7	2.6	83.0
0 + 1000	77.5	2.4	75.0
CD (P = 0.05)	NS	NS	15.6

The chlorine levels of West Coast Tall palms in the above experiment ranged between 0.75 and 0.82 and was not significantly different among the treatments.

Micronutrients

The tropical acid soils are in a fortunate position with respect to the cationic elements Fe, Mn, Cu and Zn. These cations are easily soluble and readily available under acid conditions and are not generally found limiting in the nutrition of the palm.

Availability of boron poses problem of deficiency in acid laterite, alluvial and coastal sandy soils. The boron deficiency disorder known as "Crown Choke" disease has been a serious problem in Assam and West Bengal (Baranwal *et al.,* 1989). From a recent survey in Assam (Anon., 1990), 10.8 per

cent of the palms were found affected by the disease and the total annual loss in yield due to the malady was estimated at 6.38 million nuts. Cecil and Pillai (1978) reported 5.7 ppm B in affected palms and 9.2 ppm B in comparable tissues of healthy palms. Baranwal *et al.* (1989) also reported that Ca/B ratio (on equivalent basis) was significantly lower for healthy palms when compared with diseased palms. It is interesting that the Ca/B ratio of palm in a healthy area was much lower than that of palms in the affected area (Table 39.13).

Table 39.13: Leaf B content and Ca/B ratio of palms in healthy and diseased areas (Baranwal *et al.*, 1989)

Condition of palm	*Leaf rank*	*Leaf B (ppm)*	*Ca/B ratio*
Diseased area			
Healthy palms	n/2 or (n+1)/2	7.4	95
Diseased palms	n/2 or (n+1)/2	5.4	145
Healthy area			
Healthy palms	n/2 or (n+1)/2	9.4	71
Healthy palms	frond, 14	10.2	—

Soil application of borax (decahydrate) at the rate of 50 g/palm just after the appearance of the symptoms was recommended. In slightly advanced stages, two applications of borax, 50 g each, at an interval of three to four months was found necessary for the recovery (Baranwal *et al.*, 1989).

Distribution of Microflora in the Root Zone and their Activity

Microbial population was high in multispecies high density cropping system (Bavappa *et al.*, 1987), multistoreyed cropping and mixed farming (Bopaiah, 1990) systems compared to that in monocropping of coconut. Nair (1974) described the microbial component as an important factor in enhancing the yield of coconut under the influence of cocoa as mixed crop. Bopaiah (1988) found enhanced activities of dehydrogenase, phosphatase and urease in root region soils of coconut compared to those in the interspaces.

Biological Nitrogen Fixation

Coconut based cropping systems favoured higher population of asymbiotic nitrogen fixers compared to monocropping of coconut (Potty and Jayasankar, 1983). The occurrence of the associative N_2-fixer Azospirillum was reported from coconut and a number of component crops under the different coconut based cropping systems. Studies on the distribution of Azospirillum under different management practices revealed greater number of the bacteria in plots which were not receiving fertilisers for a long time (Ghai and Thomas, 1988).

The green manure/cover legume-*Rhizobium* interaction is found to be an efficient N_2-fixing system in coconut gardens. It was found that *Pueraria phaseoloides* and *Calopogonium mucunoides* were promiscuous in their rhizobial requirement in coconut soils with acidic reaction. Studies on organic

farming with leguminous green manure crops within the coconut basin (1.8 m radius area around the bole) during the rainy season (four to five months) showed that *P. phaseoloides, Mimosa invisa* and *C. mucunoides* produced 15 to 19 kg and 25 to 28 kg of green matter per basin in sandy and laterite soils, respectively, and increased the microbial activity (Thomas and Shantharam, 1984).

Nutritional Studies on Coconut-based Cropping System

In coconut farming, fertilisers constitute the major component of energy-based input. In intensive cropping with tree crops, the application of fertilisers according to the estimated requirement for each crop is certainly not the most efficient and economic way of utilising native and applied nutrients (Oelsligle *et al.*, 1976). However component crops were fertilised based on their individual requirement for want of information on fertilising/managing the system as a whole.

A poly-culture involving coconut, namely, coconut-cacao combination, and a high density multi-species cropping system involving several component crops offer a vast scope of recycling of organic matter to a large extent. Varghese *et al.* (1978) reported biomass addition to the soil through shed leaves of a five-year-old stand of cacao under single and double hedge systems of planting to the extent of 818 kg and 1785 kg/ha/year, respectively. Organic carbon content of soil was considerably enriched through this addition (Table 39.14) and it was estimated that under double hedge system about 50 kg N, 11 kg P_2O_5 and 85 kg K_2O/ha/year were returned to soil through leaf fall.

Table 39.14: Organic carbon content of the soil in a coconut-cacao intercropping system. Verghese *et al.* (1978)

	Treatment	*Organic carbon %*		
		Pre-experimental period	*Experimental period*	
		0–30 cm	*0–15 cm*	*15–30 cm*
1.	Unirrigated coconut	0.25	0.36	0.27
2.	Irrigated coconut	0.25	0.56	0.56
3.	Coconut + cacao in single hedge + pineapple + pepper	0.25	0.61	0.56
4.	Coconut + cacao in double hedge + pineapple + pepper	0.25	0.76	0.58

Such recycling of nutrients through organic litter fall offer scope to reduce fertiliser input. Nair (1979) visualised an annual storage of 41.7 kg P_2O_5/ha in pure coconut system compared to 44 kg P_2O_5 ha in 30-year-old coconut with five-year-old cacao mixed crop system. He recommended skipping of P application in alternate quarters to coconut and thereby reducing the P input by 56 kg P_2O_5/ha/year.

In a high density multispecies cropping system with coconut and 17 component crops, the nutrient budget and balance studies indicated considerable build up of P and K in the system as a whole, while N and Mg got depleted. The depletion of Mg was uniform irrespective of the levels of fertilisers (one-third, two-third and full dose of recommended fertilisers for component crops and coconut) applied while the addition of full dose of fertilisers reduced the N depletion rate. The heavy build up of P and K in the system suggest the adequacy of one-third dose of P and K for maximum system productivity. Though there was an indication to the effect that N continued to deplete, the total yield of the main and component crops was unaffected during the period of study (1983 to 1985) even at one-third dose of fertiliser application. This aspect needs further investigation.

Diagnostic Techniques: Soil Testing Tissue Analysis

Cultivated crops are influenced by many factors, and nutrient supply from the soil is one of them. Soil testing and plant analysis have merits and demerits in diagnosing a situation specific problem related to crop nutrition. Pioneering work of IRHO scientists to judge the palm health based on critical levels in diagnostic leaf has been acclaimed as the best for coconut.

Soil Analysis

Long-term observations lead to conclude that 70 to 80 ppm of mineralisable nitrogen in soil (Subbaiah and Asija, 1956) and 10 to 12 ppm Bray-I extractable phosphorus can sustain sufficient levels in coconut (Khan *et al.*, 1986). Critical level of soil available K (1 N NH_4OAc) was found to be 50 to 65 ppm. This information, though needs revision, served as the best guide for recommending fertilisers in the absence of plant analysis. Khan *et al.* (1989) proposed that if soil available P is less than 10 ppm, full recommended dose of 320 g P_2O_5/palm/year may be applied and for a soil test value of 10 to 20 ppm, 50 per cent of the same may be applied. For soil test values of more than 20 ppm, P application can be skipped.

Further, phosphorus and potassium desorption models were constructed taking into account the response or reaction of the soils to added fertilisers (unpublished work). The models aim at maintaining the soil phosphorus (Table 39.15) and potassium (Table 39.16) fertility level at 20 ppm and 80 ppm respectively.

A similar model for potassium for red sandy loam soil was found to give an indication of higher K to be added for a given STV due to basic differences in soil characteristics.

Leaf Analysis

No systematic studies have been conducted in India to fix critical levels of major and secondary nutrients for coconut. However, the various data on leaf analysis and nutrient responses available in the country suggest the following critical levels (Frond, 14) for the tall variety of coconut.

N — 1.7–1.8 per cent
P — 0.11–0.12 per cent

K — 0.8–1.0 per cent
Ca — 0.3 per cent
Mg — 0.2 per cent

Table 39.15: P prescription for coconut on red sandy loam soil based on STV ($g\ P_2O_5$/palm/year)

STV (ppm)	*Desired level of P in soil (ppm)*									
	2	*4*	*6*	*8*	*10*	*12*	*14*	*16*	*18*	*20*
2	0	80	160	235	315	395	475	550	630	710
4		0	80	160	235	315	395	475	550	630
6			0	80	160	235	315	395	475	550
8				0	80	160	235	315	395	475
10					0	80	160	235	315	395
12						0	80	160	235	315
14							0	80	160	235
16								0	80	160
18									0	80
20										0

Table 39.16: K prescription for coconut on laterite soil based on soil test values (STV) ($g\ K_2O$/palm/year)

STV (ppm)	*Desired level of K in soil (ppm)*							
	80	*70*	*60*	*50*	*40*	*30*	*20*	*10*
0	1514	1238	1062	885	708	531	354	177
10	1238	1062	885	708	531	354	177	0
20	1062	885	708	531	354	177	0	
30	885	708	531	354	177	0		
40	708	531	354	177	0			
50	531	354	177	0				
60	354	177	0					
70	177	0						
80	0							

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DISCUSSION

K.S. Jayasekara: How severe is the Mg deficiency in coconut in Kerala?

S.R. Cecil: Magnesium deficiency is common in acid laterite and coastal sandy soils in Kerala. It is severe in acid sandy soils where foliar Mg levels of palms are in the range of 0.10 to 0.15 per cent.

W. Krishnamurthy Rao: If P is skipped for a considerable time as recommended, what would be its impact on Zn status and its effect on yield?

H. H. Khan: Zn status of the leaf tissue (Frond 14) did not change due to withholding phosphorus application and no deleterious effect on yield was recorded.

P.K. Vijayachandran: Will the present use of urea, rock phosphate and muriate of potash likely to lead to deficiency of sulphur in due course?

S.R. Cecil: Studies have shown that contribution from precipitation in the coconut growing regions (ranged between 12.2 and 28.5 kg) and the degradation of mulch in the manuring circle seems to take care of the palm's requirements of sulphur. It is however advisable to monitor the leaf tissue levels for sulphur.

COCONUT NUTRITION: EXPERIENCES IN THE PHILIPPINES

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ABSTRACT

Most research studies on the mineral nutrition and fertilisation of coconuts have been conducted in the country by the former Philippine Coconut Research Institute (PHILCORIN) and the Agricultural Research and Development Branch of the PCA for the past 25 years. The important and development-oriented findings are as follows:

Coconut seedlings need both Cl and K for normal growth and KCl and NaCl are effective sources of Cl and/or K. Young palms require N, K, Cl and S and KCl, NaCl and NH_4Cl are effective as Cl sources, while $(NH_4)_2SO_4$ and $CaSO_4 \cdot 2H_2O$ as sources of sulphur. Growth and yield of hybrids was significantly better under adequate fertilisation in different agro-climatic conditions. The nation-wide survey using leaf analysis as guide showed that low annual yields (one ton copra/ha) in most areas are due to widespread deficiencies in N, Cl, S and K in 57 provinces, with major deficiency classes as: N-S, N-K, N-K-S, N-Cl-S, and N-K-Cl-S. On-farm trials indicate that nutrient deficiencies as diagnosed by foliar analysis are effectively corrected by fertilisation resulting in yields of at least two tons copra per ha.

INTRODUCTION

Coconut is commercially grown in 63 of the 73 provinces growing it as a major crop. The largest areas are in Mindanao (51 per cent), Luzon (29 per cent) and the Visayas Islands (20 per cent). According to 1987 figures about 3.36 million hectares of agricultural land was planted with coconut which is equivalent to 27.7 per cent of the country's agricultural land.

The total coconut production has fluctuated between 1.44 and 2.69 million tons of copra during the period 1978–88, averaging about 2.3 million tons. Production is on the decline, mainly attributed to soil nutrient deficiencies

(principally in N, Cl, K, S) and senility of palms of some 20 to 25 per cent of the farms.

Yield per ha ranges from 0.85 to 1.5 tons copra per year on smaller farms (accounting for 98 per cent of the farms) and up to 3.0 tons on large estates (plantations) comprising two per cent of the total farmers. In recent years, the use of selected planting materials, hybrids with proper nutrition of palm grown in favourable soil and climatic condition has resulted in yield or productivity of two to four times the average national yield of 0.85 tons copra/ha per year.

This paper shall present the main experiences on coconut nutrition and fertilisation in the country during the past 18 years.

Soil Conditions of Coconut Areas

As a rule of thumb, coconut must only be planted in soils suitable to the crop for normal growth and high yields of both coconut and intercrops. Table 40.1 indicates that most soil conditions needed by the main crop (coconut) also satisfied the requirement of many intercrops grown under coconut in the Philippines.

Table 40.1: Requirement of soil conditions for coconut and its intercrops for high yield

Crop	*Soil Depth (cm)*	*Drainage*	*Soil pH*	*Soil type*	*Macro-nutrients ##*
Coconut	>75	Moderate to well-drained	6.0–7.5	sandy, loamy, clayey#	N, K, Cl, S, P
Intercrops:					
Corn	>50	well-drained	5.3–7.3	loamy	N, P, K, S
Peanut	>50	well-drained	5.8–6.2	loamy	N, P, K, Ca, S
Sweet Potato	>75	well-drained	5.6–6.8	loamy	N, P, K, Ca
Pineapple	>75	well-drained	4.5–5.5	sandy, loamy, clayey	N, P, K, Ca
Banana	>75	well-drained	6.0–7.5	loamy, clayey	N, P, K, Ca
Coffee	>75	well-drained	4.5–6.5	loamy, clayey	N, P, K, Ca, S
Cacao	>75	well-drained	5.5–7.0	loamy, clayey	N, P, K, Ca, S

#sandy and clayey soils suited if soil is well-drained, friable and with good structure (not compacted and well-aerated).
##micronutrients Zn, Fe, Mn, B, Cu must be adequate.

Most of the coconut areas in the Philippines, in both high yielding areas and low yielding areas have favourable soil condition in terms of chemical and textural properties (Table 40.2). A PCA survey (1975–1981) indicated the wide spread nutritional deficiencies of N, Cl, S and K as the major limiting factors in low lying areas. In the same Philippine survey covering 58 provinces and

cities it was concluded that an ideal soil environment for the widely planted Laguna tall variety is as follows:

1) Coastal flat or inland flat land form (Table 40.3a).
2) At least 80 cm soil depth.
3) Alluvial and limestones-derived soils with pH close to alkaline.
4) Average to moderate fertility level.

Table 40.2: Some properties and yield of coconut areas in the Philippines

Soil properties	*High-yielding area*		*Low-yielding area*	
	Top soil	*Subsoil*	*Top soil*	*Subsoil*
Soil pH	6.06	6.25	5.96	6.15
	(5.0–6.9)	(5.1–7.2)	(5.2–7.5)	(5.3–7.4)
Organic matter (%)	2.06	1.37	2.02	1.31
	(0.81–3.83)	(0.60–2.70)	(0.01–3.23)	(0.38–3.01)
Available P (ppm)	16.66	15.39	16.21	13.80
	(3.2–36.6)	(2.9–38.3)	(4.3–37.5)	(4.4–27.4)
Total K (ppm)	401.36	324.08	392.03	333.03
	(75.5–1298.3)	(56.0–1017.7)	(74.0–1692.0)	(38.5–1217.5)
Exchangeable bases (m.e./100 g soil)				
Mg	5.46	6.48	6.28	7.69
	(0.48–14.8)	(0.6–15.2)	(1.3–18.9)	(0.3–24.3)
K	0.56	0.45	0.51	0.39
	(0.1–1.43)	(0.1–1.43)	(0.1–1.6)	(0.1–1.4)
Ca	18.96	21.82	22.14	22.63
	(2.3–73.2)	(0.3–69.2)	(3.8–48.1)	(2.8–55.1)
Na	0.40	0.45	0.38	0.86
	(0.1–1.8)	(0.1–1.9)	(0.1–1.4)	(0.2–1.9)
Soil texture (nPs)				
Loamy	30	18	27	18
Clayey	20	10	30	14
nPs	50	28	57	32
Estimated yield				
Nut/tree (no.)	54.05		28.63	
	(37.5–68.1)		(5.0–43.3)	
Copra/ha (tons)	2.04		0.90	
	(1.60–2.836)		(0.16–1.45)	
nPs	50		57	

Figures in parentheses are ranges.
nPs — Number of provinces sampled.

In addition, Cosico and Fernandez (1983) found that average nut yield of palms growing in soils identified as Entisol, Alfisol, Ultisol, Inceptisol and Vertisol all over the country did not differ significantly (37 to 43 nuts/tree/year). However, if total farm productivity (coconut + intercrops) is considered, soils with higher base saturation as Alfisol and Inceptisol could be more suitable for coconut intercropping, a farming system in which competition for nutrients is stronger.

Table 40.3: Average yield and nutritional deficiencies of 57 coconut provinces and cities in the Philippines, PCA Study

Province	*Copra yield (t/ha)*		*Nutritional deficiencies (Low-yielding areas)*
	Low yielding	*High yielding*	
Luzon (North and Central)			
1. Isabela and Nueva Viscaya	0.67	—	N, Cl, S
2. Cagayan	0.96	1.93	N, K
3. Ilocos Norte/Sur	0.99	1.92	N
4. La Union	0.91	2.83	N, Cl
5. Pangasinan	0.72	2.25	N, K, S
6. Zambales and Bataan	1.02	1.81	N, K, S
Luzon (Southern Tagalog)			
7. Cavite	0.74	1.86	N, Cl
8. Palawan	0.77	—	N, S, P
9. Batangas	0.89	2.19	N, Cl
10. Laguna	1.14	1.93	N, Cl
11. Quezon	1.13	2.17	N, K, S
12. Marinduque	0.84	1.98	N, K, S
13. Mindoro Oriental	1.11	2.01	N, Cl, S
14. Mindoro Occidental	—	2.14	N, K
Bicol Region			
15. Camarines Norte	1.13	1.76	N, K
16. Camarines Sur	0.86	1.89	N, K, S
17. Albay	0.86	2.25	N, K, S
18. Sorsogon	1.44	2.37	N, S
19. Masbate	0.89	1.91	N, K, S
20. Catanduanes	0.78	—	N, K, S
Visayas (Central, Western)			
21. Cebu	1.01	2.26	N, K
22. Negros Occidental	0.95	1.60	N, K
23. Negros Oriental	1.01	1.94	N, S
24. Bohol	0.81	1.89	N, K, S
25. Iloilo	0.89	2.39	N, K, S, P
26. Aklan	0.96	—	N
27. Antique	0.74	2.01	N, S
28. Capiz	0.90	1.70	N
29. Siquijor	0.85	1.68	N, K
Visayas (Eastern)			
30. Leyte	0.87	2.28	N, S
31. Southern Leyte	0.91	1.68	N, S
32. Eastern Samar	0.96	1.81	N, K, S, P
33. Northern Samar	1.06	2.61	N, S
34. Western Samar	0.04	1.84	N, S
Western Mindanao			
35. Zamboanga City	0.66	2.07	N, Cl, S
36. Zamboanga del Sur	0.99	1.98	N, Cl
37. Zamboanga del Norte	0.78	1.93	N, K
38. Basilan	0.75	1.73	N, Cl, S
Northern and Central Mindanao			
39. Agusan del Norte	0.98	1.91	N, K, Cl, S
40. Agusan del Sur	0.48	1.82	N, Cl, S

Contd.

Table 40.3—Contd.

Province	Copra yield (ton/ha)		Nutritional deficiencies (Low-yielding areas)
	Low yielding	High yielding	
41. Surigao del Norte	0.72	1.83	N, S
42. Surigao del Sur	0.84	2.04	N, S
43. Misamis Oriental	0.96	2.10	N, Cl, S
44. Misamis Occidental	0.97	2.33	N, K, Cl, S
45. Lanao del Norte	0.98	2.57	N, Cl, S
46. Bukidnon	1.07	1.97	N, Cl, S
47. Camiguin	1.12	1.66	N
Southern Mindanao			
48. Davao City	0.73	1.43	N, Cl, S
49. Davao del Sur	0.93	2.16	N, Cl, S
50. Davao Norte	0.82	2.38	N, Cl, S
51. Davao Oriental	0.79	1.95	N, K,Cl, S
52. South Cotabato	0.93	2.00	N, Cl, S, Mg
53. North Cotabato	0.71	2.17	N, Cl, S, Mg
54. Sultan Kudarat and Maguindanao	0.65	1.70	N, Cl, S, Mg
Mean	0.88	1.98	
National: 1.43			

Soil Classification

Detailed-reconnaisance soil surveys with classification of soils (Soil Taxonomy-USDA) has so far been initiated in 12 provinces namely, Laguna, Batangas, Bulacan, Aurora, Rizal, Bataan, Negros Occidental, Davao Oriental, Leyte, Mindoro Oriental, Zambales and Tarlac. The surveys and preparation of the reports are in progress.

The former Bureau of Soils attempted to classify and map the soils (1:1,600,000) of the Philippines at the great group level of Soil Taxonomy. In that same year, Jarmin of the Soil Survey Division was able to produce a 1:1,000,000 scale land use map of the Philippines.

The soil map indicates that majority of the soils of the coconut growing areas belong to Tropudults, Tropudalfs and Tropepts, the latter being more on the Eutric than the Dystric great group. The volcanic soils were classified as Eutrandepts.

On the other hand, mountain soils, undifferentiated in the reconnaissance soil surveys, were classified as an association of Entisol, Inceptisol, Ultisol and Alfisol. In this respect, updating of the soil classification on hilly and mountainous areas is expected as more detailed studies are carried out and additional data are generated.

Nutrient Deficiencies

Extent: A nation-wide nutritional survey involving 57 provinces (using foliar diagnosis) indicated the major and widespread nutritional deficiencies of coconut in the Philippines as those of nitrogen, chlorine, potassium and sulphur (Magat *et al.*, 1981). This is illustrated in Fig. 40.1.

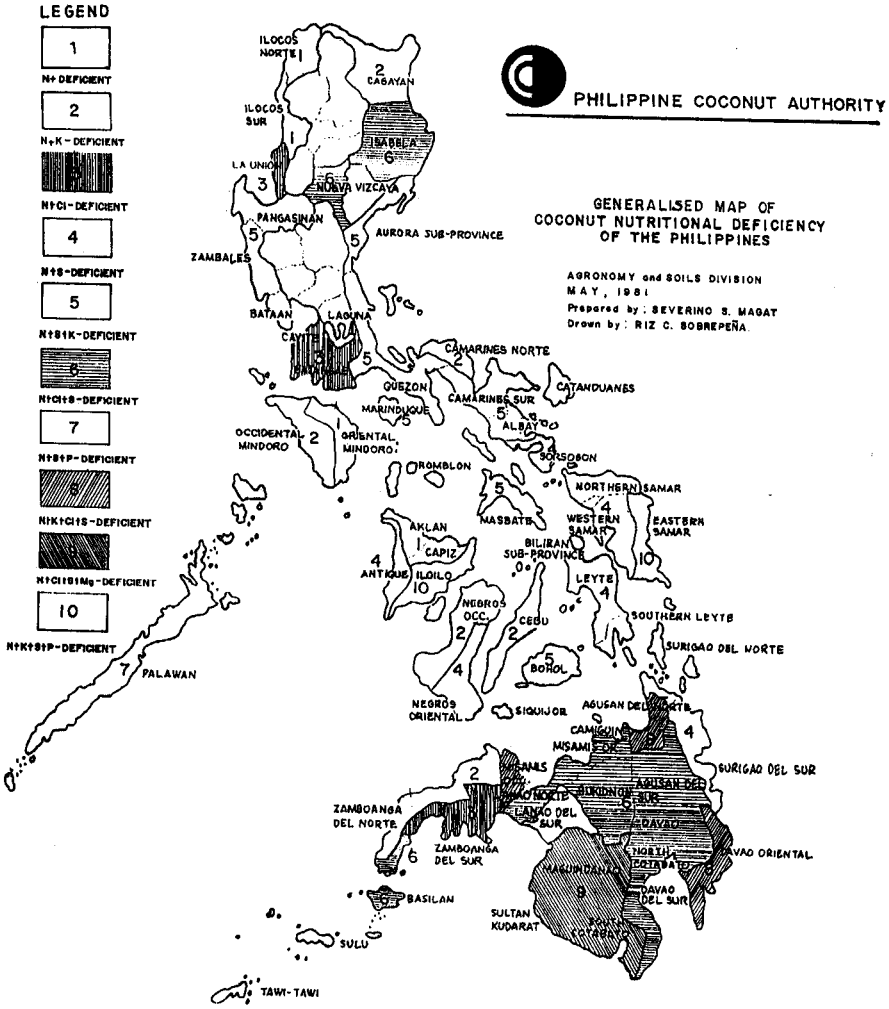

Fig. 40.1: Map of the country showing the generalised coconut nutritional deficiency classes of the provinces covered by the nutrition (leaf) survey, 1974–1980.

The report also suggested that the average copra yields of low-yielding and high-yielding areas were 0.88 tons and 1.98 tons per ha, respectively (Table 40.3) indicating that nutritional deficiency can reduce productivity by about 1 ton of copra or increase production by an average of 125 per cent by maintaining an adequate and balanced nutrition of the coconut.

Out of the 3.4 million hectares of coconut in the country (PCA, 1986), about 2 million of these is likely deficient (moderate to strong) in nutrients and fall under 10 distinct coconut nutritional deficiency classes identified by the Magat *et al.* (1981). These deficiency classes are as follows:

1) N deficient (six provinces).
2) N + K deficient (seven provinces).
3) N + Cl deficient (five provinces).
4) N + S deficient (nine provinces).
5) N + K + S deficient (10 provinces).
6) N + Cl + S deficient (11 provinces).
7) N + S + P deficient (one province).
8) N + K + Cl + S deficient (seven provinces).
9) N + Cl + S + Mg deficient (four provinces).
10) N + K + S + P deficient (two provinces).

Symptoms and Causes

Only the nutrient deficiency symptoms of N, Cl, K and S which are widespread are elaborated in this section. Boron, iron and copper deficiencies have been observed lately in new plantings, especially with improved planting materials or hybrids.

Nitrogen

Nitrogen deficiency causes stunted growth and yellowing of young and old leaves (upper and lower) delays fruiting and reduces nut yield.

The shortage of protein increases the C/N ratio, resulting in excessive carbohydrates and increased cellulose and lignin content. Such conditions thicken the cell membrane and increase the lignified tissues. Thus, coconuts suffering from N deficiency look abnormal, dry and non-succulent. Coconut palms are normal green to dark green when N levels are adequate or high and yellowish when low or critically inadequate for normal growth and high yields.

Potassium

Deficiency in potassium generally results in low yield and small nuts. As K is a mobile nutrient, lower or older leaves turn yellowish too soon while young or upper leaves remain green in colour.

The deficiency in K is due to either inadequate soil K or excessive Ca or other bases, causing nutrient imbalance and difficulty for the roots to absorb K as the natural phenomenon under mass absorption of elements under field conditions.

Sulphur

Sulphur like nitrogen is another essential constituent of protein. While N makes the $-NH_2$ radical of amino-acids which forms peptides, S makes the

$-SH_2$ radical and forms sulphur-containing amino-acids such as cystein. Hence, S deficiency is similar to N deficiency, and in coconut, colour of abnormal leaves is yellowish orange to orange instead of pale green to yellow colour of N deficient palms.

Soils very low in organic matter and continuously cropped without S fertilisation are likely to suffer from S deficiency. In the Philippines, even coconuts grown on soils derived from volcanic materials could suffer from S deficiency under high rainfall conditions throughout the year.

Chlorine

Positive response and deficiency of coconut with this element had been reported by several authors in the early seventies from studies conducted in an inland area of Davao (Uexkull, 1972; Mendoza and Prudente, 1972; Magat *et al.,* 1975). Chlorine increases thickness of coconut meat and copra weight per nut as a result of a bigger cell volume and 'sink' or economic yield. It also accelerates the plant development in terms of girth and leaf production. Moreover, it enhances better absorption of other nutrients such as K, Ca and Mg which contribute to accelerated growth and early fruiting.

Chlorine deficiency in coconuts is manifested by a small sized nut with meat thinner than normal, few leaves with narrow leaflets and presence of leaf spots (fungal diseases). This deficiency is confirmed by foliar analysis with leaf-Cl concentration of less than 0.3 per cent (Frond 14) in bearing palms.

Boron

Boron, like calcium, is an immobile nutrient. Deficiency of this nutrient affects the development of meristem or actively growing tissues. At the early stage of deficiency in the field, a weak and 'little leaf' appearance of the leaf fronds are manifested by the coconut followed by an abnormal non-splitting of leaflets appearing as 'frizzled' frond. At the advanced stage, the growing points of the plant exhibit blackening, growth failure and death of the coconut.

Iron

Deficiency of this nutrient is commonly detected as lime induced on soils rich in calcium carbonate, and on peaty soils. The field symptoms are: (a) gradual yellowing of entire leaflets, in longitudinal strips parallel to the veins, with leaf completely yellow in its advanced stage; and (b) the rachis and leaflets become shorter with the coconut exhibiting a runty appearance.

At first observation, iron deficiency symptoms are similar to those of nitrogen. However in the case of nitrogen, yellowing is uniform, while in the iron deficiency, strip-discolouration exists, with yellowing becoming general in the advanced stage.

Copper

Copper deficiency is normally detected in organic soils (peat areas). The characteristic symptoms include severe bending of rachis of the youngest leaves, accompanied by yellowing and drying of leaf tip which appears rimmed

with brown and yellow, while the middle portion remains normal green. As the symptoms develop, new leaves are deformed and are abnormally short giving the coconut a runty sagging appearance.

RESPONSE TO FERTILISATION

Nursery Seedlings

Fertilisation studies on coconut seedlings using either inorganic or organic fertilisers or both have been initiated by the Philippine Coconut Authority since the early seventies.

Common Salt (Sodium Chloride) as a Fertiliser and for the control of leaf spot disease of coconut seedlings

Magat *et al.* (1977) revealed that common salt (NaCl 60–70 g/seedling) increased significantly the girth and fresh weight of coconut seedlings grown on Cl deficient Tugbok clay loam soil. The seedlings also developed resistance to leaf spot/blight disease. Moreover, leaf analyses reveal that the critical level of Cl in seedlings (leaf 3) is likely at 0.70 to 0.80 per cent.

Fertiliser Requirement of Coconut Seedlings Grown on Three Major Coconut Soils of Davao

Different rates and kinds of fertiliser were tested on polybag-raised coconut seedlings grown on three soil types (Tugbok clay loam, San Manuel loam and Talomo sand). Of the three fertilisers (ammonium sulphate, potassium chloride and calcium superphosphate), only potassium chloride strongly influenced the growth and development of seedlings in all soils (Maravilla *et al.,* 1978). Apparently all the soils have adequate supply of N, P, S, Ca and Mg.

Effects of Chlorine Sources and Ammonium Sulphate on Growth of Coconut Seedlings

Of the chlorine sources (KCl, NaCl and NH_4Cl), NaCl at 30 g Cl gave the best result followed by KCl (Oguis *et al.,* 1979). Chlorine leaf levels significantly decreased with increasing sulphur. Correlation analysis between two elements indicated an apparent antagonism between Cl and S.

Sulphur Fertilisation of Coconut Seedlings

Sulphur fertilisation (10–12 g S = 42–50 g $(NH_4)_2SO_4$/seedling) increased significantly the height of the seedlings while Cl (30 g Cl = 60 g NaCl/seedling) improved the girth and fresh weight of the vegetative parts (Margate *et al.,* 1979). In the absence of ammonium sulphate, K_2SO_4 (60–70 g) could be an alternative source of S, provided N is not limiting.

Early Results of a Study on the Chlorine Nutritional Need of Coconut in the Philippines

Only chlorine significantly increased the girth of the seven-month old seedlings and their leaf content but not the other growth characters (Magat

and Oguis, 1979). The application of nitrogen significantly increased leaf nitrogen but decreased leaf phosphorus. This, however, did not significantly affect the growth of the seedlings.

Potential of *Ipil-Ipil* (*Leucaena leucocephala*) leaves and Agrispon as Fertiliser for Coconut Seedlings

Cadigal *et al.,* (1983) observed that girth, height, number of living fronds and vegetative parts of seedlings was influenced significantly by the application of $(NH_4)_2 SO_4$ + 70 g KCl and also at 500 g *ipil-ipil* leaves + 70 g KCl. These treatments increased leaf contents of N, K, Ca, Cl and B. The application of *ipil-ipil* alone at 500 g had also a similar effect but was not much effective when combined with KCl. This study suggests that *ipil-ipil* leaves could be used as a substitute for ammonium sulphate for manuring coconut seedlings.

Utilisation of *Eucheuma spinosum* by-product as Fertiliser for Coconut Seedlings

Application of 90 g Eucheuma by-product (50 per cent K, 45 per cent Cl) with 70 g $(NH_4)_2SO_4$ increased significantly the girth, height, number of functional leaves and leaflets over the control in three coconut populations (Cadigal *et al.,* 1983) including MAWA hybrids. The application of Eucheuma by-product increased leaf P, Ca, Cl and K. This suggests that this by-product could well be used as a substitute for potassium chloride.

Fertilisation of MAWA Hybrid Seedlings with Animal Manures and other Organic Fertilisers

The study reveals that goat manure at 840 g per seedling produced taller seedlings with more girth compared to those applied with inorganic fertiliser (60 g ammonium sulphate + 70 g potassium chloride). The two treatments contributed much to the improvement of the nutrition of the seedlings especially Cl and N.

Growth Response of Coconut Seedlings from Seednuts Collected from Palms Fertilised with Sodium Chloride

An eight-month study to determine the response of nursery seedlings from seednuts collected from mother palms fertilised with five rates of NaCl (0, 0.88, 1.76, 3.52 and 7.04 kg/tree/year) was conducted at the PCA-Davao Research Centre in 1986. Levels of NaCl at 1.76 to 7.04 kg/tree/year applied on mother palms significantly influenced earliness and total percentage germination of seednuts, girth size and leaf production of seedlings.

Inorganic Fertilisation of Coconut Seedlings Grown in an Inland-upland Soil of Albay

The application of $(NH_4)_2 SO_4$ plus KCl or NaCl, with or without dolomite improved the growth of the seedlings in terms of girth and fresh weight of vegetative parts (Cordova *et al.,* 1980). Ammonium sulphate application alone produced a depressive effect on height and on root development and

aggravated the incidence of leaf spot. Magnesium content of seedlings was depressed where KCl was applied, while N, P, K and Ca did not produce any consistent response to fertiliser application.

YOUNG PALMS (Pre-Bearing)

Effect of NPK Fertiliser on Coconut from Transplanting to Full-bearing at PCA-Davao Research Centre. (Mendoza and Prudente, 1979)

Fertiliser combinations, namely, N + KCl_1, N + KCl_2 and N + P + KCl_2, likewise, significantly influenced the formation of stouter trunk compared to control and N + P palms. Spathe production for palms applied with N + KCl_1, N + KCl_2 and N + P + KCl_2 fertilisers started 42, 47 and 45 months respectively after transplanting.

Coconut Nutrition (Chlorine) from Nursery to Full-bearing Stage

During the first five years from field planting, both K and KCl significantly influenced the growth and development of young palms (Magat and Oguis, 1979). Addition of Mg to young palms was beneficial particularly at lower rates of N and K fertilisation.

Five years after field planting, 140 palms receiving chlorine had flowered earlier than the minus-Cl plots, suggesting the influence of chlorine which accelerates flowering or bearing of coconuts.

BEARING PALMS

Yield Improvement of Coconut in Elevated Inland Area of Davao by KCl Fertilisation

The effect of increasing rates of KCl on bearing palms with blanket application of N (as ammonium sulphate) was investigated. A quadratic response of palms to KCl in terms of nuts per tree and a linear response for copra weight per nut and copra yield per tree were observed (Table 40.4) (Magat *et al.*, 1975). The increases were positively related to the Cl content of the leaves and in negatively K levels. This suggests that Cl and not K is the likely limiting nutrient.

Table 40.4: Effect of KCl on yield of palms (Magat *et al.*, 1975)

Treatment (kg KCl/tree/year)		*Nut/Tree*[1] *(no.)*	*Copra/Tree (kg)*	*Copra/Nut (g)*
	0	142.8^{b}	22.78^{c}	158.8^{c}
	0.83	161.8^{b}	26.96^{bc}	166.5^{bc}
	1.66	193.3^{a}	33.81^{ab}	176.2^{bc}
	2.40	190.3^{a}	33.43^{ab}	197.9^{ab}
	3.33	164.8^{b}	38.17^{a}	230.05^{a}
HSD	.05	24.6	8.41	33.8
	.01	33.6	11.40	45.8

Note: Means having the same letter(s) are not significantly different.
[1]Sixteen accumulated harvests at 45 days cycle.

When the KCl rate was increased at 0, 1, 2, 4 and 8 kg per tree per year, the highest nut production was obtained from 2 kg KCl per tree per year (Margate *et al.,* 1979). Copra per nut correspondingly increased with increasing KCl levels, while copra production per tree followed a linear trend response. Highest copra yield per tree was obtained with 8 kg KCl level. Leaf Cl content was markedly correlated with nut and copra yield, while no correlation existed between yield and leaf K.

Effect of NPK Fertilisers from Transplanting to Full-bearing

Cumulative data from 1972 to 1979 reveal that the palms fertilised with KCl with either N or NP produced significantly more nuts with thicker and heavier meat, hence, more copra per tree than palms without KCl (Mendoza and Prudente, 1979).

On nut production, palms with N + KCl_2 treatment gave an increase of 133 per cent and 119 per cent and 83 per cent over palms with N and N + P, respectively. Palms receiving KCl either with N or N + P, gave a mean yield of 69 kg copra per tree against 20 kg produced from palms without KCl, a difference of 245 per cent during the said period.

Coefficient of correlation between leaf and leaf nutrient levels and production show that inland tall coconuts grown on reddish brown clay loam soil of Davao apparently responded only to N and Cl. Nitrogen levels in the leaves were highly correlated with nut and copra production, while chlorine levels were correlated with copra weight per nut, copra/tree and number of nuts/tree.

Increasing Productivity of Inland Coconuts by Nitrogen, Chlorine and Sulphur Fertilisation

Four fertiliser combinations were tested to determine the response of low yielding and nutritionally deficient inland coconuts grown on dark brown Tugbok clay loam soil (Typic tropudalf) of Davao. The combined application of N, Cl and S resulted in a significant increase of 32 to 34 nuts per palm per year over the control palms (Table 40.5). The application of either 1.8 kg $(NH_4)_2SO_4$ + 2.0 kg KCl per tree per year is strongly suggested.

Table 40.5: Influence of fertiliser treatments on the number of nuts/palm/year (Magat *et al.,* 1978)

Treatment	*Year*		
	1	*2*	*3*
Control	50.6(164.2)	75.2(168.9)	53.6(170.2)
$(NH_4)_2SO_4$ + $CaMgCO_3$	55.5(154.4)	78.2(165.2)	75.8(168.1)
NH_4Cl	45.5(156.3)	79.1(205.7)**	70.6(211.4)
$(NH_4)_2SO_4$ + KCl + $CaMgCO_3$	42.2(168.0)	79.3(211.1)**	85.6(228.0)**
$(NH_4)_2SO_4$ + NaCl	46.6(155.7)	82.1(213.4)**	88.1(216.8)**
HSD .05	NS (NS)	NS (28.3)	28.5 (34.4)
.01	NS (NS)	– (35.0)	42.6 (–)

Figures in parentheses indicate copra weight (g/nut) and significance for copra weight.
**Highly significant.

Sodium Chloride Fertilisation of Bearing Coconuts
I. Early Yield Response

The graded doses of NaCl (0, 0.83, 1.76, 3.52 and 7.04 kg NaCl per palm) significantly influenced a linear trend in nut production, copra weight/nut and copra yield/palm over a three-year period. While copra production was only 13.3 kg/palm in control plots, palms receiving 7.04 kg NaCl/year produced 31.7 kg copra/tree when average values for three years were computed. The leaf analysis showed that Na increased from 0.05 to 0.07 per cent and Cl from 0.08 to 0.84 per cent. Leaf Cl was highly correlated with the three-yield indices mentioned above indicating that the increase in yield was mainly due to the correction of Cl deficiency. This study suggests that NaCl may be used as an economical source of Cl, to replace KCl which is an expensive fertiliser.

Recovery of Yellowing and Yield Improvement of Coconut Grown on a Coastal Flat Area of Davao (1973 to 1978)

Visible effect of reduction in the degree of foliar yellowing was noted within six months of fertiliser application (Prudente *et al.,* 1979). Cumulative data gathered after four-and-a-half years showed that palms treated with 2.2 kg ammonium sulphate (21-0-0) + 1.0 kg solophos (0-20-0) + 1.5 kg muriate of potash (0-0-60-44 Cl) increased nut and copra production by 16 and 29 per cent, respectively, over the unfertilised palms and 105 and 119 per cent, respectively over the palms applied with P + K only (Table 40.6). With fertilisation, the average annual copra yield per ha (123 palms) increased from 0.73 to 2.43 tons. Correlation coefficient showed that N and S highly influenced nut and copra production per tree. Nevertheless, Cl effect manifested more on weight of copra per nut indicating the existence of the deficiencies of these elements in the area.

Table 40.6: Number of nuts per palm as influenced by fertiliser treatments (Prudente *et al.,* 1979)

Treatment	*Year*					*Accum. 2nd–5th*
	1st	*2nd*	*3rd*	*4th*	*5th*	
T_1–Control	19.2	17.6	25.7	33.3	17.1	93.7
T_2–$N_0P_1K_1$	–	31.2	25.5	50.5	26.1	133.3
T_3–$N_1P_1K_0$	34.7	57.8	34.9	52.7	27.1	172.5
T_4–$N_1P_1K_1$	53.4	70.0	51.6	72.3**	46.7**	240.6**
T_5–$N_2P_1K_0$	37.2	62.3	44.6	68.2**	36.6*	211.7
T_6–$N_2P_1K_1$	55.1	75.5*	61.9**	73.1**	46.4**	256.9**
T_7–$N_3P_1K_0$	–	50.2	49.6*	64.1	32.8*	196.7*
T_8–$N_3P_1K_1$	–	71.6*	68.0**	81.1**	43.3**	264.0**
HSD .05	34.6	52.8	20.6	26.0	16.1	96.8
.01	NS	NS	25.9	32.7	20.2	121.5

* significant.
** highly significant.

Initial Response of Young Bearing Palms to Various Fertiliser Sources of Chlorine (Davao, 1974 to 1981)

Application of Cl fertiliser sources highly increased copra weight per nut by 40 to 44 per cent and copra weight per tree by 7 to 11 kg or 55 to 79 per cent over the control palms as early as the first and third years, respectively (Magat *et al.,* 1986). Nut production of NH_4Cl and KCl-treated palms increased by 10 and 24 per cent, respectively, over the control at the start of the fourth year of harvest (Table 40.7).

Table 40.7: Copra production per palm (kg) as influenced by the different fertiliser treatments

Treatment	*Year*				*Accum. Copra/Tree*
	1st	*2nd*	*3rd*	*4th*	
1. Control	9.27	9.34	9.38^{c}	13.72^{c}	40.57^{c}
2. $(NH_4)_2SO_4$ + KCl	11.40	11.68	16.88^{a}	21.22^{ab}	59.36^{ab}
3. $(NH_4)_2SO_4$ + NH_4Cl	12.19	12.28	15.86^{ab}	24.61^{a}	62.20^{a}
4. $(NH_4)_2SO_4$ + NaCl	10.40	8.22	11.66^{bc}	18.89^{b}	47.05^{bc}
HSD .05	NS	NS	4.707	4.678	14.095
.01	–	–	6.347	6.335	19.006
C.V. (%)	24.89	25.05	15.85	10.85	12.20

Note: Means having the same letter(s) are not significantly different.

Yield Improvement of Sulphur Deficient Coconuts by Gypsum ($CaSO_4 . 2H_2O$) Application

Increasing rates of gypsum (0, 0.75, 1.50, 2.25, 3.00 kg/tree/year) produced a significant linear response in nut production up to 2.5 kg per palm per year and a quadratic response up to 3 kg with an optimum rate of 2.5 kg producing 45 nuts/palm/year (Margate and Padrones, 1987) (Table 40.8). The increases ranged from 48 to 64 per cent. On copra weight per nut and per palm, a linear response was noted with an increase of 6 to 16 per cent and 47 to 79 per cent, respectively.

Sulphur accounted for 74.6, 35 and 63 per cent contributions in the improvement of nut per palm, produced whiter and thicker copra as against rubbery and shrunked copra produced by control palms. The fertiliser treatments also increased copra weight/nut and copra/palm.

Chlorine Nutrition of Coconut from 'Polybag' Nursery to Full-bearing Stage (Typic Tropudalf of Davao, Southern Philippines from 1974 to 1988)

At the nursery stage, only chlorine application improved the growth of the seedlings based on girth size which was highly correlated with increased chlorine content of leaf. During the first five years in the field, K and Cl significantly influenced the growth of the palms which were positively correlated to all growth parameters, that is, girth, number of leaflets, living fronds and leaf production. During the fifth year, Cl fertilisation resulted in 115 per cent more flowering palms than the unfertilised ones. Chlorine application consistently increased nut production, copra/nut and copra yield/tree which

were correlated with Cl content of leaf. However, the positive effects of other nutrients like N, K and Mg on yield as well as interaction effects were inconsistent over the years.

Table 40.8: Effect of increasing rates of $CaSO_4$ on the yield of coconut palms (yearly average of three- and- a-half years period) and on the oil content of copra

Treatment (kg $CaSO_4$/palm/year)	*Nuts/palm (no.)*	*Copra/nut (g)*	*Copra/palm (kg)*	*Oil content (%)*
0 (control)	28.7	250.8	6.8	62.8
0.75	42.6	265.8	10.0	63.0
1.50	42.5	280.1	10.4	61.9
2.25	43.1	285.2	10.7	59.6
3.00	47.1	291.4	12.2	62.3
Mean	40.8	274.68	10.0	62.0
Stat. Sig.	**	*	**	NS
HSD .05	6.4	48.6	2.3	NS
Trend: Linear	**	*	**	NS
Quadratic	*	NS	NS	NS

NS — not significant.
* — significant.
** — highly significant.

At nursery stage the seedlings require Cl at the rate of 30 g Cl/seedling. Under field conditions, the requirement increases with age from 40 g to 1,000 g/palm levelling off at the fifth year from planting (Table 40.9).

Table 40.9: Suggested guide on Cl needs (nursery to full-bearing) of coconuts, local tall variety

Stage and Age	*Cl/palm (g)*	*Fertiliser Source* (g)*	
		KCl or	*NaCl*
Nursery:			
2 months	10	25	20
5 months	20	50	40
Field:			
field planting	40	100	80
6 months	100	230	200
1 year	200	450	400
2 years	400	900	800
3 years	600	1,400	1,200
4 years	800	1,800	1,600
5 years and above	1,000	2,250	2,000

*KCl = 44% Cl, 60% K.
NaCl = 50% Cl.

Based on the relationship between leaf nutrient levels (with the growth) and yield of coconuts, the critical levels of Cl for the different leaf positions and growth stages are: nursery stage (leaf 3) = 0.70 per cent Cl; pre-bearing

(leaf 4) = 0.30 per cent Cl with optimum leaf Cl at 0.50 per cent, 0.60 per cent and 0.55 per cent Cl for nuts/palm, copra weight/nut and copra yield/palm, respectively.

A Report on the Nation-wide Performance of Exotic Hybrids Tested in the Philippines by PCA, 1977 to 1987

Four hybrid crosses (introduced from the Ivory Coast) were planted in 1977 in 133 PHF's all over the country. These hybrids were: (1) YMD × WAT (MAWA or PB 121); (2) EGD × WAT; (3) RMD × WAT; and (4) CRD × WAT (PD 111). In 1982, only 26 representative PHF's were selected and retained by the PCA for further field observations.

The performances of the exotic hybrids in 26 pilot farms covering the eight coconut regions of the country indicate the location-suitability of these hybrids under Philippines conditions. Based on the average number of nuts per palm, the hybrids are generally found to be best suited for planting in Mindanao, particularly in southern, northern and western Mindanao. The least favourable locations for hybrids establishment particularly YMD × WAT were in Bicol, southern Tagalog and the rest of Luzon.

In terms of annual copra yield/ha, the four exotic hybrids gave significantly higher yields over talls in three PCA centres while in the pilot farms, the copra yields were decreasing in the order: highly suitable, suitable and fairly suitable areas.

Basis of Fertiliser Recommendations

The several techniques used in identifying the fertiliser needs of coconut are: (a) soil analysis; (b) crop deficiency symptoms; (c) leaf analysis; and (d) field fertiliser experiments/trials. Each has its advantages and disadvantages. Most often the selection of the methods depends on the available facility and manpower resources. The conduct of field fertiliser trials (FFT) in the research centres or stations and verification in on-farm fertiliser trials (OFFT) are the best methods but these are time-consuming and expensive.

Soil Analysis

Soil analysis has been practiced with some degree of confidence but users have not been satisfied with reliability and usefulness of the method. In the Philippines, the Bureau of Soils and Water Management (BSMW) depends on soil analysis to formulate fertiliser recommendations.

Crop Deficiency Symptoms

Deficiency symptoms, should provide quick qualitative detection of nutritional deficiencies and must be verified through soil and leaf analysis. Constant exposure of workers to typical deficiency symptoms of coconut palms under field condition increases the accuracy of detection. In the country, this method is just used as a preliminary tool in fertiliser formulation.

Leaf Analysis (Foliar Diagnosis)

Knowing that leaf analysis has been used successfully to a great extent by IRHO in the Ivory Coast (West Africa), the Philippines started developing this

Table 40.10: Critical level of nutrients in plant-bearing stage (Frond 14)

	Macronutrients (%)								*Micronutrients (ppm)*			
	N	*P*	*K*	*Ca*	*Mg*	*Na*	*Cl*	*S*	*B*	*Fe*	*Mn*	*Zn*
Local Tall												
Fremond (1966) IRHO	1.8–2.0	0.12	0.80–1.0	0.50	0.20	0.40	0.50	0.15–0.20	—	50	60	60
Kanapathy (1971) Malaysia	1.8	0.12	0.80–1.10	0.30	0.30	—	—	—	—	50	60	60
Fremond (1975) IRHO	2.0	0.14	1.0	0.55	0.26	0.20	—	—	14	115	185	15
Magat (1979) Philippines	1.8	0.12	0.80	0.30	0.20	0.10	0.30–0.40	0.13	9–11	—	—	—
CRI SL* (1988) Sri Lanka	1.8–2.1	0.11–0.12	1.2–1.4	0.35–0.50	0.25–0.35	0.40	0.30–0.60	0.15–0.20	8	40–115	60–120	60
Chew (1982) – (dwarf) Malaysia	1.8–2.0	0.12	0.6–0.8	0.15–0.20	0.25	—	—	—	8	40–45 +	60 +	—
Hybrids												
Manciot *et al.* (1979) — IRHO	2.2	0.12	1.4	—	0.20	—	—	—				
Magat (1988) Philippines (optimum levels)	1.8–2.0	0.12–0.13	0.90–1.10	0.32–0.35	0.30–0.33	0.15–0.17	0.45–0.50	0.15–0.16				

* Coconut Research Institute of Sri Lanka (optimum levels).

method to formulate the fertiliser recommendations of coconut areas in the country (Magat, 1978). The nutrient demand of bearing coconuts and the critical levels of leaf nutrient concentrations (leaf 14) of tall varieties (Table 40.10) serve as guides in foliar diagnosis. For coconut hybrids, critical and optimum levels of leaf nutrients (Table 40.11) had been presented (Magat, 1978).

Table 40.11: Critical and optimum levels of leaf nutrients of coconut hybrids (leaf ranks 4, 9 and 14)

Leaf rank	*Leaf nutrient (%)*							
	N	*P*	*K*	*Ca*	*Mg*	*Na**	*Cl*	*S*
				Critical level				
4	1.95	0.13	1.70	0.35	0.25	0.30	0.65	0.17
9	1.80	0.12	1.00	0.34	0.30	0.20	0.55	0.15
14	1.80	0.12	0.90	0.32	0.30	0.15	0.45	0.15
				Optimum level				
4	2.20	0.15	1.90	0.41	0.29	0.37	0.74	0.19
9	2.00	0.13	1.17	0.38	0.33	0.25	0.60	0.17
14	2.00	0.13	1.10	0.35	0.33	0.17	0.52	0.16

*Considered normal level.

Rate and Source of Fertilisers

The inorganic and the organic forms of fertilisers may be applied singly or combined to coconut following the guide below (Table 40.12) as to the rate of desired nutrients, depending on the age or stage of the coconut palms. The most common fertiliser combination for coconut is $(NH_4)_2 SO_4$ + KCl. This combination supplies the four nutrients widely deficient in coconut soils namely, N, K, Cl and S. Several sources or forms of nutrients are available and the choice depends mainly on availability and economics.

Table 40.12: A guide on the rate of nutrients applied according to age of palm

Age	*Nutrient rate (g/palm)*					
	N	*K*	*Cl*	*P*	*Mg*	*S*
Field planting	30	75	66	13	30	18
6 mos	40	125	111	22	50	25
1 year	100	300	260	44	75	60
2 years	150	450	400	63	150	90
3 years	200	600	530	72	200	120
4 years	300	800	700	87	250	180
5 years and older	400	1000	900	131	300	240

Timing and Frequency of Application

At the pre-bearing age of one to three years the annual recommended dose of fertiliser is applied in split applications, the first half at the start of the rainy season and the remaining half, six months after or about a month before

the end of the rainy season. In areas with almost even distribution of rainfall throughout the year, the first half of fertiliser is applied anytime and the remaining half six months later.

For palms of bearing age, the annual rate of fertilisers are applied in one application for areas with an even rainfall distribution (one-and-a-half to three dry months) and split application for areas with distinct dry and rainy seasons.

Method of Fertiliser Application

Weeding is done first around the base of the palm, with a radius of 0.5 to 0.75 m for young palms and 1 to 1.5 m for bearing palms. Then, the recommended fertiliser or fertiliser combination is broadcast to each tree as uniformly as possible over the circle-weeded area. Finally, the broadcast fertiliser is incorporated (to a depth of 5 to 8 cm) with the use of a suitable digging tool. This is necessary for nitrogenous fertilisers (like ammonium sulphate) to minimise/eliminate possible losses through ammonia volatilisation.

For strongly sloping and hilly areas, fertilisers are equally distributed in 10 to 12 holes (10 to 12 cm deep and 7 to 10 cm wide) dug around the base of palm within 1 to 2 m radius.

Utilisation of Leaves and Husks as Fertiliser

It is known that one ha of coconuts (average of 150 palms) producing 12 to 14 leaves and 100 nuts/tree/year contains in the harvest the following amount of nutrients: 49 kg N, 7 kg P, 96 kg K, 5 kg Ca, 8 kg Mg, 11 kg Na, 64 kg Cl and 4 kg S. The husk contains 60 per cent of the K, 18 per cent of N and 26 per cent of Mg exported from the harvest.

Thus to reduce the rates of fertiliser application and cost by 20 to 30 per cent to maintain target yields, it is recommended that the farm wastes such as coconut husks and leaf fronds be left in the field to undergo nutrient leaching, decomposition and mineralisation with these nutrients becoming available for the crop eventually.

Present Fertiliser Practices

For normal and accelerated growth of seedlings and young plantings, two fertiliser combinations are being used $(NH_4)_2SO_4$ + KCl or $(NH_4)_2SO_4$ + NaCl (if soil is adequate in K) while for pre-bearing and bearing palms (yield of 2 to 5 tons copra depending on variety/hybrid) the same fertiliser combinations are also used, rates depending on the age of coconuts (Tables 40.13, 40.14).

Table 40.13: Fertilisers (per seedling) for nursery stage

Age (Month)	*Fertiliser combination (Quantity in g)*	
	$(NH_4)_2SO_4$ + KCl	*$(NH_4)_2SO_4$ + NaCl**
2	20 + 25	20 + 20
3	40 + 45	40 + 40

* Common salt.

Table 40.14: Fertiliser (per tree) from field planting to bearing stage

Age	*Fertiliser combination (Quantity in grams)*	
	$(NH_4)_2SO_4$ + KCl	*$(NH_4)_2SO_4$ + NaCl**
Coastal Coconut[1]		
Field planting	150 + 100	150 + 80
6 months	200 + 150	200 + 120
1 year	500 + 500	500 + 400
2 years	750 + 750	750 + 600
3 years	1000 + 1000	1000 + 800
4 years	1250 + 1250	1250 + 1000
5 years or older	1500 + 1500	1500 + 1200
Inland Coconut[2]		
Field planting	150 + 200	150 + 160
6 months	200 + 250	200 + 200
1 year	500 + 600	500 + 480
2 years	750 + 900	750 + 720
3 years	1000 + 1500	1000 + 1250
4 years	1250 + 1700	1250 + 1350
5 years or older	1500 + 2000	1500 + 1700

* common salt (for soils adequate in K).
[1] planted *within* 2 km from coastline.
[2] planted beyond 2 km from coastline.

FUTURE THRUST AREAS

Research Aspects to Increased Fertiliser Efficiency

1) Studies on fertilisation of coconut and intercrops, using improved planting materials (hybrids) and organic and chemical fertilisers.

2) Influence of moisture deficits (water stress) on mineral nutrition and fertiliser utilisation by crops.

3) Relationship of plant nutrition and disease/pest incidences.

4) Physiological role of important macronutrients and micronutrients.

5) Influence of soil physical properties on mineral nutrients.

6) Improvement of current methodologies on soil and leaf analysis.

Production Aspects to Increased Fertiliser Use

1) Strong linkage between research and extension workers, fertiliser manufacturers and mass media in promoting the use of fertilisers to increase yields.

2) Encouragement in the fertilisation of intercrops to increase yields of both intercrops and coconut.

Other Technical Considerations

1) Regular (at least every two years) working group meeting for technology/research updates and evaluation.

2) Joint meeting of related areas of concern as fertilisation, intercropping, crop protection and socio-economic groups for a meaningful interaction and maximisation of resources and outputs.

3) Exchange of expertise on research and extension/training through study/lecture tours and exchange visitor programmes on a short-term basis (three to six months).

4) Establishment of a workable information network system, covering basic computer facilities and software on fertilisation of coconut-based cropping systems.

Summary

Fertilizer/mineral nutrition studies in the Philippines revealed the following:

1) Coconut seedlings need chlorine and potassium for better growth and development.

2) KCl and NaCl are effective sources of chlorine and/or potassium for seedlings.

3) Young palms require N, K, Cl, S and Mg in some cases.

4) Bearing palms need Cl for high copra/nut and copra yield and N for more nut production.

5) KCl, NaCl and NH_4Cl are all effective sources of Cl for bearing palms.

6) The growth and yield of hybrids are significantly better under adequate nutrition or fertilisation across different agro-climatic conditions.

7) Chlorine minimises leaf spot diseases.

8) The nation-wide nutritional survey based on leaf analysis revealed that low coconut yields (less than 1 t copra/ha) in most areas are due to widespread deficiencies in N, Cl, S and K, with the identification of 10 distinct nutritional deficiency classes.

9) Studies and on-farm trials on fertiliser effects indicate that the nutritional deficiencies as diagnosed by foliar analysis can be effectively corrected using commonly available fertiliser sources, increasing yields to an average of 2 tons copra/ha/year.

10) Substantial research and exprience in the country provided the means in generating an average fertiliser recommendation for the country according to age, distance from coastal areas and soil K status.

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COCONUT NUTRITION: EXPERIENCES IN SRI LANKA

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ABSTRACT

The Coconut Research Institute of Sri Lanka, commenced field and laboratory studies from 1933 on various aspects of the nutritional requirements of coconut. Studies on balanced nutrition, time and placement of fertilisers, different sources of fertiliser nutrients and their efficient utilisation, diagnostic aspects (soil, leaf and nut water analysis) as complementary tools in nutritional studies have been conducted.

Much attention is presently given to the use of organics and a discriminatory approach to fertiliser recommendations. This paper highlights the changes in fertiliser recommendations leading to the current practices in the industry. Future studies will be devoted to placing soil analysis on firmer grounds; nutrition of coconut under multiple cropping systems and drought situations.

INTRODUCTION

The Coconut has been cultivated for centuries in Sri Lanka but the use of scientific cultural practices came into place only after 1930 with the establishment of the Coconut Research Institute. Considerable amount of research has been undertaken in the field of soil fertility, principally, the study relating fertiliser inputs in relation to yield. Incontrovertible evidence has now been gathered from these field experiments to show that the coconut palm responds favourably to fertiliser application under various soil and agroclimatic conditions.

Agroclimatic Zones and the Soil Types

In Sri Lanka coconut is cultivated in a wide range of soil types of agroclimates. In the dry zone (DZ: unimodal rainfall with less than 1000 mm), coconut soils are mainly coastal sands-sandy regosols (Entisols), whereas in the wet zone (WZ: bimodal rainfall in excess of 1875 mm), the soils are largely

lateritic soils, lateritic soils with plinthite (Ultisols) and red yellow podsolic soils. These two groups of soils are poor in fertility status and subject to heavy leaching.

In contrast, the soils which fall into the intermediate zone (IZ: rainfall between 1000 and 1875 mm), consists in addition to the sandy regosols and red yellow podsolic soils (RYP), a limited area of deep loamy soils (regosols and RYP without plinthite). These loamy soils offer ideal conditions for the growth of the palms. There are very deep, well-drained sandy loam soils, with a fair proportion of clay and organic matter, ideal for coconut. Two other soils, the alluvial soils (Entisols) of variable drainage found close to rivers and rivulets are fertile soils but in some locations are too clayey and heavy for coconut; and the gravelly soils-reddish brown earths (Alfisols) which contain less gravel than the degraded lateritic soils are more fertile but physical conditions can be an impediment.

Nutrient Responses and Fertiliser Recommendations

Results of series of investigations in varied soil type and agroclimatic regions have revealed that in the majority of coconut soils, nitrogen, phosphorus and potassium are deficient besides magnesium deficiency which is also widespread.

Results of the field studies have clearly demonstrated the need for a balanced NPKMg fertiliser mixture for the healthy growth and high yields of young palms, which improves vegetative growth and promotes early bearing. Young palms require a greater proportion of N and P and less K than adult palms. The adult palms have shown striking yield responses for NPK mixtures and Mg as well.

Fertiliser for Young Palms

The recommendations for young palms are based on three field experiments from seedling stage: (1) at Letchemy Estate, Nattandiya (regosols, IZ) (1940); (2) at Ratmalagara Estate, Madampe (RYP; IZ) (1948), and (3) on virgin jungle clearing at Pothukulama Research Station, Pallama (regosols, IZ) (1961).

At Nattandiya (1), palms receiving the complete NPK treatment gave 65 nuts/palm in the fifteenth year, while the untreated palms gave 38 nuts/palm. When fertilisers were restored to the untreated palms from the fifteenth year onwards, the difference in yield between the two groups of palms persisted (Loganathan, 1977) demonstrating unequivocally that neglect at the seedling stage can have a very damaging effect on future production.

The experiment at Madampe (2) showed that P caused early flowering, 70 per cent of the palms flowered in seven years compared to 26 per cent without P (Salgado, 1956). From the thirteenth to the sixteenth year, palms receiving complete NPK fertilisers from the time of field planting, gave a yield of 21.3 kg copra, compared to 8.7 kg/palm/year, that is, about 150 per cent increase in yield (Loganathan and Balakrishnamurti, 1976).

At Pallama (3), about 75 per cent of the young palms treated with complete NPK mixture were in flower at the end of the fifth year, in comparison with 30 per cent of untreated palms (Salgado, 1956). The current recommendations for young palms are based on the findings of these experiments.

Fertiliser for Adult Palms

The first statistically designed fertiliser field experiment on coconut in 1934 (Salgado, 1948; Eden *et al.,* 1963) was conducted at Bandirippuwa Estate, Lunuwila. The sandy loam (overlying lateritic gravel: semi-wet zone) is the typical soil type of a large proportion of the coconut growing area of the north-western province of Sri Lanka.

Under these conditions K proved to be the most important nutrient. The effect on nut number and copra was highly significant for the two levels tested.

Year	Increase (kg/ha)	
	0.28 kg K/palm	0.56 kg K/palm
1936	29	56
1939	31	134
1951	744	947

The same experiment showed that K improved the copra out-turn of the nuts, less nuts for a candy (254 kg).

Treatments	Nuts/candy
Control	1281
0.28 kg	1164
0.56 kg	1140

Based on the very early results of this experiment, the first fertiliser mixture was formulated in 1939 (Salgado, 1939).

Sulphate of ammonia	1.362 kg
Saphos phosphate	0.908 kg
Muriate of potash	0.908 kg
Total (applied biennially)	3.178 kg

From 1939, two experiments were conducted at Kumbaloluwa Estate, Veyangoda and Eddunkelle Estate, Ahangama of the western and southern provinces where lateritic soils (WZ) form the dominant soil type.

Significant findings from these two experiments were: (a) early response was obtained unlike at Bandirippuwa Estate; (b) yield increases from 110 per cent in the second year to almost 145 per cent in the third at Ahangama, and at Veyangoda still higher; (c) P at the low dosage of 0.119 kg/palm/year gave dramatic responses in these soils and became a limiting factor to the response N and K in combination; (d) differences in the inherent fertility of the two soils continued to be maintained, in spite of fertiliser application; and (e) in the fifth year gave 1227 kg copra/ha yield at Ahangama as against 720 kg at Veyangoda in the NPK treated plots.

With the available data from Ahangama (up to 1950) and Veyangoda (up to 1948) and the ongoing major experiment at Lunuwila, Salgado in 1951 for the first time recommended fertiliser mixtures based on soil type (Table 41.1). In the three experiments so far conducted, the levels tested were low and the recommended fertiliser dosages were also low, applied biennially.

Table 41.1: Fertiliser recommendation for adult coconut in Sri Lanka (Salgado, 1951)

Soil type	*Formulations (kg/palm/year)*							
	Sulphate of ammonia (20.6% N)		*Saphos phosphate (27.5% P_2O_5)*		*Muriate of potash (60% K_2O)*		*Total*	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
Cinnamon sands and coarse marine sands; Laterites	0.79	0.68	0.68	0.56	0.68	0.56	2.14	1.80
Loam and sandy loams	0.68	0.56	0.56	0.45	0.56	0.45	1.80	1.46
Clay soils	0.68	0.56	0.56	0.45	0.45	0.34	1.69	1.35
Lateritic gravels	0.68	0.56	0.68	0.56	0.68	0.56	2.03	1.69

(a) Estates — neglected.
(b) Estates — regularly manured.

Field experiments established in comparatively richer soils of the island, at Madampe and Nattandiya (referred under young palms) and Marandawila Estate, Bingiriya (sandy loam, IZ) gave significant increases in yield for NPK fertilisers. The responses from these experiments indicated that higher dosages would bring further increases in crop yield and this formed the basis for the third revision on fertiliser in 1960, at the increased rate of 3.2 to 3.6 kg/palm/year (Table 41.2) (Nethsinghe, 1960).

Table 41.2: Fertiliser recommendation for adult coconut in Sri Lanka (Nethsinghe, 1960)

Soil Type	*Formulations (kg/palm/year)*			
	Sulphate of ammonia	*Saphos phosphate*	*Muriate of potash*	*Total*
Cinnamon sands and coastal marine sands; Laterites and lateritic gravels of southern and western provinces.	1.125	1.125	1.350	3.60
Lateritic loams of southern and western provinces	1.287	1.031	1.287	3.60
Lateritic gravels and lateritic loams of north-western province	1.125	0.900	1.125	3.15
Non-lateritic reddish brown loams and sandy loams	0.900	0.900	0.900	2.70
Matuarine clay soils	0.599	0.599	0.599	1.80

In the second experiment carried out at Bandirippuwa Estate, Lunuwila in 1960 where higher levels of fertiliser was tested, significant yield responses to 2.04 kg sulphate of ammonia (SA)/palm/year, was obtained and the same was

observed at Madampe. The latter also showed that with phosphorus deficient soil, the best performance was observed with 0.68 kg saphos phosphate (SP.) Based on these findings the fourth revision was effected in 1967 with the rates of application for maximum production increasing from 1.8 to 3.6 kg to 3.6 to 4.5 kg/palm/year (Table 41.3) (de Silva, 1967).

Table 41.3: Fertiliser recommendation for adult coconut in Sri Lanka (de Silva, 1967)

Soil Type	*Formulations (kg/palm/year)*			
	Sulphate of ammonia	*Saphos phosphate*	*Muriate of potash*	*Total*
Cinnamon sands and coastal sands; Lateritic loams and lateritic gravels of wet zone	2.250	0.900	1.350	4.50
Lateritic loams and lateritic gravels of intermediate zone	2.025	0.900	1.125	4.05
Deep reddish brown loams and sandy loams; Deep alluvial loams and estuarine and lagoon clay soils	1.800	0.900	0.900	3.60

Loganathan and Balakrishnamurti (1979) analysing the long-term experiment at Naiwala Estate, Veyangoda showed that palms responded to levels as high as 1.8 kg of muriate of potash (MOP)/palm/year in most of the years of the experimentation, and at Madampe which had a similar soil type as at Lunuwila and Veyangoda, the maximum yield was reached at 2.1 kg MOP; supporting evidence for an increase of K in mixtures. Both the Veyangoda and Ratmalagara experiments point to a reduction of SA to about 1.5 kg/palm/year.

Based on the results of the three long-term experiments at Lunuwila, Madampe and Veyangoda, the 1967 recommendation was changed to two mixtures (Table 41.4) (Loganathan, 1977, 1978). The current recommendation is a rationalisation of the 1979 recommendations to a single adult palm mixture (APM), with appropriate changes in dosages for soil types and agroclimates.

Magnesium in Coconut Nutrition

The observation trials at Mattegoda Estate (Polagasowita) and at Walgama Estate (Pannipitiya) showed marked improvement in yields when treated with Mg sources (Table 41.5 and 41.6) (Nethsinghe, 1961).

Three statistically designed field studies on Mg nutrition of coconut were commenced in 1967 and 1972: (i) 5^4 NPKMg experiment on adult palm at Marandawila Estate (Bingiriya) deep sandy loam soil; Semi-DZ and at Monrovia Estate (Ratgama–lateritic gravelly soil; WZ). (ii) A 4×3×3 experiment on young seedlings at Lunuwila (sandy soil; IZ), with the primary objective to determine effect of Mg on growth, flowering and initial yield of four different categories of seedlings (T×D, D×T, T×T and open-pollinated talls). In the

experiment at Bingiriya, the main effect of Mg for five years, was not statistically significant, however the response to Mg in the years of high copra yield showed a better performance — 1.362 kg kieserite increased the copra yield by 143 kg/ha (average of five years) and by 227 kg/ha (average of three good years, 1974 to 1976). (This was in the semi-dry zone, where the response to Mg is not expected to be high (Table 41.7).

Table 41.4: Fertiliser recommendation for adult coconut in Sri Lanka (Loganathan, 1977; 1979)

Soil Type and Climate	*Formulations (kg/palm/year)*			
	Sulphate of ammonia	*Saphos phosphate*	*Muriate of potash*	*Total*
1. a. Lateritic loams and lateritic gravels (boralu or cabook soils) of the wet zone b. Lateritic loams and lateritic gravels of the intermediate rainfall zone c. Cinnamon sands, coastal marine sands and lagoon sand deposits and the sandy soils of the southern coastal belts	1.5	0.7	1.6	3.8
2. a. Deep reddish brown loams, sandy loams and clay soils in the intermediate and dry zones b. Limestone derived chocolate brown loams soils c. Deep alluvial loams in valley and flood plains of rivers and estuarine and lagoon clay soils	1.1	0.6	0.9	2.6
3. Coastal marine sands and lagoon sandy deposits	1.3	0.3	1.1	2.7

Table 41.5: Mg sources and yield of palms (40 palms–Mattegoda estate, Nethsinghe, 1961)

Treatment	*Yellow palms*		*Green palms*	
	1957	*1960*	*1957*	*1960*
Control	1459	1254	—	—
2.3 kg NPK only	1506	1447	2419	2520
2.3 kg NPK + 0.45 kg $MgSO_4$	1522	1796	—	—
2.3 kg NPK + 0.45 kg dolomite	1583	1764	—	—

Table 41.6: Effect of Mg on yield of palms (10 palms – Walgama estate, Nethsinghe, 1961)

Treatment	*Yellow palms*		*Green palms*	
	1957	*1960*	*1957*	*1960*
Control	186	138	355	259
NPK only	191	164	348	352
NPK + 0.45 kg $MgSO_4$	225	222	423	458
NPK + 0.90 kg $MgSO_4$	224	327	500	538
NPK + 1.35 kg $MgSO_4$	200	274	428	473

Table 41.7: Effect of magnesium on copra yield at Bingiriya.
Average of five years (1974–78) and average of three good years (Loganathan, 1978)

Kieserite (kg/palm/year)	*kg copra/ha*		*Response (kg/ha)*	
	Av. 5 years	*Av. 74,75,78*	*Av. 5 years*	*Av. 74,75,78*
0	2186	2298	–	–
0.681	2281	2442	95	144
1.362	2329	2525	143	227
2.043	2331	2549	145	251
2.724	2285	2513	99	215

The experiment at Ratgama was abandoned after 1973 but the results up to that year showed promise (Table 41.8). At Lunuwila in a sandy soil, the addition of kieserite along with NPK treatment had a significant effect on the number of new leaves of young palms which is very closely related to the productivity of coconut palms.

Table 41.8: Effect of Mg on copra yield at Rathgama (Loganathan, 1972 and 1973)

Kieserite (kg/palm/year)	*kg copra/ha*		*Response (kg/ha)*	
	1972	*1973*	*1972*	*1973*
0	1814	1414	–	–
0.681	1891	1593	77	179
1.362	1960	1703	146	289
2.043	2020	1743	206	329
2.724	2072	1713	258	299

At the conclusion of the experiment in 1983, the yield in terms of nuts and copra showed a significant linear response to Mg, but not for the in between classes of palms (Table 41.9). The results point to the necessity of incorporating Mg into the fertiliser mixtures for annual application.

Table 41.9: Influence of Kieserite on yield of young palms, Lunuwila (160 palms/ha) (Jeganathan, 1983)

Kieserite g/palm/year	*D × T*	*T × D*	*T × T*	*OP*	*Mean*	*Response nuts/ha*
			Nuts/ha/year			
0	4915	5502	3324	3747	4372	–
290	8920	4382	4955	5884	6035	1663
580	10124	7582	6000	5835	7385	3013
			Copra-kg/ha/year			Copra/ha
0	1007	1114	670	817	902	–
290	1930	976	1177	959	1260	358
580	1561	1484	1329	1332	1426	524

Urea in the NPK Mixture

In 1975, urea was introduced as a source of nitrogen in the fertiliser mixtures, as preparations were underway to manufacture urea in Sri Lanka.

Experiments conducted on the comparison of urea and SA on the performance of palms have shown that there was no significant difference between the two sources of nitrogen. The first experiment on sources of nitrogen (SA and urea) and frequencies of manuring was commenced in 1967 at Mawatte Estate, Dankotuwa (lateritic gravel; IZ) (Table 41.10). The results indicated that SA performed better than urea, although not statistically significant.

Table 41.10: Copra yield under sources of nitrogen (Loganathan, 1974)

Treatment	*Annual Application*		*Biennial Application*	
	kg/copra/ha	*%*	*kg copra/ha*	*%*
Control	1003	100	1003	100
Ammonium sulphate	1116	111.3	1120	111.7
Urea	1060	105.7	1042	103.9

Examination of the copra for 'rubberiness' showed that absence of sulphur in the treatment had not affected the quality of copra. The experiment at Pallama (sandy loam; IZ), gave a cumulative yield of copra (10 years) that showed a definite bias for SA, in combination with either saphos phosphate or triple superphosphate, (Table 41.11). The superior performance of SA on yield may be due to a higher availability of N compared to urea.

However, no difference in leaf sulphur content was evident, whatever be the source of nitrogen. The lack of response to sulphur despite its low content (4.3 ppm available SO_4-S) in the soil is quite surprising. It appears that contribution from precipitation in the coconut growing regions ranging between 12.2 and 28.5 kg of S/ha/year meets with the crops requirement (Dias, 1988; Amarasiri, 1987).

Table 41.11: Effect of sulphate of ammonia and urea on yield of copra and sulphur content in leaf, Pallama (Dias, 1985)

Treatment	*Copra yield** *kg/ha*	*Sulphur in leaf* *ppm*
Control	17398	159
SA + SP	24706	166
SA + TSP	31971	162
U + SP	22061	160
U + TSP	19003	156

SA—Ammonium sulphate, U—Urea, SP—Saphos phosphate, TSP—Triple superphosphate.
Rate of N = 150 kg/ha/year.
*Yield for 10 years.

The third experiment at Mannakulame Estate, Kakkapaliya (sandy soil; IZ) comparing three sources of nitrogen (SA, urea and ammonium chloride) showed significant linear and quadratic responses to nitrogen but no differences between the three sources. Over the years, however, SA performed better. This fact requires further elucidation.

Nutrient Requirements of Improved Cultivars (HYV)

In the recent past improved cultivars CRI 60 (T × T) and CRI 65 (D × T), with yield potentials of 100 nuts/palm/year (220 g copra/nut) and 120 nuts/palm/year (210 to 215 g copra/nut) respectively were introduced. These hybrids, particularly CRI 65 were superior to the local talls, both in precocity and production.

A nutrient balance approach, estimating the nutrients lost annually to the soil in the nuts and fronds, removed from a single palm for the two cultivars, was done. The computation was based on the nutrient values obtained for the typica-talls and the T × D hybrids (Jeganathan, 1974), on the assumption that the nutritional requirements for the corresponding new cultivars are the same (Table 41.12). From the data it is apparent that if the potential for the CRI 65 is to be exploited then the requirements of both N and K are insufficient and Mg grossly inadequate, by current recommendations.

Even for the typica, at 60 nuts/palm/year and 12 fronds, the quantity of Mg removed (0.054 kg) was not compensated from dolomite additions (0.06 kg). Hence the widespread occurrence of Mg deficiency.

Thus, there is need to initiate new field studies on these cultivars. Current recommendations are rationalisations from both the YPM and APM mixtures — one-and-a-half times the dosage. Future fertiliser recommendations, either for the typica or the new cultivars must include Mg with NPK.

Use of Organic Manures in Coconut

Experiments conducted at Lunuwila and Bingiriya on the comparison of organics with inorganics for adult palms showed that there was no significant difference between the two forms (Balakrishnamurti, 1975). As organics

contain low amount of plant nutrients, comparatively larger quantities of these fertilisers are needed. Unless the organic material is in close proximity to the holdings, the price factor for both quantities and transport can be discouraging. However, promising results are forthcoming from the use of green manures produced *in situ*. With the escalating price of imported fertilisers, the use of organics is becoming inevitable. Much work is in progress in the field of organics, including microbiological studies.

Table 41.12: Estimate of macronutrient lost to the soil annually from a single palm

	N	*P*	*K*	*Ca*	*Mg*
	kg				
CRI 65					
Potential					
120 nuts	0.416	0.061	0.914	0.071	0.068
12 fronds	0.143	0.014	0.118	0.021	0.093
Total removed	0.559	0.075	1.032	0.092	0.161
CRI 60					
Potential					
100 nuts	0.334	0.036	0.665	0.042	0.031
12 fronds	0.098	0.007	0.027	0.013	0.035
Total removed	0.432	0.041	0.692	0.055	0.066
Nutrients supplied from 4.5 kg APM mixture and 1.2 kg Dolomite applied annually	0.56	0.11	1.20	0.51	0.145

Diagnostic Systems — Soil Testing and Plant Analysis

Much progress has been made in the use of leaf analysis, both for diagnostic and predictive purposes. Basic information, for the use of leaf analysis, like the most suitable leaf for sampling, time of sampling (diurnal and seasonal), the sample size, has been worked out for the conditions prevailing in Sri Lanka (Jeganathan, 1976; 1981; Jeganathan *et al.*, 1976; de Silva *et al.*, 1977). Loganathan and Atputharajah (1986), and Loganathan and Balakrishnamurti (1979) from calibration studies of the long-term experiments at Madampe, Pallama and Veyangoda obtained sufficiency values for the major nutrients, in the fourteenth leaf:

N	P	K	Ca	Mg	Cl
1.9–2.1	0.11–0.13	1.2–1.5	0.35–0.53	0.25–3.0	0.30–0.40

The above findings are being gainfully used in the nutrient survey studies and in the discriminatory approach to fertiliser recommendations to the industry (Jayasekara — personal communication).

A more interesting and challenging prospect is the use of coconut water as a diagnostic tool for studies in coconut nutrition. In the early field experimental studies at Lunuwila and Madampe, soil analysis satisfactorily explained the high responses to K application in the latter (0.017 K m.e. per cent) compared

to the former (0.17 K m.e. per cent). However, traditional methods for assessing soil P failed to interpret the response to P, at the low order of availability. Nut water analysis, however, proved a better guide in interpreting the different response patterns to K and P fertilisers at Lunuwila and Madampe (Salgado, 1954).

Comparing leaf and nut water analysis from the field studies on K-Mg interaction, there was sufficient evidence from the response patterns to indicate that nut water analysis can be used as an additional tool in the interpretation of field experimental data for Na, K, Mg and Cl (Jeganathan, 1990).

Ease of sampling, minimum sampling error, limited preparative phase in analysis are positive features in its favour. The development of instrumentation, especially flame emission and absorption, makes direct estimation of cations, on the diluted samples of nut water, an added advantage. P, S and Cl are estimated by colorimetry, turbidimetry and coulometry, respectively. However, N still remains elusive.

Soil analysis, like leaf analysis, has many fundamental problems to be resolved, like time of sampling, depth and distance of sampling, sampling intensity and size of sample, extraction procedures and calibration studies.

It was noted earlier that 0.17 m.e. per cent of potassium at Lunuwila caused no response to potassium application, indicating sufficiency. In a similar soil type (lateritic gravel) at Veyangoda, in spite of the high exch. potassium (0.28 m.e. per cent) in the soil, the palms responded to potassium. At Veyangoda, the soil being gravelly and shallow, the total quantity of available potassium in the entire root zone was low, even though exch. K was high. So depth and volume of soil can be a conditioning factors in the interpretation of data (Loganathan and Balakrishnamurti, 1979).

With phosphorus, which generally accumulates on the surface soils, critical concentration can be easily resolved. In the experiment at Pallama, the lack of response to phosphorus was due to the adequate availability of P (Olson's extractable P) at 8.8 ppm as opposed to 4.6 ppm at Madampe. Thus a critical value of 9 ppm for soil P was established (Nethsinghe, 1965a).

Studies on establishing critical values for exch. Mg failed to show any differences between soil samples taken from areas of the same plantation showing Mg deficiency in the palm, as against areas which showed healthy green palms. Therefore, exch. Mg in the soils was not a suitable criterion for assessing Mg availability. The Mg content in 10^{-2} molar $CaCl_2$ gave a positive correlation with leaf Mg ($r = 0.48$) (Nethsinghe, 1965b).

The samples indicate the difficulties encountered in establishing soil critical values and the caution in interpretation. The other inherent weakness with plantation crops, like coconut is the extent covered, and the concomitant soil variation. A sampling exercise for advisory purposes showed wide variations, with respect to samples collected from both the manure circle and centre of squares, and the two depths sampled (Jeganathan, 1985).

Using soil analysis for interpreting field experiments and in developing critical values is in itself a daunting task, but the more difficult part is their use

for diagnostic purposes in the field. Unless and until these problems are overcome, and costs minimised, the use of soil testing as a routine measure is hazardous.

Future Needs

From the point of view of soils, soil minerological studies need closer attention. The coconut sector covers such a vast area that diversities in both distribution and mineral composition do exist. Understanding clay minerology and release mechanisms, particularly for K and Mg, are important as they have become problem areas in the nutrition of the crop.

Sampling systems in soils have to be established for proper evaluation of soil fertility and re-examined regularly, for the realities that fertiliser usage will continue to change and with it the variability patterns for proper assessment. Research on extractants and extraction procedures needs to be undertaken for specific environment, the choice for one element and multi-nutrient extraction has to be made, as these systems have their advantages and disadvantages.

Intensification of research efforts in nutrition under stress and drought conditions, is of paramount importance as this has become a very regular phenomenon causing drastic drops in production.

With the introduction of intercropping, multiple cropping and biofarming and the need to minimise on inorganic supplementation, future success on maintaining soil fertility will depend on the judicious use of organics and inorganics. Much work has already gone into the use of leguminous cover crops as sources of N. Intensive microbiological studies have to be conducted on rates of decomposition, transformation and release of nutrients under the various systems envisaged. Modelling soil organic matter levels, after long-term application of crop residues, and farmyard and green manures by computer simulation models and validation are worth the exercise.

If in the course of time, integrated approach to crop nutrition is our goal, we must then give serious consideration to the use of soil testing and leaf analysis for 'diagnostic' purposes, as opposed to 'predictive' use. These tools presently used for fertiliser adjustments, needless to state, are based on the use of inorganics.

With such a complex mix under coconut, our whole approach to experimentation and interpretation has to be revolutionalised.

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COCONUT NUTRITION : IRHO EXPERIENCE IN DIFFERENT COUNTRIES

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ABSTRACT

Since 1970, research has been directed towards the mineral nutrition of hybrids, particularly the PB 121 (MYD × WAT). Like tall coconuts, hybrids adapt very well to the low natural fertility level, provided they are given appropriate fertilisers.

Mineral exports by hybrids were substantial, in line with the exceptional productivity of hybrids, though, they are about the same as for tall coconuts if considered per ton of copra. The husk is responsible for most of the exports with 67 per cent of the potassium and 85 per cent of the chlorides. Dehusking in the field makes for considerable input savings, especially if potassium deficiency is predominant, particularly as it is more effectively corrected by fertilisation.

Responses to fertilisation vary considerably and are presented in the form of a few nutritional complexes, with a particular reminder of the importance of chlorides in nutrition. Fertilisation operations are governed by leaf analyses, which prove to be very accurate with coconut. Research should continue to work on long-term fertility conservation, and concurrently, on regeneration techniques.

Coconut-based intercropping also merits efforts from research in the future with particular emphasis on more fundamental studies of competition phenomena between root systems within the intercropping system. To conclude, mention is made of the merits of research on planting material variability and mineral nutrition with a view to defining specific fertilisation, and perhaps, discovering more economic ecotypes or hybrids.

INTRODUCTION

At the outset, research was conducted in Africa, primarily in the Ivory Coast, on the West African Tall (WAT). The advent of hybrid varieties, notably PB 121 which was the first hybrid to be confirmed and extended from 1970

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onwards in the Ivory Coast and throughout the world, changed development prospects, since PB 121 is both higher yielding and more precocious than all the tall varieties. Many producer countries have adopted it to renew and extend very old coconut groves from which most of their production still comes. It was therefore necessary for research to enhance its knowledge of this new planting material, whilst also studying other types of hybrids which are gradually completing and diversifying the range of available material. The first commercial PB 121 plantations, set up in the Ivory Coast, were therefore accompanied by the introduction of an experimental design based on fertiliser experiments and studies of mineral immobilisation and exports by the hybrid. This research was subsequently extended to other producer countries, particularly Indonesia, the Philippines and, more recently, Brazil.

SOILS SUITABLE FOR COCONUT

Like all other crops, coconut palms need a good physical medium and regular and appropriate supplies of nutrients and water, but they adapt very well to the natural low level of fertility in the desaturated ferralitic soils usually found in the areas where they are grown. They are even capable of using the very poor sandy soils along coastal strips and give excellent results provided they receive adequate fertilisation. On the other hand, they are also capable of producing excellent yields in the most clayey soils. They adapt to very acid soils, such as peat soils, or even very alkaline soils such as the coral soils in the Pacific. In both cases there are trace element deficiency problems which can be overcome.

Soil depth, in relation to water supply, plays a major role in crop performance. In a deep, mellow soil, even if it is very impoverished and very sandy, coconut palms can take root down to 4 m, thereby gaining access to substantial water reserves, or even the upper capillary fringe of a very deep water table (Pomier and Bonneau, 1987). This ability enables them to survive and even produce substantial yields in very dry regions such as of Mozambique, and achieve very high yields in the tertiary and quaternary sands in the Ivory Coast, with water deficits of between 400 and 800 mm per year (de Taffin *et al.*, 1991).

Soil fertility also plays a determining role in crop performance, though to a lesser degree, since highly cost-effective mineral deficiency correction is possible in most cases through fertiliser applications. Nevertheless, there are limits that cannot be exceeded. This is the case with certain soils degraded by overcropping in regions with a high population density. For example, in the Ivory Coast the soils in certain old coconut groves along the coastal strip have been overworked, with total removal of the husks, leaves and plant waste provided by the vegetation, resulting in a drop in topsoil organic matter content from 3 per cent under the original forest to less than 0.5 per cent. Experimental attempts to replant failed, as even the high mineral fertiliser rates used at the time were unable to correct the deficiencies (especially nitrogen) completely. It was impossible to obtain over 1.5 tons of copra with hybrid material under conditions where cost-effectiveness was marginal and

which were, in any case, incompatible with the investment possibilities of the small holders involved. Using conventional legume cover crops was also impossible, since they would have been unable to establish themselves in such an environment (Pomier *et al.*, 1986). Research was therefore directed towards other solutions, notably the use of bushy legumes for regeneration of these very impoverished soils. The first adaptation trials showed the excellent performance of two *Acacia* species, with their young tap root system, and of *Albizia*. Indeed these plants revealed a good striking rate, rapid growth and a good nodulation ability. They also showed that they were able to provide a substantial amount of firewood for domestic use, which had become scarce and expensive in sectors with a high population density. Thus, an experiment, PB CC 46, was set up in 1986 on land belonging to a few volunteer smallholders, to study and compare the performance under replanting conditions of the PB 121 hybrid and these three legumes grown separately (with or without urea applications for coconut), or intercropped (every third coconut row replaced by two legume rows). It was soon discovered that *A. falcataria* could not withstand sea spray and was replaced by Filao (*Casuarina equisetifolia*), which, though not a legume, is capable of nodulation and atmospheric nitrogen fixation. An effect of these intercropped legumes on coconut N content was seen for the first time in February 1991 (fifth year) (Table 42.1).

Table 42.1: PB CC 46 Effect of intercropped legumes on the N contents (Frond 14) of PB 121 coconuts

Treatments	*Nitrogen %*
Grown alone	1.79
Casuarina	2.11
A. mangium	2.17
A. auriculiformis	2.24

NUTRITIONAL REQUIREMENTS AND NUTRIENT UPTAKE IN RELATION TO PRODUCTIVITY, WITH SPECIAL EMPHASIS ON HYBRIDS

Mineral Exports According to Planting Material

Samples taken from coconuts have long been assessed by different authors working on various tall coconut ecotypes. Results vary considerably from one study to the next, while the basis for the assessment carried out is not always very clearly stated (planting material, planting density, fertilisers, production, sampling method). Pillai and Davis (1963) published a precise and complete study on the talls of the west coast of India, planted at 70 trees per acre (173 trees/ha) and producing 40 nuts per tree, that is, 6,920 nuts per ha and approximately 1,500 kg of copra/ha/year.

No information of such study on hybrid material was made up to 1970. It was therefore necessary to measure the mineral exports by PB 121 (MYD × WAT) planted on a large scale in the Ivory Coast—the material which was much higher yielding than all the tall varieties.

The study began in 1975 at the Marc Delorme Coconut Research Station at Port Bouet, on the oldest PB 121 plot planted in 1963. Mineral exports were thus measured on 12-year old trees producing the equivalent of 6,700 kg of copra/ha/year (Ouvrier and Ochs, 1978). The raw results for the amounts of nutrients exported by nut harvests, without taking leaves or immobilisation in the stem into account, are shown in Table 42.2, compared to those measured by Pillai and Davis in 1963. It can be seen, of course, that mineral exports by the hybrids are considerable, in line with their exceptional productivity, though they are about the same as those for the tall coconut if considered for 1 ton of copra (Table 42.2). The results of a similar study carried out on tall varieties in Nigeria led to much higher values for nitrogen and potassium: 33 and 69 kg per ton of copra respectively. Potassium and chlorides dominate, which partly explains the importance of these nutrients in coconut mineral nutrition. They are closely followed by nitrogen. The other major nutrients, such as phosphorous, calcium, magnesium, sodium and sulphur are quantitatively much more modest, which in no way detracts from their qualitative importance.

Table 42.2: Mineral exports by PB 121 hybrid coconuts in the Ivory Coast and by the tall coconut (west coast of India — excluding stems and leaves)

Element	*PB 121 (6,700 kg copra/ha)*	*West Coast of India tall variety (1,500 kg copra/ha)*
a : In kg/ha/year		
N	108	28.4
P	15	5.9
K	193	54.6
Ca	9	7.8
Mg	15	1.6
Na	20	–
Cl	125	–
S	9	–
b : In kg/ton of copra		
N	16.1	18.9
P	2.2	3.9
K	28.8	36.4
Ca	1.3	5.2
Mg	2.2	1.1

Mineral Exports Depending on the Crop Management Method

The husk is responsible for the greatest proportion of exports: 67 per cent of potassium, 85 per cent of chlorides. This is a clear indication of the mineral savings made in a farming system that avoids husk removal (especially given the mineralisation of nitrogen), which means that their return to the soil is extremely rapid under the usual dehusking conditions in the field Ouvrier and de Taffin, 1985).

The exports accounted for so far do not take into account immobilisation in the leaves, roots or stem. Eventually, under normal, prudent cropping

conditions, the mineral elements contained in the leaves and roots return to the soil at more or less short intervals, in the same way as husk minerals when husks are not removed. These mineral elements are therefore continuously recycled and should not be included when taking stock of long-term fertility. This is not the case with the stem, as immobilisation is of very long duration: 40 to 60 years, with very frequent final utilisation for various purposes. However, there are regions with a high population density, where all coconut plant debris are removed, notably for firewood purposes. In this case, mineral removal from soil is much greater than for dehusked nut exports. Other studies carried out at Port Bouet by the same team make it possible to calculate such end-results: the situation is monitored by regularly dissecting young PB 121 coconuts planted at 160 trees/ha, measuring biomass evaluation in all the organs, and its mineralisation from planting up to 89 months (Ouvrier, 1984; 1990). This can be done between the fifth and the sixth year (third production year), as this is an age where the coconut can be considered to be functioning stably. It is therefore possible to calculate, very approximately, the mean annual mineral exports of a coconut hybrid stand for different crop management methods (Table 42.3). It can be seen that minimum exports (stem + dehusked nuts) only amount to 129 kg/ha/year for nitrogen, 109 kg for potassium and 40 kg for chlorine, merely to mention the most substantial. If husks are exported, the removal from soil are multiplied by:

a) If husks are exported	b) If dry leaves are exported
1.2 for N	1.7 for N
2.4 for K	2.9 for K
3.4 for Cl	5.0 for Cl.

Nitrogen dominates in mineral exports, but this nutrient is easily exceeded by potassium when husks are removed, which confirms the results obtained in the study conducted on 12-year old coconuts (Table 42.2). However, it should be noted that exports by six-year old coconuts are virtually the same as those by 12-year old coconuts for lower copra yields (5 t rather than 6.7 t). This difference may be due to age, but also to mineral nutrition conditions, which are probably not exactly the same at the two sites.

Table 42.3: Mineral exports by young PB 121 hybrids, in kg of nutrients/ha/year for a yield of 5 t of copra

Particulars	*N*	*P*	*K*	*Ca*	*Mg*	*Na*	*Cl*	*S*
Stem (immobilisation)	48	6	54	11	9	5	28	2
Dehusked nuts	81 (129)	12 (18)	55 (109)	2 (13)	7 (16)	1 (6)	12 (40)	6 (8)
Husks	26 (155)	4 (22)	150 (259)	11 (24)	11 (27)	10 (16)	94 (134)	3 (11)
Leaf removal	69 (224)	15 (37)	60 (319)	72 (96)	31 (58)	21 (37)	64 (198)	10 (21)

Figures in parentheses indicate cumulated values.

Mineral Exports Depending on Nutrition Level

What might be the effect of soil fertility and fertilisation on mineral exports by hybrids ? To reply to this question, research has been directed

towards estimating exports based on the treatments in fertiliser experiment PB CC 16 set up at Port Bouet in the Ivory Coast in 1970 with several types of hybrids, on sandy soils (tertiary-quaternary colluvium) (Ouvrier, 1984).

This factorial experiment studying N, P, K and Mg only responds to KCl and Kieserite applications. This paper will only be looking at an analysis of KCl effects in the presence of the average rate of Kieserite (750 g/tree/year). The corresponding results are given in Table 42.4.

The increasing KCl rates very substantially increase yields of copra and the K contents of the husk and shell, but not of the meat. Mass and content increase combine to considerably increase exports from a ha of crops. However, dehusking in the field results in a very clear reduction in exports, and the higher the KCl rate the greater the reduction. This cropping practice is therefore even more economical when the fertility or fertilisation level is high. If we now calculate exports per ton of copra produced, we see that they increase in line with KCl rates when husks are removed, but remain virtually constant when nuts are dehusked in the field.

Table 42.4: Effect of potassium fertilisation on yields, on the K contents of leaf 14 and on yield components, and consequently on mineral exports by the crop (PB CC 16 — Age 10 years: 143 trees/ha)

KCl rates g/tree/year	*K rates kg/ha/year*	*Yield kg copra/ha/year*	*Contents as % K DW*			
			Leaf 14	*Husks*	*Shells*	*Meat*
0	0	1 301	0.46	0.87	0.16	0.78
1 500	107	3 379	1.38	1.60	0.30	0.77
3 000	214	3 713	1.67	1.97	0.36	0.77

KCl rates g/tree/year	*K rates kg/ha/year*	*Yield kg copra/ha/year*	*Exports in kg of K/ha/year*		*Exports in kg of K/t of copra*	
			With husks	*Without husks*	*With husks*	*Without husks*
0	0	1 301	24.0 (100)	10.3 (100)	18.4 (100)	709 (100)
1 500	107	3 379	82.3 (343)	28.5 (277)	24.4 (133)	8.4 (106)
3 000	214	3 713	103.9 (433)	32.6 (317)	28.0 (152)	8.8 (111)

To conclude this section, it should be remembered first of all that husks are responsible for the majority of potassium and chlorine exports and that dehusking in the field makes for considerable input savings when potassium deficiency is dominant (which is very frequently the case), all the more so as the deficiency is corrected better by fertilisation.

The long-term fertility of extensive small holdings depends on it, as it a fortiori does, on all the other crop residues the exportation of which impoverishes the soil not only in minerals, but also in organic matter. In an intensive cropping situation, husks represent the equivalent of 200 to 300 kg of KCl/ha/year according to estimates. This should not be forgotten when calculating the

profitability of alternative industrial uses (fibres, compost, energy), which should financially compensate for the corresponding loss in fertiliser elements.

RESPONSES TO FERTILISATION

These responses obviously differ substantially and will be described for some typical case sites or particular nutritional complexes.

Potassium and Magnesium Nutrition and Fertilisation

There are numerous soils, especially in Africa, where the main or even the only deficiency is potassium, sometimes combined with magnesium. This is the case with many soils generally of sedimentary origin, with a good supply of phosphorus and rich enough in organic matter for nitrogen nutrition to pose no major problem. This is the case, for example, with the sandy soils of the tertiary colluvium at Port Bouet in the Ivory Coast. These soils are poor in exchangeable K and Mg (0.04 and 0.10 m.e. for 100 g of soil respectively), rich in total P, and nitrogen nutrition is ensured naturally, apart from the odd exception. The PB 121 hybrid's response to potassium and magnesium fertilisation in this context is illustrated by the mean results of experiment PB CC 16 (Table 42.5).

Table 42.5: PB CC 16 — 1970. Effect of potassium and magnesium fertilisers on copra production in kg/tree/year (t/ha/year), and on leaf contents for potassium (% K) and magnesium (% Mg)

Kieserite[+] *kg/tree*	*Potassium chloride*[++] *kg/tree*			*Means*
	0	*1.5*	*3.0*	
0	8.00 (1.22)	19.10 (2.90)	12.80 (1.95)	13.30 (2.02)
	†0.52/0.239	1.436/0.110	1.658/0.065	1.205/0.105
0.75	7.70 (1.17)	22.60 (3.43)	26.20 (3.98)	18.80** (2.86)
	0.459/0.249	1.38/0.163	1.675/0.170	1.172/0.194**
1.5	8.90 (1.35)	23.10 (3.51)	24.40 (3.71)	18.80** (2.86)
	0.465/0.355	1.294/0.236	1.605/0.216	1.121/0.269**
Mean	8.2 (1.25)	21.6** (3.28)	21.1** (3.21)	Interaction
	0.482/0.248	1.370**/0.170**	1.646**/0.150**	5.4* (0.80)

[+] 33% MgO) [++] (60% K_2O)
* Significant difference at 1%
** Significant difference at 5%
† Leaf contents of K and Mg in that order.

Yields increase from 1.2 to 4 tons of copra in the best treatment (3 kg of KCl, 0.75 kg of kieserite), that is, 3.3 times more. Fertilisers increase leaf contents for K and Mg. The response curves and surfaces calculated from these results show that maximum theoretical production would be 26.6 kg of copra/tree with 2.4 kg of KCl and 1.3 kg of kieserite, but the fertiliser rates that give the maximum yields are not the most cost-effective. To ensure maximum cost-effectiveness, it is necessary to adopt the economically optimum application rate, which therefore depends on the economic conditions at the place

and the time in question. At the time, in the Ivory Coast, yields of 25.8 kg of copra/tree/year were obtained with 2 kg of KCl and 1 kg of kieserite. The corresponding leaf contents amounted to 1.4 per cent for K and 0.2 per cent for Mg. Under these conditions, the fertilisation operation as a whole made it possible to achieve an added value of 25.8 – 7.5 = 18.3 kg of copra, with a very good cost-effectiveness ratio. These results were also obtained at a time when nuts were not being dehusked in the field. Dehusking in the field, which is now common in the Ivory Coast, should produce the same results with much lower rates. The optimum leaf content for K (1.4 per cent), which is well above that found for tall coconuts in general (0.9 per cent) was confirmed in another experiment, PB CC 18, which shows that yields still increase significantly when leaf K contents increase from 1.33 to 1.65 per cent (Table 42.6).

Nevertheless, we shall see in the following section that there are situations where this optimum content is not applicable.

Table 42.6: PB CC 18 — 1970. KCl rates, leaf K contents and nut production

KCl rate, g/tree	1 200	2 400
Leaf content, % K	1.33	1.65**
Nuts/tree	107	124**

** Significant difference at 1 per cent.

Potassium and Chlorine Nutrition and Fertilisation

There would be no question of interpreting responses to KCl applications without bearing in mind chloride nutrition, which is of paramount importance for coconut, but it is sometimes difficult, as knowledge stands, to determine the respective effects of potassium and chloride on yields. In the previous experiment, PB CC 16, located a few kilometres from the sea, the chlorine effect, if there is one, is very difficult to separate from the clear and substantial potassium effect. The high critical levels for potassium in this experiment can be suspected of being merely the expression of an additional effect of the Cl^- ion, for which the leaf content increases from 0.3 to 0.7 per cent under the effect of potassium chloride, but this remains to be proven. Moving just a few dozen kilometres from the coastline, for example, Dabou, the chloride effect becomes preponderant, since sodium chloride increases yields by over 50 per cent compared to the sodium sulphate used as a control (Table 42.7), regardless of the potassium effect. The leaf Cl^- content of control palms is also much lower (under 0.1 per cent).

Two experiments in Indonesia, located at comparable distances from the sea (Bangun Purba and Bah Lias Estates, North Sumatra), also bear witness to a considerable potassium chloride effect on yields (Ollagnier and Wahyuni, 1984). They are set up on soils much richer in potassium, such that the leaf contents of the control are already over 1.4 per cent (critical level of PB CC 16 in the Ivory Coast). However, the Cl^- contents of around 0.1 per cent in the control increased to 0.3 to 0.4 per cent when KCl was applied (Table 42.8). In both cases, the effect of potassium chloride must be attributed to chloride alone. In a third experiment in Indonesia (Bergen-Lampung), the KCl effect

could be due to the combined action of the two ions but an analysis of the correlations tends more towards dominant chloride action: copra/tree depending on K^+ (Cl = constant) r = 0.0001; copra/tree depending on Cl^- (K = constant) r = 0.69***.

Table 42.7: DA CC 01. Effect of sodium chloride

Treatments	*Sodium sulphate*	*Sodium chloride*
KCl 0		
Copra/tree	8.1 (100)	12.2 (100)
Contents, % K	0.388	0.402
Contents, % Cl	0.076	0.549
KCl 1		
Copra/tree	15.5 (191)	24.2(198)
Contents, % K	1.38	1.44
Contents, % Cl	0.136	0.661

Table 42.8: Indonesia. Effect of potassium chloride

Treatments	*Location*		
	Bangun Purba (North Sumatra)	*Bah Lias Estate (North Sumatra)*	*Bergen (Lampung)*
KCl 0			
Copra/tree	8.7	11.4	17.2
Contents, % K	1.41	1.50	0.686
Contents, % Cl	0.037	0.120	0.046
KCl 1			
Copra/tree	15.7**	16.7**	27.0**
Contents, % K	1.53**	1.56*	0.819
Contents, % Cl	0.257**	0.430**	0.243**
KCl 2			
Copra/tree	—	18.7**	27.5**
Contents, % K	—	1.60**	0.892
Contents, % Cl	—	0.530**	0.412**

In this last experiment, as in numerous situations in commercial plantations on clayey soils poor in K and rich in exchangeable Ca or Mg, it seems difficult to increase leaf contents for potassium to the 'Ivorian' established critical level. Might this be due to cation antagonism between K and Ca or Mg in the soil? There are even very clayey red soils in west Java where increasing leaf contents for potassium to more than 0.7 to 0.8 per cent is impossible, unless massive amounts of fertiliser are used that are incompatible with farm economics.

Much therefore remains to be done in this field before any final conclusions can be reached as to the critical level for potassium. On the other hand, the effect of chlorides is easily obtained as soon as leaf contents drop to

0.1 per cent moving away from the coast, sometimes only a short distance such as in the Ivory Coast and the Philippines (Magat *et al.*, 1988). Part of this effect can be explained by the role played by the chlorine ion in the physiological mechanisms linked to stomatal opening and osmoregulation (Braconnier and D'auzac, 1989; 1990). Fertilisation can therefore be centred on correcting this deficiency using the cheapest chloride and taking into account any effect of the accompanying cation.

Nitrogen Nutrition and Fertilisation

The experiments in the Ivory Coast show that nitrogen nutrition in a well-managed plantation, with legume cover crops and no leaf exports, is naturally satisfactory, despite the relatively low organic matter and total nitrogen contents in the soils used. When certain old exhausted coconut groves are replanted, nitrogen deficiencies occur and require large quantities of urea to correct them (critical level around 2.2 per cent frond 14), which are not cost-effective. Hardy bushy legumes were therefore used.

In Indonesia, there has been no significant response to nitrogen fertiliser, even on sites characterised by relatively low leaf contents (1.8 to 2 per cent). On the other hand, in Mozambique, with local Tall × Malayan Yellow Dwarf hybrids on coastal sands in a dry climate with a fairly high water table, a response is obtained for nitrogen fertiliser alone (Table 42.9).

Adjustment of the response curves to Mitscherlich's law gives critical levels that decrease according to age and which are lower than those in the Ivory Coast: 1.95 per cent N at seven years, 1.85 per cent at 10 years, and 1.80 per cent at 13 years.

Table 42.9: Experiment MP CC 07 (Boror). Effect of urea on leaf nitrogen contents (leaf 14) and on production

Fertiliser Urea (kg/tree/year)	*6–8 years old*		*9–11 years old*		*12–13 years old*		*All 6–13 years*
	Leaf N content	*Number of nuts/tree*	*Leaf N content*	*Number of nuts/tree*	*Leaf N content*	*Number of nuts/tree*	*Number of nuts/tree*
N0 (0)	1.82	74	1.73	63	1.65	88	74
N1 (0.7)	1.93**	86	1.81	70*	1.70	104**	88*
N2 (1.4)	1.98**	89*	1.81	85*	1.75**	108**	93**
N3 (2.1)	2.00**	94**	1.88	93**	1.81**	117**	100**

* Significant difference at 5 per cent.
** Significant difference at 1 per cent.

Phosphorus Nutrition and Fertilisation

There is little or no response to phosphorus on the sandy soils of the Ivory Coast, whose only strong point is to be less poor in phosphorus. The yield increases obtained (5 to 6 per cent) are very modest when compared to the response to potassium fertilisation. The response to phosphate fertilisation was observed in two other experiments with PB 121, one in Benin in an irrigated area, the other in Indonesia (Bergen-Lampung), both on soils very poor in total phosphorus (100 ppm). The yield increases obtained remain

limited at 3 to 4 kg of copra per tree per year for 3 kg of rock phosphate. The critical level for phosphorus would seem to be higher than the 0.12 per cent that was proposed in accordance with the very first results. It would appear to be nearer 0.135 per cent fluctuating of course in line with the economic data at the time and the place.

Nutritional Complex on Deep Peat Soils

The RSUP coconut project on deep peat soils in Riau Province, Indonesia, was used to study coconut mineral nutrition on this very special medium. The deep peat soils (over 4 m thick) are quite poor in useful mineral elements. N and K, in that order, are deficient and relatively high fertiliser rates are required. Mg, Ca, Zn and B are naturally sufficient, at least during the early years after planting. The main deficiency is copper. It appeared suddenly at the age of seven months in the treatment without copper in the trace element experiment. The visible symptoms, which had never been described until then, are very typical, with the appearance of young leaves affected by yellowing and peripheral drying out, followed by a total halt to growth, which can lead to terminal decay in young coconuts. If no copper is applied, virtually all the coconuts die, as seen in a small plot that was overlooked and that received no fertilisers. Around 10 other trials were devoted to correcting these deficiencies. They showed that applying copper sulphate to the soil was an easy and effective way of preventing this deficiency, using the following schedule: 2 g/plant in the nursery, 20 g/plant in the planting hole, 50 g/plant in the month third and 100 g/plant in the month tenth. Copper sulphate corrects even very acute deficiencies, at least up to a certain degree of decay beyond which the plant is unable to recover.

It has been impossible so far to detect the effect of zinc, though, with copper, it is supposed to be the main trace element deficiency in oil palms on peat soils in Malaysia. It became necessary to set up a further set of trials to study iron deficiency, which appeared unexpectedly. This deficiency gives rise to generalised yellowing of young coconut palms, the growth of which is simply retarded. It can be prevented by applying 50 g of iron sulphate in the planting hole. It occurs at five months and seems to disappear naturally after a few months, even without intervention (Ochs and Bonneau, 1988).

FERTILISER APPLICATION METHODS

Programming Methodology

The choice of fertiliser rates to be applied in practice obviously cannot be based on the principle of pure and simple restitution of the amounts of mineral elements exported. Sometimes more has to be applied to take into account losses by leaching (particularly Cl, K and Mg) or irreversible fixation (phosphorus) and to increase the concentration in the soil to an adequate level. Sometimes less has to be applied or no applications are required at all if the soil has sufficient quantities or if the natural balance is positive (nitrogen, chlorine etc.).

This choice is guided by leaf analysis, which proves to be remarkably accurate with coconut. Critical levels have been determined in a certain number of situations, but they can vary substantially from one situation to another, as already mentioned, especially for potassium and nitrogen. The critical level does not always indicate the rates required to correct the deficiencies that it merely reveals. It is therefore essential to refer to a specific experiment to ascertain both the critical level applicable in a given situation and the fertiliser rate capable of correcting the corresponding deficiency. In commercial plantations this is done using effective technology that combines reference experiments and annual leaf analysis surveys, to ensure true mineral nutrition management as close as possible to the optimum (Ochs, 1985). On smallholdings, the same method can be applied subject to a few changes in the organisation and in objectives, since it is not always desirable or possible to propose optimum fertilisation.

Fertiliser Rationing

The fertiliser response curves usually tally with Mitscherlich's law of less than proportional increases, which means that small rates lead to a relatively higher increase in yields than higher rates. Fertiliser rationing, that is, using smaller application rates than the optimum, leads to lower yields but even lower fertiliser costs, thereby improving the cost-effectiveness of the operation. For example, it has been calculated in the Ivory Coast based on experiment PB CC 16, which has already been mentioned and which showed that the economically optimum fertiliser was 2 kg of KCl + 1 kg of Kieserite per tree per year, that 25, 50 and 75 per cent rationing of the optimum rates should theoretically only reduce production by 10, 25 and 45 per cent whereas the production of the control without fertiliser only reaches a quarter of its potential (Table 42.10).

Table 42.10: Effect of fertiliser rationing (KCl + Kieserite) on production of PB CC 16

Rates *kg fertiliser/tree/year*	*Production* *kg copra/tree/year*	$R = \frac{\text{added value}}{\text{cost of fertiliser}}$
MR = 3.7 (123)	26.6 (103)	$\frac{873}{259} = 3.37$
OR = 3.0 (100)	25.8 (100)	$\frac{837}{210} = 4.00$
2.3 (75)	23.5 (91)	$\frac{734}{161} = 4.56$
1.5 (50)	19.7 (76)	$\frac{563}{105} = 5.36$
0.8 (25)	14.4 (56)	$\frac{324}{56} = 5.79$
0 (0)	7.2 (28)	–

OR = Economically optimum rate.
MR = Rate ensuring maximum production.

In addition, the gain: cost ratio increases from 4 to 5.4, for example, for the half-rate. This is a particularly worthwhile measure when growing coconut, which is usually in the hands of smallholders who are often incapable of investing enough for the theoretically optimum rates required to ensure maximum profits.

Application Techniques

Given the substantial fertilisation requirements of hybrids (with husk exports) and the assumed susceptibility of KCl and Kieserite to leaching on the very sandy soils in the Ivory Coast, it seemed essential to conduct experiments to determine the best season for an annual fertiliser application and to study any effect of split applications. Experiment PB CC 18 (1970 planting) was programmed for this, comparing a single application in April (start of rainy season) and in August (between seasons) or three split applications throughout the year (April-August-November), for two KCl and Kieserite rates. The results recorded up to 1986 did not even reveal the slightest difference in effect on mineral nutrition and yields. This surprising result shows that these very sandy soils (only 5 to 10 per cent clay) are capable of sufficiently slowing the downward movement of fertiliser solutions for the very deep root system to be able to absorb them, even with a single application per year. This result is very interesting for farming operations, since it means that growers are no longer obliged to apply fertilisers following a precise and restrictive procedure, and there is no risk of reducing the coefficient of utilisation of standard fertilisers.

FUTURE DEVELOPMENTS IN THIS FIELD

In a recent article published by the Central Plantation Crops Research Institute in Kasaragod (Khan *et al.*, 1990), a reminder is given that only 1 per cent of the world's coconut groves are given fertilisers, which partly explains the low average yields obtained on generally poor soils and with non-improved planting material. However, the experiments conducted in the network associated with IRHO/CIRAD, which are described above, show that mineral fertilisers are efficient and cost-effective with cost-effectiveness coefficients high enough to compensate for the inevitable losses in the shift from a controlled environment to smallholding conditions. The only exceptions encountered are soils that have reached an extreme degree of exhaustion and certain very specific soils in West Java, which require further studies.

There is also a very effective survey and programming methodology based on leaf analysis, which makes it possible to alter the type of fertilisers used and the rates applied in accordance with their true effectiveness.

The results described in this paper were obtained on hybrid planting material, primarily PB 121, but there is also traditional local material that reacts in the same way in proportion to its potential productivity. For example, in the Ivory Coast, the West African Tall—(local Tall) seems well able to produce 0.9 tons of copra/ha/year, as opposed to 1.2 tons for the PB 121, without fertiliser and under the same growing conditions, and potassium and

magnesium fertiliser applications increase yields to 2.4 tons for the WAT (Coomans and Ochs, 1976) and to 4 tons for the PB 121 hybrid, that is, a ratio of approximately three times more, but the additional production is 2.8 tons of copra for the hybrid, as opposed to only 1.5 tons for the WAT, for the same fertiliser costs, which tips the cost-effectiveness balance for the operation in favour of the improved planting material.

Whilst not neglecting the possible impact of attempts to rehabilitate a crop by using fertilisers in old coconut groves, provided it is possible to choose those that warrant it, in principle it is much more effective in the long term to act when extending or renewing coconut groves with improved planting material. As regards the role of research in this field, it should not be forgotten that despite the results already obtained, it should continue to be directly involved in drawing up and monitoring development programmes through adaptive applied research. Effective policies should be proposed to promote innovations.

Research on long-term fertility conservation, and at the same time on regeneration techniques, should be continued and stepped up. Experiments in this field are particularly difficult because, apart from very poor short-term techniques that often fall far wide of the facts, it is difficult to judge the very long-term effects of fertiliser rationing, for instance, to give a mineral nutrition example. Leaf analysis provides a very good diagnosis of mineral nutrition, but as far as soil is concerned nothing similar exists to provide an accurate estimate of the discrete evolution of other factors in long-term fertility, particularly organic matter in the soil, which plays a major role.

Coconut-based intercropping systems also merit a research effort, with more fundamental studies of competition phenomena between root systems within the intercropping system. IRHO and its partners are trying to promote highly extensive programmes along these two lines.

To conclude, it is worth mentioning the merits of research on mineral nutrition suited to the planting material involved. It was proved some time ago that leaf contents for mineral nutrients differ very significantly in hybrid comparative trials, with uniform fertilisation. This should be taken into account to see whether these differences are worth exploiting, to determine fertilisers and critical levels specific to different ecotypes and hybrid varieties and even to see whether it would eventually be possible to find planting materials that are less demanding in inputs.

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DISCUSSION

G. Dev: How is Cl useful in increasing coconut yield—Is it an essential element or does it protect from diseases?

R. Ochs: Both. There is a favourable influence on yield even without drought and sometimes it offers protection against foliar diseases like Helminthosporium.

RESPONSE OF COCONUT TO POTASSIUM APPLICATION

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ABSTRACT

Potassium is found to be a dominant nutrient removed by coconut palm due to readily available forms of nutrient with easy access of plant roots. The results of response studies conducted by various major coconut producing countries have shown that yield (number of nuts or copra/palm) and yield attributes (number of inflorescences or bunches/palm, number of female flowers/bunch, percentage of nut set and copra content/nut) are greatly influenced by the potassium application. Potassium application also improves the crop quality as frond length, height, girth and number of leaves, weight and volume of husked and unhusked nuts and copra weight/nut. Foliar concentration of K gives the best idea of critical levels. Potash application enables the coconut to get through the dry season more easily. Potash also increases the resistance of coconut to disease, insect pests and lodging damages.

INTRODUCTION

Coconut palm is a potash loving plant, the mineral nutrition of which has been under investigation from the early years of coconut research. Potassium is required by coconut in amounts greater than any other nutrient but supply from natural resources is limited. No comprehensive trials were conducted on the requirement of potassium for coconut till 1953 in India. To achieve appreciable yields, an adequate knowledge of response of coconut to applied potassium is required.

Soils and Climatic Conditions

In India coconut is grown under highly heterogeneous conditions of soil, ranging from littoral sand to clay, in situations from poorly drained low-lying marshes to well-drained uplands and hill slopes and in strongly acid to calcareous coral soils. The morphological and some of the physico-chemical

characteristics of typical coconut-growing soils from different agro-climatic regions of India have been discussed by Khan *et al.* (1978). Most of these soils are low in available nutrients and extensive areas of coconut plantations are often found in highly leached laterite zones of South India.

Physiological Parameters and Deficiency Symptoms

Potassium is reported to be physiologically important, but its role in the formation of yield remains a mystery. Manciot *et al.* (1981) described the physiological importance of the plant's metabolism, in accelerating the movements of stomata (water economy), in activating enzymes, in the transport of metabolites and in cell division. These areas have not been adequately studied for the coconut.

Numerous coconut plantations suffer from potassium deficiency. The general trends of potassium deficiency in coconut throughout the world are presented in Table 43.1 as described by Manciot *et al.* (1981). The first visual symptom appears on the leaflet as the rust coloured spots in two longitudinal bands on either side of the mid-rib and slight yellowing of the lamina, more marked towards the tip of leaflet. Thereafter, yellowing intensifies leaving only a narrow median band still green, thinning down to necrosis. The rusty spots invade the whole leaflet and form large patches of irregular outline. According to Nelliat (1973), the deficiency symptoms in the initial stages of coconut growth are drying up of the leaf tips and the development of scattered olive green spots, starting from leaf tips. Later the spots increase in size and turn reddish-brown.

Ollagnier (1985) observed that potassium deficiency in coconut manifests itself by two types of visual symptoms such as yellowing, particularly on the centre of the crown possibly as a consequence of enzymatic dysfunction in the leaves and drying of leaves at the base probably because of inadequate supply. Such leaves often hang down beside the trunk. Coconut palms affected by foliar yellowing were reported to be in a state of unbalanced nutrition, particularly involving potassium, calcium and magnesium (Cecil *et al.*, 1978).

Nutrient Removal and Potassium Uptake Pattern

The export of major nutrients by coconut palm had been estimated by a number of researchers in different countries. Pillai and Davis (1963) estimated, the nutrient removal by coconut yielding around 60 nuts, to be 720 g N, 330g P_2O_5 and 1080g K_2O palm/year. On the basis of estimation of 5000 nuts/ha and 175 palms/ha in India, the potassium uptake was 93 and 146 kg/ha, respectively (Nelliat, 1974). However, in Sri Lanka it was 189 kg/ha (on the basis of estimation of 175 palms/ha — Nathanael, 1969) and 249 kg/ha in the Ivory Coast on 6.7 tons copra/ha production (Manciot *et al.*, 1979). About 75 per cent of the total amount of potassium taken up by coconut palm is removed through harvest as bunches. As much as 60 per cent of the potassium removed in bunches is present in husks and another 24 per cent is accounted for by kernel (Ouvrier and Ochs, 1982).

Table 43.1: General tendency of deficiencies in coconut throughout the world

Country	*Main tendency of deficiencies*	*Occasional deficiencies*	*Fertilisers to be recommended*
Africa			
Ivory Coast			
Quaternary sands	K-P-Mg	N	Potassium chloride-Superphosphate-Kieserite-Urea
Tertiary sands	K-Mg	Cl-B	Potassium chloride-Kieserite-Borax-Magnesium chloride
Soils with concretions	K-P		Potassium chloride-Single superphosphate
Benin			
Coastal sands	K	N	Potassium chloride-Urea
Mozambique	N	K	Urea or Ammonium sulphate-Potassium chloride
Madagascar	S-P-Mg	K-B	Mg sulphate-Single superphosphate-Borax-Potassium chloride- Kieserite
Seychelles			
Coral soils	Mn-Fe-N	S-K	Mn and Fe sulphate-Ammonium sulphate-Potassium chloride
Granite soils	N	Mn-Fe	Urea-Mn and Fe sulphate
Asia			
Philippines	N-Cl-S	K	Ammonium chloride-Ammonium sulphate-Potassium chloride
India			
Coastal soils	K-Mg	N	Potassium chloride-Kieserite-Urea
Soils with concretions	P-K-N		Superphosphate or natural phosphate Potassium chloride-Urea
Sri Lanka	P-K	N	Potassium chloride-Saphosphosphate-Urea or Ammonium sulphate
Indonesia			
Volcanic soils	N-P-Mg	K-B	Ammonium sulphate or Urea-Superphosphate-Kieserite-Potassium chloride
Alluvial soils	N-K	B	Ammonium sulphate-Potassium chloride
Malaysia	K	N	Potassium chloride-Urea or Ammonium sulphate
Thailand	N-P-K	Mg	Potassium chloride-Ammonium sulphate or Urea-Single superphosphate-Kieserite
America			
Mexico	N	K	Ammonium sulphate or Urea-Potassium chloride
Brazil	N-P-K		Ammonium sulphate or Urea-Single Superphosphate-Potassium chloride
Jamaica	N-P-K		Ammonium sulphate-Single superphosphate-Potassium chloride
Oceania			
Atolls	Fe-Mn-N	N-K	Fe and Mn sulphate-Urea-Potassium chloride
High islands developed coral soils	K	N-B	Potassium chloride-Ammonium sulphate-Borax
Volcanic soils		Cl-K-B	Potassium or Ammonium chloride-Borax

Ramanandan and George (1982) also observed potassium followed by nitrogen to be dominant nutrients removed by coconut. The removal was found highest by the palms growing on coastal sand followed by red sandy loam and lowest in the laterite soil.

CROP RESPONSE

Yield and Yield Attributes

The yield of coconut and the yield attributes (number of inflorescence or bunches/palm, number of female flowers/bunch, percentage of nut set and copra content/nut) has been reported to be greatly influenced by the potassium application. In a long-term experiment in the Philippines, the fresh copra/nut and the cumulative copra yield/ha (Mendoza *et al.*, 1978) and female flower production and number of nuts/palm was found increased significantly in podsolic soils of North Sumatra with potassium application (Rosenquist, 1981). Margate *et al.* (1979) observed from long-term studies with KCl fertilisation of bearing coconuts in inland and upland areas of the Philippines a significant effect of potassium application on nut production/tree, average copra production and annual crop production in the first year and in the succeeding years as well.

An estimate of copra production/ha showed that 8 kg KCl treatment gave the highest values followed by KCl (2), KCl (3), KCl (1) and KCl (0) treatments. Looking at the average annual production, palms treated with 2 kg KCl/tree/year produced the highest yield, an increase of about 47 per cent.

In a long-term experiment in India, Muliyar and Nelliat (1971) observed yield response to potassium application from the fifth year onwards. Its application increased nut production by 12 per cent and copra out-turn/palm by 22 per cent.

Coconut palms which suffered potassium deficiency during the pre-bearing period were on an average 15 per cent less productive than palms adequately supplied with potassium. Potassium improved the setting (35 per cent) and thereby the yield in a CPCRI experiment at Kasaragod from 1953 to 1965. Copra content of nut was also improved by potassium application resulting in a marked increase in the copra out-turn/palm (44 per cent).

Potash has a spectacular effect on the number of inflorescences produced by the tree; by three times it intensified the yield by its action on the number of nuts and the copra/nut, the total copra being doubled. The IRHO's studies have very clearly demonstrated the highly significant correlation between potassium levels and copra production/tree (Manciot *et al.*, 1981). The effect of rainfall was manifest in higher yields in plots receiving higher potassic fertiliser than control plots (Quencez and de Taffin, 1981) (Table 43.2). Muliyar and Nelliat (1971) also reported that potash showed significant impact on yield in the fifth year and both lower and higher doses gave significantly higher yields than no potash treatment.

Crop Quality

In a coconut experiment on the podsolic soils of north Sumatra, Rosenquist (1981) observed an increase in relative frond area, frond length, female

flowers/palm in MAWA hybrids and in the Solomon Islands. Manciot *et al.* (1981) observed a significant increase in the height of immature trees due to increase in annual rate of potash application. Palms receiving higher levels of NPK flowered earlier than those receiving sub-optimal doses. Palms which receive no potassium may fail to flower at all even when given high rates of nutrients (von Uexkull, 1978).

Table 43.2: Comparison of yield increase in kg copra/tree/year between non-manured plots (K_0) and manured plots (K_3)

Year (n)	*Rainfall (n – 1)*	*Plot K_0*		*Plot K_3*		*Increase*
		Yield	*Increase*	*Yield*	*Increase*	*$K_3 - K_0$*
1959	1639	6.8		11.6		
1960	2567	8.5	1.7	17.5	5.9	4.2
1963	2010	5.1		13.7		
1964	2614	6.2	1.1	15.7	2.0	0.9
1965	1902	4.2		8.9		
1966	2397	4.7	0.5	13.0	4.1	3.6
1967	1620	2.3		6.6		
1968	2039	4.9	2.6	10.3	3.7	1.1

(Quencez and de Taffin, 1981).

Muliyar and Nelliat (1971) studied the main effect of N, P and K on nut characters at CPCRI, Kasaragod (Table 43.3).

Table 43.3: Main effects of N, P and K on nut characters

Main effect	*Mean value and percentage increase/decrease over no nutrient for different characters (10-year average)*				
	Wt. of nuts unhusked (g)	*Vol. of nuts unhusked (cc)*	*Wt. of nuts husked (g)*	*Vol. of nuts husked (cc)*	*Copra weight per nut (g)*
N_0	987.1	2619	535.3	583.1	179.2
N_1	928.6** (–5.9)	2502 (–4.4)	482.1** (–9.9)	530.9** (– 9.0)	161.8** (–8.0)
N_2	890.6** (–9.8)	2401** (–8.2)	467.0** (–12.8)	516.6** (– 11.4)	162.1** (–9.5)
P_0	931.1	2517	489.8	537.5	168.9
P_1	932.2 (–0.2)	2513 (–0.1)	499.1 (1.9)	550.9 (2.5)	169.5 (0.4)
P_2	930.7 (0.6)	2496 (–0.8)	495.5 (1.2)	542.2 (0.09)	167.7 (–0.7)
K_0	895.0	2331	476.9	530.4	163.3
K_1	953.6** (6.6)	2562** (9.9)	503.3* (5.5)	550.2 (3.7)	171.0* (4.7)
K_2	957.7** (7.0)	2632** (12.9)	504.1* (5.7)	550.1 (3.7)	171.8* (5.2)

* Significant at 5 per cent level; ** Significant at 1 per cent level.
( ) figures in the parentheses denote percentage increase or decrease over no nutrient.
(Muliyar and Nelliat, 1971)

The effect of green manuring and first order interactions were negligible. While nitrogen had an adverse effect on nut characters, potash had a marked effect. P was totally ineffective. As compared to nitrogen, the effect of

potash tends to be enhanced at a higher level of application. The potassium application increased the weight and volume of husked and unhusked nuts and copra weight/nut.

Critical Levels

The critical level for potassium has been revised several times. Earlier IRHO fixed 0.45 per cent as the critical concentration taking into account the best yields obtained at the time with tall material on sandy soils of mediocre fertility. Further results from the same experiment, led to revise the value to 0.8 to 1.0 per cent of dry matter (Manciot *et al.*, 1981). There was a highly significant correlation between leaf potassium levels and yield in copra/tree (Quencez and de Taffin, 1981). However, the experiments in Ivory Coast of West Africa, worked in favour of an optimal leaf level of 1.4 per cent potassium (Ollagnier and Wahyuni, 1986). The suggested critical values (Frond 14) were N:1.8 to 2 per cent; P: 0.12 per cent and K:0.8 to 1.0 per cent on dry matter basis.

Fertiliser Recommendations

Seedlings of coconut receiving N:P:K:: 0.50:0.50:1.75 kg ratio were found better in growth (Louis and Krishnaswamy, 1978). For palms yielding less than 60 nuts annually, the optimum amount of K application ranges between 0.89 and 1.21 kg/year/palm (Muliyar and Nelliat, 1971). The amounts of fertilisers recommended for the ordinary tall variety of coconut is 500g N + 320g P_2O_5 + 1200g K_2O and that for high yielding genotypes, 1000g N + 500g P_2O_5 + 1500g K_2O/palm/year. Under rainfed conditions, 500g N, 300g P_2O_5 and 1000g K_2O with 500g MgO could be taken as an ideal dose of fertiliser application in early bearing periods of coconut in root (wilt) affected areas of Kerala (Amma *et al.*, 1982). However, for the WCT palms under rainfed conditions, an annual fertiliser dose of 500g N, 320g P_2O_5 and 1200g K_2O/palm/year is the recommended dose (Nelliat, 1978). The WCT palm responded up to 750:670:1500: 750 g N:P_2O_5:K_2O:MgO/palm/year, respectively under irrigated conditions.

K recommendations for coconut have been summarised for various coconut producing states of India by Tandon (1988) as given in Table 43.4.

Table 43.4: K recommendations for coconut crop in India

State	*Recommendations*
Kerala	140–680 g/palm*
Assam	1200 g/palm
Karnataka	135–1200g/palm*
Tamil Nadu	300–1200g/palm*
Andhra Pradesh	150–600 g/palm*
West Bengal	300–1200 g/palm*

*depending upon age.

Resistance to Disease, Insect-pests, Lodging Damage and Drought Tolerance

Potassium plays a very important role in the development of resistance to disease and insect-pests in coconut plant. It controls the leaf rot disease of

coconut (Uthaman and Koyamu, 1957), which was found to be associated with inadequate supply of potash in the soils (Menon *et al.*, 1950). Coconut palms receiving adequate potassium did not show any increase in the intensity of Thanjavur wilt disease in India (Bhaskaran and Ramanathan, 1983) and leaf spot disease in Philippines (Abad *et al.*, 1978)

Adequate potassium application improves water use efficiency and drought resistance ultimately. Potassium encourages root elongation, turgidity and the rate of root regeneration (Munson, 1980). Examination of these data justified the conclusion that good mineral nutrition (notably potassic) enables coconut to get through the dry season more easily, leading to a notable yield increase compared to unfertilised trees.

CONCLUSION

With the present discussions it may be concluded that potassium plays a key role in the nutrition of coconut palm which removes potassium in greater amount than any other nutrient. It plays an important role in physiological parameters and an adequate supply of potassium prevents the plant from various physiological diseases/disorders. Potassium increases the resistance of plant to insect-pest, lodging damages and shows a property of drought tolerance.

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DISCUSSION

P.B. Shanthappa: Can we reduce the fertiliser application rates by recycling by-products?

Mahatim Singh: If recycling of the crop residues is managed properly the doses of K can be reduced because some of the residues like coconut husk contain a lot of potassium.

WATER MANAGEMENT STUDIES ON COCONUT IN INDIA

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ABSTRACT

Variability of rainfall, coupled with inadequate irrigation resources and poor water management are the main causes of low productivity of palms even in traditional coconut growing states.

Studies based on climatological approach at Kasaragod revealed that water requirement (W.R.) of adult palm is equal to the potential evaporation (Eo). Lysimetric studies at CWRDM, Calicut have shown that evapotranspiration (ET) rate of a five-year old palm increases from 2.9 mm/day in December to 5.5 mm/day in April and falls to 2.3 mm/day in June. At Coimbatore, the transpiration rate of coconut leaves was measured to be 7.5 $\mu g/cm^2/sec$. and the estimated W.R. ranged from 55 l/day in December to 115 l/day/palm in June.

An annual increase of 31 nuts/palm/year at Nileshwar was due to basin irrigation with 300 l at five days interval in sandy loam soil. In littoral sand, flood irrigation with 5 cm depth increased yield by 85.4 nuts/palm/year over pre-irrigation yield. At Kasaragod, irrigation with 20 mm at Irrigation Water (IW): Cumulative Pan Evaporation (CPE) ratio of 1.00, recorded the highest cumulative yield of 918 nuts/palm after 16 years of planting. At Calicut, irrigation with 30 or 45 mm of water at IW : CPE ratio of 1.00 resulted in significant improvement in yield of West Coast Tall palms when practiced along with mulching. Studies at Kasaragod have shown that in heavy rainfall areas, sea water can be used for irrigating coconut palms without any adverse effect on productivity of palms and soil conditions.

Drip irrigation has been found most suitable for water scarcity areas. In littoral sandy soil at Kasaragod, 32 l/palm/day through drip, produced 38 per cent higher nuts than basin irrigation with 200 l per four days.

Considerable improvement in productivity of palms under rainfed conditions have been reported through practices controlling run off, increasing infiltration, conserving soil moisture etc.

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INTRODUCTION

Variation in soil moisture ranging from near saturation (June to August) to severe moisture stress (December to May) is one of the major causes of low productivity of palms even in the traditional coconut growing states like Kerala and Karnataka where the annual rainfall ranges from 2,500 to 3,500 mm.

Information on water requirement of coconut and location specific agro-techniques for run off control and soil moisture conservation is needed for designing water management practices for coconut. The paper describes the results of the work done on various aspects of water management on coconut in India.

Water Management for Coconut in Relation to Climate

Water management is location specific and depends upon climate, soil, topography, ground water table etc. Moisture stress period prevails for 14 to 15 weeks in the southern and 18 to 21 weeks in the northern parts of Kerala (Rao and Vamadevan, 1982). Yusuf *et al.* (1986) analysed rainfall patterns of Kasaragod for 65 years and found that of the 3,500 mm annual rainfall, 75 per cent occurred within a short period from June to August and the period from December to middle of May remains rainless. The coconut palms suffer due to poor insolation and excess moisture in the former and due to moisture stress in the later periods. Summer irrigation and drainage are needed in these periods for healthy growth and productivity of palms. In southern Kerala, the annual rainfall of about 2500 mm is better distributed and the palms never experience severe moisture stress and thus productivity is higher. Under Kerala conditions, the effective rainfall under coconut was up to 41 per cent of the total precipitation (Rao *et al.*, 1988).

Effect of Soil Moisture Deficit on Productivity of Coconut

Coconut is mostly grown on soils poor in water holding capacity. Severe stress conditions lead to drooping of leaves, breaking of leaf petioles and even death of palms. According to Coomans (1975) water stress results in lower leaf production and consequently less number of inflorescences. Female flower production is affected, flower and early fruit abscission is generally increased resulting in reduced fruit set. A period of drought occurring 15 to 16 months before the opening of spadices might lead to an abortion of spadices (Menon and Pandalai, 1960). This explains why the abortion of spadices occurs in the rainy season. Moisture stress during initiation of flower primordia which takes place about one year before the opening of spathe affects the nut yield two years later. Coomans (1975) observed a negative correlation between fruit set and accumulated water deficit over a period of five months prior to one year. He also observed maximum influence of water availability during the period between appearance of floral primordia and ovary differentiations. There are three stages in reproductive cycle of coconut, namely, initiation of flowers and fruit set, period of fruit enlargement and period of fruit ripening. The first

stage determines the number of ripe fruits produced while the second stage determines the fruit size. The water availability at the second stage is most crucial for yield. Nambiar *et al.* (1969) identified three phases in development of nut, namely, slow progressive growth for about three months after fertilisation, rapid growth for about four months and finally decline in growth rate for about two months. Moisture stress at the second phase adversely affects the size of nut and copra content. Prasada Rao and Nair (1986) have reported that decrease in yield started from the eighth month with the maximum reduction in the thirteenth month after the drought was over.

Effect of Waterlogging on Productivity of Coconut

Under water logged conditions, palms suffer from stunted growth probably due to oxygen deficiency. Waterlogging also causes reduced nitrogen supply, decrease in nutrient content in the order of K, N, P, Ca and Mg, malfunctioning of roots, formation of toxic compounds and greater solubility of metal ions like manganese which are toxic. Prolonged anaerobic condition results in death of roots and palms. Under waterlogged conditions, palms are also susceptible to *Phytophthora* infection resulting in immature nut fall.

Water Requirement of Coconut

Climate is the major determinant of the water needed for optimum growth and yield of coconut palms. Crop water requirements are normally expressed by the rate of evapotranspiration (ET) in mm/day or mm/period. The evaporation (Eo) together with the crop coefficient (Kc) give the water requirement of crop. Since the growth and reproductive stages occur simultaneously after the juvenile period, coconut palm requires readily available moisture throughout its life cycle.

Shanthamalliah *et al.* (1978) reported that total water requirement of one year old coconut seedlings was 1591 and 1533 mm per year when irrigation was given at 80 to 100 per cent and 60 to 100 per cent respectively of available soil moisture. It was also reported that coir dust mulching with 15 cm thickness reduced water demand by 40 to 55 per cent. In water scarcity areas burying of pots with 20 l capacity up to the neck at a distance of 75 cm from the seedling on either side and filling them periodically with water is a common practice to supply sufficient moisture for establishment. The water requirement of young palms in the initial years (up to three years) is very low as the number and size of leaves are small.

The consumptive use of water for adult coconut palms varies with climate and soil and the irrigation requirement depends on the method of application. At CPCRI, Kasaragod, the optimum water requirement was found equal to potential evaporation rate. The IW/CPE ratio of 1.00 (IW = 20 mm) was found to be the best for irrigation scheduling. Jayakumar *et al.* (1988) have reported that the consumptive use of water for coconut palm of six years age ranges from 2.7 to 4.1 mm per day. They have also quantified the crop coefficient values for coconut for different months. Rao (1989) determined

evapotranspiration of five year old coconut palm using lysimeter and reported that the ET increased from 2.9 mm per day in December to 5.5 mm per day in June. Joshi *et al.* (1988) recorded maximum ET of 6.6 mm per day when irrigation was scheduled with 20 mm of water at IW/CPE ratio of 1.00 during March. The ET rates were reduced to 4.0 and 2.3 mm per day when the IW/CPE ratios were 0.75 and 0.50, respectively. Vasu and Wahid (1990) using tritiated water have estimated transpiration of adult coconut palm to be 65 l per day. Mohandas *et al.* (1989) at Coimbatore (Tamil Nadu) measured the transpiration rate of coconut leaves to be 7.5 $\mu g/cm^2/sec.$ and estimated the total transpiration as 90 l per day. Varadan *et al.* (1990a) have estimated the irrigation depth and interval for coconut based on soil, crop and climatic approach for the various districts of Kerala. From the above review, it is clear that there is much variation with regard to consumptive use of coconut palm and the variations are mostly due to the soil, climate and method adopted for quantification.

Response of Coconut to Irrigation

Coconut requires ample and frequent supply of water throughout its life and responds well to irrigation. The depth and frequency of irrigation however, varies with soil type, climate, yield potential, age and level of management. Vijayalakshmi and Marar (1959) reported that in deep sandy soil of Nileshwar, Kerala, irrigation increased the annual yield by 5 to 30 nuts/palm. Summer irrigation increased female flower production and arrested button shedding (Venkitesan, 1973) and improved yield by 20 nuts/palm/year compared to rainfed conditions (Marar, 1963).

Bhaskaran and Leela (1978) observed an increase of 39 and 31 nuts/palm/year respectively when the low and medium yield group palms were irrigated with 800 l of water once in seven days in basins of 2 m radius. In littoral sand, flood irrigation with 5 cm of water once in five days significantly increased the number of functional leaves and yield (96.6 nuts/palm/year) compared to basin irrigation with 800 l of water once in a week (33.4 nuts/palm/year).

Higher female flower production, setting percentage and yield of nuts were recorded when dwarf palms were irrigated (5 cm in one m radius basins) in alternate days compared to once in 15 days. The highest response was recorded in Malayan Yellow Dwarf palms (Louis *et al.*, 1980).

Systematic studies based on climatic approach on irrigation requirement of West Coast Tall (WCT) coconut palms (early bearing stage) were conducted at Kasaragod (Nelliat and Padmaja, 1978). The response to three depths of irrigation water (IW) namely, 20, 40 and 60 mm at three frequencies based on IW/CPE ratios of 1.00, 0.75 and 0.50 revealed that while growth characteristics did not differ significantly, frequencies of irrigation at IW/CPE of 1.00 and 0.75 significantly increased leaf number, female flower production and yield over IW/CPE ratio of 0.50. The seasonal water requirement with 20 mm IW at IW/CPE ratios of 1.00 and 0.75 was 930 and 680 mm respectively. The results of the above experiment after 16 years of planting revealed that cumulative yield since bearing was significantly influenced by quantity and frequency of

irrigation. Influence of different levels and frequencies of irrigation are presented in Table 44.1. The mean yield of the palms under the above treatment namely, IW/CPE ratios of 1.00 and 0.75 with 20 mm IW were 123 and 121 nuts/palm/year, respectively.

Table 44.1: Cumulative yield of palms as influenced by depth and frequency of irrigation

Depth of water (mm)	*IW/CPE ratio*			*Mean*
	1.00	*0.75*	*0.50*	
20	918	872	637	809
40	834	783	776	798
60	769	698	741	736
Mean	841	784	718	

In another experiment at CPCRI, Kasaragod, COD × WCT hybrid produced 147 nuts/palm/year with 20 mm of IW at IW/CPE ratio of 0.75 compared to 122 nuts/year/palm under rainfed condition during 1986 to 1988. Similar trend was observed with WCT × COD hybrid and WCT also.

Varadan *et al.* (1990b) have reported that nut yield of coconut WCT palms increased significantly when IW was given at 30 to 45 mm with IW/CPE ratio of 1.00 along with mulching at 50 kg per palm.

Several workers have reported that coconut palms can withstand salt concentration ranging from 0.6 to 1.0 per cent (Shanmugam, 1973). Studies at CPCRI, Kasaragod revealed that irrigation with sea water at the rate of 90 l/palm in basins of 1.5 m radius twice a week was as good as irrigation with fresh water and increased yield by 41 per cent over rainfed palms in sandy soils. In sandy loam soil, irrigation with sea water combined with fresh water in the ratio of 1:2 recorded the highest yield (Table 44.2).

Table 44.2: Effect of sea water and fresh water irrigation on the yield of coconut (1967 and 1968)

Treatment	*Mean yield (nuts/palm/year)*
a) Sandy Soil	
1. Irrigation with sea water	42.2
2. Irrigation with fresh water	43.0
3. Unirrigated	30.0
b) Sandy loam soil	
1. Unirrigated	52.6
2. Sea water + fresh water (2:1)	60.8
3. Sea water + fresh water (1:2)	80.5
4. Sea water alone	67.1
5. Fresh water alone	53.6

Experiments conducted during 1977 to 1979 at CPCRI, Kasaragod on sea water irrigation of coconut in littoral sand revealed that EC of the soil increased during summer months but after the monsoon there was no significant difference in EC of soil which were irrigated either with sea water or fresh water. These results show that in high rainfall areas sea water could also be used for irrigation in sandy soils without any effect on the coconut palm or soil characteristics.

Irrigation Methods for Coconut

The surface irrigation methods commonly adopted for irrigation of coconut are flooding, basin irrigation, sprinkler or perfosprays and drip irrigation.

Though higher yield of coconut is realised under flood irrigation than basin irrigation (Bhaskaran and Leela, 1978), there is considerable wastage of irrigation water under flood irrigation, as practiced in certain areas of Tamil Nadu and East and West Godavari districts of Andhra Pradesh.

In basin irrigation, water is applied in the basins of 1.8 to 2.0 m radius around the palm and there is partial wetting of root zones. Irrigation channels are provided in the centre of the two rows and each basin is connected with this channel. In this method also there is loss due to deep percolation and surface evaporation. Application of water in the basin through use of hose pipe is being advocated to reduce water loss in transit. This is being done in the Kallada Tree Irrigation Project in Kerala (Anonymous, 1982).

Sprinkler irrigation or perfosprays is most suited for intercropping or mixed cropping systems in coconut gardens where the entire surface is required to be wetted. Irrigation efficiency is high in this method compared to basin and flood irrigation.

Drip irrigation is ideally suited for widely spaced crop like coconut and it saves water, energy, labour and the efficiency is high. Based on the study during 1985–87 at CWRDM, Calicut it was concluded that the yield of coconut with drip irrigation at the rate of 30 l/palm/day during January to May was comparable to basin irrigation at the rate of 600 l/palm/week (Table 44.3). The benefit cost ratio for drip and basin methods were worked out to be 4.8 and 1.2 respectively (Anonymous, 1988).

Table 44.3: Mean yield of coconut under different irrigation methods

Treatments	*Yield of nuts/palm/year*			*Mean*
	1985	*1986*	*1987*	
1. Basin irrigation @ 600 l/palm/week	59.3	58.3	72.3	63.3
2. Ring irrigation @ 300 l/palm/week	50.8	50.3	46.8	49.3
3. Sprinkler irrigation @ 60 l/palm/day	48.7	56.3	60.3	55.1
4. Drip irrigation @ 30 l/palm/day	59.3	67.5	51.2	59.3
5. No irrigation	51.5	68.0	36.7	52.1

Drip irrigation demonstration for coconut at the rate of 30 l/palm/day in various districts of Kerala by CWRDM during 1985 to 1988 has shown that the yield of nuts improved significantly from the third year after starting of the irrigation (Anonymous, 1988).

In littoral sandy soils at Kasaragod, drip irrigation at the rate of 32 l/palm/day recorded 32.9 nuts/palm/year which was 38 per cent higher than the yield under basin irrigation with 200 l/palm at four days interval and 57 per cent higher than rainfed condition (Anonymous, 1989).

Water Management Practices for Coconut Under Rainfed Conditions

Despite the efforts for development of water resources and providing subsidy for installing irrigation systems, vast areas under coconut will remain under rainfed condition especially in Kerala. Coconut palms on the west coast suffer from severe moisture stress during November to May (Yusuf and Dhanapal, 1988). *In situ* soil water conservation and reduction of surface evaporation are the two approaches which will alleviate moisture stress under rainfed condition. Conservation practices such as contour bunding and terracing (Vijayalakshmi and Marar, 1959) and opening short linear trenches across the slope in a staggered manner (Rethinam, 1987) were suggested for intercepting run off water.

For reducing surface evaporation and improving soil water retention, the following methods were suggested:

i) Mulching with coconut husks, coir dust and dried coconut leaves.
ii) Cover cropping to reduce evaporation loss.
iii) Intercultivation.
iv) Application of common salt at the rate of 2 kg/palm in the basin.

Studies on the response to husk burial in coconut gardens (1937 to 1943) at Kasaragod in red sandy soil (Marar and Kunhiraman, 1957) indicated beneficial effect on productivity after three years which continued up to six years. Trenches with 0.3 to 0.45 m depth and 1.8 m length dug up in between rows of coconut trees were filled up at the rate of 1000 husks per trench. The treated plots yielded 22 nuts/palm more than the control. The experiment was repeated during 1948 to 1950 and the results were similar. At Pilicode, Kerala, husk burial at 37.5 cm depth was found to be economically viable. Results of husk burial at the rate of 1000 coconut husks in trenches of 150 cm length and 40 cm depth between rows recorded maximum available moisture at Veppankulam (Balasubramaniam *et al.*, 1985). Husk burial in the basin of the coconut palm in 2 m radius also improved the yield. The total yield per palm for four years was 235 and 265 nuts/palm for trench burial and mulching basins, respectively compared to 177 nuts/palm under control.

Available water capacity of littoral sandy soil has increased from 0.7 to 1.94 per cent by the incorporation of coir dust at the rate of 50 kg/palm as mulch material (Joshi *et al.*, 1982) and mulching with 50 kg green leaves/palm reduced the soil temperature by 6°C at a depth of 0 to 20 cm in laterite soil (Varadan and Rao, 1983).

Water Management Practices for Coconut under High Rainfall Conditions

In high rainfall regions like Kerala and coastal Karnataka, coconut palms in certain places suffer due to waterlogging especially during rainy season. Paddy fields converted to coconut gardens also experience waterlogging problem in rainy season. Shallow channels (relief drains) are opened to remove surplus water and are connected to main drains to lower the water table. But no systematic studies have been reported on drainage requirement and design for coconut since this crop is normally grown in upland conditions.

Surface drains to a depth of 1.5 m in between rows of coconut palms, to remove excess water from the root zone during rainy season as well as during irrigation, had increased the yield of nuts from 35.7 to 66.1/palm/year, at the Agricultural Research Station, Nileshwar.

Future Thrust Areas

The following areas of work are suggested:

1) Since the major cropped area under coconut is under rainfed condition, agro-techniques are to be developed for *in situ* soil water conservation for individual holdings and groups of holdings on watershed basis.

2) As drip irrigation has been found to be effective for coconut especially in rolling topography, refinement of quantity of irrigation for drip method under different agro-climatic conditions is needed.

3) The water demand or consumptive use of water of coconut has to be quantified for different stages of growth based on soil-crop-climate method.

4) Drainage requirement for coconut has to be quantified and suitable techniques including design to be developed for adoption at individual and group levels.

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DISCUSSION

K.S. Jayasekara: 1) Out of 4.6 mm/day ET, how much is accounted for surface evaporation? 2) Have you studied water uptake pattern in deep soil layers in coconut?

Mohd. Yusuf: 1) It is not possible to separate evaporation components from the evapotranspiration for tall trees like coconut. 2) Water extraction has been studied up to 120 cm soil depth.

Mwinjaka: Is one year data enough to conclude that sea water does not affect the productivity of palms and soil conditions?

Mohd. Yusuf: The experiment on the use of sea water for irrigation purpose was started in 1958 and continued till 1968. The data presented pertains to latter part of two years.

COCONUT BASED FARMING SYSTEMS RESEARCH AND DEVELOPMENT IN THE PHILIPPINES

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ABSTRACT

Research conducted focused on intercropping, livestock integration, processing, farmer and community characterisation and assessment. The need to fertilise both the coconuts and intercrops was demonstrated for coffee and cacao. On-farm trials on appropriate management of promising intercrops, cropping patterns and livestock were undertaken. Likewise, processing and establishment of rural-based livelihood projects on coconut were proposed for implementation.

Rapid rural appraisal of coconut communities identified key factors that affect the practices of farmers. Case studies revealed the key ingredients for successful CBFS, that is, interaction among technology and farmer and environment. Moreover the need to strengthen farmers' organisation, effective transfer of technology and linkages among different support systems is emphasised for future programmes.

INTRODUCTION

Coconut occupies 30 per cent of the total agricultural area of the country, covering about 3.112 million hectares. The Philippines supply about 52 per cent of the total global supply of exported copra and oil. Approximately 18 million people (almost one-third of the country's population) are directly or indirectly dependent on the crop for their livelihood (PCA, 1988).

As in other crop-based industries, the coconut industry is characterised by wide income discrepancy problems. The production sector which is the larger segment of the industry is generally composed of small farmers with low production technology, thus low income.

The major problem of low income in the production sector, 91 per cent of whose members are smallholders (<5 ha), could be attributed to several interacting factors that are either beyond or within the control of these

farmers. Amongst others, these include the declining and unstable prices of coconut products; declining productivity of coconut trees due to senility and/or non-adoption of recommended coconut management practices; under utilisation of coconut farms either due to tenure, negative attitude of the farmers, absence or a weak socio-economic organisation or ineffective support services or credit and their combinations.

Against this backdrop, the development of coconut based farming systems (CBFS) as a means to increase and stabilise the income of small coconut farmers becomes strategic. The CBFS integrates complementary enterprises in coconut farming such as intercropping, livestock integration, processing of coconut products/by-products and intercrops and marketing. CBFS increases productivity per unit area, enhances employment opportunities and buffers the effects of low and fluctuating copra prices. Meanwhile the sustainability of the system has to be secured.

Normally, the coconut farmer and his family live within the coconut farm on which they depend for their every day subsistence and livelihood. Income from coconut monocropping is low, averaging only P 2,000/ha/year (1 US Dollar = ₱27; Sept. 1991) (Villegas, 1991). This amount is considerably lower than the current poverty threshold level. Thus, every household generally maintains one or more livestock and plants various crops, mostly staple, vegetables and fruit trees in patches around the house, a form of CBFS, mainly for their own consumption and whenever possible, to augment their cash income.

At present, less than 35 per cent of the areas planted with coconut are used for CBFS. Of these areas, about 0.4 million hectares are used for extensive cattle production. More than 2.1 million hectares are still available (Felizardo, 1983).

Since the early seventies research has been undertaken by different agencies in the country independently of each other. The Philippine Coconut Authority (PCA), the Department of Agriculture (DA), some state Universities and Colleges, notably the University of the Philippines at Los Banos (UPLB), Visayas State College of Agriculture (ViSCA) and the University of Southern Mindanao and PCARRD are the more active institutions conducting this research. An Interagency Working Committee (IWC) involving these six agencies was created in 1989 with the support of IRHO/CIRAD, to implement a programme complementing the existing National Coconut-Based Farming Systems.

INTERCROPPING

Early CBFS studies provided benchmark information on the status of technology on intercropping under coconut (Sangalang *et al.*, 1990).

Main Crop Species Under Coconut

A survey in nine provinces of Luzon and Visayas revealed that there were 26 species of annual crops grown under coconut with rice, corn, peanut, cassava, sweet potato and *gabi (taro)* being the most popular (Cuevas *et al.*, 1974). Among perennials, banana, particularly the Saba variety, was found to

be the most common intercrop. Also reported was the scattered planting of a number of fruit trees, such as lanzones (Creencia, 1975). Lately pineapple has become very popular and successful.

In Mindanao, many farmers and some private companies are more interested in cacao, coffee and black pepper, while small farmers grow root crops, corn and others. Results have shown that the production and profitability of different intercrops generally vary across locations. Moreover, the production and profitability of the same intercrop varies widely even within the narrow confines of adjacent provinces (Alviar *et al.*, 1975).

Research on intercropping has focused mainly on the characterisation of the responses of various crops to shading. Screening trials showed the highly diverse yield responses of different annual crops when grown under shade. Satisfactory intercrops are those which give yields greater than 60 per cent of their yield in the open such as corn, sorghum, sunflower, peanut, eggplant, arrowroot, garlic and bush sitao (Carandang, 1975). *Taro, ramie,* sweet pepper, *gabi* and hot pepper which gave higher yields under shade than in the open are classified as shade-loving crops (Paner, 1975; Carandang, 1975).

Extensive screening of 26 vegetable species under shade showed that tomato, Chinese cabbage, *pechay* and cucumber have a potential for wet season planting. Bush lima and cabbage were found promising during the dry season (Abilay, 1983).

VARIETY SCREENING

Annuals

Contrasting reports on the yield response of some crops under shade, such as *gabi* and arrowroot, suggested the need to select varieties that are tolerant to shade. Varietal screening trials have identified shade-tolerant varieties of crops under coconut. On-station experiments on root crops identified suitable varieties of sweet potato (VSP–2, 18.7 t/ha), cassava (Vassourinha, 20.2 t/ha), yam (Ubi–Cebu, 18.05 t/ha), arrowroot (Cuenca, 11.7 t/ha) and *gabi* (PRG-068, 7.13 t/ha) for planting in partially shaded areas. Suitable varieties/hybrids of mung bean, peanut, corn, tomato, cucumber, cabbage, pole and bush *sitao*, and white potato were likewise identified in a number of on-station and on-farm trials (Abilay *et al.*, 1983).

Yield reduction also varied with the degree of shading for different crops or varieties. In soybean, a 30 per cent yield reduction was noted with 40 per cent shading (Catedral and Lantican, 1977) while in mung bean, the reduction was about 70 per cent. In sweet potato, at zero and 31 per cent shade and under coconuts with 43 per cent shade, yield and yield components were reduced by 6 to 97 per cent (Mwanga, 1986).

Perennials

Variety trials on coffee showed that Robusta variety (Ivory Coast and Philippine strains) gave significantly higher yields than Arabica and Excelsa (Blancaver, 1990). Local cacao hybrids gave yields comparable with the high

yielding foreign introductions in terms of dried bean weight when tested in UPLB (Sangalang and Moncada, 1989). Breeding trials in Kabacan, Cotabato identified cacao hybrids that gave higher yields than the local control (Trinitario). All test varieties, however were found susceptible to pod borer, pod rot and rat infestation. Pod borer, moreover, was observed to prefer green pods to red and maroon pods.

Intercrop Characteristics

The morphological and physiological effects of shading on different crops were also studied to identify desirable characteristics for predicting high yield which can be used as selection criteria for shade tolerance.

In mung bean, the characteristics associated with shade tolerance were higher harvest index, more pods per plant, fewer leaves at maturity, shorter root and stem length, and greater resistance to *Cercospora* leaf spot. Similarly, higher harvest index and more pods per plant were found to be positively correlated with peanut yield (Abilay, 1981).

In sweet potato, the total leaf protein, chlorophyll and carotenoid contents, among others, generally increased with shading. With a 5 to 25 per cent increase in total protein and carotenoid level, the development of a high yielding and highly nutritive and shade-tolerant sweet potato variety was found to be feasible (Mwanga, 1986).

Coconut Characteristics

Identification of the suitable characteristics of coconut for CBFS is also being studied. Initial results revealed that in the development of coconut varieties suited for intercropping, those characteristics correlated with reduction of sunlight, such as fewer leaflets and shorter fronds and petioles, should be considered. However, the inheritance of these characteristics and their relationship with yield should first be established (Barile and Sangalang, 1990).

Crop Management

The need to fertilise both the coconut and the intercrops was demonstrated by separate experiments conducted in Davao and Cotabato, using coffee and cacao as intercrops, respectively (Pahm and Cabangbang, 1990). Technology generation on appropriate management options for promising intercrops and cropping patterns is also being conducted, such as fertiliser (type, rate, timing etc.), crop establishment, crop mix, pest control, and spacing plant density trials, among others.

To package location and situation-specific technologies, the Dept. of Agriculture, through the Regional Integrated Agricultural Research Systems (RIARS), conducted field verification trials of promising coconut intercropping models in selected provinces of the country from 1983 to 1989.

Livestock Integration

For livestock integration, feed resource assessment to determine the available herbage and optimum stocking rate of the existing vegetation under

coconuts was conducted. In addition, assessment of the nutritive value of available forage and the adaptability and management requirements of different species under coconuts were studied. Upgrading of native *carabao* by artificial insemination as well as screening of forage grasses and legumes, their establishment and suitable crop combinations under coconut were also studied.

A study assessing the stocking rate of native pastures under coconuts in Sta. Cruz, Laguna for goats and sheep showed that across season and cutting interval, grasses predominated, followed by broad leaves, legumes, then shrubs. It was also found that more frequently cut herbage had higher protein, but lower calcium content. Dry season forages were found to be more digestible and higher in dry matter, crude protein and calcium but lower in ash and cell wall analyses (Trung *et al.*, 1990).

Feed selectivity trials for goats and sheep were also conducted. It was discovered that grasses and legumes were preferred by both sheep and goats over broad leaves and shrub fodder during both dry and wet seasons.

Coconut Processing

The coconut industry is vulnerable to changes in the foreign market for coconut oil, copra and copra meal. As a medium- to long-term strategy, it would be wise to develop the domestic market for coconut products (Sangalang *et al.*, 1990). Coconut processing and utilisation research activities focus on the downstream processing of coconut oil into coconut fatty acids, fatty acid esters, fatty alcohols and their derivatives. Production of non-traditional, low cost and nutritious coconut food products such as soft cheese, hard cheese, yoghurt and coco beverages, are also being supported with the objective of developing small-scale coconut-centred enterprises for coconut villages. Production of non-edible coconut products such as charcoal and coir fibre are likewise being improved. Coco lumber from the old coconut trees is already widely used as a housing material in the countryside.

The establishment of rural-based livelihood projects on coconut products such as coconut oil, soap, coconut brown sugar and syrup, dehydrated mature coconut meat and dehydrated young coconut meat have been proposed (Sanchez *et al.*, 1988). During 1991 the Industrial Technology Development Institute of the Department of Science and Technology started to sell a very cheap (US $ 25) and popular soap production unit.

Communication

The findings of a study on extension of innovative farming technologies to coconut farmers indicated that effective technology transfer in coconut farming requires a multi-media approach composed of radio, interpersonal contacts and reading materials (Gomez, 1988).

Land Suitability Classification

Land classification for coconut was undertaken using land use system analysis. The land quality requirements for selected crops such as banana,

coffee, cacao, mung bean, peanut, pineapple, black pepper, sweet potato, cassava and pasture grass were likewise formulated.

Results indicated that only 25 per cent (around 790 thousand ha) of coconut areas are assessed as better coconut land (S1 and S2), the rest are barely suitable (S3) for intensive coconut production. S1 and S2, potential areas for expansion of coconut, cover around 406 thousand ha (UPLB, 1989).

The study identified the following priorities:

i) Rehabilitation through fertilisation or replanting and expansion in S1 and S2 area.

ii) Intercropping in S1 and S2 areas.

iii) Intensification of other crops in S3 and S4 areas.

Crop Modelling

A model in FORTRAN that can predict the annual performance of an established coconut farm over a 20-year period when it is replanted at various rates was developed by UPLB researchers (Peralta *et al.,* 1983). Inputs to the model include, among others, a general description of the location, farm size, variety, planting pattern, spacing and replanting management options such as fertiliser, pest control and coconut intercropping schemes. The simulation enabled the identification of areas requiring more research such as the effects of the coconut canopy on intercrop yields, the behaviour of the system in different geographical settings, expansion of the intercrop data base to provide planners with more options and output generation reflecting meteorological uncertainties such as typhoons (Peralta *et al.*, 1983).

Methodologies

The farmer's decision prevails when it comes to modifying his farming systems. Since researchers are responsible for providing farmers with adequate and comprehensive information on which to base a farm decision, studies on approaches to community characterisation and assessment as well as understanding the complexities of the farmers', CBFS have been given priority in recent years.

Using Rapid Rural Appraisal or RRA as a methodology, FSSRI-UPLB was able to identify the key socio-economic indicators that influence the existing farming system practices of coconut farmers in a community. RRA facilitates the accurate description of target clients (that is, the coconut farmer, the farm household and the farming community) as well as the external factors that affect their CBFS, such as the bio-physical characteristics of their farms, access to support systems such as market, input supply, infrastructures and credit, and socio-cultural and political pressures, among others.

RRA provides an accurate description of the total cause and effect of the interacting internal and external forces affecting a coconut farmer. Any effort to change the existing FS should be based on such descriptions and in close consultation with the farmers alone. Whenever possible, the programme should focus less on changing the farmer's whole enterprise and more on enhancing productivity within the existing FS. The goal is to make the farmers adequately and reasonably self-reliant.

To better understand the complexities of a farmer's CBFS, successful farmers' practices were documented and analysed using the whole farm approach. The project identified the key ingredients that contribute to a successful CBFS. The need for positive interactions between technology, farmer and environment was emphasised. In order to be adoptable, a technology should be simple enough to be implemented by the farmers, the technology requirements should be available or accessible to the farmers; and the impact should be achieved within a short time. Successful credit and transportation are also important factors. Farmers are entrepreneurial, open to new technology and willing to use the necessary support services. The bio-physical characteristics of the farm should generally be compatible with the crop requirements. However, the market potential of the commodity is the single most important factor that could sometimes make a farmer-entrepreneur plant a crop that may not grow very well in his farm.

The failure of past development programmes on CBFS was also looked into and been attributed to different factors. On an organisational level, there is a lack of coordination between agencies working on the coconut industry. Credit is not accessible to farmers who need it most. The information campaign for market assistance is also ineffective, which often results in excess production and low prices of farm products. Due to logistical constraints, promising research results were not effectively transferred to extension workers and farmers. Inputs, particularly good quality planting materials and fertilisers, are not available when and where they are needed. On a scientific level, there is a lack of scientific knowledge which restricts the formulation of recommendations on particular crops/varieties suitable for different coconut cover or density.

General Discussion

There is already a wealth of information gathered from the experience of researchers and successful farmers on alternative technology options in coconut farming. The suitability of present coconut areas for different crops has been evaluated on a macro-level (UPLB, 1989) and at farm level. Holistic analysis of farmers' CBFS and coconut communities have identified key indicators that could guide researchers and development workers. The important aspect at this time is how to fit the available technologies into the farmers' system (socio-economic, cultural and bio-physical compatibility) and enhance the available technology's eventual utilisation in the farm and the community (adoption/adaptation) to increase farmers' productivity and income.

What was found lacking in past development programmes was the effective transfer of viable technologies to communities that could use them. At one time, two assistance packages were offered to coconut farmers, that is, technology and technology + credit. Previous workshops pointed out the need for a third package: credit + technology + marketing (Hilario, 1985).

Technically, there are still research gaps that restrict the formulation of firm recommendations, particularly with regard to intercropping. Reported

research conclusions often fail to determine environmental conditions and specify the bio-physical characteristics of the system.

The pressures imposed on coconut micro and macro-environments under different types and intensity of diversification are still not known. Ideally the CBFS alternatives offered should enable the coconuts to survive, compete and/or relate symbiotically with the other components of the system. Thus, research is being conducted in the Philippines to determine the coconut-intercrop association at different coconut densities, using different crops and varieties. The main aim of the study is to check the performance of crops when subjected to various conditions of light transmission and competitivity (or complementarity) at soil level. This is done by modifying part of the existing coconut plantation density and by removing some trees to achieve, on the same site, different light transmission ranges and bio-physical components of the system (Benard, 1990). Measuring the global radiation and the photosynthetically active radiation (PAR) under cover in different locations, both of which depend on the site and the extent of the canopy should result in a single model capable of establishing the suitability of any particular coconut cover for some main crops or varieties.

CONCLUSION

In order to attain the ultimate goal of CBFS, which is to promote the socio-economic well-being of the small coconut farmer, it is necessary to strengthen the national structure for coordination credit and marketing, improve logistical support for technology transfer, make planting materials and fertilisers more available and enhance basic knowledge of crop diversification under coconut.

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DISCUSSION

S.B. Kadrekar: Whether the economics of the farming system have been worked out?

Guy H. Benard: The economics aspect is part of the suitability of the system.

EXPERIENCES IN COCONUT BASED FARMING SYSTEMS IN SRI LANKA

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ABSTRACT

This paper examines the agronomic feasibility of adopting coconut based farming systems (CBFS) for increasing the production and productivity of coconut in Sri Lanka, particularly in small holdings.

Four principal types of CBFS practised in Sri Lanka, namely intercropping with seasonal and annual crops, mixed cropping with perennial crops, alley cropping with a combination of tree legumes and seasonal crops and mixed farming involving cattle and pasture, are described. Since coconut plantations are maintained under rainfed conditions, greater emphasis is given to rainfall as a major determinant of cropping systems. Also, attention is focused on high density multi-species cropping systems due to the decreasing size of coconut holdings.

The benefits of CBFS in terms of increasing nut and copra yield of coconut palms have been attributed to complementary effects of crop and/or animal association. The importance of on-farm research approach as a catalyst for developing CBFS acceptable to small farmer is emphasised.

INTRODUCTION

General

Sri Lanka is a tropical island covering a total land area of approximately 6.56 million hectares and based on the rainfall pattern, there are three distinct agroecological zones—wet, intermediate and dry.

Coconut Sector

Coconut palm occupies a pre-eminent position in the plantation sector with a total extent of 419,500 ha and accounts for 22.6 per cent of agricultural land-use. Of this hectarage, 70 per cent is in the 'coconut triangle' and Southern Coastal belt within the Low Country Wet and Intermediate Zones. The smallholder sector accounts for 86 per cent of the total area under coconut with the majority of the holdings are less than 2 ha (Agriculture Census, 1982)

and were essentially maintained as monoculture providing low economic returns. The most practical approach to alleviate this situation is through the adoption of Coconut-Based Farming Systems (CBFS).

Scope of CBFS

The present system of planting coconuts at 8 × 8 m and the favourable environment particularly, rainfall and soil in the Low Country Wet and Intermediate Zones makes it possible to grow a range of crops, trees and raise livestock in association with coconut. Diversification of coconut lands minimises the risk of over-dependence on coconut *per se* and cushion against fluctuations in price of coconut. It is estimated that some 200,000 ha of coconut lands in the "Coconut Triangle" and Wet Zone have the potential for adopting CBFS.

Coconut Based Cropping/Farming Systems

During the last two decades, the Coconut Research Institute (CRI) has been engaged in research on the possibilities of optimising the use of coconut lands in the Wet Zone and Coconut Triangle, with different cropping/farming systems, involving seasonal, annual and perennial crops and livestock components. More recently, research on CBFS with annual and fruit crops has been strengthened at the Regional Agricultural Research Centre (RARC) at Makandura, NWP. The major findings on four different cropping/farming systems are presented in this section.

Coconut Based Intercropping Systems (CBIS)

CBIS involves the cultivation of seasonal and long-term annual crops in young (zero to five years) and mature (above 35 to 40 years) plantations. Based on these results obtained from studies at CRI and RARC, cassava, ginger, yams, banana and pineapple are identified as promising intercrops for wet and intermediate zones and are popular among land owners because of their ease of management and ready market. The yield performance of promising intercrops under mature coconut stands are given in Table 46.1.

CBFS involving annuals are popular among small holders because of the short pay back period and high cash returns. For this reason, intercropping with either annuals or fruit crops or a combination of both is widely practised in young plantations during the pre-bearing stage.

Among multi-period fruit crops, feasibility studies in banana, pineapple and passion fruit under coconut are being conducted at RARC, Makandura. In pineapple, studies conducted at RARC (1988) have shown that one double row and two single rows are the best systems under coconut, giving a fruit yield of 23.2 t/ ha. Furthermore, several low country vegetable and leafy vegetable species have been tested for their suitability under coconut (Anonymous, 1986/87). These studies have shown that brinjal cv. Lenairi, winged bean cv. UPS 122, creeper type of spinach, red stem green leaf type *Amaranthes* sp. and broad leaf type *Alternanthera* species performed better under coconut shade (Table 46.1).

Table 46.1: Yield performance of seasonal and annual intercrops under coconut

Type of crops	*Crops*		*Yield/ha/year*
1. Food crops			
Root and tubers	Cassava	*Manihot esculenta*	11.0 t
	Sweet potato	*Ipomea batatas*	4.8 t
	Taro	*Colocasia* spp.	6.5 t
	Cocoyam	*Xanthosoma* spp.	19.6 t
Grain legumes	Cowpea	*Vigna unguiculata*	815 kg
	Groundnut	*Arachis hypogaea*	1900 kg
	Pigeon pea	*Cajanus cajan*	1000 kg
	Soybean	*Glycine max*	780 kg
	Winged bean	*Psophocarpus palustris*	1117 kg
Cereals	Sugar cane	*Saccharum officinarum*	45.0 t
	Maize	*Zea mays*	800 kg
Fruit crops	Banana	*Musa* spp.	49 t
	Pineapple	*Ananas comosus*	14 t
	Passion fruit	*Passiflora edulis*	06 t
	Papaw	*Carica papaya*	10 t
2. Spices and condiments			
	Ginger	*Zingiber officinale*	20.0 t
	Turmeric	*Curcuma longa*	7.3 t
3. Vegetables and leafy vegetables	Bushitao	*Vigna* spp.	2.0 t
	Winged bean	*Psophocarpus palustris*	3.2 t
	Brinjal	*Solanum melongina*	9.5 t
	Thampala	*Amaranthes* spp.	28.3 t
	Mkunuwenna	*Alternanthera* spp.	79.3 t
	Nivithi	*Spinach* spp.	10.8 t

Coconut Based Mixed Cropping Systems (CBMS)

Mixed cropping refers to a system in which other perennials are grown in association with coconut. Our experience with CBMS largely involves cultivation of pasture and fodder species, export agricultural crops such as black pepper and coffee and fruit crops under mature coconut stands in the Wet and Intermediate Zones.

Since natural pasture species under coconut were unproductive, *Brachiaria miliiformis* (Cori grass) and Guinea B were recommended as the most suitable pasture and fodder varieties for coconut lands (Santhirasegaram, 1966). Ibrahim and Ferdinandez (1984) showed that *Brachiaria dictyoneura* gave 40 per cent more herbage dry matter than Cori grass. However, Cori grass is still the most widespread pasture species grown under coconut. The herbage dry matter yields of several other pasture and fodder species tried are given in Table 46.2. Work done at the CRI has also shown that nutrient value of pasture could be improved by mixing with a pasture legume species such as Centro, Pueraria and Siratro. Among them, Centrosema is known to mix well with Cori, Ruzi and Guinea grasses and also withstand heavy grazing (Ferdinandez, 1978).

Table 46.2: Mean herbage yield of pasture and fodder species under coconut

Species	*Herbage dry matter (kg/ha/year)*
Brachiaria miliiformis (Cori grass)	7766
Brachiaria brizantha (Pallisade grass)	8974
Brachiaria dietyoneura (Koronivia grass)	10854
Brachiaria ruziziensis (Ruzi grass)	7489
Digitaria decumbens (Pangola grass)	6700
Setaria sphacelata (Setaria)	8135
Panicum maximum (Guinea B)	7588
(green panic)	7699
LSD (P = 0.05)	1045

In long-term feasibility studies undertaken by the CRI in 1977, satisfactory yields in black pepper, coffee, cocoa, cinnamon and clove have been reported from the Wet Zone (Table 46.3). Of these crops, black pepper, coffee and cinnamon are popular mixed crops in small holdings while cocoa is popular in the estate sector. However, the long gestation period renders them less attractive to the small landholders compared with annual intercrops. Betel is another mixed crop popular among small holders in the coconut triangle because of its high profitability and ready market. Recent studies undertaken at RARC, Makandura showed that *Citrus* sp. Lemonime is a promising mixed crop for coconut plantations in the wet and intermediate zones, as it produces fruit throughout the year and has a ready market. Feasibility studies on growing lime (*Citrus* sp.), mango (*Mangifera indica*), cashew (*Anacardium occidentale*) and mulberry (*Morus alba*) as mixed crops under coconut are in progress at the CRI.

Table 46.3: Yield performance of perennial mixed crops under coconut

Mixed crop	*Planting density/ha*	*Mean yield (kg/ha/year)*
Cocoa: *Theobroma cacao*	850	720
Coffee: *Coffea canephora*	850	333
Black pepper: *Piper nigrum*	850	930
Clove: *Syzygium aromaticum*	120	136
Cinnamon: *Cinnamomum verum*	25260	435
Lemonime: *Citrus* sp.	500	24000
Lime : *Citrus* sp.	500	5000
Betel: *Piper betel*	14500	35500

Coconut Based Alley Cropping Systems (CBAS)

This system of cropping has been introduced recently for coconut replanting/new-planting areas, especially in the Intermediate Zone. This system consists of establishing hedge-rows of nitrogen fixing multi-purpose trees such as *Gliricidia sepium*, 4 × 0.5 m apart (5000 plants/ha) between

coconut rows, planted on the avenue system at 10 × 5 m (200 trees/ha). For successful establishment of coconut seedlings in the drier parts of the Intermediate Zone, Gliricidia tree legume could provide partial shade and a favourable microclimate and early growth of coconut seedlings. Periodic loppings of Gliricidia trees (18.75 t/ha) could also supply sufficient green manure/surface mulch to coconuts and seasonal crops grown in the alley between hedgerows. Among seasonal crops, cowpea, groundnut, pigeon pea, cassava, maize and yams have shown considerable promise in alley cropping trials in the intermediate zone.

Coconut Based Mixed Farming Systems (CBMFS)

CBMFS refers to the utilisation of coconut plantations for integrating with livestock on natural/improved pasture. Using the vast experience on improved pasture production and raising of cattle under coconut, CRI set up an integrated mixed farming model in the Intermediate Zone of Coconut Triangle (Liyanage *et al.*, 1988). Santhirasegaram (1967) recommended Local × Jersey × Sindhi cross-bred cattle to the "coconut triangle" areas. Since pasture production in the intermediate zone is seasonal, attempts have been made to introduce leguminous tree fodder such as *Gliricidia sepium* and *Leucaena leucocephala* (cv. K 636) into coconut pasture system. Experience gained over the past five years clearly indicated that Gliricidia has a greater potential to supply good quality fodder, particularly during the dry season. In the integrated mixed farming model, four Local × Jersey cross-bred cattle were allowed to graze on Cori grass/Pueraria mixed pasture during the wet season on a rotational system. During the dry season, cattle were fed with 5 kg fresh fodder mixed with 10 kg urea treated paddy straw (4 kg urea in 100 l water sprayed on 100 kg straw). This system produced sufficient forage (35 t/ha/year) to maintain four dairy animals without giving concentrates. The performance of pasture/legume mixture, tree fodder and animal components in this system are shown in Table 46.4. These results indicated that the mixed farming system could considerably improve the productivity of coconut lands.

Table 46.4: Performance of pasture/fodder and cattle in the mixed farming system

Component	*Productivity*
B. miliiformis	17.95 t/ha/year (DM)
P. phaseoloides	7.46 t/ha/year (DM)
L. leucocephala	7.19 t/ha/year (fresh fodder)
L. leucocephala + *G. sepium*	2.0 t/ha/year (fresh fodder)
Jersey × Local cattle	306–590 g/day (live weight gain)
	3.48 l/day (milk yield – 1st lactation)

Although mixed farming systems with buffalo and sheep grazing on natural pasture under coconut are also being practised in some estates, it is not done on a commercial basis as yet.

Cropping Systems in Relation to Rainfall

The distribution of rainfall in the Coconut Triangle and Wet Zone is bimodal with two distinct rainy seasons, south-west (*Yala*) and north-east (*Maha*). Wet and wetter parts of the intermediate zone are suitable for intercropping and mixed cropping systems, while drier parts of the intermediate zone favour intercropping with seasonal and annuals and mixed cropping systems involving certain drought tolerant species.

High Density Crop Models

Although it is recognised that a combination of several crop species together could make more efficient utilisation of resources, experience on coconut based high density cropping systems is very limited. One such system established in 1977 included a combination of cocoa, coffee and black pepper planted in a mature coconut plantation in the Wet Zone. The component crops consist of a single row of cocoa in the centre between coconut rows, two rows of coffee on either side of the cocoa row, two pepper vines trained on to Gliricidia support along the coconut row and another pepper vine trained to each palm. This arrangement of crop components gave a density of 305 cocoa plants, 484 coffee plants and 664 pepper vines and 156 coconut palms per ha. The results indicated that the productivity of coconut lands in the Wet Zone could be raised substantially without detriment to coconut palms (Table 46.5) whose yield has also been increased by 14.5 per cent. The system is particularly amenable to coconut small holdings with limited land in the Wet Zone.

Table 46.5: Productivity of high density crop model (9th year)

Component crop	*Planting density/ha*	*Yield/ha/year*
Coconut	156	13,628 (nuts)
Cocoa (Trinitario)	305	306.9 kg
Coffee (Robusta)	407	136.7 kg
Black pepper (on Gliricidia)	508	1069.9 kg
Black pepper (on coconut)	156	136.3 kg

Competitive and Complementary Effects of Different Components

Coconut being the main crop, long-term effects of different components in CBFS are of primary concern to growers. The interactions between components can result in either: (1) adverse effect on the palm due to negative interactions or competition between components, or (2) beneficial effect on the palm due to positive interaction or complementarity between components.

Competitive Effects

There is a general belief among some coconut growers that coconut yields would decline due to cropping system, particularly with long duration perennial crops, due to competition with each other for soil moisture and plant nutrients. In the absence of any information available from Sri Lanka on the extent to which soil moisture competition would reduce the yield of coconut, it

is recommended that selection of crops or crop combinations to suit rainfall pattern, and limiting mixed cropping to areas receiving more than 1500 mm rainfall per year could reduce or eliminate competition for soil moisture. Absence of major nutrients, particularly nitrogen and potassium on a legume pasture led to a significant reduction in copra yield of palms (Salgado, 1950). Absence of nitrogen and potassium fertiliser to Cori grass resulted in a 14 per cent reduction in nut yield of palms (Santhirasegaram, 1966). Based on these findings, it is recommended that the application of adequate amounts of fertiliser to coconut and other components separately would reduce competition for nutrients in CBFS.

The effect of shade from coconut canopy on crop components below is another aspect of competition in the cropping system, which has received less attention.

Complementary Effects

There is sufficient data from Sri Lanka to show that coconut palms have in fact benefited from CBFS, due to complementary effects between crop and/or animal components in the system. Early work done at the CRI (Santhirasegaram, 1966) has shown that in the intermediate zone improved pasture species, namely, *B. miliiformis* and *B. brizantha* increased nut yields by 6 per cent relative to control (Table 46.6). Long-term trials in the wet zone with black pepper, coffee etc. demonstrated a similar trend of increasing nut and copra yield, which ranged from 5 to 34 per cent and 13 to 33 per cent, respectively over monoculture (Table 46.7). The beneficial interactions of crop association have been attributed largely to improved nutrition of the palm, better retention of soil moisture, reduced weed competition and improved soil fertility (Table 46.8). The shade from coconut palms also provides optimum conditions to complement the growth of shade loving/tolerant crops such as cocoa, coffee, pepper, clove, yams, ginger and turmeric.

Table 46.6: Effect of pasture on the yield of coconut (nuts/ha/year)

Treatment	*1956*	*1957*	*1958*	*1959*	*1960*	*1961*	*1962*	*1963*	*Mean*	*Per cent Increase*
Control	7577	7795	6962	7958	7879	10257	9504	11463	8674	0
B. brizantha	7412	8748	7602	8511	8921	10492	10178	11989	9230	6.4
B. miliiformis	6930	9195	7103	9139	9139	10403	9709	12021	9203	6.1

The complementary effects of pasture/livestock association on coconuts were also demonstrated in mixed farming trials in the intermediate zone using cattle (Liyanage *et al.*, 1988). Although coconut palms in the mixed farming model were fertilised with sub-optimal doses of phosphate and potash without nitrogen, nut and copra yields of these palms were comparable with those in control plots during the initial stages and in the fourth year, there was in fact a 17 and 11 per cent increase in nut and copra yield, respectively (Table 46.9) due to continuous recycling of animal waste and crop residues (Table 46.10).

In addition, cattle association contributed to approximately 73 kg of dung and 30 l of urine per palm per year which could be substituted for the entire nitrogen and part of phosphorus and potassium requirement of the palm accounting for about 69 per cent saving on the cost of fertiliser. This has considerable practical importance especially to coconut small holders who seldom use chemical fertilisers for coconut. The coconut palm in turn provides a better grazing environment to cattle, as the microclimate under coconut shade is more conducive to them than in the open.

Table 46.7: Effect of mixed cropping systems on coconut yield (1977 to 1987)

Cropping system	*Mean yield (nuts/ha/year)*	*Per cent increase*	*Mean copra yield (t/ha/year)*	*Per cent increase*
Coconut only (control)	6123	–	1.79	–
Coconut + Cocoa	7504	22	2.18	22
Coconut + Coffee	8216	34	2.26	26
Coconut + Pepper	6424	05	2.03	13
Coconut + Clove	7191	17	2.13	19
Coconut + Cinnamon	7633	26	2.35	31
CV%	12.5		7.5	
Sig.	–		–	
SE	25.32		0.31	

Table 46.8: Effect of mixed cropping on soil fertility (0 to 15 cm depth)

Cropping system	*Physical*		*Chemical*				*Biological*
	Bulk density	*Moisture*	*Org. carbon (%)*	*Total N (ppm)*	*Avail. P (ppm)*	*Exch. K (me/100g)*	*Earth worm population/ m^2*
Coconut monoculture	1.56	9.06	0.86	957	9.6	0.14	28
Coconut + Cocoa	1.26	18.55	1.42	1184	29.4	0.18	214
Coconut + Coffee	1.23	12.91	1.36	1022	27.8	0.15	218
Coconut + Pepper	1.27	11.20	1.27	1461	55.9	0.12	191
Coconut + Clove/Banana	1.19	11.30	1.20	1154	32.3	0.18	204
Coconut + Cinnamon	1.25	10.69	1.44	1249	28.9	0.16	233
SE	0.195	1.20	0.275	8.7	2.4	–	–

Table 46.9: Effect of mixed farming on the yield of coconut

Farming system	*1987*		*1988*		*1989*	
	Nuts/ha	*Copra (kg/ha)*	*Nuts/ha*	*Copra (kg/ha)*	*Nuts/ha*	*Copra (kg/ha)*
Integrated system	12624	2170	10592	1822	16072	3319
Monoculture system	12416	2193	10642	1884	13600	2980
% increase	–	–	–	–	17.5	11.4

Table 46.10: Effect of mixed farming system on soil fertility

Farming system	*pH*	*Org. carbon (%)*	*Total N (%)*	*Avail. P. (ppm)*
Integrated system	6.0	1.63	0.101	27
Monoculture system	5.9	0.96	0.077	10

MANAGEMENT OF CROPPING SYSTEMS AND EVALUATION OF CROP/FARM MODELS

Management of Cropping/Farming Systems

Systematic cultivation practices include correct choice of plant/animal components according to the agro-climatic zone, soil type, age of palms, appropriate planting system, optimum planting density, orientation of rows along east-west direction and leaving an area of 2 m away from the palm.

Among management practices, regular manuring with a balanced fertiliser mixture is the most important. Periodic pruning, training of vines, mulching and pest and disease control of crop components are also contributing to their performance. With regard to mixed farming systems, selection of suitable animal species, feed availability and grazing system to adopt are important management decisions.

Evaluation of Crop/Farm Models

Despite the technical feasibility of CBFS demonstrated by the CRI from 'on-station' trials, acceptability has not been all that impressive as only 20 per cent of the potential area has so far been actually utilised for cropping/farming systems. It was therefore proposed that crop/farm models relevant and acceptable to the farmer may be developed in the on-farm research (OFR) trials for different agro-ecological zones. The programme started during 1987 has so far progressed quite satisfactorily. It is hoped that the OFR approach will act as a catalyst in the development of CBFS in small holdings.

Future Thrust Areas

Considering the low productivity of existing coconut plantations in Sri Lanka, there is a critical need to optimise land-use through CBFS. Therefore, research and development efforts on CBFS will remain a priority area in the future programmes. In this context, the following issues need to be addressed in planning future strategy:

1) Encourage replanting/new-planting of coconuts and develop suitable CBFS to compensate for economic losses during the unproductive period.

2) In replanting/new-planting programmes, avenue planting system should be adopted (for example, 10 × 5 m, 12 × 5 m, 15 × 5 m), with wider rows along east-west direction to facilitate better light penetration.

3) Screening of cultivars for shade tolerance. Of the three agro-ecological zones, Intermediate Zone has the widest scope for CBFS in Sri Lanka.

However, recurrent droughts have been a major reason for the slow progress of inter/mixed cropping. To overcome this situation, feasibility studies of CBFS with irrigation should be undertaken.

4) Since the average holding size of coconut (0.58 ha) is likely to be reduced further due to land fragmentation, further research on high density cropping systems is needed.

5) Greater attention should be placed on furthering our understanding of OFR with farmer participation, to develop suitable crop/farm models to suit the agro-climate and farmers' field conditions.

6) Since most of the productive land is in the Wet and Intermediate Zone, possibility of expanding CBFS in these areas should receive a high priority. Also, developing CBFS on marginal coconut lands in the Wet and Intermediate Zones and irrigated highlands in the Dry Zone (Mahaweli area) should be studied.

7) Integrated systems with crop/livestock should be popularised as there is a considerable, yet largely unexploited potential for raising livestock in the Coconut Triangle.

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DISCUSSION

M. Abdul Kalam: 1) In India black pepper is successfully trained on coconut trunk. What is your experience in Sri Lanka?

2) Whether Gliricidia can be considered as a suitable standard for pepper as it has a weak stem?

M. de S. Liyanage: 1) Black pepper can be trained on coconut palms. But the yield was lower compared to the yield of vines trained on Gliricidia.

2) Gliricidia stakes tend to collapse with heavy rains and wind because of shallow roots. But seedlings can be used as a support with success.

Fred Opio: Have you extended some of your research to farmers' fields? If so which crop combination do farmers prefer?

M. de S. Liyanage: Yes. In the Intermediate Rainfall Zone a popular crop combination with young coconut is ginger, banana and pineapple.

M. Sannamarappa: What is the promising coconut farming system accepted by the farmers and what is the net income from such systems?

M. de S. Liyanage: Pepper + coconut, coconut + pineapple + banana + ginger and coconut + coffee + pasture are the popular systems accepted by the farmers. Pepper gives the highest return of SL Rs. 30000/ha/year when priced at SL Rs. 60/kg.

M.K. Nair: In the high density model, you have put a number of component crops beside cacao. Our experience is that if cacao is a component crop, it is difficult to grow any other crop except pepper. Can you elaborate?

M. de S. Liyanage: We tried this model to collect preliminary data. We also found that cocoa has a big canopy and would not fit into a mixed crop model. In the other model, we have a combination of black pepper on coconut and on Gliricidia between two palms and two rows of coffee in the centre.

EXPERIENCES IN COCONUT BASED FARMING/CROPPING SYSTEMS IN THE SOUTH PACIFIC

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ABSTRACT

Coconut is one of the most widely grown tree crops in the tropics. It occupies about 20 per cent of the cultivated land area in many Pacific Island countries. The traditional practice is to intercrop with a variety of traditional crops and/or integrate with livestock. The rationale for this practice is that the same land can be simultaneously and profitably utilised, so that the productivity of the land is increased. This practice minimises resource demand and encourages efficient resource use, especially given the low levels of resource endowments. It can also encourage the adoption of improved husbandry practices most traditional farmers would otherwise be unwilling to adopt given high input costs. In this paper some of the common coconut based farming systems practised in the South Pacific are highlighted.

INTRODUCTION

Coconut is the most widely grown tree crop in the South Pacific. Available information indicates that over 80 per cent of farm households are directly engaged in its cultivation, employing over 25 per cent of the rural work-force. It accounts for over 20 per cent of the total cultivated land area and ranks as the leading export commodity in many Pacific Island countries. However, in recent years its importance in the export trade has been declining as a result of low export prices, low economic returns to growers and stiff competition in the international market for the traditional exported coconut products, such as copra and coconut oil.

Recent agricultural censuses indicate that about 0.6 million hectares are covered by coconut, producing about 3.8 billion nuts or nearly one (0.96) million tonnes of copra equivalent per year. But over 60 per cent of the palms are over 50 years of age (Table 47.1). There has however, been some effort to

Table 47.1: Coconut acreage and age distribution in the Pacific (1988) (estimates)

Age (years)	*Fiji*		*Cook Islands*		*P.N.G.*		*Solomon Islands*		*Tonga*		*Vanuatu*		*Western Samoa*		*Other Pacific Islands**	
	Area (ha)	*%*	*Area (ha)*	*%*	*Area ('000 ha)*	*%*	*Area (ha)*	*%*	*Area (ha)*	*%*	*Area (ha)*	*%*	*Area (ha)*	*%*	*Area (ha)*	*%*
0–20	13120	26.8	148	19.4	57.3	23.1	9665	15.4	2776	13.7	8280	12.0	10010	19.8	18042	18.6
21–39	9510	18.7	163	21.3	45.9	18.5	12180	19.2	4316	20.3	13590	19.7	2700	5.4	17072	17.6
40–49	3970	7.8	65	8.5	25.3	10.2	6503	10.3	3201	15.2	6350	9.2	27720	15.5	9409	9.7
50–60	14090	27.7	218	28.5	65.2	26.3	20014	31.7	5377	25.5	20010	29.0	21600	42.8	29391	30.3
Over 60	10170	20.0	170	22.3	54.3	21.9	14774	23.4	5397	25.6	20770	30.1	8320	16.5	22116	22.8
Total	50,860	100	763	100	248.0	100	63,137	100	21,067	100	69,000	100	50,440	100	96,030	100

* Includes Kiribati, Marshall Is., Federated States of Micronesia, Tuvalu, Tokelau, Wallis Futuna and New Caledonia.

Source: APCC, 1987. *Coconut Statistical Year Book 1986.* APCC Publication, Jakarta, Indonesia.

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replant. Burgess (1981) and Opio (1987) established that after year 40, yields from coconut drop below the expected economic level of about one tonne per ha, and unless an appropriate coconut based farming system is adopted, it would be uneconomic to maintain local tall monocrop coconut beyond year 40. It is probable though that yields from hybrids may remain economic at such a stage but lack of information related to their performance under different environments has limited their evaluation.

Coconut Based Farming Systems

In many Pacific countries, the traditional practice is to intercrop older coconuts with other crops. Most small landholders intercrop coconut with short-term crops (taro, maize, beans etc.) in some arbitrary rotational sequence. In the plantation sector, intergrazing or intercropping with other long-term crops (cocoa, coffee etc.) is widely practised. The rationale for this conventional wisdom is that the same land can simultaneously and profitably be used to produce other crops and livestock enterprises such that the productivity of the land is increased (Jodha, 1980; Opio, 1987; 1989; 1990b). It is also regarded as a simple but an effective diversification strategy that can minimise the risk associated with over dependence on one type of commodity. Proponents of coconut based systems argue that the system is a 'self-provisioning' requirement for small holders, whose long-term planning horizon is limited and lacking in resources.

Cropping Systems

Among the permanent cultivation systems, sedentary fallow system where bush fallows or grassland short fallow gardening are practised is common (Fig. 47.1). These are characterised by slash, clear and/or burn practice, followed by an intensive mixed rotational cropping practice before the land is allowed to rest. This practice, in most parts of the Pacific is characterised by clearly defined family holdings and plot divisions, where permanent, semi-permanent crop and livestock enterprises are introduced, of which coconut is the predominant crop. Small plots generally located around the homestead are sparsely intercropped with few coconuts, but larger fields and/or permanent cultivation are normally located some distance away from the homestead.

Permanent cultivation or plantations characterised largely by tree crop development, especially coconut, is the predominant land-use intensification system. The evolutionary change from fallow systems to permanent cultivation seems to have occurred as a result of the development of mixed-subsistence agriculture involving coconut and other crops grown in some rotational pattern, which has also encouraged permanent settlement.

In many island countries, where there is shortage of land, such as, Tonga and Cook Islands, few crop enterprises are grown in rotation. Instead, a permanent or semi-permanent cropping system has evolved, which has encouraged intercropping and/or multiple cropping systems to be adopted. In recent years attempts have been made to introduce simple crop rotational practices involving mixed crops based on soil and rainfall pattern, which is

intended to encourage rotations on plantation land and minimise fertiliser use by incorporating some legume crops in the production systems. This is characterised by intensive continuous cropping involving root crops and pulses.

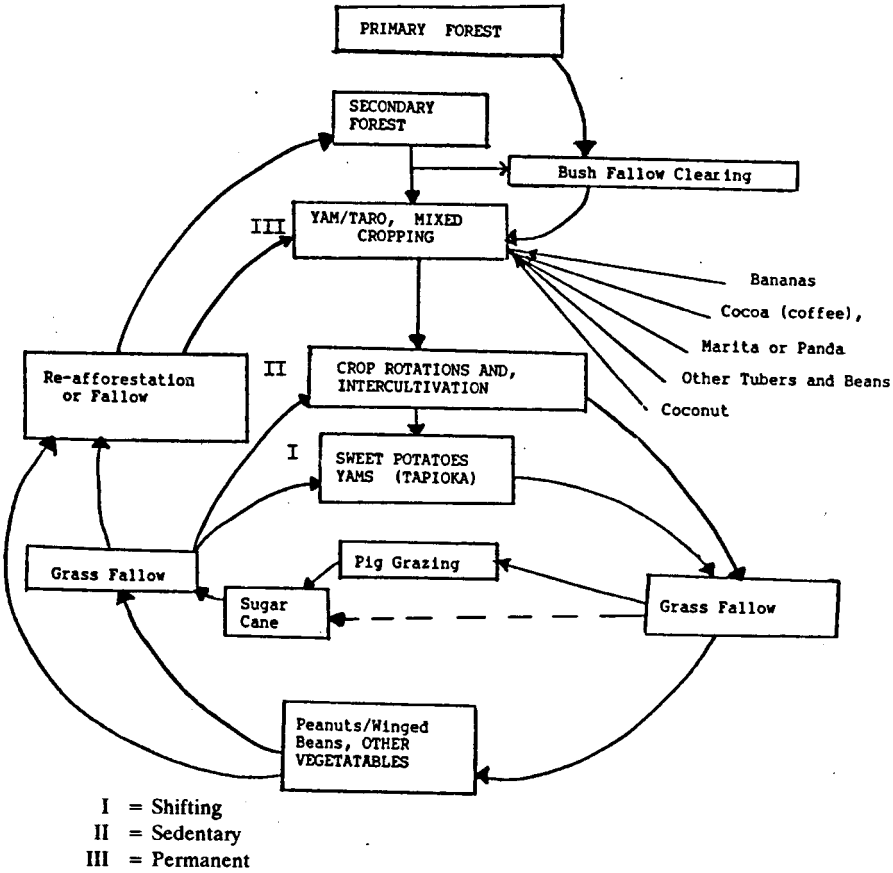


Fig. 47.1: Pacific farming and production systems.
(Adapted from Opio F., 1983. The role of agriculture in the South Pacific).

On an average, farm households cultivate food gardens of about 400 to 600 sq. m. per crop, but there are considerable variations in areas between crops within a country and between countries. The main food crops grown in home gardens are root crops. Taro (*Colocasia* spp. *Xanthosoma* spp., *Alocasia* spp. and *Cyrtosperma* spp.), cassava, sweet potatoes and yams are the common root crops. Sweet potatoes locally known as *kumala* and cassava are grown in over 80 per cent of the gardens. Yams and taro or *dalo* are grown in more than 60 per cent of the gardens. Where farm households specialise in taro production for subsistence and cash purposes, the two species of taro (*Colocasia esculenta* and *taamu* (*Alocasia macrorrhiza*) are grown in more than 80 per cent of the gardens. *Taamu* is either intercropped with taro or planted around the edge of

the plots and/or sparsely intercropped with coconut. Burgess (1981) estimated the ratio of coconut intercropping with other food crops in Western Samoa and found that it was about 1:3.

Cash enterprise production is generally devoted to off-homestead land, where larger areas are cropped mainly with mixed-subsistence and pure cash crops, but generally intercropped with coconut. In many South Pacific Island countries, cultivated cash crop areas vary with farm types. Subsistence farm households, on an average cultivate less than 30 per cent of the available arable off-homestead land.

Although cash enterprises vary from country to country, of less significance are livestock enterprises. Pigs and poultry are the major livestock reared by most farm households. Chickens are kept mainly for subsistence purposes and pigs are raised as mixed subsistence enterprises. Both pigs and poultry are free-ranged and allowed to scavenge around the homestead, occasionally they are fed on food scraps and coconut. On an average, farm households keep about 12 to 16 pigs and at least 20 to 25 chickens. Goats and cattle are also kept by some farmers. These are kept by large-scale farmers but few small-scale farmers rear them around the homestead. They are usually tethered along the roadside or under coconuts. In general, livestock enterprises are kept for subsistence purposes but may be sold when there is a cash flow problem.

a) Traditional Intercropping Systems

Under typical subsistence and mixed-subsistence farming practices, coconut is intercropped with a variety of annual crops, most of which are shade tolerant. Mostly short-term food crops are preferred. But this depends on the degree of light penetration. Although light, soil fertility and climatic factors remain the major constraints influencing the adoption of coconut based farming systems, recent research in various parts of the Pacific has revealed that simple crop husbandry practices, such as alley cropping, rotations and fallow systems, can enhance intercropping or multiple cropping practices and maintain soil fertility. Yields under such practices have been found to be significantly high (Table 47.2).

b) Continuous Intercropping Systems

In recent years the practice of wide spacing or "hedge planting" has been introduced to minimise the problem of poor light penetration, such that continuous intercropping can be adopted at any stage of crop development. Hedge planting is based on wider spacing between the rows and closer spacing between the plants such that inter-row cultivation is possible throughout the crop development and its productive life-cycle. Research results from Tonga have revealed that at the spacing of 15 m × 5 m giving about 130 palms per ha compared to the conventional spacing of 9 m × 9 m, coconut yields from hedge planting are generally higher. Table 47.3 indicates that the yield differentials are sometimes more than 25 per cent higher than those of conventional planting. This is primarily because inter cultivation encourages adoption of

appropriate technology (for example, animal traction) and improved husbandry practices. Besides, hedge planting allows for continuous intercultivation which minimises the problem of land shortages, encourages intensive land utilisation and increases the productivity of land under coconut.

Table 47.2: Comparative yield levels of mature local talls (LLT) and intercrops (ITCP) with over 60 per cent light penetration (9 m × 9 m spacing)

Type of intercrops	*Botanical names*	*Yield levels under given climatic conditions*					
		Wet		*Moderately wet*		*Dry*	
		LLT	*ITCP*	*LLT*	*ITCP*	*LLT*	*ITCP*
(a) Annual Crops							
Bele	*Hibiscus nanibot*	High	High	High	Medium	Low	Low
Cassava	*Manihot esculenta*	High	Medium	High	Medium	Low	Medium
Ginger	*Zingiber officinale*	High	High	High	High	Low	V. Low
Pigeon peas	*Cajanus cajan*	High	Low	High	High	Low	Low
Sweet potatoes	*Ipomoea batatas*	High	Medium	High	High	Low	Medium
Taro	*Colocasia esculenta*	High	Medium	High	Medium	Low	Low
Yams	*Dioscorea alata*	High	High	High	High	Low	Low
(b) Perennials							
Bananas	*Musa* spp.	High	High	High	High	Low	Low
Cocoa	*Theobroma cacao*	High	High	High	High	Low	Medium
Coffee	*Coffea arabica*	High	Medium	High	High	Low	Low
Kava	*Piper methysticun*	High	High	High	Medium	Low	Medium
Passion-fruit	*Passiflora edulis*	High	High	High	High	Low	V. Low
Vanilla	*Vanilla planifolia*	High	High	High	Medium	Low	Low
Pasture* (Batiki)	*Ischaemum indicum*	High	High	High	High	Low	Medium

* See Table 47.4 for details of pasture grasses recommended for coconut undergrazing.

Source: Institute for Research, Extension and Training in Agriculture (IRETA) Annual Reports 1986, 1987, 1988, 1989 and 1990.

Pottier D., 1983. *A Pasture Handbook for Samoa*, IRETA, University of the South Pacific, School of Agriculture, Apia.

c) Agro-Forestry Systems

In recent years, the concept of agro-forestry has been strongly advocated by various researchers. In effect, one can argue that coconut intercropping is in itself an agro-forestry practice. Current research shows that a number of timber and fruit trees grow very well under coconut shade. Although there are no conclusive results yet, available information on agro-forestry practices involving pine trees, *asi* (local timber tree), limes and lemons provide promising results. In atoll soils, pandanus has been adopted as a traditional intercrop which has performed very well under such conditions for a very long time.

Crop Competition and Complementary Effect of Component Crops under Different Systems

Although coconut is traditionally intercropped with a variety of crops and/or intergrazed with various livestock species in the South Pacific, the degree of compatibility depends on among other things, farming practices, age

of the coconut, spacing, soil fertility, and more importantly, the level of light penetration. Nair (1979), Burgess (1981) and Liyanage *et al.* (1984), argued that the introduction of intercrops at a young stage minimises intercultivation and reduces weed competition. Table 47.2 showed that under wet and moderate rainfall conditions, yields of coconut (Liyanage *et al.*, 1984) and various intercrops are moderate to high. But under dry conditions, yields are generally low except for cassava, which is more drought resistant.

Table 47.3: Comparative yield levels for selected local talls under conventional spacing and hedge planting in Tonga (copra equivalent)

Age (years)	*Conventional planting (spacing 9 m × 9 m) (t)*	*Hedge planting (spacing 15 m × 5 m) (t)*	*Percentage increase in yield*
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0.37	0.41	20
6	0.49	0.60	21
7	0.68	0.84	27
8	0.81	0.96	19
9	0.98	1.15	17
10	1.10	1.30	18
11	1.37	1.63	19
12–14	1.55	1.94	25
15–19	1.63	NA	–
20–24	1.40	NA	–
25–29	1.59	NA	–
30–34	1.44	NA	–
35–40	1.19	NA	–
40–50	0.93	NA	–
Over 50	0.73	NA	–
Av. plant pop.	124	133	–

Observation based on 15 farms in Tonga. Hedge planting was first introduced in Tonga in 1976 by the Department of Agriculture to encourage continuous intercropping.

Apart from few pasture grasses and timber species (*Acacia* spp. etc.), coconut and other intercrops were found to mutually benefit from each other. Cocoa is the most compatible tree crop and it is found to derive maximum benefit from intercropping throughout its productive life span. At various stages of cocoa development, coconut provides shade. The extent to which there is mutual benefit depends on husbandry practices. For instance in Tonga and Western Samoa, the practice of fertilizing bananas and passion fruit have been found to increase yields of coconut and intercrops by more than 20 to 30 per cent. In Tonga, the use of banana as coconut intercrop is being advocated to encourage indirect fertilisation of coconut palms. In Western Samoa, many passion fruit growers prefer to use live coconut trunk as posts for setting trellises. Fertilising passion fruits is also mutually beneficial.

There is an on-going research to establish whether different insect pollinators that attend component crops (for example, passion fruit) are also attracted to the coconut inflorescence which in turn could enhance overall pollination under coconut based farming system. If indeed this turns out to be the case, then a new dimension in agro-forestry research will have evolved. Thus some indication could be provided as to how, for example, insect pollinators allocate their visitation time in the face of diverse floral resources inherent in such multiple cropping system.

While competition from complementary crops and pasture species appear significant, there is little evidence to date to indicate the extent of competition in a coconut based farming system in the South Pacific. Finlay (1981) indicated that in Kiribati under atoll soils, coconut roots were found to extend up to 15 m in search of nutrients. He concluded that in such a situation, there can be some competition for nutrients between the component intercrop(s) and coconut. Pottier (1983) identified the recommended Batiki, Cori and Koronivia grass as suitable pasture species under coconut in the South Pacific. But they also indicate that elephant grass, para grass and guinea grass were unsuitable for pasture under coconut based farming systems in the South Pacific (Table 47.4). These grasses tend to compete for nutrients.

Table 47.4: Pasture rating for coconut undergrazing in the Pacific

Species (common name)	*Botanical name*	*Performance*	*Degree of shade tolerance*	*Degree of competition with coconut*	*Suitability for undergrazing*
Batiki grass	*Ischaemum indicum*	moderate	very high	high	highly recommended
Cori grass	*Brachiaria miliiformis*	high	very high	high	highly recommended
Guinea grass	*Panicum maximum*	high	high	very high	not suitable
Elephant grass	*Pennisetum purpureum*	moderate	moderate	high	not recommended
Koronivia grass	*Brachiaria humidicola*	high	very high	moderate	highly recommended
Palisade grass	*Brachiaria brizantha*	high	high	moderate	highly recommended
Para grass	*Brachiaria mutica*	very low	low	high	not recommended
Pangola grass	*Digitaria decumbens*	very low	very low	moderate	not recommended

Source: Pottier, D. 1983. *A Pasture Handbook for Samoa*, IRETA, University of the South Pacific, School of Agriculture, Apia.

Intercropping and Rotational Grazing Practice

The practice is to intercrop coconut continuously for two or more years and fallow it. During the fallow period, the land under coconut is sometimes grazed. Rotations in association with intercultivation and livestock grazing have been adopted in an attempt to maintain soil fertility. In some Pacific Island countries, where land is not a major constraint, the common practice is to grow root crops for two to three years in rotation with legume crops under long-term crops, mainly coconut. On small plots, especially around the homestead, vegetables and other seasonal legume crops are grown in rotation. But due to the continuous nature of the production systems, land is allowed to rest

from time to time to allow it to rejuvenate, while a new piece of land is brought into cultivation under a similar rotational pattern.

Intercropping is a traditionally well based practice in the South Pacific. Opio (1987) examined intercropping under coconut and suggested several possibilities under which the low returns from coconut enterprise could be improved. Research evidence suggests that intercropping gave higher and more dependable gross returns than monocropping (Santhirasegaram, 1967; Nair, 1979; Nelliat and Bhat, 1979; Jodha, 1980; Burgess, 1981; Liyanage *et al.*, 1984; Opio, 1987).

A wide variety of compatible crops/pasture grasses have been identified and evaluated which have given promising results under the coconut based farming system (Tables 47.2 and 47.4).

Coconut Husbandry

In the South Pacific, coconut production is neither labour nor capital intensive. Its production is associated with relatively high labour inputs in the first year of establishment. A total of 336 man hours/ha are required at the establishment stage. But in the subsequent periods, labour requirements are reduced, averaging 119 man hours per year to maintain one ha of coconut plantation. The main activities demanding labour throughout the productive cycle include weeding, fertilising, harvesting, processing and selling. However, most traditional farmers do not fertilise their coconuts because of the high cost of fertilisers. On the basis of these labour requirements, it is estimated that one adult male labour unit can manage about 3 to 4 ha of coconut plantation.

Similarly, coconut does not require expensive capital inputs. The major capital inputs are associated with establishment and processing. At 1987 prices a total cost of US $ 77.05, US $ 69.35 and US $ 92.00 per ha are required in the first year of establishment in Western Samoa, Tonga and Vanuatu, respectively. In the subsequent periods, an average of US $ 13.40, US $ 21.00 and US $ 27.43 are required each year for various farm activities in Western Samoa, Tonga and Vanuatu, respectively. Assuming regular replacement of farm inputs such as bush knives, copra knife and gumboots, coconut production is clearly not capital intensive. But the most significant capital cost is the construction of hot-air drier which should be enough to process the crop from any amount of land area. This is estimated at US $ 270, US $ 350 and US $ 500 in Western Samoa, Tonga and Vanuatu, respectively.

Intercropping/Rotational Grazing Model

Figure 47.2 shows the intercropping/rotational grazing model adopted in this study for the evaluation of net returns from intercropping enterprises. In the model it is assumed that:

1) Farm families plan to allocate their resources to meet both family food needs and cash requirements.

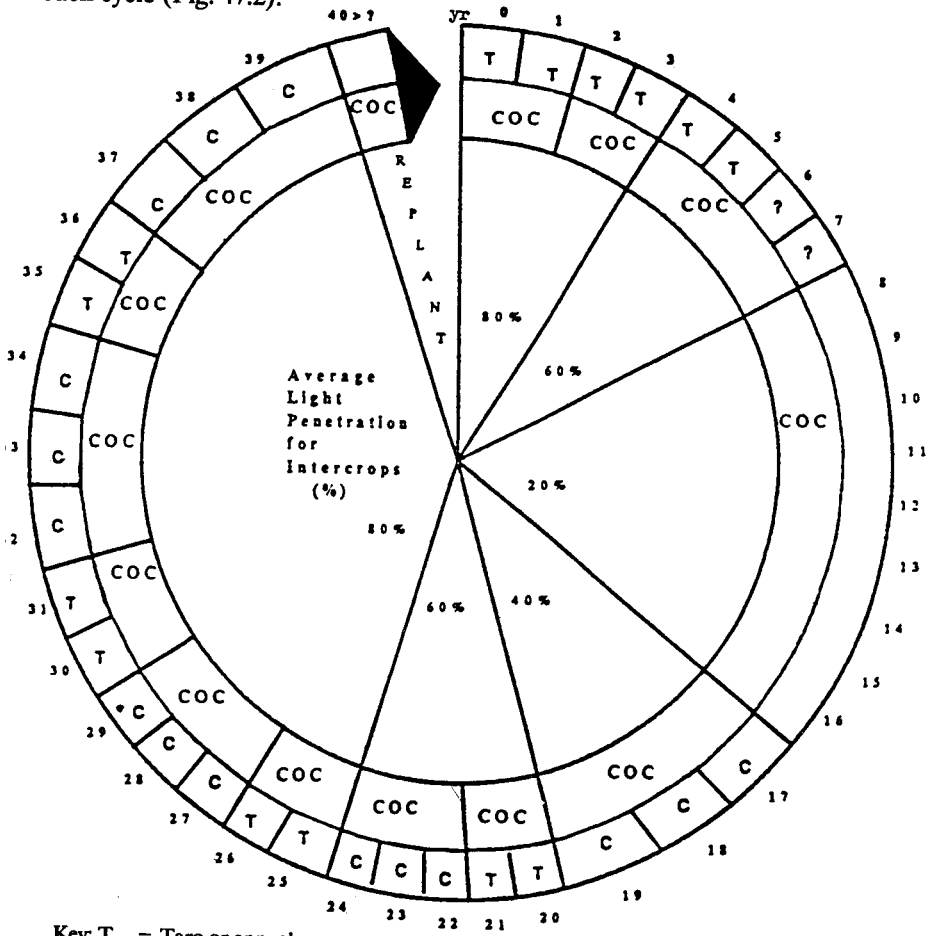
2) Intercropping at the traditional spacing of 9 m × 9 m with annual crops is possible in the first five to seven years only but not between eight and

19 years, because of low light penetration (except with cocoa and coffee which are believed to be more adapted to such condition).

3) Rotational grazing/intercropping is introduced from year 20 and maintained till year 40 or after. In exceptional cases, it is possible to introduce grazing from year 17.

4) The rotational grazing/intercropping practice is based on a traditional two or three years continuous cropping followed by a three-year fallow/grazing period.

Of course intercropping/rotational intergrazing model is based on traditional fallow practices where continuous intercropping of coconut for two to three years is adopted followed by three or more years of undergrazing of coconut during the short fallow period. The same process is repeated after each cycle (Fig. 47.2).



Key: T = Taro or annual crop
C = Cattle/goat
COC = Coconut.

Fig. 47.2: Intercropping/rotational grazing *module* for coconut plantation.

Intercropping/rotational intergrazing of coconut at different stages depends also on the degree of shade tolerance which the intercrops have and the systems of farming. Some shade tolerant crops can be introduced earlier, while others cannot until very late. Intergrazing on the other hand, is limited to cattle and goats, although it is possible to introduce pigs.

This model is based mainly on the availability of family input supply especially land and labour. It is envisaged that in the long-run, farm families would expand their on-farm activities to utilise surplus resources and maximise the use of land under coconut so that the overall productivity of the land is substantially increased.

Economic Evaluation of the Model

Comparative results of different intercrop/rotational grazing enterprise combination net returns for Fiji are presented in Table 47.5. The results indicate that returns from coconut monocrop can substantially be increased by intercropping. Intercropping/rotational grazing local talls (LLT) with *taro* provided the highest net accumulative return under a coconut based farming system. This seemed to explain why many traditional farmers favoured intercropping with *taro* than other crop species. In addition *taro* provides immediate and high returns as an annual crop. Although there was no significant difference in net returns between coconut intercropping with taro and *taro* intercropping/rotational grazing with cattle, the returns to labour from coconut intercropping with taro gave marginally lower return to farmers effort than that of rotational intercropping with *taro*/grazing with cattle.

This suggests that intercropping/rotational intergrazing is a worthwhile venture. Thus the practice of intercropping/rotational grazing should be more encouraged under the traditional system. And since continuous intercropping with annual crops is not always possible as most traditional farmers do not practise regular fertilisation, intercropping/rotational grazing appears to offer the best alternative of coconut based farming system in view of the traditional fallow practice.

Table 47.5 also shows the net present values from intercropping and grazing mature Local Talls (LLT)/kava/cattle or LLT/taro/cattle at 10 per cent discount rate. The results indicate that the return to labour from rotational grazing and intercropping were relatively higher than the minimum wage of F $ 0.62 per hour. Thus intercropping and rotational grazing with cattle provides a reasonable alternative use of land to a normal fallow period, with a significant increase in income.

Conclusion and Future Prospects for the Coconut Industry

The major areas of future thrust in the development and improvement of coconut in the Pacific and for that matter elsewhere should include:

a) More research effort to determine:

i) appropriate crop components which are compatible with coconut ecological systems under given spacing, age, climatic and soil conditions;

ii) suitable cropping sequences under given traditional farming systems;

iii) appropriate agro-technology of coconut based farming system; and,

iv) appropriate biological pest control measures likely to be adopted by the majority of traditional farmers who make up the bulk of coconut farmers.

b) A concerted effort by each producing country to minimise competition in the international markets through:

i) the development of differentiated coconut products and reduction in overdependency on a few exported coconut products such as copra and coconut oil; and,

ii) creation of international market intelligence organisation that will act as the watch-dog for small producing countries in Africa, Asia, Latin America and the Pacific.

Table 47.5: Discounted net returns per ha under coconut based farming system in Fiji (mature Local Talls (LLT) at 10 per cent discount rate) (1987 prices)

Year	*Mono LLT*	*LLT/ Taro*	*LLT/ Cocoa*	*LLT/ Kava*	*LLT/ Cattle*	*Intercropping/ Rotational grazing*		*Mono cocoa*	*Pasture (cattle)*
						LLT/ Kava/ Cattle	*LLT/ Taro/ Cattle*		
20	409.50	2555.00	514.59	–471.00	108.00	–471.00	2555.00	666.33	–375.00
21	372.28	1661.47	1103.22	–428.18	1083.66	–428.18	1661.47	594.77	629.94
22	388.41	388.41	1002.86	4290.65*	984.81	4290.65*	78.51	540.54	573.17
23	308.65	308.65	911.70	308.65	884.19	26.90	884.19	491.49	520.32
24	279.69	279.69	828.92	279.69	803.20	803.20	803.20	446.84	473.32
25	254.31	2118.65	596.58	254.31	740.39	740.39	2118.65	249.23	430.38
26	299.53	1871.32	589.06	–190.06	702.83	–190.06	1871.32	226.53	390.66
27	280.16	280.16	528.81	133.28	647.95	133.28	87.71	205.85	355.43
28	223.70	223.70	395.46	2197.86*	589.52	2197.86*	589.52	187.20	322.81
29	203.36	203.36	170.19	203.36	528.31	203.36	528.31	146.28	293.78
10 years accumulated Net Return (F$)	3019.59	9890.41	6641.39	6578.56	7072.86	7306.40	11177.88	3755.06	3614.81
Av. return to labour/manhr F$	2.54	8.31	5.58	5.53	5.94	6.14	9.39	3.15	3.04

*Kava is a three to five-year semi-perennial crop, thus a three year cropping sequence was adopted for this study.

Sources: 1. Department of Agricultural Economics, University of the South Pacific, School of Agriculture Data Bank 1990.

2. Annual Reports of the Institute for Research, Extension and Training in Agriculture (IRETA) various issues.

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EXPERIENCES IN COCONUT BASED FARMING SYSTEMS IN INDIA

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ABSTRACT

A sole crop of coconut, at the recommended spacing of 7.5 × 7.5 m does not fully utilise the available soil and air space and incident solar radiation. Crops identified as compatible ones with coconut include many tuber crops (cassava, elephant foot yam, yams, colocasia), rhizome-spices (ginger, turmeric), pulses (cowpea), oilseeds (groundnut, soybean), upland rice, fruit crops (banana, pineapple) and vegetables among the annuals and cocoa, black pepper, clove and nutmeg among perennials. Many intensive crop combinations which involve different annuals and perennials over a period of time such as multistoreyed cropping system and high density multispecies crop models have also been developed. Mixed farming systems, which integrate other enterprises like dairying and sericulture provide higher employment generation and enhanced net income. Among the annual crops, elephant foot yam and ginger are the most profitable. The additional employment generated ranged from 76 to 900 mandays/ha/year in different systems.

INTRODUCTION

Coconut is mostly a crop of small farmers in India, the average size of a holding being 0.22 ha. More than 90 per cent of the five million coconut holdings in the country are less than one ha in size (Thampan, 1988). These small holdings neither provide gainful employment opportunities for the family labour throughout the year nor generate sufficient income to meet the family requirements. The possibilities of increasing the productivity and net returns from coconut stands by introducing compatible subsidiary crops and integrating livestock are discussed in this paper.

Scope for Multiple Cropping in Coconut

A spacing of 7.5 × 7.5 m is recommended for field planting of coconut (175 palms/ha) but in the homestead gardens of Kerala, the density is much higher (200 to 250 palms/ha) whereas in the *malnad* region of Karnataka state much wider spacings are adopted with densities as low as 120 palms/ha. Experimental evidences have shown that a sole crop of coconut, at the recommended spacing of 7.5 × 7.5 m does not fully utilise the available resources.

Coconut palm like all monocots has a typical adventitious root system. Under favourable conditions, as many as 4000 to 7000 roots are found in middle-aged palms. Kushwah *et al.* (1973) reported that about 74 per cent of the roots produced by a palm under good management did not go beyond 2 m lateral distance and 82 per cent of the roots were confined to the 31 to 120 cm depth of soil. Recent studies have confirmed that more than 80 per cent of the root activity was confined to a lateral distance of 2 m from the trunk (Anil Kumar and Wahid, 1988). Thus the active root zone of coconut utilises only 25 per cent of the available land area and the remaining area could be profitably exploited by raising subsidiary crops.

The venetian structure of the coconut crown and the orientation of leaves allow part of the incident solar radiation to pass through the canopy and fall on the ground. The apparent coverage of ground and shade cast by the canopy, and the magnitude of radiation transmitted through the canopy vary according to the age of palms as shown in Fig. 48.1 (Nelliat *et al.*, 1974). Besides age, spacing, soil fertility, varietal characteristics and time of the day also influence the light penetration. The life span of coconut palms may be divided into three phases, namely, pre-bearing trees up to eight years (good light transmission,

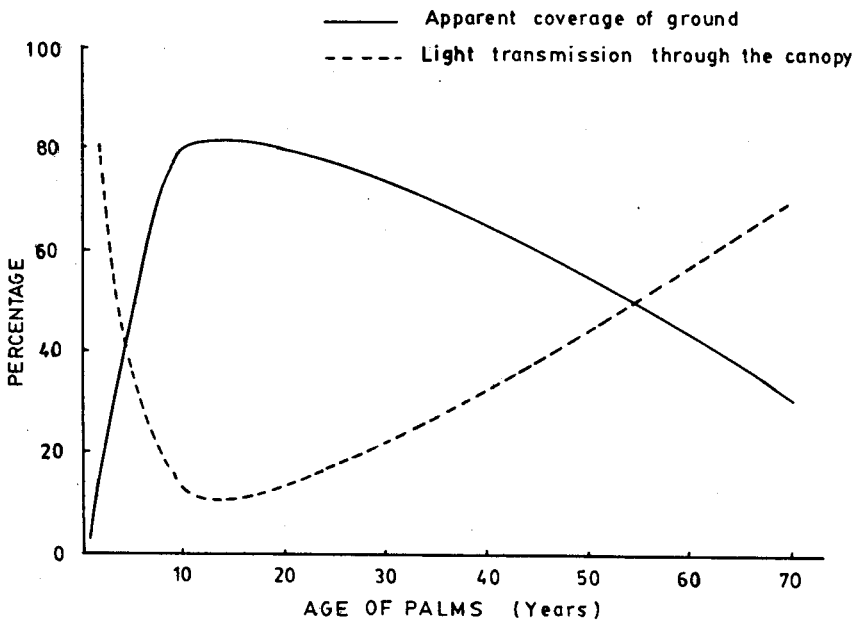

Fig.48.1: Light transmission through coconut canopies of various age groups (Nelliat *et al.*, 1974).

but decreasing with age), young palms of eight to 25 years (poor light transmission) and mature trees aged over 25 years (light transmission increasing with age) (Nair, 1979). Nair and Balakrishnan (1976) estimated that as much as 56 per cent of the sunlight was transmitted through the canopy during the peak hours (10 to 16 hours) in palms aged around 25 years. The diffused sunlight facilitates growing a number of shade tolerant crops in the interspaces.

Coconut Based Cropping Systems Research in India

Research on intercropping in coconut gardens was initiated during the thirties, and was intensified in the seventies with the establishment of the Central Plantation Crops Research Institute at Kasaragod. It received further impetus with the launching of the All India Coordinated Coconut and Arecanut Improvement Project in 1972 and establishment of centres in different coconut growing states. At present, research is in progress at Kayangulam, Pilicode, Kasaragod (all in Kerala), Goa and Ratnagiri (Maharashtra) along the West Coast, Veppankulam (Tamil Nadu) and Ambajipeta (Andhra Pradesh) in the East Coast and Arsikere (interior Karnataka) besides Sipighat in the Andaman Islands.

Cropping Systems

Coconut based cropping systems involving annuals, perennials and combinations of both annuals and perennials have been developed to suit the availability of resources like labour, rainfall and irrigation facilities, finance, soil characteristics and the farmers' needs and market demands. The crops found suitable for raising as subsidiary crops in coconut gardens include tuber crops (cassava, elephant foot yam, yams, colocasia, Chinese potato), rhizome spices (ginger and turmeric), cereals (upland rice), pulses (cowpea), oilseeds (groundnut and soybean), fruit crops (banana and pineapple) and vegetables (snake gourd, bottlegourd, amaranthus and brinjal) among the annuals and beverage crops (cocoa) and spices (clove, nutmeg and black pepper) among the perennials.

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a) Tubers and Rhizomatous Spices

Tropical tubers like cassava and elephant foot yam and rhizomatous spices like turmeric and ginger are the most popular intercrops raised in coconut gardens. The tuber crops partially meet the food requirements of a farm family and almost always find a place in the homestead gardens of Kerala. The productivity of tuber crops and rhizomatous spices raised as intercrops in coconut in different centres in Kerala is summarised in Table 48.1.

b) Millets and Cereals

Experiments conducted at Pilicode (Kerala) during the late thirties and early forties have shown that millets like *varagu* (*Paspalam scrobiculatum*), pearl millet (*Pennisetum typhoides*) and finger millet (*Eleusine coracana*) performed well as intercrops in coconut garden, when sowing was taken up at the

beginning of the south-west monsoon season. However, due to lack of demand, these crops are not grown at present (Gopalasundaram and Nelliat, 1979). Among the three varieties of upland rice (Rohini, Chennellu and Culture 12814) tried, Rohini recorded the highest yield of 1946 kg/ha at Kasaragod.

Table 48.1: Productivity (t/ha) of tubers and rhizomatous spices raised as intercrops

Crops	*Locations*		
	Kasaragod	*Kayangulam*	*Pilicode*
Cassava (*Manihot esculenta*)	14.8	15.9	13.8
Elephant foot yam (*Amorphophallus companulatus*)	13.5	5.4	5.2
Greater yam (*Dioscorea alata*)	13.6	5.5	–
Lesser yam (*D. esculenta*)	9.3	–	–
Sweet potato (*Ipomea batatas*)	8.4	–	–
Colocasia (*Colocasia esculenta*)	9.2	–	–
Ginger (*Zingiber officinale*)	8.6	–	2.4
Turmeric (*Curcuma longa*)	10.9	–	4.4

Source: Menon and Nayar, 1978; Nambiar *et al.*, 1988; CPCRI unpublished data.

c) Pulses

Many pulses like green gram, black gram, red gram, horse gram and cowpea have been tried as intercrops at different areas and among them, cowpea performed better as a rainfed crop yielding 300 to 500 kg/ha (Gopalasundaram and Nelliat, 1979). Further studies are necessary to identify suitable varieties and standardise the agro-techniques.

d) Oilseeds

Groundnut and soybean have been reported to be compatible intercrops with coconut. At Pilicode the groundnut variety TMV-2, yielded as much as 1326 kg pods and 1448 kg haulms/ha and was highly profitable (Leela and Bhaskaran, 1978). Recent studies at Kasaragod have shown that soybean can be successfully grown as an intercrop during the post-rainy period under irrigated conditions. The variety PK-472 had recorded the highest yield of 980 kg/ha (Hegde and Yusuf, 1992).

e) Vegetables

Only limited work has been done on intercropping vegetables in coconut gardens. Raising of chillies, potato and french beans was found to be a profitable practice in *maidan* areas of Karnataka (Rethinam, 1989). Recent experiments at Kasaragod have indicated the suitability of vegetables like snake gourd, bottle gourd, amaranthus, coccinia and bitter gourd as compatible crops with coconut.

f) Fruit Crops

Banana is a highly profitable intercrop in coconut gardens, which is very popular in areas with good irrigation facilities. Reddy *et al.* (1980) reported

that in Godavari delta of Andhra Pradesh, banana was the best intercrop with complementary effect on coconut yield. At Veppankulam (Tamil Nadu), banana as an intercrop recorded a mean yield of 6 kg/bunch and the additional net profit obtained was Rs. 5,748/ha (Ramanathan, 1985). In Kerala, Palayamkodan, Robusta, BB Batheesa, Karpooravally and Poovan were identified as suitable varieties for intercropping (Nambiar *et al.*, 1988; Suma *et al.*, 1989) and gave mean yields ranging from 8 to 12.8 kg/bunch.

Pineapple also performs well in the partially shaded conditions of coconut gardens. At Kasaragod, a mean yield of 1.54 kg/fruit was recorded. However, pineapple requires irrigation during the dry period for its successful cultivation.

Perennials

A number of perennials like cocoa, clove, nutmeg, pepper, jack, breadfruit, mango and timber yielding trees are often raised as mixed crops in coconut plantation (Nelliat *et al.*, 1979). However, productivity of such a system is low due to improper selection of companion crops and adoption of unscientific management practices.

Cocoa has been identified as an ideal mixed crop with coconut. Experiments conducted at Kasaragod and Pilicode since 1970 have proved beyond doubt the profitability of growing cocoa as a mixed crop in coconut. Comparison of the performance of cocoa raised in single hedge and double hedge systems in a coconut garden, planted at the recommended spacing of 7.5 × 7.5 m has shown that even though the productivity of cocoa per ha was slightly high in the double hedge system, single hedge system was more desirable. The productivity of coconut was also improved when cocoa was grown as a mixed crop (Table 48.2).

Table 48.2: Productivity of coconut and cocoa in the coconut-cocoa mixed cropping experiment at Kasaragod

Cropping system	*Coconut (nuts/palm/year)*		*Cocoa (pods/year) (1974–'88)*	
	Pre-experimental (1966–'70)	*Experimental period (1972–'87)*	*Per plant*	*Per ha*
Coconut-sole crop	68.0	106.6	–	–
Coconut + cocoa single hedge	56.7	108.3	32.3	11,270
Coconut + cocoa double hedge	39.1	88.5	19.3	12,545

The experiment conducted at Pilicode in a 50-year old WCT coconut plantation spaced at 9 × 9 m from 1970 to 1983 has shown that the productivity of coconut was not affected by mixed cropping with cocoa. Under this wider spacing 9 × 9 m for coconut, the double hedge system of raising cocoa was found to be superior, yielding 378 kg dry beans/ha/year (1976 to 1983) as against 165 kg in the single hedge system (Nambiar *et al.*, 1988). The net returns

from cocoa were estimated to be Rs. 2,542 and Rs. 5,880/ha under the single and double hedge systems, respectively.

Perennial spice crops like clove, nutmeg and pepper (trained on coconut and on live standards) are also popular mixed crops. Potty *et al.* (1979b) evaluated the performance of six varieties of pepper in the multistoreyed cropping system and suggested that Karimunda and Panniyur-I perform better under mixed cropping situations.

Multistoreyed Cropping Systems

This is an intensive four crop combination which includes coconut, black pepper (trained on coconut trunk), cocoa and pineapple. The system requires irrigation during the summer months and ensures efficient foraging of soil without undue competition between component crops and intercepts solar radiation at different heights. Pineapple performs well in such a system in the initial five or six years and will have to be removed once cocoa develops its full canopy. The productivity of crops in the multistoreyed cropping system at Kasaragod is given in Table 48.3.

Table 48.3: Yield of crops in the multistoreyed cropping system

Crops	*Coconut + cocoa SH* + pepper + pineapple*	*Coconut + cocoa DH* + pepper + pineapple*
Coconut (nuts/palm/year)		
(i) Pre-experimental period	45.2	38.3
(ii) Experimental period	104.5	88.8
Cocoa (pods/plant/year)	32.3	25.6
Pepper (kg/vine/year)	0.64	0.42

* SH — single hedge; DH — double hedge.

High Density Multi-species Cropping Systems

High density multi-species cropping systems, involve growing a large number of crops to meet the diverse needs of the farmer such as food, fuel, timber, fodder and cash, and are ideally suited for smaller units of land and aim at maximum production per unit area of land, time and inputs with minimum or no deterioration of land (Bavappa and Jacob, 1982). Such a system was established at Kasaragod in 1.2 ha of an 18-year-old coconut plantation spaced 8 × 8 m during 1983. The system included 17 crops (mango, bread fruit, jack, nutmeg, clove, *sapota*, acid lime, guava, pepper, *ipil-ipil*, banana, papaya, coffee (San Ramon), elephant foot yam, colocasia and cassava) in addition to coconut and the population was increased to 13,030 plants/ha.

The annual crops (except banana) were withdrawn from the system in stages as the perennials grew and utilised more and more space and sunlight. Some perennials like lime, *sapota*, mango, guava, pepper, *ipil-ipil*, papaya and coffee were also withdrawn from the system as their performance was not satisfactory.

The experimental area was divided into three plots and one-third, two-third and full dose of recommended levels of fertilisers are being applied for

each crop. The mean yield of coconut and other crops during the past few years were comparable (Table 48.4) under different levels of manuring indicating scope for reducing the fertiliser input.

Table 48.4: Mean yield of crops in coconut based high density multi-species cropping system at Kasaragod (1985–86 to 1989–90)

Crops	*Produce and unit*	*Fertiliser levels*		
		One-third	*Two-third*	*Full*
Coconut	nuts/ha/year	23634	23166	23010
Pineapple	fruits (kg/ha/year)	2676	2509	2765
Banana	bunches (kg/ha/year)	1194	1425	1465

Coconut Based Mixed Farming Systems

Coconut offers considerable scope for raising shade tolerant forage crops in the interspaces and integrating animal enterprises. Fodder grasses like hybrid napier (Pusa Giant and NB 21), Guinea grass and Guatemala grass yield about 50 to 60 t green fodder/ha/year under coconut shade (Jacob Mathew and Shaffee, 1977), which is sufficient to maintain five cross-bred milch cows. Among the legumes, Brazilean lucerne and cowpea perform well yielding about 30 t/ha (Sahasranaman and Pillai, 1976).

A family model mixed farming unit was maintained at CPCRI, Kasaragod from 1972 to 1988. Fodder crops were raised in 1.04 ha of a 60-year old coconut garden, pepper was trained on coconut trunk and intercrops like banana, cassava and vegetables were raised along the borders and field bunds. Five cross-bred Jersey cows were given to the family and a biogas plant was also erected. The cow dung slurry from the gas plant and urine were recycled within the experimental area. The output from one ha of the model is furnished in Table 48.5. This system generated maximum employment opportunities.

Table 48.5: Mean annual output from one ha of mixed farming unit

Items	*Output*	
Coconut	11,270	Nos.
Milk	7,089	l
Pepper	80	kg
Banana	250	kg
Beef (estimated)	350	kg
Biogas	2.8–3.5	m^3/day
* Dung	14.6	t
* Urine	3600	l

* Recycled within the system.

Coconut Based Sericulture

In *maidan* areas of Karnataka state, where coconuts are generally grown at a wider spacing of 9 × 9 m or more, growing of mulberry as a mixed crop and

silk worm rearing is very popular. Shanthamallaiah *et al.* (1985) reported that sericulture yielded about 420 kg of silk worm cocoons/ha of coconut garden/ year. In addition, the yield of sole crop of coconut was also increased to 85 nuts from 76 nuts/palm/year. The net income was more than trebled and employment potential doubled.

Complementary Interactions in Coconut Based Cropping Systems

Experiments conducted during the last two decades have indicated many complementary interactions between component crops in the systems. The beneficial effects include improvement in soil fertility status, enhanced microbial activity, higher interception of light, better micro-climate and reduced weed growth which helped to achieve higher productivity.

Cocoa raised as mixed crop in coconut adds considerable quantity of organic matter to the soil. A five-year-old cocoa crop in the system through its shed leaves and prunings, was estimated to add 818 and 1985 kg dry matter (oven dry weight)/ha/year, respectively in single and double hedge systems. This helps in recycling of plant nutrients, besides improving soil organic carbon status (Varghese *et al.*, 1978b). Nair and Rao (1977a) reported that activity of nitrogen fixers like *Beijerinckia*, phosphate solubilisers like *Pseudomonas* sp. and *Aspergillus niger,* and *Escherichia* sp., *A. flavus* and *A. fumigatus* which produce growth promoting substances was much higher in coconut-cocoa mixed stands compared to coconut monocrop stands. The available phosphorus content of rhizosphere soil was found to be 65 ppm in coconut + cocoa double hedge, 41 ppm when cocoa was grown in single hedge, compared to 20 ppm in coconut sole crop (Nair and Rao, 1977b). Leela and Bhaskaran (1978) also observed improvement in soil available N, P, K and Ca status of coconut intercropped with groundnut.

The micro-climate inside a mixed crop system was characterised by lower maximum temperature, smaller diurnal variation and less evaporative demand compared to pure crop stands (Nair and Balakrishnan, 1977). Raising groundnut as an intercrop, suppressed weed growth in coconut plantations and maintained good tilth for the major part of the year (Sahasranaman, 1964; Leela and Bhaskaran, 1978).

Management of the Systems

The success or failure of a coconut based farming system is often decided by the choice of the system components, based on the availability of light, age of coconut palms and their spacing, soil type, climatic conditions, moisture availability, irrigation facilities, canopy architecture and light requirements of subsidiary crops and market demand. Lalitha Bai and Nair (1982) studied the shade response of different intercrops and classified sweet potato as shade sensitive, coleus and colocasia as shade tolerant and ginger and turmeric as shade loving. Attempts have also been made to identify varieties suitable for multiple cropping situations in crops like banana, citrus, pepper and turmeric (Valsamma *et al.*, 1987; Potty *et al.*, 1979a; Suma *et al.*, 1989). Varghese *et al.*

(1978a) indicated the need for crop rotation among the annual intercrops and application of adequate fertilizers for both the main crop of coconut and the intercrops to maintain the productivity of the system. It is also necessary to maintain the population of companion crops at optimum levels by proper placement of the subsidiary crops, especially perennials besides canopy management by pruning etc.

Economics

Adoption of any system by the farming community will ultimately be decided by its economic advantages. The monocrop of coconut provides employment opportunities for only around 150 mandays/ha/year and gives a net income of Rs. 10,400/ha. The various systems that have been developed and discussed in this paper generate additional employment to the tune of 130 to 606 mandays/ha/year and the estimated net returns range from Rs. 18,670 in the case of coconut + cassava system to Rs. 50,000/ha in coconut based mixed farming (Table 48.6).

Table 48.6: Economics and employment potential of coconut based farming systems

Systems	*Net returns (Rs/ha/year)*	*Additional employment (mandays/ha/year)*
Coconut – sole crop	10,400	–
Coconut + cassava	18,670	130
Coconut + elephant foot yam	20,940	131
Coconut + ginger	36,590	500
Coconut + banana*	25,675	NA
Coconut + cocoa*	24,600	NA
Coconut + clove*	38,500	NA
Multistoreyed cropping system*	30,300	191
Coconut based mixed farming*	50,000	600

NA = Not available.
* = under irrigated conditions.

FUTURE THRUST

Based on the results of research conducted during the past few decades, many new cropping and farming systems have been developed and management practices also formulated. Future research activities will mainly concentrate on the following aspects:

i) Work on the screening of new crops and crop varieties needs to be continued for developing new models. In addition, research on breeding of crop varieties specially suited for inter/mixed cropping situations should be initiated.

ii) Many new crop models have been planted in suitable agroclimatic regions of the country based on the experience gained so far. Evaluation of these models and newer ones will continue to select the best ones.

iii) Systematic studies on rooting pattern, canopy architecture, light profile, nutrient enrichment and depletion processes, microbial activity, soil moisture utilisation pattern and microclimate will be taken up.

iv) Attempts will be made to develop suitable computerised system analysis models by integrating the information collected on different aspects with a view to developing appropriate management practices for the system as a whole rather than for the individual components of the system.

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DIFFERENTIAL FERTILISER RECOMMENDATION FOR COCONUT BASED ON NUTRIENT AND PRODUCTIVITY LEVEL

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ABSTRACT

Large fluctuations in annual coconut production in Sri Lanka are found to be primarily due to rainfall and fertiliser usage. Annual fertiliser use in coconut is 30,000–50,000 metric tons and the estimated percentage consumption is 25 per cent of the recommended level.

Analyses of leaf samples collected from nearly 300 small holdings and 120 estates show that about 80 per cent of coconut palms are deficient in both potassium and magnesium while only 20 per cent are deficient in nitrogen and less than 10 per cent are deficient in phosphorus. Data show that the present nutritional order of priority for adult coconut in Sri Lanka is K > Mg > N > P. Chlorine and sulphur deficiencies are confined to less than 10 per cent of palms, whereas boron deficiency was noted only with young coconut seedlings in localised areas.

Presently CRI SL provides two fertiliser recommendation programmes — general fertiliser recommendation (GFR) consists of two fertiliser mixtures — one for young palms (YPM 13-12-17) and the other for adult coconut (adult coconut mixture APM 0-6-32-5 with urea). Differential Fertiliser Recommendation (DFR) is based on the leaf/soil nutrient level, present/potential/target yield and resources of the plantations. DFR computer model provides only the required fertiliser for individual field/estate to achieve sustainable high productivity with increased profits.

INTRODUCTION

Coconut in Sri Lanka occupies nearly 4,19,500 ha with an annual production of 1900 to 3000 million nuts. Large fluctuations in annual coconut production in Sri Lanka are found to be primarily due to the changes in rainfall pattern and the fertiliser usage (Abeywardena, 1971). About 29 per cent of the area under coconut is in the Dry Zone (annual rainfall < 1000 mm), while 51 per cent is distributed in the Intermediate Zone (annual rainfall 1000 to 1500 mm).

Annual fertiliser usage in coconut is in the region of 30,000 to 50,000 metric tons and the estimated percentage consumption was stagnating around 25 per cent of the recommended level during the last few decades (Anonymous, 1990).

Estimates indicate that mostly the large coconut estates are being regularly fertilised and the production in the estate sector seems to be a controlling factor in the local price of coconut products. Until 1988, the Coconut Research Institute of Sri Lanka (CRI SL) recommended two general fertiliser mixtures for the coconut growers in Sri Lanka (Anonymous, 1986).

1) Young coconut: (< 5 years or up to bearing) — Young Palm Mixture (YPM 13-12-17) containing urea, saphosphosphate and muriate of potash at the rate of 500g/palm applied at six monthly intervals and increased up to 2000 g/palm/year at five years age.

2) Adult coconut: Adult Palm Mixture (APM 12-6-32) containing urea, saphosphosphate and muriate of potash at the rate of 2 to 3 kg/palm/year depending on the soil type and agroclimate.

Widespread potassium (K) and magnesium (Mg) deficiency symptoms even in the large coconut estates that are being fertilised regularly showed the need to provide two different fertiliser recommendation packages/programmes to the large coconut estates and small holdings.

Hence the above two general mixtures for young and adult coconut are now being recommended mainly for small holdings. For the estate sector a new fertiliser recommendation package known as the differential fertiliser recommendation (DFR) was developed and introduced in November, 1988. This paper describes the development and basis of the DFR package for coconut based on nutrient and productivity level of the coconut plantation.

Sufficient Nutrient Levels

Macy (1936) introduced the concept of "critical nutrient percentages" in leaf dry matter, but due to the "luxury consumption" behaviour of several nutrients observed in coconut (Loganathan and Balakrishnamurthi, 1975; 1980; Magat, 1976) the term used at the CRI SL is "sufficiency range".

'Sufficient' nutrient levels required in the diagnostic leaf (Frond 14) of the coconut palm for sustainable growth and high productivity are given in Table 49.1 (Nathanael, 1958; 1961; 1967; Jayasekara, 1988). 'Sufficiency' nutrient ranges are based on the correlation studies with yield. Studies (Jayasekara, 1989; 1990) show that about 80 per cent of the coconut palms have adequate or excess levels of leaf nitrogen while about 90 per cent have adequate or excess levels of leaf phosphorus. However, nearly 80 per cent of the palms are deficient in both potassium and magnesium. Frequency histogram for the potassium nutrient show a wide variation in leaf K levels in both small holdings and estate sector (Jayasekara, 1989). Data on chlorine and sulphur show that about 20 per cent of palms have low levels, requiring corrective measures. Boron was not found to be deficient except in two cases under the study.

Table 49.1: 'Sufficient' nutrient levels required in the diagnostic leaf (Frond 14) of a coconut palm for sustainable growth and high productivity as established at the CRI SL

Nutrient level in the fourteenth leaf (dry mass)							
N	Nitrogen	1.9–2.1	%				
P	Phosphorus	0.11–0.13	%	B	Boron	8–10	ppm
K	Potassium	1.2–1.4	%	Fe	Iron	40	ppm
Mg	Magnesium	0.25–0.35	%	Mn	Manganese	60	ppm
Ca	Calcium	0.35–0.50	%	Cu	Copper	12–14	ppm
Na	Sodium	0.40	%	Zn	Zinc	60	ppm
Cl	Chlorine	0.30–0.60	%	Mo	Molybdenum	270	ppb
S	Sulphur	0.15–0.20	%				

Plant Removal of Nutrients

Nutrient concentration and the amount of biomass produced by different components of the coconut palm are given in Table 49.2. Data show that coconut husk contains high level of potassium. Table 49.3 shows the removal of major nutrients from a coconut plantation with a production level of 15,000 nuts/ha/year. It is observed that with the increase in coconut yield, the removal of potassium from the soil rhizosphere also increases.

Table 49.2: Approximate nutrient levels and biomass of different plant components of a coconut palm

Plant component	*Nutrient level (% dry mass w/w)*				*Average biomass*
	N	*P*	*K*	*Mg*	
Leaf lamina	2.0	0.12	1.2	0.3	1.5 kg/frond
Petiole	0.3	0.2	0.2	0.3	2.0 kg/frond
Flower parts	0.3	0.2	0.1	0.2	0.4 kg/inflorescence
Husk	0.6	0.1	1.5	0.2	0.4 kg/nut
Shell	0.3	0.1	0.1	0.1	0.2 kg/nut
Meat	2.5	0.3	0.6	0.1	0.2 kg/nut
Nut water	0.19	0.05	1.6	0.13	300 ml/nut
Coir dust (dry)	0.3	0.04	1.2	0.2	0.2 kg/nut
Coir dust (wetted)	0.3	0.02	0.4	0.1	–

Nutrient Losses/Leaching/Fixation

Nutrients are also lost from the rhizosphere into deep subsoil by leaching during the heavy rains, specially in sandy soils. Studies show that potassium and magnesium nutrients are leached below the one m depth of a sandy soil after a 450 mm of rain (Jayasekara, 1990). Nutrient losses are significant in lands where the run-off and/or soil erosion are high, especially in sloping lands. Hence soil/water conservation techniques and the use of organic manure may help to reduce the nutrient losses due to leaching and run-off/soil erosion. Under these conditions, several split application of fertilisers is found to be beneficial.

Table 49.3: Approximate annual removal of nutrients from a coconut plantation (150 palms/ha) with a production level of 15000 nuts/ha/year (100 nuts/palm/year)

Component	*Amount removed (kg)*			
	Nitrogen (N)	*Phosphorous (P)*	*Potassium (K)*	*Magnesium (Mg)*
1. Flower parts	2	1	1	1
2. Frond				
a. Petiole	11	7	7	11
b. Leaflets	54	3	32	8
3. Nut				
a. Husk	4	6	90	12
b. Shell and kernel	84	12	22	8
c. Nut water	8	2	72	6
Total	163	31	224	46

The above amounts correspond to 354 kg of urea, 258 kg of saphos phosphate ($Ca\text{-}PO_4$, 27.5 per cent P_2O_5) or Eppawala rock phosphate (Apatite $Ca\text{-}F\text{-}PO_4$, 30 per cent P_2O_5), 450 kg of potassium chloride and 380 kg of dolomite or kieserite.

DFR-Nutrient Removal

Under the DFR package, fertiliser type/rate is initially estimated to provide the nutrients that are being lost from the rhizosphere under different yield categories (Table 49.4). The exact values depend on the processes such as recycling of nutrients by plant decay and rainfall, leaching, run off/erosion and fixation. The equivalent fertiliser type/rate also needs to be adjusted depending on the soil, agro-climate, and management process. The values in Table 49.4 are related to a 'well-managed' estate with loamy soil in the Intermediate (rainfall) Zone.

Table 49.4: Equivalent fertiliser type/rate to be applied as maintenance dosage based on the nutrient removal factor under different yield categories

Yield category			*Equivalent fertiliser (kg/palm/year)*			
Nuts/palm	*Nuts/acre*	*Nuts/ha*	*Urea (N)*	*Saphosp. (P)*	*KCl (K)*	*Dolomite (Mg)*
up to 47	3000	7406	0.8	0.6	1.6	1.0
47–62	3001–4000	7407–9875	0.6	0.6	1.4	1.0
63–78	4001–5000	9876–12344	0.7	0.6	1.6	1.0
79–94	5001–6000	12345–14812	0.9	0.7	1.8	2.0
95–125	6001–8000	14813–19750	1.0	0.7	2.0	2.0
126–156	8001–10000	19751–24688	1.1	0.8	2.1	2.5
157–188	10001–12000	24689–29625	1.2	0.8	2.1	2.5
189–219	12001–14000	29626–34562	1.3	1.0	2.2	3.0

DRF-Leaf Nutrient Level

Jeganathan (1985) clearly showed the high variability in soil samples for nutrient studies and confirmed the importance of leaf analysis in the

determination of nutritional status of coconut. Hence under the DFR programme, leaf nutrient levels are being used and the soil analytical data are used only as a guide.

After estimating the equivalent fertiliser type/rate for the maintenance based on the nutrient removal for a given target yield level, it is necessary to readjust the fertiliser rate again to maintain the 'sufficient' nutrient level required in the coconut palm for sustainable growth and production.

Table 49.5 gives the basis for the adjustment of fertiliser rate depending on the leaf nutrient status, that is, when the leaf nutrient level is within the 'sufficient' range, only the maintenance dose of fertiliser based on removal (Table 49.4) is recommended. However, if the leaf nutrient level is deficient, then one-and-a-quarter times or one-and-a-half times the maintenance dose of fertiliser (Table 49.4) is recommended. Similarly, when the leaf nutrient level is in excess, the maintenance rate of fertiliser is reduced by a third, or a half, or suspended. The multiplying factor depends on the importance (that is, quantitatively) of nutrients to maintain the production and the required nutritional status of coconut palm.

Table 49.5: Basis for the adjustment of maintenance fertiliser rate depending on the leaf nutrient status/level of coconut palm in relation to the required 'sufficiency' nutrient ranges (R is the maintenance rate as in Table 49.4)

Nitrogen N (1.9–2.1%)

Nutrient Range	*Factor × Maintenance Rate*
<1.2	1.5 × R
1.2<–1.6	1.2 × R
1.6<–2.2	R
2.2<–2.5	0.33 × R
2.5<	0.0 × R

Phosphorous P (0.11–0.13%)

Nutrient Range	*Factor × Maintenance Rate*
<0.06	1.5 × R
0.06<–0.11	1.2 × R
0.11<–0.13	R
0.13<–0.25	0.25 × R
0.25<	0.0 × R

Potassium K (1.2–1.4%)

Nutrient Range	*Factor × Maintenance Rate*
<0.6	1.5 × R
0.6<–1.0	1.2 × R
1.0<–1.8	R
1.8<–2.5	0.5 × R
2.5<	0.0 × R

Magnesium Mg (0.25–0.35%)

Nutrient Range	*Adjustment to KCl and Mg fertilisers*
<0.15	KCl = 0.75 × R; Kieserite 1.0 kg; Dolomite 3 kg
0.15<–0.2	Kieserite 1.0 kg; Dolomite 3 kg
0.2<–0.25	Dolomite 1.5 × R
0.25<–0.4	Dolomite R
0.40<–0.6	Dolomite 0.5 × R
0.6<	Dolomite 0.0 × R

DFR — Anticipated Target Yield

DFR model is based on the anticipated target yield and the leaf nutrient level of the coconut. Anticipated target yield is decided considering the 'present' and 'potential' yield categories for a given plantation based on the cultivar, age, soil, agro-climate, management, etc. Usually the anticipated target yield is taken as the next higher yield category to the present level as shown in Table 49.4. However, if the leaf nutrients are severely deficient, then rather than trying to adjust the leaf nutrient status for a higher target yield, it is beneficial first to correct the nutritional deficiencies at the existing moderate yield level.

DFR-Constraints

DFR model assumes the validity of the established 'sufficient' nutrient ranges for coconut and the nutrient removal levels under different yield categories. Fine adjustments and verification of these values are in progress under growers' field conditions for different stratified groups based on soil, agroclimate, and management. However, simple simulation studies show that fine accuracy may not be necessary as the final fertiliser rate to the coconut palm needs to be in practically measurable quantities kg/palm/year.

DFR model considers the individual nutrient levels (that is, 'sufficiency' ranges) as used by Chan (1972) and Yogaratnam and Silva (1978), Turner (1985), and Ulrich and Hills (1967), for fertiliser recommendation in orchard, rubber and banana, respectively. Sumner and Boswell (1986) discussed the problems associated with the use of "critical/sufficient" nutrient levels in fertiliser recommendations, specially under multiple nutrient deficiencies. Beaufils (1957) introduced the use of 'norms' and the ratio of different nutrients for fertiliser recommendation known as Diagnosis and Recommendation Integrated System (DRIS). Review by Walworth and Sumner (1987) about the DRIS, shows the importance of accuracy in fertiliser rate, specially for short-term annual crops. However, perennial crops such as coconut where the rainfall pattern has a major influence, a simple model such as DFR may be as good as DRIS. Under the DFR programme, leaf nutrient level and productivity are monitored annually with relevant adjustments until the required nutrient levels and yields are achieved. Hence, it is similar to conducting a fertiliser experiment in a given coconut field/plantation to obtain the 'best' and specific fertiliser package under the given condition.

DFR-Benefits

A computer programme was developed for the DFR model and the leaf nutrient and the productivity levels are the input variables. DFR computer model is a user friendly package and output gives the fertiliser type/rate with cost of the package as given in Table 49.6.

The DFR computer model is capable to adjust 'sufficiency' ranges and nutrient removal factors for a range of plant, soil, agroclimate and management conditions. Studies are in progress to provide DFR for a given economic condition also (that is, both cost of fertiliser and price of coconut).

Table 49.6: Example of the differential fertiliser recommendation under the DFR package

Differential Fertiliser Recommendation (DFR) for One Year Field-wise

Soils and Plant Nutrition Division, Coconut Research Institute, Lunuwila, Sri Lanka.
Estate Name/Address : Prateayawa Estate, Dultyagitiga.
Owner's Name/Address : Mr. K. Rernagdo, No. 1, Buerns Rd., Col. 7.
Reference Number : –

Field Inspection/Leaf-soil Sampling: 1991-02-22 DFR Date:1991-03-24

Present Yield Category (Approx.) : 3500 nut/acre/year [55 nuts/palm/year]
'Potential' Yield Category (Approx.) : 8000 nut/acre/year [125 nuts/palm/year]
'Target' Yield anticipated by DFR : 4500 nut/acre/year [70 nuts/palm/year]

Field block number	*Straight fertiliser rates (kg/palm/year)*						*NPKMg total cost/palm/ year*
	Urea (N)	*Eppawalal apatite (P1)*	*Saphos phosphate (P2)*	*KCl (K)*	*Dolomite (Mg1)*	*Kieserite: Mg palms only (Mg2)*	*Rs. (SL)*
Lower side	1.1	0.5	0.2	2.5	3.0	1.0	48.16
Hill side	1.1	0.5	0.2	2.5	3.0	–	38.16
North side	1.1	0.5	0.2	2.5	3.0	–	38.16
South side	1.4	0.4	0.4	1.9	3.0	1.0	46.35

Coconut growers are expected to provide transport and labour facilities to collect leaf/soil samples and other information. After about two years in the DFR programme, cost of chemical analysis needs to be reimbursed by the growers. During 1989/90 period, CRI SL has provided the DFR services to about 550 large coconut estates, mainly in the private sector. Demand for the DFR service is increasing and its public acceptance is an indication of its importance and benefits to the coconut grower.

Other benefits of the DFR programme are: (1) compilation of a computer data-base to monitor nutritional, agronomic and management conditions of coconut plantations, (2) increase the awareness of the planting community on 'judicious' application of fertilisers and efficient management and (3) interaction between researchers and planters. Although the data-base cannot be compared with conventional survey type studies, it provides a guide about the coconut plantations without additional cost.

ACKNOWLEDGEMENT

DFR was developed from the valuable research conducted by the past and present soil scientists and the technical/field staff at the CRI SL. The author is grateful to Mr. L.L.W. Somasiri, Dr. R. Mahindapala, Dr. (Mrs) C. Jayasekara, Mr. Ray Wijewardene and Mr. M. Jeganathan for their constructive suggestions during the initial developmental stages of the DFR model and to Mr. T.S.G. Peiris for preparing the computer programme. Finally the encouragement and acceptance of the DFR package by the large number of coconut growers are gratefully acknowledged.

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DISCUSSION

T. Ovasuru: Why there are differences in yield between small holders and large estates? Is it due to material or management?

K.S. Jayasekara: Small holders do not apply fertilisers (except organics) and K and Mg are limiting the yield. Even in the large estates which were using

NPK fertilisers yields are low due to Mg deficiency. Hence we introduced the DFR based on leaf analysis and yield level.

H.H. Khan: It is interesting to note that in some estates the N content of leaves was around 2.5 to 2.6 per cent. What was the yield level?

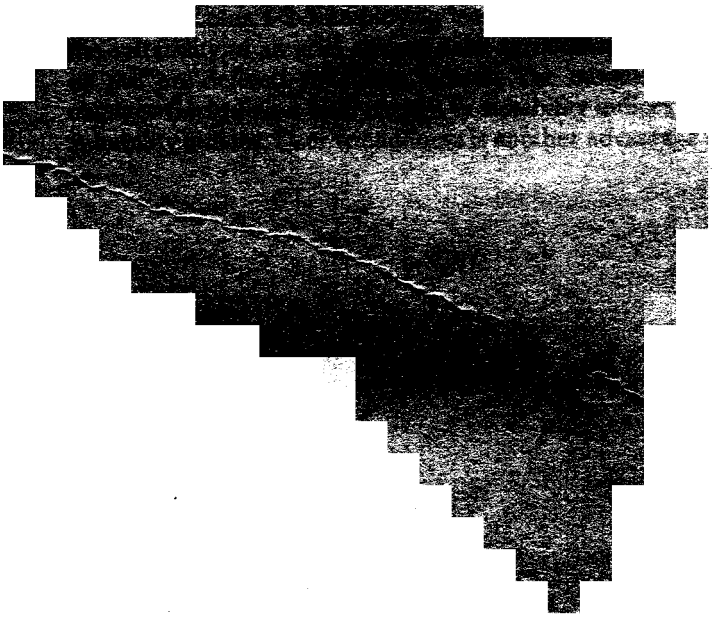
K.S. Jayasekara: Some large estates which had N levels around 2.5 to 2.6 per cent are getting about 20,000 nuts/ha/year.

A.I. Jose: The response of K presented may be the combined effect of K and Cl, since K was supplied as KCl.

K.S. Jayasekara: Sri Lanka being an island country and as coconut area is in coastal belt, we do not find any Cl deficiency. Leaf Cl levels are above 0.6 per cent.

G. Dev: The model has an important component of losses and fate of applied nutrients. Do you have all the required details about this for all soils for making fertiliser recommendations on coconut?

K.S. Jayasekara: We have data on some soils for losses of K and Mg under field conditions. Further studies are in progress on these aspects.



A COMPUTER MODEL FOR ASSESSING THE AGROCLIMATIC AND EDAPHIC FEASIBILITY OF AN AREA FOR COMMERCIAL COCONUT CULTIVATION

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A computer model has been designed to indicate the agroclimatic and edaphic feasibility of an area for commercial coconut cultivation. This model devised in Lotus 1-2-3 employing 'nested @ IF function' is useful to indicate the suitability of an area against each agroclimatic and edaphic factor based on the pre-defined suitability indices. The model can easily accommodate changes (including a total change in suitability indices) to be incorporated in suitability indices. User friendliness is another advantage of this programme.

INTERCROPPING OF VEGETABLES IN COCONUT GARDENS

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ABSTRACT

Among the different vegetable crops tried in a coconut garden, snakegourd (10,580 kg/ha), amaranthus (6,610 kg/ha) and brinjal (6,120 kg/ha) in *kharif*; bottlegourd (7,930 kg/ha), ridgegourd (3,830 kg/ha) and coccinia (3,810 kg/ha) in *rabi* and amaranthus (7,560 kg/ha), brinjal (6,310 kg/ha) and coccinia (4,060 kg/ha) in summer were highly productive and economical. Snakegourd-ridgegourd-amaranthus sequence was found to be most remunerative (Rs 22,217/ha/annum) followed by amaranthus-bottlegourd-brinjal (Rs 20,920/ha/annum). Coccinia, a perennial crop also can be grown successfully in coconut garden and it yields about 10,700 kg/ha. Intercropping helped to create additional employment to the tune of 215 to 365 mandays/ha/year in different sequences of intercropping.

INTRODUCTION

Coconut is grown in about five million holdings in the country and about 98 per cent of the holdings are below 2 ha in extent (Thampan, 1988). The income derived from most of the coconut holdings is insufficient to sustain dependent families and also does not provide an adequate on-farm employment. Vegetable crops constitute one such group of annuals which can be conveniently grown as intercrops in a coconut garden to alleviate such problems. In India, vegetables are grown in 1.2 per cent of the total cultivated area and the total production is about 30 million t per year. As against per capita requirement of 400 g vegetables per day the average intake is 75 g. To provide at least 50 per cent of per capita requirement of vegetables, it is necessary to produce about 55 million t of vegetables by 2000 A.D. Various research workers have reported about the feasibility of growing vegetables in a coconut garden in different countries (Sahasranaman, 1961; Abilay, 1983; Liyanage *et al.*, 1984; Rethinam, 1989).

In India, coconut is cultivated in about 1.5 million ha and if in a considerable area vegetable intercropping can be done, the vegetable requirements can be met and production and productivity of the land could also be increased. With these objectives in view a trial on intercropping of vegetables in a coconut garden was taken up to find out the suitable vegetable crops for different seasons of the year and their profitability.

MATERIALS AND METHODS

This trial was initiated in a 30-year old coconut garden during June 1989 in the experimental farm of Central Plantation Crops Research Institute, Kasaragod. The coconut palms were spaced at 7.5 × 7.5 m. The soil of the experimental plot was red sandy loam (Arenic Paleustult). The pH of the soil was 5.6. Mean rainfall during *kharif, rabi* and the summer of 1989 were 3211.6, 291.4 and 498.8 mm, respectively and 2819.2 mm, 221.8 mm and 148.2 mm, respectively during 1990. Vegetable crops were grown in the interspaces, in plots of 112.5 sq. m. in randomised block design and were replicated three times.

The vegetable crops grown during different seasons with their varietal names are furnished below:

	June to September (kharif)	*October-January (rabi)*	*February-May (summer)*
1.	Amaranthus (Kannara local)	Bottlegourd (Arka bahar)	Brinjal (Arka navaneet)
2.	Vegetable cowpea (Pusa barsati)	Bhendi (Pusa sawani)	Tomato (Pusa early dwarf)
3.	Bittergourd (Priya)	Chilli (N.P-46-A)	Chilli (NP-46-A)
4.	Brinjal (Pusa purple cluster)	Dolichos (Arka komal)	Watermelon (Arka manik)
5.	Coccinia (Local)	Coccinia(Local)	Coccinia(Local)
6.	Snakegourd (Arka sheetal)	Ridgegourd (Pusa nasdar)	Amaranthus (Co-1)

The above crops were selected based on their suitability for a particular season. The spacing and fertiliser schedule followed for various vegetable crops is given in Table 51.1. Bottlegourd, coccinia, bittergourd and snakegourd were trailed on a *pandal*. Other crops were raised on a flat bed system. Crops were raised as rainfed in *kharif* (June-September) but during other seasons, irrigation was given during rainless periods.

Pre-experimental coconut yield was recorded for the period 1985 to 1989. Incident sunlight was recorded between 10:00 and 11:00 hours and 14:00 and 15:00 hours at the top of the intercrop canopy using Steady State Porometer. The incident light varied from 35 to 66 per cent.

RESULTS AND DISCUSSION

Yield of Vegetable Crops

Among the vegetable crops grown in *kharif*, snakegourd gave higher yield followed by amaranthus and brinjal (Table 51.2). These crops in rainy season

Table 51.1: Cultivation details of various vegetable crops

S.No.	Vegetable crops	Scientific names	Duration (days)	Method of planting	Plants per ha**	Inorganic fertilizers (kg/ha)*		
						N	P_2O_5	K_2O
1.	Amaranthus	*Amaranthus* spp	75	Flat bed	333333 (30 cm between rows)	100	50	50
2.	Vegetable cowpea	*Vigna unguiculata* (L) Walp.	90	Ridges	148148 (45 × 15)	25	50	100
3.	Snakegourd	*Trichosanthes anguina* L	116	Ridges	9259 (120 × 90)	75	50	50
4.	Bittergourd	*Momordica charantia* L	124	Ridges	9259 (120 × 90)	75	50	50
5.	Bottlegourd	*Lagenaria leucantha* Buch	114	Ridges	6172 (180 × 90)	50	50	50
6.	Coccinia	*Coccinia indica* Wight & Am.	Perennial	Pits	3086 (180 × 180)	50	100	50
7.	Ridgegourd	*Luffa acutangula*(L) Roxb.	112	Basins	6172 (180 × 90)	50	50	50
8.	Watermelon	*Citrullus lunatus*	114	Basins	3703 (300 × 90)	100	75	100
9.	Brinjal	*Solanum melongena* L	130	Ridges	22222 (75 × 60)	75	50	25
10.	Chilli	*Capsicum annum* L	175	Ridges	49382 (45 × 45)	75	50	25
11.	*Bhendi*	*Abelomoschus esculentus* (L) Moench.	72	Ridges	55555 (60 × 30)	50	25	25
12.	Tomato	*Lycopersicum esculentum* Mill.	96	Ridges	27777 (60 × 60)	75	50	25

*10 t/ha FYM applied uniformly;

**Figures in parenthesis indicate spacing in cm.

were found to tolerate dripping of water from coconut leaves and shade to a greater extent. Performance of bottlegourd followed by ridgegourd and coccinia was encouraging when grown in the *rabi* season. Among the crops tried in summer, amaranthus gave a higher yield followed by brinjal. Performance of bittergourd in *kharif*, chilli in *rabi* and watermelon in summer was not satisfactory due to the incidence of downy mildew in bittergourd, leaf curl in chilli and occurrence of more male flowers in watermelon.

Table 51.2: Yield and monetary returns of vegetables grown in different seasons

S. No.	Crops	Yield (q/ha)	Cost of cultivation (Rs/ha)	Additional gross returns (Rs/ha)	Additional net returns (Rs/ha)
Kharif (June-September)					
1.	Amaranthus	66.10	5850	9915	4065
2.	Bittergourd	24.27	7225	8494	1269
3.	Brinjal	61.20	7975	15300	7375
4.	Coccinia	28.30	7100	8490	390
5.	Snakegourd	105.79	9620	26447	16827
6.	Vegetable cowpea	28.50	8050	9975	1925
Rabi (October-January)					
1.	Bottlegourd	79.3	9620	19825	10285
2.	*Bhendi*	34.6	7055	10380	3325
3.	Coccinia	38.1	4575	9525	4950
4.	Dolichos	24.8	7250	7440	190
5.	Chilli	18.6	7650	6510	–1140
6.	Ridgegourd	38.3	7575	9575	2000
Summer (February-May)					
1.	Brinjal	63.10	9125	15775	6050
2.	Amaranthus	61.60	5850	9240	3390
3.	Tomato	39.10	9675	11730	2055
4.	Watermelon	19.80	7150	4950	–2200
5.	Coccinia	40.60	4500	12180	7680
6.	Chilli	26.50	6250	7950	1700

Performance of Crop Sequences

Yield and monetary returns from various vegetable crop sequences are presented in Table 51.3.

Growing of amaranthus-bottlegourd-brinjal combination gave a higher total yield (208.5 q/ha) followed by snakegourd-ridgegourd-amaranthus sequence (205.7 q/ha). Performance of bittergourd-chilli-chilli sequence was not satisfactory (69.4 q/ha). Best possible combination will be to select either snakegourd or brinjal or amaranthus in *kharif*, bottlegourd or *bhendi* or ridgegourd in *rabi*, and brinjal or amaranthus or tomato in summer and make suitable sequences.

Table 51.3: Yield, monetary returns and employment potential from various vegetable crop sequences

S. No.	Vegetable crop sequences	Total yield (q/ha)	Total cost of cultivation (Rs/ha)	Additional net returns (Rs/ha)	Additional employment (mandays/ ha/year)
	Kharif *Rabi* *Summer*				
1.	Amaranthus + Bottlegourd + Brinjal	208.5	24595	20920	260
2.	Bittergourd + Chilli + Chilli	69.4	21125	1829	290
3.	Brinjal + Dolichos + Watermelon	105.8	23375	5365	300
4.	Snakegourd + Ridgegourd + Amaranthus	205.7	23045	22217	305
5.	Vegetable cowpea + *Bhendi* + Tomato	102.2	24780	7305	365
6.	Coccinia + Coccinia + Coccinia	107.0	17175	13020	245

Effect on Coconut Yield

The average yield of coconut palms has increased from 90.8 nuts/palm/year during 1985–89 to 98.7 nuts/palm/year during 1990–91 indicating beneficial interaction of vegetable cultivation as intercrops in coconut gardens.

Monetary Returns

Among the vegetable crops grown in *kharif*, intercropping with snakegourd resulted in higher returns followed by brinjal and amaranthus. During the *rabi* season bottlegourd gave a higher income followed by coccinia and *bhendi*. Growing coccinia was profitable in summer followed by brinjal and amaranthus (Table 51.2).

Adoption of various vegetable crops resulted in considerable extra monetary returns. Among these, snakegourd + ridgegourd + amaranthus sequence gave the highest net returns followed by amaranthus + bottlegourd + brinjal. Bittergourd + Chilli + Chilli combination resulted in lower monetary returns.

Employment Potential

Growing of the vegetables as intercrops has been found to enhance considerably the employment generation which ranged from 245 to 365 mandays in addition to about 150 mandays required to manage one ha of coconut garden.

Pest and Diseases

There was no severe incidence of pests and diseases in various vegetable crops except downey mildew on bittergourd and leaf curl of chilli caused by jassids and thrips, and shoot and fruit borer (*Aulocophora foreicellis*) insect in brinjal when grown in *kharif* and bacterial wilt in brinjal when grown in summer. The insects and diseases noticed on different vegetable crops were controlled with appropriate chemicals.

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DISCUSSION

K. Aravindakshan: Will it be profitable to grow vegetables in coconut garden when the yields are much below those in the open ?

M.R. Hegde: As the results have indicated many of the vegetables are giving profitable returns and it is over and above the returns realised from coconut.

THE DEGREE OF INFLUENCE OF RAINFALL ON COCONUT

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ABSTRACT

Coconut yield in Sri Lanka shows considerable fluctuation mainly due to the irregular distribution of rainfall during the preceding year. Rainfall during January/February is most influential on the total yield and the yield would increase with high rainfall and higher number of rainy days. The rainfall during March/April is also influential in increasing the yield. The rainfall during May/August has a depressing effect on crop and rainfall in excess of 450 mm is not utilised by the palms. The impact of rain during July/August is minimal. The rainfall during September/October and November/December shows a depressive effect on yield and November/December rainfall in particular has significantly a depressive effect.

INTRODUCTION

Coconut in Sri Lanka is normally harvested bi-monthly, and generally at the end of January/February, March/April, May/June, July/August, September/October and November/December. The yield variation has been observed between picks and between years. The variation has long been known to be influenced, mainly, by the distribution of rainfall in the previous year of the harvest.

However, since the study of influence of climatic factors on yield is difficult due to erratic variation in rainfall, only a few studies have been carried out in this area (Smith, 1966; Abeywardena, 1968 and Rao, 1986). Studies on the influence of annual rainfall on the total yield, have failed to take into account the degree of influence of rainfall of different sub-periods of the year.

This paper examines the results of a preliminary study undertaken with emphasis to ascertain the degree of influence of rainfall parameters of bi-monthly periods of the year on cumulative yield.

MATERIALS AND METHODS

The crop data from 1969 to 1988 and daily rainfall from 1958 to 1988 for this analysis were obtained from Ratmalagara estate of the Coconut Research Institute (CRI). The mean annual yield per ha over the 20 years period is 9,983 nuts with the maximum of 13,210 in 1971 and minimum of 5,898 in 1980. The mean annual rainfall over the 31 years is 1549.0 mm and with the minimum value (852.6 mm) in 1987 and maximum value (2390.3 mm) in 1984.

RESULTS AND DISCUSSION

Degree of Influence of Total Rainfall

A comparison of the annual yield versus time representing a 20-year period, shows that the fluctuation of yield is irregular. The correlation coefficient obtained between yield and different parameters of annual rainfall, during the harvesting year, or the preceding year, or two years prior, or their combinations, was low. By comparing individual points as well it was not possible to find any quantitative relationship with yield indicating that the parameters of annual rainfall are not adequate to identify the degree of influence of rainfall on yield. Thus the correct approach would be to divide the year into a number of sub-periods.

Degree of Influence of Four-Monthly Rainfall

Let JA(4), MA(4), and SD(4) denote the total rainfall during January to April, May to August and September to December of the preceding year of the harvest. The correlation coefficients (r), between yield and the cumulative rainfall in four-monthly sub-periods of the previous year of harvest for six groups of 15 consecutive years from 1969 to 1988 are shown in Table 52.1. Such groups were considered to obtain a better unbiased estimate of r rather than considering 20 years at once. The mean correlation coefficient (or mean coefficient of determination, R^2) presented hereafter refer the mean values over these six groups.

Table 52.1: Correlation coefficients between yield versus four-monthly rainfall

Year group	*JA(4) Jan./April*	*MA(4) May/August*	*SD(4) Sep./December*
69–83	0.4802	0.3586	–0.6322**
70–84	0.5157*	0.3925	–0.5092*
71–85	0.5584*	0.3655	–0.4733
72–86	0.5431*	0.1843	–0.6011*
73–87	0.6172**	0.2327	–0.4512
74–88	0.6007**	0.1994	–0.4114
mean	0.5526*	0.2880	–0.5132*

* Significant at 5 per cent level.
** Significant at 1 per cent level.

The r values during January to April are positive and statistically significant except one. This reveals that higher rainfall in this period is more favourable to increase the yield. Including $JA(4)^2$ into the model did not improve the R^2, indicating yield would increase with higher rainfall.

Minimum r values were obtained for the relationship between rainfall and yield during May to August. By adding the $MA(4)^2$ into the model the R^2 was significantly improved and both parameters in the quadratic model were either significant at 5 per cent or 10 per cent. This suggests that the crop response to rainfall is quadratic and rainfall above the maximum point is not utilised by the palm. The maximum points obtained for six-yearly groups as mentioned above are in the range of 509 to 544 mm. Therefore it can be concluded that the yield could be reduced when the cumulative precipitation during May to August exceeds 544 mm.

All the r values for the period September to December are considerably negative and are significant either at 5 per cent level or at 10 per cent level. It suggests that there may be harmful effects due to heavy rainfall during September to December. Addition of $SD(4)^2$ into the linear model, slightly improved R^2, but neither F—values nor parameters of the model were significant. The maximum point varied greatly from 221.4 to 663.5 mm.

The r values observed for the three sub-periods by Abeywardene (1968), using 30 years data at once, are 0.2528, 0.5424 and −0.0452, in the wet intermediate zone (mean annual rainfall is 1935.4 mm). The pattern of that is totally different from the results in this study. That is due to the fact that the degree of influence varies from zone to zone. To understand this phenomenon further, the influence of two-monthly periods is considered below. Within these periods, the effect of other climatological factors could be considered as uniform.

Distribution of Two-Monthly Rainfall

The monthly rainfall pattern in this area generally consists of two peaks. One peak due to the south-west monsoon rains during May and June ('Yala' season) and the other due to the north-east monsoon rains during October and November ('Maha' season). On the criteria proposed by Peiris and Senaviratne (1989) it has shown that the chances of commencement of rain in 'Yala' on or before the second of May and in 'Maha' on or before the eighteenth of October is 50 per cent. They have also shown that there is no cyclic pattern in the rainfall.

Let JF, MA, MJ, JA, SO and ND denote the total rainfall during January/February, March/April, May/June, July/August, September/October and November/December in the previous year of harvest respectively. The frequency charts were drawn for the cumulative rain in these periods. From the W-statistics (SAS Institute Inc., 1985), the distribution of rainfall in March/April, September/October and November/December was found to be approximately normal. The skewness and kurtosis of these distributions are close to zero. The distribution of rainfall in generally dry periods, January/February and July/August were skewed to right. A normal distribution using suitable transformation or gamma distribution could be fitted (Diwakara, 1973) to

obtain more details. The cumulative probability density functions were also drawn to obtain probabilities for specific events. The mean (x), standard deviation (s), five quartiles, Q_{100} (maximum), Q_{75}, Q_{50} (median), Q_{25}, Q_0 (minimum) and the probability of rain exceeding the mean in a given year (P_r) of the six subperiods are given in Table 52.2.

Table 52.2: Statistics of two-monthly cumulative rainfall

	JF	*MA*	*MJ*	*JA*	*SO*	*ND*
x	80.4	279.3	330.7	118.8	369.0	370.7
s	73.3	158.3	137.8	81.0	137.7	175.7
Q_{100}	298.6	871.3	693.1	366.0	674.4	742.5
Q_{75}	111.5	360.7	433.1	187.8	463.8	498.9
Q_{50}	75.4	240.6	318.0	89.6	355.5	344.7
Q_{25}	18.3	177.9	224.4	54.1	287.8	233.3
Q_0	0.0	87.5	74.4	25.9	97.5	0.0
P_r	0.452	0.427	0.445	0.392	0.378	0.455

Degree of Influence of Two-Monthly Rainfall

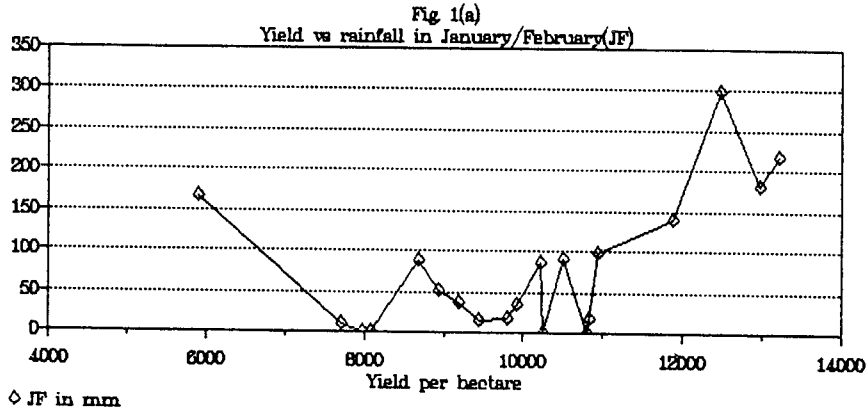
The plot of yield versus JF, MA, MJ, JA, SO and ND are shown in Fig. 52.1(a) to (f) respectively and the mean correlation coefficients between yield and rainfall are given in Table 52.3.

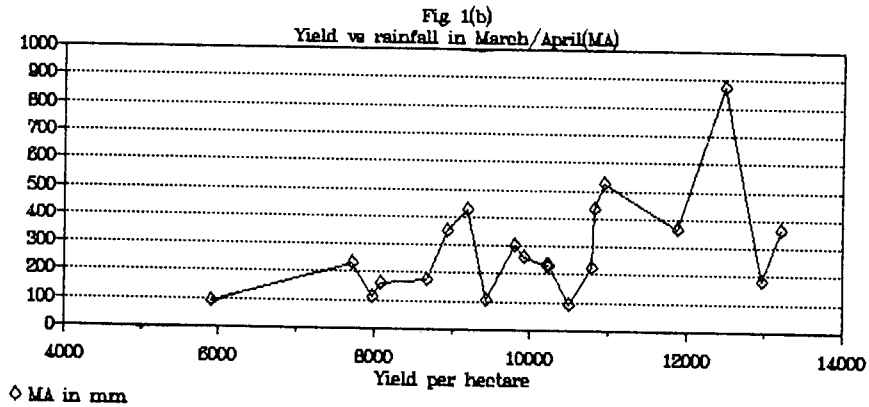
Table 52.3: Mean *r* values of two-monthly cumulative rainfall

Period	*min.*	*mean*	*max.*
JF(January/February)	0.313	0.405	0.529
MA(March/April)	0.331	0.499*	0.657
MJ(May/June)	0.148	0.250	0.367
JA(July/August)	0.154	0.210	0.292
SO(September/October)	–0.371	–0.169	0.039
ND(November/December)	–0.710	–0.512*	–0.224

* Significant at 5% level.

The mean *r* values between yield and cumulative rainfall during January/February and March/April were 0.405 and 0.499 respectively. By adding JA^2 and MA^2 separately into the linear models, R^2 had not improved in both cases. Thus it is clear that rainfall during these periods is favourable to increase the yield. The b-values in the linear model in JF is higher than MA suggesting the response to rainfall during January/February being more influential than during March/April. The highest mean correlation between rainy days and the cumulative rainfall (r = 0.794) was observed in January/February. This further reveals that there is a higher potential to increase the yield for high rainfall along with a higher number of rainy days during January/February than March/April. That may be due to less rain generally occurring in January/February, and consequently there being insufficient soil moisture to cope with the higher evaporation rate and low humidity during January/February.





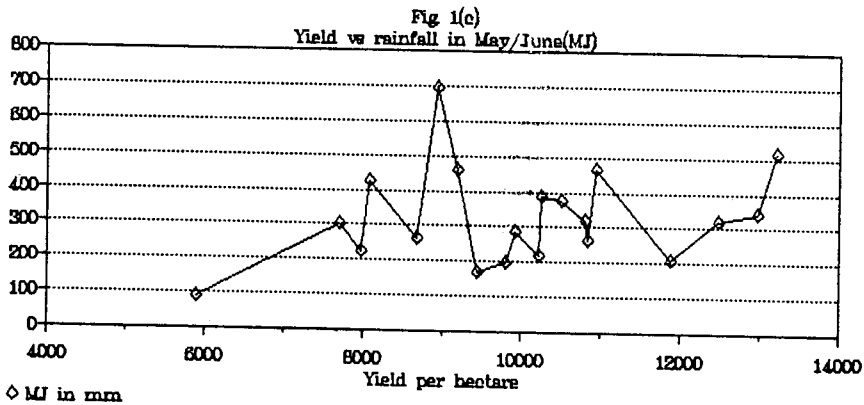
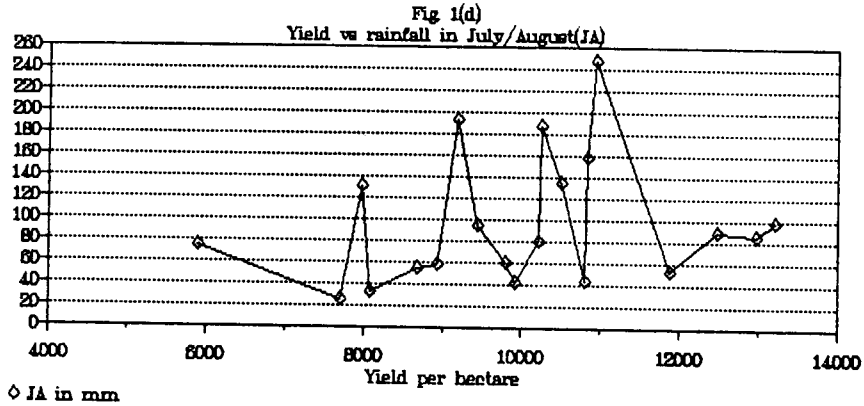
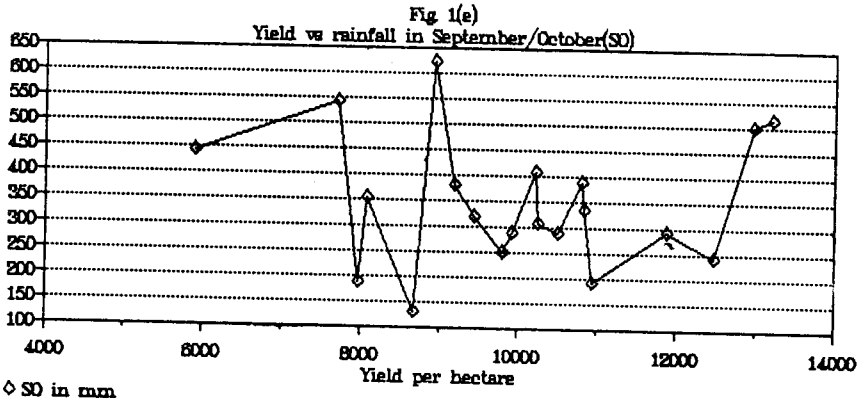


Fig. 52.1a–c: Relationship between coconut yield and degree of two-monthly rainfall (JF, MA and MJ).





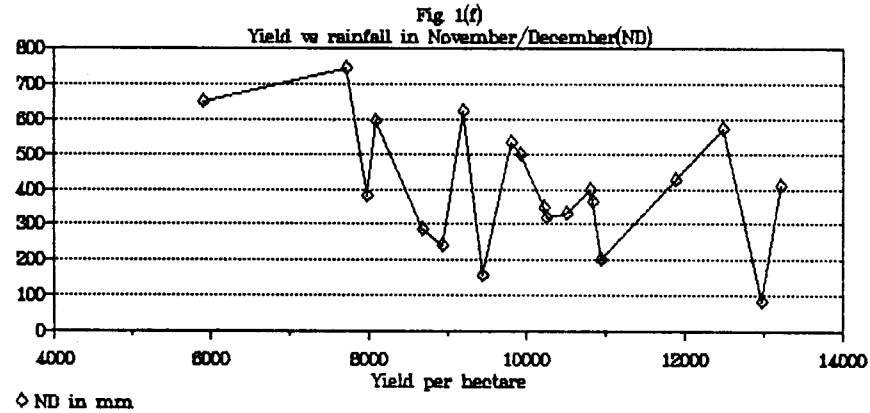


Fig. 52.1d–f: Relationship between coconut yield and degree of two-monthly rainfall (JA, SO and ND).

It is clear from Fig. 52.1(a) that high yield has occurred when the rainfall exceeded 100 mm. But the probability of rain exceeding 100 mm during January/February is 0.285. Most high yielding points in Fig. 1(b) were below precipitation line 400 mm. This could be due to the fact that the palm could tolerate around 400 mm of rainfall during this period. However the chance of rain exceeding 400 mm in March/April is very low. These results show that these two factors are more influential in yield fluctuation.

The mean r values in May/June and July/August, although low, should not be neglected. By adding MJ^2 into the linear model, R^2 was considerably improved from 6.99 to 30.42 and the two parameters in the quadratic model are either significant at 5 per cent level or at 10 per cent level. Therefore it is clear that crop response to rainfall is a quadratic relationship. The maximum points in six-yearly groups vary between 415 mm and 463 mm indicating the yield is depressed after rainfall exceeds around 460 mm during May/June.

The mean correlation in July/August is low. It did not show any significant depressing effect for high rain, may be due to low distribution of rainfall. That shows the influence of rain during July/August is minimum

The mean r obtained during September/October is negative, but low. Interestingly, r varies from 0.039 to –0.0371. Fig. 52.1(e) also shows that there are harmful effects due to high rainfall. The R^2 slightly improved for square root function than parabolic function indicating that the harmful effect was very low.

The mean correlation coefficient (-0.512) observed during November/December is highly negative and significant at the 5 per cent level. In fact the highest negative value is -0.710. Therefore it is clear that high rainfall is significantly harmful to the yield. However by fitting different models, it was not possible to obtain unique response pattern. It shows that the response is very complex and difficult to explain.

Finally by fitting multiple regression models to yield using JF, MA, MJ, MA*MJ, ND2 and RD1 (rain days in January/February) for six-yearly groups, the R^2 values were 89.18, 92.73, 83.89, 87.57, 92.96 and 92.43 per cent. All the coefficients are significant at least at 5 per cent level except RD1 on three occasions. The mean R^2 is 89.77. It indicates that about 89 per cent of yield fluctuation could be explained by these variables which will be useful for short-term yield forecasting.

CONCLUSION

The study shows the degree of influence of parameters of rainfall in two-monthly sub-periods in the year prior to the harvest on coconut in the dry intermediate zone. The most influential period is January/February and the least influential period is July/August. The rainfall during May/June has a depressing effect and rainfall in excess of 450 mm is not utilized by the palm. High rainfall during September/October has discernible effects while the high rainfall during November/December is significantly harmful to the palm.

The underlying factors for the fluctuation of yield due to rainfall are very complex and require concerted and joint efforts of agronomists, biometricians, soil scientists etc. to understand the mechanism and to formulate measures to alleviate yield fluctuation. The study also shows, that about 89 per cent of the fluctuation of yield could be explained using some of these parameters, which is useful for short-term yield predictions.

To study further about this feature, it would be useful to divide the year into monthly periods, where the external environment within periods could be minimal. Also studying the effects of rainfall on six picks separately is necessary.

ACKNOWLEDGEMENTS

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DISCUSSION

G.S.L.H.V. Prasada Rao: (1) What is the lag period between rainfall and its effect on nut yield?

(2) Instead of the total rainfall, the dry spells and its cumulative effect on nut yield may give a better relationship?

T.S.G. Peiris: (1) One Year.

(2) No. You cannot correlate dry spell to the yield because dry spell has no unique definition. In fact, I considered the longest dry spell in each of the two-month periods and also the total number of dry days. However, no useful correlation was obtained.

EFFECT OF GROWING GREEN MANURE LEGUMES IN THE BASINS OF ROOT (WILT) AFFECTED COCONUT PALMS

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The root (wilt) disease of coconut, caused by mycoplasma-like organisms has affected nearly 340 million palms in Kerala (Anonymous, 1985). In the absence of definite control measures and the debilitating nature of the disease, concept of living with the disease by developing suitable management practices to maintain the productivity of diseased palms is emerging. This communication reports the feasibility of *in situ* cultivation and incorporation of green manure legumes in the coconut basins (1.8 m radius around the bole) and its effect on root (wilt) disease and yield of palms.

A field experiment was conducted with three green manure legumes and a control without green manure in a farmer's garden in a laterite soil at Vallikunnam (Alleppey district, Kerala) in a heavily root (wilt) affected tract for a period of five years. *Calopogonium mucunoides* Desv., *Pueraria phaseoloides* (Roxb.) Benth. and *Mimosa invisa* Mert. were the legumes tested. Twenty-five to 30 years old 'West Coast Tall' coconut palms in the early and middle stages of root (wilt) disease were selected for the study and each treatment was replicated eight times. Seeds of the legumes were sown (25 g/basin) in 1.8 m radius basins with the onset of monsoon in June and shoot portion at 120 days growth was harvested and incorporated in respective basins. The palms also received the recommended fertiliser treatments at the rate of 500 g N, 320 g P_2O_5, 1200 g K_2O and 500 g MgO. Yield data and foliar disease symptoms namely, flaccidity, yellowing and necrosis, of the palms were recorded for a period of five years. Root (wilt) disease index was computed on the basis of a formula developed by George and Radha (1973). Yield and disease index data

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were analysed statistically by co-variance analysis using pre-treatment values as ancillary variables.

The mean biomass yield of *C. mucunoides, M. invisa* and *P. phaseoloides* were 24.93, 27.88 and 24.61 kg/basin, respectively. Cultivation of legumes in the basin and incorporation *in situ* did not cause any significant change in the root (wilt) disease index of the treated palms over a period of five years (Table 53.1).

Table 53.1: Effect of basin management with green manure legumes on root (wilt) disease and yield of coconut palms

Treatment	*Root (wilt) disease index*		*Nut yield/palm/year*	
	pre-treatment	*post-treatment**	*pre-treatment*	*post-treatment**
M. invisa	18.00	17.91	32.32	54.46
P. phaseoloides	12.38	16.58	39.51	63.84
C. mucunoides	21.12	20.91	42.96	52.21
Control	19.38	24.18	26.50	38.93
LSD (P = 0.05)		NS		17.12

*Values are averages of fourth and fifth years.

Palms under the treatment of *C. mucunoides* and *M. invisa* showed marginal improvement whereas palms under *P. phaseoloides* showed slight deterioration. The increase in disease index observed in *P. phaseoloides* treatment was less than the increase recorded in control palms. On the other hand, the nut yield of the palms increased significantly due to cultivation and incorporation of green manure legumes in basins. There was also improvement in the yield of control palms which could be attributed to the addition of inorganic fertilisers. But the palms under the treatment of green manures showed a much higher increase in yield than the control palms. The increase in yield could be due to the increase in microbial activity, nutrient supply and addition of organic manure in the green manure treatments. The present study suggested that yield of disease affected palms could be improved by *in situ* cultivation and incorporation of green manures and inorganic nutrients without further deterioration in the root (wilt) disease condition.

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EFFECT OF NPK FERTILISERS ON COCONUT GROWN ON CORAL SOILS OF LAKSHADWEEP

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Information on a suitable fertiliser schedule for coconut based on experimental findings is lacking under the conditions of Lakshadweep. Shamsuddin (1986) has suggested application of 360 g N, and 720 g K_2O per palm per year in the form of urea and muriate of potash respectively for coconut. A manurial experiment was conducted by C.P.C.R.I. on coral soil and the results are presented below:

The soil of the experimental site is highly calcareous (93.8 per cent $CaCO_3$), deep to very deep, well drained and structureless. The fine and coarse grained particles are made up of weathered coral and the clay content is around two per cent. The experimental soil analysed pH 8.1, organic carbon 0.35 per cent and available phosphorus 15.2 ppm with very poor available potassium status.

A field experiment was laid out in the year 1983 in Minicoy Island with different combinations of NPK on Laccadive ordinary coconut. There were seven treatments, namely, six fertiliser combinations and a control laid out in a randomised block design and replicated four times. Each treatment plot consisted of five palms. The treatments are as follows:

1) Control ($N_0P_0K_0$).
2) 600 g K_2O without N and P ($N_0P_0K_1$).
3) 1200 g K_2O without N and P ($N_0P_0K_2$).
4) 250 g N and 600 g K_2O without P($N_1P_0K_1$).
5) 500 g N and 1200 g K_2O without P ($N_2P_0K_2$).
6) 250 g N, 160 g P_2O_5 and 600 g K_2O ($N_1P_1K_1$).
7) 500 g N, 320 g P_2O_5 and 1200 g K_2O ($N_2P_2K_2$).

The fertiliser sources were urea, single superphosphate and muriate of potash for N, P and K respectively. They were applied in two split doses during the month of June (one-third) and September (two-third dose) in all the years.

The growth parameters such as leaf production, total functional leaves, number of yellow leaves per palm and coconut yield were recorded periodically. Soil and leaf (Frond 14) samples were collected during 1990 and analysed following standard methods.

The control plot and the treatments where nitrogen and potassium were not applied have produced low yield in all three years. Treatments $N_2P_0K_2$, $N_1P_1K_1$ and $N_2P_2K_2$ produced significantly more coconuts than control and also over plots where potassium alone was applied. It can be seen that the coconut yield was significantly high in treatment combination with and without phosphorus (Table 54.1). Though available P content in the soil increased with phosphorus addition, the effect of P enrichment on the nut yield was not noticed in this experiment. There was no significant difference in coconut yield between the $N_1P_1K_1$ and $N_2P_2K_2$. However, $N_1P_1K_1$ dose has given an increased yield of 123 to 160 per cent over control.

Table 54.1: Mean number of coconuts produced per palm/year in various treatments

Treatments	*1988*	*1989*	*1990*	*Mean of 3 years*
Control	21.50	32.25	33.50	29.08
$N_0P_0K_1$	37.50	54.00	45.75	45.75
$N_0P_0K_2$	38.00	63.75	73.75	58.50
$N_1P_0K_1$	47.00	65.00	69.00	60.33
$N_2P_0K_2$	65.30	85.00	87.75	79.35
$N_1P_1K_1$	72.30	82.00	75.25	76.52
$N_2P_2K_2$	54.00	83.75	73.75	70.50
CD at 5%	24.72	28.78	29.91	–

Leaf Production—Annual leaf production as an index of response to fertiliser application was significant during 1988 and 1990 while it was not significant during 1989. The treatments where nitrogen and potassium are applied together influenced the production of leaves on par with NPK combination. The treatment $N_2P_2K_2$ produced significantly more number of leaves than control and in treatments which did not receive nitrogen.

When the total number of functional leaves were considered $N_2P_2K_2$ treatment produced maximum number of leaves (33.9) followed by $N_1P_1K_1$ (33.2) and $N_2P_0K_2$ (32.6) compared to control (23.1). This indicated the importance of nitrogen and potassium in manuring coconuts in Lakshadweep. Similarly, when the number of yellow leaves per palm was taken into account, it could be seen that the palms in the control plot had the maximum yellow leaves (7.3) compared to all other treatments (3.05 to 4.4).

The yellowing of leaves noticed in treatments receiving potassium might be due to its depressing effect on magnesium uptake (Khan *et al.*, 1986) and also due to the highly calcareous nature of the soil. However, the least yellowing was recorded in $N_1P_1K_1$ treatment.

Application of fertilisers increased the soil available phosphorus and potassium significantly over control. Organic carbon contents of the soil increased marginally over control plot. The information suggested that soil fertility of coral soils can be improved with application of inorganic fertilisers.

Foliar Nutrients

The effect of fertiliser application was much evident from the significantly higher nitrogen and potassium content in treatments $N_2P_0K_2$, $N_1P_1K_1$ and $N_2P_2K_2$ as against control and other treatments (Table 54.2). It is noteworthy that the potassium content in the control plots was below the critical level and that all the treatments having different levels of potassium gave significantly higher potassium content in leaf than control. Though phosphorus content of the plant also increased with fertiliser application, differences among treatments were not significant. Interestingly phosphorus content of the leaf was the highest (> 0.14 per cent) in all the treatments. It was evident that improved nutrition consequent upon the fertiliser application was influencial in increasing the yields.

Table 54.2: Leaf nutrient contents (%) as influenced by NPK treatment

Treatments	*N*	*P*	*K*	*Ca*	*Mg*	*Na*	*S*
Control	1.70	0.14	0.38	0.60	0.32	0.34	0.18
$N_0P_0K_1$	1.72	0.14	1.15	0.57	0.25	0.43	0.20
$N_0P_0K_2$	1.70	0.15	1.28	0.60	0.25	0.37	0.20
$N_1P_0K_1$	1.81	0.15	0.79	0.56	0.29	0.45	0.21
$N_2P_0K_2$	2.00	0.16	1.12	0.57	0.27	0.42	0.21
$N_1P_1K_1$	1.96	0.16	0.96	0.58	0.29	0.42	0.21
$N_2P_2K_2$	2.01	0.16	1.29	0.56	0.24	0.40	0.21
CD at 5%	0.15	NS	0.20	NS	NS	0.06	0.02

Treatments $N_1P_0K_1$, $N_2P_0K_2$, $N_1P_1K_1$ and $N_2P_2K_2$ recorded significantly higher sodium and sulphur in the leaf than control. This result is in conformity with the findings of Fremond and Ross (1957) who reported that application of potassium also enhances sodium content in the leaf. The analysis of leaf samples for micronutrients did not reveal any significant difference between treatments. However, copper, iron and zinc were in the sufficiency range (Cu-5-7 ppm; Fe 60-80 ppm; Zn 14-18 ppm) while manganese recorded below the critical level (Mn-12-16 ppm).

Thus annual application of 250 g N, 160 g P_2O_5 and 600 g K_2O/palm/year could be recommended for palms growing in Lakshadweep.

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EFFICIENCY OF WATER USE IN COCONUT UNDER DIFFERENT SOIL/PLANT MANAGEMENT SYSTEMS

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Coconut yield in Sri Lanka under rainfed conditions is often adversely affected by long dry periods of four to five months or more between the monsoonal rains. Hence efficient use of available water is necessary to achieve the potential coconut yields.

Several field studies were conducted to assess the nutrient and water balance of coconut under different soil/plant management systems. Results show that an adult coconut with 35 fronds (150 m^2 leaf area) transpires 30 to 120 l water/day depending on the atmospheric evaporative demand and the soil water level. Stem flow and canopy drippings during the rains have increased water content in rhizosphere. Pastures and cover crops were found to have increased the infiltration of rain water with a 80 per cent reduction in run off in gravelly soil. Burying husk/coir dust in pits has increased the water storage capacity of sandy soil by 40 per cent. With the onset of dry period, root water uptake was initially confined to the top 0 to 50 cm layer of soil. After two weeks, roots extract water mainly from layers below 1 m depth in deep sandy soils.

High efficiency of water use was achieved by improving the rainfall acceptance and soil water storage capacity. However, results show the necessity to conserve the stored soil water by the coconut palm under long dry periods.

VA MYCORRHIZAL STATUS OF A COCONUT BASED HIGH DENSITY MULTI-SPECIES CROPPING SYSTEM

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A coconut based high density multi-species cropping system involving 18 component crops and three fertilizer regimes (namely, one-third, two-third and full doses of recommended fertilizers for each component crop) was laid out in 1983 at Central Plantation Crops Research Institute, Kasaragod. In 1985–86, soil samples and root samples were collected once in two months from the component crops, namely, banana, clove, coconut, coffee, pepper, pineapple and *subabul*. The objective of the study was to assess the changes in VAM status (percentage of root infection-incidence) and the extent of root colonization (infection grading) in the system with reference to season and soil fertility.

Secondary or tertiary roots were collected from all the component crops and fixed in F.A.A. These were subsequently processed according to Phillips and Hayman (1970) and observations were compiled as per Giovanetti and Mosse (1980).

Data obtained on the per cent incidence, per cent infection grading (Table 56.1), pattern of VAM infection and extent of colonization revealed that even though all the crops were grown under similar conditions of soil fertility and moisture, the pattern was distinct for each crop.

Banana, clove, pepper, pineapple and *subabul* receiving one-third dose of fertilizer showed the maximum infection grading in August, and minimum in October in banana and coffee, and also in pepper and *subabul* under one-third fertilizer regime. Banana, coconut and pepper receiving two-third fertilizer dose showed maximum infection grading in October whereas the infection grading was minimum with clove, coffee and pineapple.

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Table 56.1: VAM status in a coconut based HDMSCS at Kasaragod

	Per cent colonisation				
	April	*June*	*August*	*October*	*December*
Banana					
1/3 dose	60(18)	56(26)	60(42)	50(23)	66(39)
2/3 dose	73(26)	17 (7)	63(22)	70(45)	76(41)
Full dose	57(21)	70(27)	60(22)	70(35)	60(26)
Clove					
1/3 dose	80(31)	63(17)	68(36)	53(26)	53(29)
2/3 dose	66(23)	100(48)	66(36)	40(14)	70(32)
Full dose	57(16)	20 (4)	70(36)	40(14)	60(20)
Coconut					
1/3 dose	50(12)	26 (9)	40(14)	56(26)	56(21)
2/3 dose	57(22)	33(14)	26 (8)	60(26)	50(24)
Full dose	53(18)	40(15)	43(15)	40(13)	50(16)
Coffee					
1/3 dose	66(18)	100(40)	56(21)	43(14)	56(21)
2/3 dose	100(41)	46(18)	53(19)	43(14)	63(21)
Full dose	73(26)	40(13)	30(11)	43(16)	70(29)
Pepper					
1/3 dose	70(22)	76(26)	63(33)	46(13)	60(18)
2/3 dose	70(23)	53(17)	30(14)	63(23)	56(21)
Full dose	60(18)	66(26)	27(11)	56(20)	53(17)
Pineapple					
1/3 dose	53(17)	66(20)	60(24)	33(14)	40(11)
2/3 dose	80(31)	60(18)	76(28)	33(13)	46(18)
Full dose	100(29)	70(26)	70(22)	46(14)	56(20)
Subabul					
1/3 dose	63(23)	36(22)	66(35)	30(12)	66(26)
2/3 dose	80(26)	53(15)	20 (7)	30(11)	46(16)
Full dose	60(18)	76(32)	53(37)	60(19)	66(26)

Figures in parentheses indicate infection grading.

Two peaks of activity of VAM were seen in the rhizosphere of banana and pepper during June and October in the treatment with full dose of fertilizer whereas rhizosphere of coffee had peak activity in December and April. In the case of *subabul*, these peaks occurred during August to December.

Banana and pepper showed similar trends of infection grading at all the three levels of fertilizer application. When infection grading as an index of mycorrhizal activity was considered, pepper and coffee grown with one-third dose of fertilizer application supported the maximum activity, whereas for banana, clove, coconut and pineapple two-third dose was found to influence maximum activity. In addition, coffee alone had similar values in one-third and two-third doses of fertilizer. In the case of *subabul*, maximum mycorrhizal activity was seen in the treatment with full dose of fertilizer. However, coconut harboured maximum activity in both one-third and two-third doses of fertilizer.

It is generally known that mycorrhizal activity increases up to an optimum level of fertilizer application and gradually decreases thereafter.

Concentration of nutrients in the host tissue also decides the VAM species colonizing the plant and its extent. Thus, the dose of fertilizer applied has a direct bearing on the mycorrhizal activity and this may vary with host-fungus combinations.

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EFFECT OF COCONUT-PEPPER MIXED CROPPING ON SOIL FERTILITY AND CROP PRODUCTIVITY

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Kerala accounts for 96 per cent of the area and production of black pepper in India. Pepper is cultivated mainly as a mixed crop in coconut gardens and the present investigation examines the effect of growing pepper as a mixed crop on soil fertility, crop productivity and disease incidence.

Two villages, Pannikottur and Peruvanna in Calicut district (Kerala state) were identified during 1986 for the study. From these, 50 gardens were selected at random. The soil is ultisol, medium in N, poor in P and poor to medium in K. The mean annual rainfall is 4000 mm received in 136 rainy days.

Soil samples were collected up to a depth of 50 cm from each of the gardens at the time of starting the study (1986) and during the year 1990. Separate samples were collected from the experimental plots and from the plots where farmers' practices (application of FYM alone) were followed. The soil samples were analysed for major, secondary (Jackson, 1967) and micro-nutrients (Lindsay and Norvell, 1978) following accepted procedures. There were about 10,000 coconut palms and 30,000 black pepper vines distributed at the rate of 100 palms and 300 black pepper vines/ha in the experimental area. In the 50 households, 14,000 vines were treated as experimental vines and the remaining as untreated control receiving farmers' practices (application of FYM alone).

The standard used to trail black pepper was mostly *Erythrina indica* planted 2 m away from the base of the coconut. The standard was pruned in May and September to regulate shade and the lopping was used to mulch pepper basins. The predominant black pepper varieties were Karimunda (49 per cent), Panniyur-1 (28 per cent), Arakulammunda (14 per cent), Narayakodi (5 per cent) and Kuthiravally (1 per cent) and the remaining were unspecified varieties. Majority of the vines were five to seven years old. Lime was applied at the rate of 500g/vine/year in April. The black pepper vines were

manured at the rate of 5 kg FYM, 0.5 kg each of neem cake and bone meal along with 100, 40 and 140 g N, P_2O_5 and K_2O/vine/year. The coconut palms were of the age group of 30 to 40 years and were manured at the rate of 50 kg green leaves, 25 kg FYM and NPK at the rate of 0.34, 0.17, 0.68 kg respectively per palm per year. The black pepper vines were protected against *Phytophthora* foot-rot and slow decline by drenching copper oxychloride 0.2 per cent (10 g/vine) and spraying Bordeaux mixture (1 per cent) twice during May and September. Phorate at the rate of 3 g a.i./vine was applied twice in June and September.

Application of inputs for four years to coconut and black pepper increased the soil fertility status compared to plots receiving inputs in accordance with farmers' practices. Among the major nutrients, the maximum build up was due to application of P, followed by N and K. The higher organic matter recorded in the experimental plots may be attributed to integrated nutrient management adopted, owing to the application of organic manures and inorganic fertilisers and incorporation of loppings from the *Erythrina* standards.

Plant analysis indicated an increase in the nutrient status in coconut and black pepper due to treatment effect (Table 57.1). In coconut, nitrogen uptake was maximum followed by K and P and a depression in the uptake of magnesium was evident indicating the antagonistic effect of potassium on magnesium uptake and the necessity to include magnesium in the manuring schedule of coconut.

Regarding micronutrients, the increase in the status of Fe and Mn was marginal compared to Cu and Zn. The health of pepper vines was also much improved due to systematic fertiliser application and nutrient management. Among the varieties, Panniyur-1 is more efficient in extracting nutrients except Zn and Mn. The varieties Arakulammunda and Karimunda seem to be alike in their efficiency in nutrient extraction from soil as evident by the nutrient content of black pepper leaves.

There was 53 per cent increase in yield of coconut and 72 per cent increase in yield of black pepper (Table 57.2).

Table 57.1: Effect of integrated nutrient management on nutrient status of black pepper leaf

Nutrients	*Arakulammunda*			*Panniyur-I*			*Karimunda*		
	Farmers' practice	*Exptl. plot*	*% increase*	*Farmers' practice*	*Exptl. plot*	*% increase*	*Farmers' practice*	*Exptl. plot*	*% increase*
N %	2.0	2.31	15	2.40	3.10	29	2.20	2.60	18
P %	0.1	0.11	9	0.12	0.14	17	0.12	0.13	8
K %	2.0	2.40	20	2.20	2.70	23	2.10	2.50	19
Ca %	2.7	3.50	30	2.00	2.80	40	2.70	3.50	30
Mg %	0.26	0.26	0	0.16	0.17	6	0.17	0.17	0
S %	0.12	0.16	33	0.12	0.18	50	0.11	0.12	9
Fe mg/kg	120	127	6	115	149	30	116	131	13
Mn mg/kg	455	629	38	482	580	20	718	757	5
Zn mg/kg	16	21	31	19	24	26	17	18	6
Cu mg/kg	127	231	82	132	305	131	117	216	85

Table 57.2: Effect of coconut-pepper mixed cropping on pepper productivity (yield kg/vine)

Year	*Farmer's practices*	*Experimental plot*	*Increase (%)*
1986–87	0.356	1.100	209
1987–88	0.413	1.178	185
1988–89	0.336	0.836	149
1989–90	0.498	1.227	146
Mean	0.401	1.085	172

Adoption of integrated disease and pest management brought down incidence of *Phytophthora* foot-rot from 6.1 to 1.9 per cent and slow decline from 6.4 to 2.2 per cent indicating that the 'antiphytopathogenic potential' of a soil is likely to be higher in mixed cropping systems than in a sole crop system.

The mixed cropping systems are always labour intensive, compared to labour requirement for monocropping of coconut. The employment potential of farmers was increased by 15 to 20 per cent due to the adoption of mixed cropping.

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MULTICROPPING TRIALS IN COCONUT IN GOA

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Coconut is the second important cash crop of Goa and due to lack of manurial and irrigation practices, the yields are low. Though agro-climatic conditions in Goa are conducive for raising many crops in combination with coconut, multiple cropping is very rarely practised. Hence, trials were carried out to explore the feasibility of raising suitable crops in the interspaces of coconut under Goan conditions.

Both rainfed and irrigated crops were tried in small blocks for each variety of the crops. For rainfed cultivation, the tuber crops namely, tapioca, sweet potato, greater and lesser yams and elephant foot yam were tried. The area planted with each variety of tapioca, sweet potato and elephant foot yam was 200 sq m. For greater and lesser yams 500 sq m each and for cinnamon and pepper it was 0.1 and 0.28 ha, respectively. Tapioca and elephent foot yam were tried for two years, sweet potato for one year only and other yams for three years. All the crops were planted with the onset of monsoon (June) except sweet potato which was planted during July. Pineapple was cultivated with a population density of 46,530 plants/ha. One ratoon crop of pineapple was also taken. The palms of variety Benaulim were about 15 years old and stand was not uniform and interspaces and the shade effects varied. These palms were manured separately and were not irrigated.

Among tapioca clones, H-123 gave the highest yield (14.6 t/ha) followed by H-2304 (13.8 t/ha). The yields are similar to those recorded by Nair (1979) under Kerala conditions. The yields of these two clones are about half of what is obtained as monocrop. Tapioca is an introduction to Goa to study its potential as a source of animal feed for which a demand exists. Tapioca appears to be a promising intercrop in the coconut gardens.

The yields obtained from the sweet potato clones indicated that Cross-4 has performed well during *kharif* and gave the highest yield of 13 t/ha with a

gross return of Rs. 6,500/ha. During *kharif* no sweet potato is grown in Goa though it is popular as a *rabi* crop. Tuberisation of the local clone in *kharif* was very poor and this may be one reason for the lack of cultivation of sweet potato during the rainy season. The *rabi* crop is taken in the rice fallows from October onwards. During the rains, these areas are under paddy and hence sweet potato can be grown in the interspace of the coconuts on raised beds on uplands during this season.

Among greater yams (*Dioscorea alata*), Da-60 yielded 15.6 t/ha with an average tuber weight of 550 g followed by Da-80 (12.8 t/ha). The cooking qualities of these two clones were also found to be very good. Since these yams are of potential use only among the tribal people, its scope in Goa is limited. Elephant foot yam yielded 21.5 t/ha with a gross return of Rs. 5,375/ha in coconut plantation. This yam is popular in Goa as a vegetable and hence marketability is not a problem.

In general, tapioca, sweet potato and elephant foot yam offer better scope for cultivation as intercrops in coconut gardens though tapioca may require some promotional efforts. However, separate manuring of intercrop and coconut and rotation of tuber crops are necessary to sustain the yield of coconut and to prevent adverse effects (Varghese *et al.*, 1978).

The yields of cinnamon are quite low probably on account of the limited period of rainfall (Table 58.1).

Table 58.1: Yield of cinnamon under coconut

No. of harvests	*Quills (g/plant)*	*Kg/ha*	*Value @ Rs. 124/kg*
Ist harvest (2 years)	11.34	40.0	4,960.00
2nd harvest (2 years)	34.62	122.1	15,028.00
Cumulative yield (4 years)	45.96	162.1	20,100.40

Since the returns are high owing to its high demand and price, it is worth growing as a mixed crop with coconut.

The Kew pineapple yielded 45 t/ha of good quality pineapples weighing on an average 1.5 kg per fruit over a period of two years (including ratoon). This fruit fetches a good price in the market (Rs. 3 per kg) owing to the tourist trade and is a preferred intercrop in coconut gardens.

Black pepper grows satisfactorily and the plants started yielding from the third year onwards. The average yield obtained was 0.76 t/ha and 0.44 t/ha of dry pepper, respectively for Panniyur-I and Karimunda. No serious diseases or pests were observed. However, irrigation of the vines is necessary for good growth and fruiting at least during the initial years. The returns from black pepper are the highest.

Thus it may be summarised that tapioca, sweet potato and greater yams and cinnamon may be successfully raised as rainfed intercrops in coconut whereas pineapple and black pepper can be combined with coconut wherever irrigation facilities are available yielding good returns to the farmers.

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PEST MANAGEMENT

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INTEGRATED CONTROL OF *OPISINA ARENOSELLA*

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ABSTRACT

Opisina arenosella is a serious defoliator pest of coconut in Sri Lanka and considerable money and effort are expended for its control. The pest is adequately controlled by a complex of predators and parasitoids, but during periods of prolonged drought and the accompanying changes in environmental conditions, pest outbreaks occur. The introduction of exotic parasitoids, and the mass release of laboratory bred parasitoids during an outbreak, have not been successful. While biological control is encouraged, chemical control using systemic insecticides is recommended to control pest outbreaks.

Studies on the possible use of sex pheromones for *O. arenosella* control enabled the identification and synthesis of pheromone components, but field trials were unsuccessful.

INTRODUCTION

Coconut is a major plantation crop in Sri Lanka and is extensively grown both as home-garden small holdings and on a plantation scale in the more systematically cultivated estate sector. Both the small holdings and the estate sector plantations are equally affected by pest and disease attacks. Five insects recognised as major pests in Sri Lanka are the black beetle, *Oryctes rhinoceros* L. (Coleoptera: Scarabaedae), the red weevil, *Rhynchophorus ferrugineus* F. (Coleoptera: Curculionidae), the coconut leaf miner, *Promecotheca cumingi* Baly (Coleoptera: Hispidae), the coconut caterpillar, *Opisina arenosella* Walker (Lepidoptera: Oecophoridae) and the coconut scale, *Aspidiotus destructor* Sign (Homoptera: Diaspididae).

The coconut caterpillar was for a long time known as *Nephantis serinopa,* being described by Meyrick in 1906, until Becker (1981) found that *Opisina* and *Nephantis* were monotypic genera and the type species of both in the

British Museum were conspecific. *Opisina arenosella* had been first described by Walker in 1864 from unknown hosts.

The coconut caterpillar is a serious pest in Sri Lanka and outbreaks of the pest vary in extent and intensity from year to year but each year approximately 50 ha of coconut are infested by *O. arenosella* and require attention. A system of integrated control with emphasis on biological control has been adopted for the control of *O. arenosella* in Sri Lanka.

DISTRIBUTION

a) World Distribution of *O. arenosella*

All available records on the world distribution of *O. arenosella* indicate that the species at present is confined to only four countries—India (Nirula, 1955); Sri Lanka (Jayaratnam, 1941); Burma (Ghosh, 1923) and Bangladesh (Alam, 1962).

b) Distribution in Sri Lanka

In Sri Lanka *O. arenosella* has been recorded from the eastern, northern, southern, western, north-western and central provinces (Dharmaraju, 1963). *O. arenosella* is now present in all the coconut growing areas in Sri Lanka, but periodically recurring severe infestations are generally confined to the coastal belt of the region, eastern, southern, north-western and western provinces (Fig. 59.1).

Damage

Damage caused by *O. arenosella* is due entirely to larval feeding and appears in the form of irregular brown patches which correspond to larval feeding areas where the lower epidermis and all the tissues other than the upper epidermis have been eaten by the caterpillars. The occurrence of persisting populations of the pest causing over 40 per cent visually assessed leaf damage is considered as an outbreak. In Sri Lanka, *O. arenosella* outbreaks were recorded mainly from the coastal areas with a few inland pockets. Endemic populations occur in these areas and outbreaks have been recorded at varying intervals of time (Table 59.1). In southern and eastern provinces 54

Table 59.1: Frequency of *O. arenosella* outbreaks in the different provinces over a 20-year period

Province	*Frequency of occurrence (years)*				*Total outbreaks*	*No. of estates infested*
	2–5	*6–10*	*11–15*	*16–20*		
Southern	4	6	7	37	54	48
Eastern	5	3	2	38	48	40
North-western	2	1	6	28	37	34
Western	4	1	0	12	17	15
Others	0	0	0	3	3	3
Total	15	11	15	118	159	140

and 48 outbreaks respectively were recorded over a 20-year period from 1965. A total of 159 outbreaks on 140 estates were recorded during this period giving the high average of seven to eight outbreaks per year for the whole country. However, these outbreaks were not uniformly distributed. Some years and some areas recorded more outbreaks than others (Fig. 59.2). Thus the years 1978 to 1980 recorded 10 to 11 outbreaks per year in the southern province and 14 to 15 per year in the eastern province.

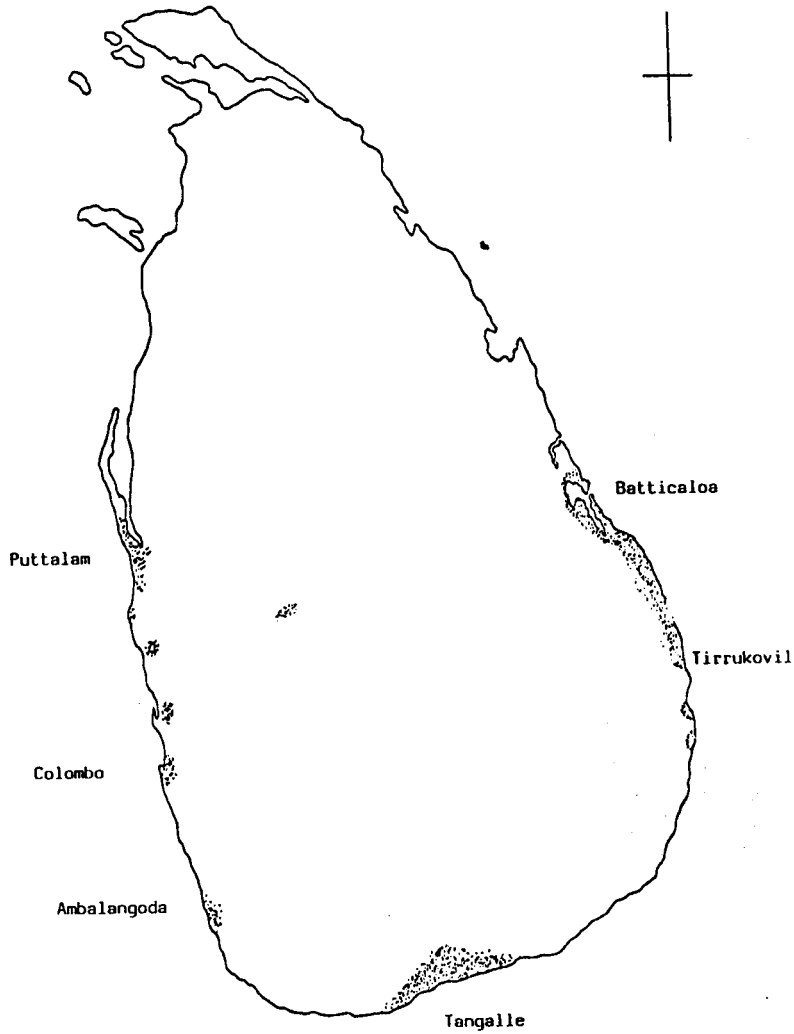

Fig. 59.1: Areas frequently attacked by *Opisina arenosella.*

Assessment of Damage

Assessment of damage caused by a single *O. arenosella* larva was made by enclosing 200 first instar larvae using pill-box and sleeve cages under field conditions and a mean of 1823 ± 100 mm^2 per insect was obtained (Table 59.2).

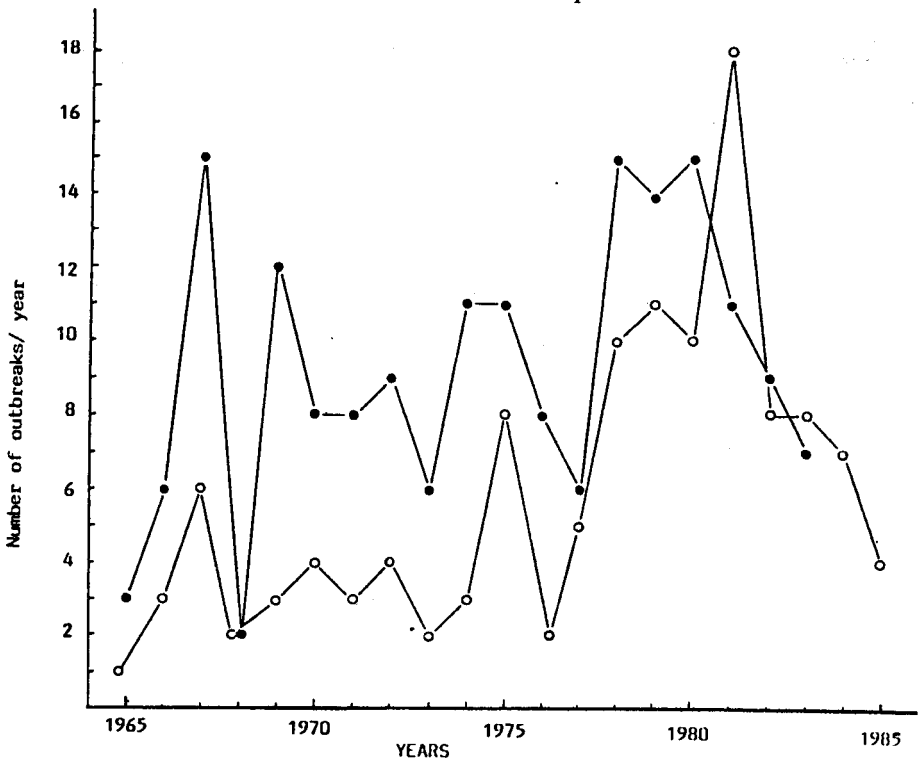

Fig. 59.2: *O. arenosella* outbreak patterns in the southern and eastern provinces of Sri Lanka, 1965 to 1985.
o Southern province
● Eastern province

Table 59.2: Leaf area consumed by *O. arenosella* larvae during different larval instars

	Leaf area consumed (mm^2) during larval instar number								*Total*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	
Number of insects	34	34	34	34	34	23	9	2	34
Total area consumed	254	1528	5714	12075	17512	15689	8332	879	61983
Mean	7.5	44.9	168.1	355.1	515.1	682.1	925.8	439.5	1823.0
S.E.	1.97	5.41	27.06	45.07	59.33	74.24	129.07	183.52	100.4

Accurate estimations of damage levels and economic thresholds for *O. arenosella* are difficult for several reasons, such as non-availability of accurate yield records over a period and rapidly changing damage levels during the increase phase. For control purposes eye-estimations are usually made of *O. arenosella* damage and categorised as mild, moderate, heavy and very heavy which correspond approximately to damage levels of 20, 40 60 and 80 per cent of the total foliage. The degree of damage and the intensity of the

infestation are estimated through population counts on samples of 20 leaflets collected randomly from the leaf range of 12 to 14 from each of five palms at the rate of one palm per ha of infested area. Counts are made of all the live, dead, parasitised, diseased and other stages of the pest and the parasitoids on each of the 20-leaflet samples. When an infestation is observed, a population count as described above is carried out and based on the results of these population counts appropriate control measures are recommended.

Control

The approach to *O. arenosella* control in Sri Lanka is essentially an integration of biological, chemical and cultural control methods. Under favourable weather conditions, when occasional rain and mild temperatures prevail, the natural enemies of *O. arenosella* comprising a complex of indigenous predators and parasitoids are able to keep the pest under adequate control.

Indigenous Predators

Indigenous predators recorded on *O. arenosella* are listed in Table 59.3 and their impact on *O. arenosella* populations is difficult to estimate as these predators do not often leave behind quantifiable evidence of their activity. However sometimes the unexpected reductions occurring in pest populations after observed predator activity cofirms their importance in the biological control programme.

Table 59.3: Distribution of predators of *O. arenosella* in Sri Lanka and India

Host stage attacked	*Predator species*	*Distribution*	
		Sri Lanka	*India*
Egg	*Tripheleps* sp. (Heterop: Anthocoridae)	A	P
Egg/larvae	*Sphedonolestes aurescens* Dist. (Heterop: Reduviidae)	A	P
Larvae/Pupae	*Corvus splendens* (Aves: Corviidae)	P	P
Larval/adult	*Rhene* sp. (Araneae: Salticidae)	P	X
Larval/adult	*Hyllus* sp. (Araneae: Salticidae)	P	X
Larval/adult	*Plexippus* sp. (Araneae: Salticidae)	P	X
Adult	*Astochia* sp. (Dipt.: Asilidae)	P	X
Larva	*Parena laticincta* Bates (Coleop: Carabidae)	P	P
Larvae	*Phaeodromius nigrolineatus* Chaud. (Coleop: Carabidae)	A	P
Larvae	*Pymotes (Pediculoides) ventricosus* (Acari: Pyemotidae)	A	P

P = Present A = Absent X = No information

Insects

Parena laticincta (Coleoptera: Carabidae) is a small (approximately 10 mm) metallic green beetle whose adults and larvae feed on the larvae of *O. arenosella* (Dharmaraju, 1963). *Astochia* sp. (Diptera: Asilidae) are long-bodied insects measuring 26 to 30 mm in length with equally long wings folded over the abdomen. The adult *Astochia* is a predator on the adults of *O. arenosella,* catching its prey more often on the wing than in a resting position (Perera, 1987).

Spiders

A number of spiders belonging to the family Salticidae have been recorded as important predators of the larvae and adults of *O. arenosella. Rhene* sp., *Hyllus* sp. and *Plexippus* sp. are the more important spider predators. *O. arenosella* larvae killed by spiders can be easily recognised as they are completely dried and always fungus-free in contrast to larvae which die of other causes and usually have fungal growth on their bodies.

Vertebrate Predators

Birds form an important component of the predator complex. The crow, *Corvus splendens* (Aves: Corviidae) is frequently seen foraging among infested leaves for larvae and pupae (Perera, 1987).

The Indigenous Parasitoids

A number of indigenous hymenoptera and diptera are recorded as parasitoids of *O. arenosella* larvae and pupae in Sri Lanka (Table 59.4). *Apanteles taragamae* Viereck (Hymenoptera: Braconidae) is a solitary internal larval parasitoid found predominantly in the eastern and southern provinces of Sri Lanka, and very rarely seen in the other provinces. *A. taragamae* parasitises first and second instar larvae only. *Aphanogmus manilae* Ashm. (Hymenoptera: Ceraphronidae) and *Eurytoma albotibialis* Ashm. (Hymenoptera: Eurytomidae) have been recorded as hyperparasitoids of *A. taragamae.*

Goniosus (Perisierola) nephantidis Mues (Hymenoptera: Bethylidae) is a gregarious larval ectoparasitoid found in all the provinces in Sri Lanka. It parasitises third to fifth instar and prepupal larvae of *O. arenosella.* Before egg-laying the host larva is paralysed and the adult female is often seen to feed on the host body fluids. *Aphanogmus manilae, Pediobius detrimentosus* Gahan. (Hymenoptera: Eulophidae) and *Pediobius imbreus* Walker (Hymenoptera: Eulophidae) are recorded as hyperparasitoids of *G. nephantidis.*

Eriborus trochanteratus Morley (Hymenoptera: Ichneumonidae) is a solitary larval endoparasitoid giving the highest per cent larval parasitism.

Stomatomyia (Spoggosia) bezziana Baranof (Diptera: Tachinidae) is a larval endoparasitoid which attacks third to fifth instar larvae, with one to two and rarely three developing from a single host although up to nine eggs (rare) have been recorded on field collected larvae. This is a parasitoid that is found only in the eastern coast of Sri Lanka. A number of hyperparasitoids have been

recorded from *S. bezziana* of which the more important are: *Neasteropaeus* sp. (Hymenoptera: Encyrtidae), *Syntomosphyrum obscuriceps* Ferr. (Hymenoptera: Eulophidae); Exoristobia philipiiensis Ashm. (Hymenoptera: Encyrtidae); *Eurytoma albotibialis* Ashm. (Hymenoptera; eurytomidae) and *Pediobius* sp.

Table 59.4: Distribution of parasitoids of *O. arenosella* in Sri Lanka and India

Host stage attacked	*Parasitoid species*	*Distribution*		*Remarks*
		Sri Lanka	*India*	
Larvae	*Apanteles taragamae* (Hym: Braconidae)	P	P	**Introduced from India (established)
	Bracon brevicornis (Hym: Braconidae)	P**	P	
	Goniozus nephantidis (Hym: Bethylidae)	P	P	
	Elasmus nephantidis (Hym: Elasmidae)	A	P	
	Stomatomyia bezziana (Dipt: Techinidae)	P	A	
	Eriborus trochanteratus (Hym: Ichneumonidae)	P	A	
	Trathala sp. (Hym: Ichneumonidae)	P	A	
Pupae	*Brachymeria nephantidis* Gahan (Hym: Chalcididae)	P	P	
	Brachymeria nosatoi Habu. (Hym: Chalcididae)	P	P	
	Trichospilus pupivora Ferr. (Hym: Eulophidae)	P	P	
	Xanthopimpla punctata F. (Hym: Ichneumonidae)	X	P	
	Xanthopimpla sp. (Hym: Ichneumonidae)	P	X	
	Coryphus nursei (Hym: Ichneumonidae)	X	P	
	Thelairosoma gracilis (Dipt.: Tachinidae)	A	P	

Brachymeria nephantidis Gahan (Hymenoptera: Chalcididae) is a solitary pupal endoparasitoid with an egg to adult period ranging from 15 to 18 days (Dharmaraju, 1963). It is the most important pupal parasitoid of *O. arenosella* in Sri Lanka and is found in all the provinces. *Trichospilus pupivora* Ferriere (Hymenoptera: Eulophidae) is a gregarious pupal endoparasitoid of *O. arenosella* with an egg to adult period of 16.3 ± 0.2 days. *T. pupivora* is found more frequently in the cooler climates of the western and north-western provinces. A major disadvantage of *T. pupivora* is its susceptibility to temperatures above 34°C.

Xanthopimpla sp. and *Trathala* sp. (Hymenoptera: Ichneumonidae) are solitary pupal endoparasitoids rarely found to parasitise *O. arenosella* which is perhaps only a casual host.

EXOTIC PARASITOIDS

Past attempts at classical biological control on *O. arenosella* in Sri Lanka have not been very successful. One primary larval parasitoid namely *Elasmus nephantidis* Rohwer (Hymenoptera: Elasmidae) and five parasitoids of related hosts were tested through laboratory and field trials resulting in partial success with one larval parasitoid *Bracon hebetor* Say. (Hymenoptera: Braconidae), which has now become part of the *O. arenosella* parasitoid complex in Sri Lanka. The other parasitoid introductions were *Trichogramma* sp. (Hymenoptera: Trichogrammatidae), *Bessa (Ptychomia remota* Aldrich (Diptera: Tachinidae), *Tetrastichus israeli* Muni and Kurian (Hymenoptera: Tetrastichidae) and *Antrocephalus pandens* Walker (Hymenoptera: Chalcididae). Large numbers of these exotic parasitoids were released on coconut caterpillar infestations with the appropriate stage of the pest. None of these exotic parasitoids established although they could be conveniently reared in the laboratory using alternative hosts.

PERFORMANCE OF THE PARASITOIDS

The performance of the different parasitoids of *O. arenosella* is highly variable and is perhaps the reason for the periodic occurrence of pest outbreaks. Census data collected at bi-monthly intervals over a three- to four-year period from climatically different areas gave some indications of their performance. *A. taragamae* was observed to perform better in the drier areas and recorded an overall mean per cent parasitism of 13.2 ± 5.1 in the southern province. *G. nephantidis* gave a low but steady parasitism in most areas and recorded mean values of 2 to 3 per cent. *E. trochanteratus* was the most successful and recorded values of 5 to 10 per cent in the western and southern provinces. Of the two pupal parasitoids, *B. nephantidis* and *T. pupivora* the former was found to be the most effective in the southern province not only as a pupal parasitoid but in the entire complex of *O. arenosella* parasitoids. Thus *B. nephantidis* gave peak percentage parasitism of 65.4 ± 6.2 in the southern province over the study period.

CHEMICAL CONTROL

The use of insecticide sprays for *O. arenosella* control has always been difficult and hazardous involving considerable spray drift, especially when used on tall palms. Trunk injections of systemic insecticides have been used successfully for the control of insect defoliators of coconut and oil palms (Stelzer, 1970; Rai, 1973; Nadarajan and Channabasavanna, 1981; Wood *et al.*, 1974).

Furthermore, the analysis of census data collected over a six-year period examined together with the parasitoid releases in the same areas during the same period showed that mass releases of laboratory-bred parasitoids during a pest population peak had very little or no effect on control.

While accepting biological control as the most important and preferred method of control, chemical control is recommended when a pest infestation is at a peak or outbreak level (40 per cent visual leaf damage) or on the increase and moving towards outbreak proportions. The trunk injection technique involves drilling a hole of approximately 8 cm deep on the trunk, at an angle of 45° from the horizontal and a convenient height from the base, using a 10 mm drill bit and pouring 6 to 8 ml of the undiluted insecticide (monocrotophos 60 per cent) into the cavity. After 24 hours the cavity is filled with cement and sand mixture and sealed off. This is followed by the release of laboratory-bred parasitoids after a two-to three-month interval.

Analysis of nut water, kernel and oil was carried out by Shell International Ltd., England, on samples collected at post-treatment intervals of two days, one week, two weeks, four weeks and 10 weeks, but residues in nut water were found to be less than 0.01 ppm with no residues detected in the nut meat (Stelzer, 1970).

As an integration of chemical and biological control, the treatment of alternate palms in a coconut caterpillar infestation (Kanagaratnam *et al.,* 1988) proved to be as effective as treating all the palms, thus saving considerably on treatment costs.

PHEROMONE STUDIES

Studies were carried out through a coordinated research programme between the Coconut Research Institute, Sri Lanka and the Overseas Development and Natural Resources Institute of England on the possible use of the sex pheromones of *O. arenosella* as a pest control tool. In preliminary investigations using virgin females and unmated males, it was possible to detect components of sex pheromones using an electro-antennogram (EAG). These sex pheromone components were isolated and the collected/synthesised product was tested under field conditions using different types of pheromone traps. Although a good response was observed in the laboratory using the EAG (Dr. D.R. Hall-personal communication) the response under field conditions was poor.

COST BENEFIT ANALYSIS

Studies (Perera, 1987) on yield loss due to 20, 40, 60 and 80 per cent estimations of foliar damage gave yield losses of 2864, 4340, 7270 and 12466 per ha over a period of 42 months, the latter being the period estimated for an *O. arenosella* infestation to come under control without extraneous control measures (see Table 59.5).

The monetary loss in rupees per ha plotted against the per cent defoliation and control costs (Fig. 59.3) gives the economic injury level at 15.5 per cent defoliation. Thus for a palm with 30 leaves the economic injury level would be four to five leaves completely damaged.

Table 59.5: Estimated harvest/ha for six-month periods from defoliation-*Opisina* simulation

Treatment	*Months from defoliation*							*Loss in yield*	*Monetary value rupees (£)*
	1–6	*7–12*	*13–18*	*19–24*	*25–36*	*37–42*	*1–42*		
Control	3986	2186	3450	3044	4286	3279	20231	0	0
20%	3957	2120	2513	2270	3657	2850	17367	2864	5728 (£ 143)
40%	3975	2270	1670	1500	3582	2894	15891	4340	8680 (£ 217)
60%	3695	1332	1332	1275	2757	2570	12961	7270	14540 (£ 364)
80%	3545	768	732	600	2120	2588	7765	12466	24932 (£ 623)

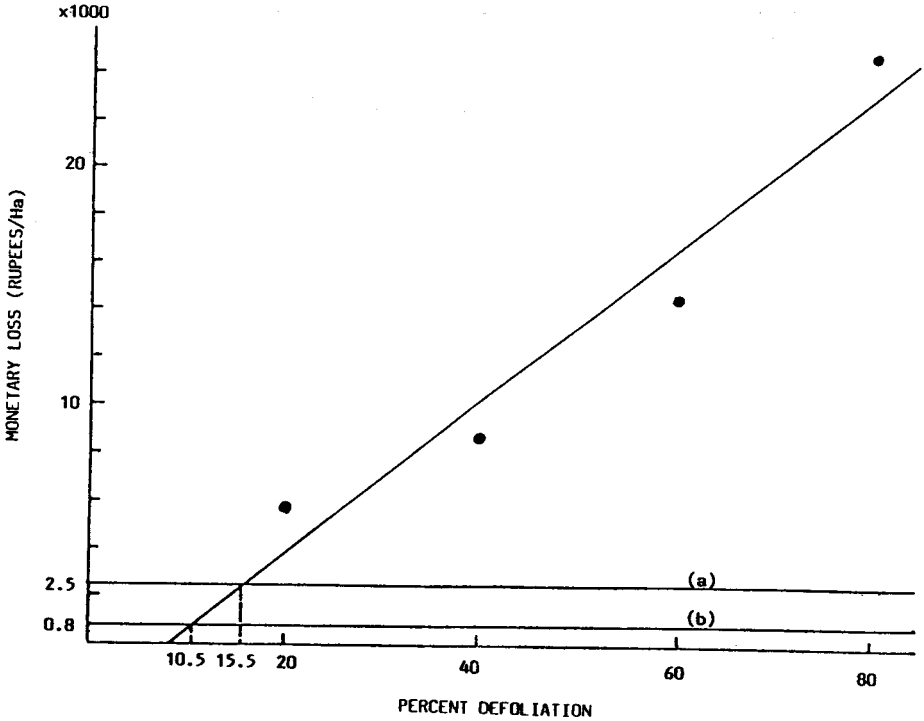

Fig. 59.3: Economic thresholds for *Opisina arenosella.*
a) Chemical control
b) Cultural control

FUTURE THRUST AREAS

Perera (1987) and Cammell *et al.* (1991) have recorded that potassium deficiency could make a palm susceptible to *O. arenosella* attack. This is an area of research that needs further investigation.

The present guilds of parasitoids of *O. arenosella* both in India and Sri Lanka (the two countries where the pest is a major problem) although very useful have still not been able to prevent the occurrence of outbreaks. Also there does not seem to be much variation in the parasitoid complex between India and Sri Lanka. It is therefore important that some thought should be given to the possibilities of introducing natural enemies of related species. Among others that may be considered *Argyrophylax fumipennis,* a common parasitoid of *Artona catoxantha,* a microtype egg layer with a very high fecundity, could be investigated for possible introduction.

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Much of the information presented in this paper has been extracted from research investigations carried out at the Coconut Research Institute of Sri Lanka. I am therefore grateful to the Director, Dr. R. Mahindapala, and the Board of Management of the CRI for granting me the opportunity to conduct these investigations. My special thanks are due to the staff of the Crop Protection Division of the CRI, Sri Lanka who were associated with me in the investigations. I thank the staff of the Divisions of Soils and Plant Nutrition and Biometry at the CRI for analytical assistance.

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DISCUSSION

G.B. Pillai: *Eriborus trochanteratus* is reported as an efficient parasitoid in Sri Lanka. Is it subjected to hyperparasitism by *Trichospilus pupivora* and *Brachymeria nephantidis*?

P.A.C.R. Perera: It is true that *Eriborus trochanteratus* is hyperparasitised by *T. pupivora* and *Pediobius imbreus* and to a much lesser extent by *B. nephantidis*. In spite of this hyperparasitism, it continues to be an efficient larval parasitoid of *O. arenosella*.

G. De Taffin: Are there any toxic residues in the coconuts when systemic insecticides are used?

P.A.C.R. Perera: The residues in the meat have been found to be very low and well within the FAO tolerance limits. However, as a precautionary measure growers are advised to harvest the mature nuts before insecticide application.

M. Rajamannar: Repeated stem injection may cause extensive damage to the trunk. Instead can we adopt root feeding technique?

P.A.C.R. Perera: The root feeding technique is possible, but is laborious and not as effective as trunk injection. Effectiveness on the leaf persists for a period of four to six months and hence reinfestation is unlikely.

INTEGRATED CONTROL OF RHINOCEROS BEETLE

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ABSTRACT

The rhinoceros beetle, *Oryctes rhinoceros* L. is one of the key pests of the coconut palm. Adoption of mechanical, cultural, chemical and biological methods in an integrated manner is feasible for the effective management of the pest.

Release of the reduvid predator *Platymeris laevicollis* can also be combined with the above operations, provided the crown treatment with insecticide is eliminated from the schedule.

The entomogenous fungus *Metarhizium anisopliae* produces epizootics in *Oryctes* population. Baculovirus of *Oryctes* is one of the most successful microbial control agents employed for the biosuppression of the pest in several countries. Success achieved from the introduction of baculovirus in Minicoy and Androth in Lakshadweep and the impact of re-release of baculovirus to an already infected contiguous area are also highlighted.

INTRODUCTION

The rhinoceros beetle, *Oryctes rhinoceros* L. is a ubiquitous pest of the coconut palm. The beetle bores through into the unopened fronds and inflorescences causing severe damage resulting in substantial reduction in the yield of palms. Field control trials carried out in a heavily infested tract in farmers' fields had revealed substantial reduction in the intensity of pest infestation on palms and the consequent increase in yield to the extent of five to eight nuts per palm per year (Sahasranaman, 1969). As the beetle breeds in cattle dung, farmyard manure, dead coconut logs and stumps and other decaying organic debris, tackling the immature stages of the pest in its breeding sites is feasible.

Monitoring of the bettle population on the crowns of palms and detection of all possible breeding sites of the pest are essential components of the pest management technology. The intensity of damage could be assessed in terms of the number of infested palms, leaf damage, spathe damage, fresh incidence on

the spindle and the number of beetles present on the crowns of palms. Management of the pest by adoption of mechanical, cultural/sanitational, chemical and biological methods had yielded encouraging results.

FIELD CONTROL

A field experiment was laid out in farmers' fields at Thamarakulam, Alappuzha District, Kerala (India) during 1964 to 1971 with a view to assessing the combined efficacy of beetle control operations such as mechanical, cultural, sanitational and chemical methods in bringing down the pest incidence on the crowns of palms. An area comprising 172 plots having a palm population of 2867 was selected for the study and the data were collected from 10 per cent sample palms (285 numbers) selected as per stratified random sampling technique. The treatments included:

1) Extraction of beetles from the crowns of palms during the peak period of pest abundance.

2) Treatment of all possible breeding sites of the pest in and around the area with aldrin 0.01 per cent in January, April, July and October.

3) Filling the innermost leaf axils of the border palms with 225 g 5 per cent HCH/Chlordane dust and sand mixture in April–May and October–November corresponding to pre- and post-monsoon periods.

4) Provision of beetle traps containing decaying organic debris treated with aldrin 0.1 per cent suspension.

5) Maintenance of field sanitation by disposal of accumulations of decaying organic debris, so as to prevent multiplication of the pest in the experimental area.

The data collected from the sample palms and the general observations of all palms are presented in Tables 60.1 and 60.2. The leaf damage had come down to 4.80 from 26.25 per cent, spathe damage to one from 38 and fresh incidence to 15 from 45 per cent of the pre-treatment condition. The reduction in pest incidence and crop damage recorded in the annual observations of all palms also showed similar trend (Anonymous, 1969). Leaf damage had come down to 8.75 from 24.56 per cent, spathe damage to 65 from 771 per cent and fresh incidence to 59 from 436 per cent of the pre-treatment condition. It was observed that quicker reduction in pest incidence and crop damage was obtained in the integrated control experiment than obtained by the individual method of insecticide treatment to the breeding places of the pest. In Sasthamkotta, where the chemical treatment of the breeding places alone was carried out the leaf damage came down to 8.38 from 20.5 per cent, spathe damage to one from 17 and fresh incidence to 27 from 96 per cent of the pre-treatment condition (CPCRI unpublished data).

NATURAL ENEMIES

The insect and mite predators/parasites associated with the breeding sites of the beetle also exert some degree of suppression of the pest. The presence of

indigenous predators such as *Santalus parallelus, Scarites* sp., *Harpalus* sp., *Pheropsophus* spp., *Agrypnus* sp. nr. *bifoveatus* etc. was recorded. However, evaluation of the predatory potential of these revealed that they exert only very meagre pest suppression. As such, no attempt has been made for mass multiplication and release of the indigenous predators.

Table 60.1: Observations of 285 sample palms of the integrated control experiment at Thamarakulam centre (1964 to 1971)

Observations	*Percentage of leaf damage*	*Number of spathes damaged*	*Number of palms with fresh incidence*
Pre-treatment	26.25	38	45
Post-treatment			
first round	26.28	14	36
second round	17.00	4	35
third round	10.29	1	31
fourth round	9.11	0	19
fifth round	5.58	1	20
sixth round	4.82	1	23
seventh round	8.15	12	40
eighth round	7.68	0	22
ninth round	6.95	0	13
tenth round	5.77	3	17
eleventh round	7.93	6	14
twelfth round	7.29	3	15
thirteenth round	4.74	4	5
fourteenth round	4.80	1	15

Table 60.2: Annual general observations of 2867 palms of the integrated control experiment at Thamarakulam centre (1964 to 1971)

Observations	*Percentage of leaf damage*	*Number of spathes damaged*	*Number of palms with fresh incidence*
Pre-treatment			
July–Sept. 1964	24.56	771	436
Post-treatment			
1965	15.71	97	274
1966	9.99	99	177
1967	7.84	69	93
1968	6.70	76	108
1969–1970	7.74	89	71
1971	8.75	65	59

The exotic reduvid predator *Platymeris laevicollis,* introduced from Zanzibar, was mass multiplied and released in the field (Antony *et al.,* 1979). Even though the predator exerted some degree of pest suppression, as revealed by the presence of a higher proportion of dead beetles on the crowns of palms, there was no build up of the predator population in any of the release

sites. In an adaptive research programme carried out by the Department of Agriculture in Kollam district, Kerala State an integrated approach including mass multiplication and field release of *P. laevicollis* was made. When the component of predator release was also incorporated, the leaf axil filling treatment with insecticide had to be eliminated from the schedule.

BIOSUPRESSION

The entomopathogen *Metarhizium anisopliae* produced epizootics in the natural population of *O. rhinoceros* when climatic factors such as low temperature and high relative humidity conditions prevailed. Nirula *et al.* (1955) recorded a high degree of infection of the fungus during the monsoon period. Conditions were ideal for the mycosis when the moisture levels of the breeding medium were 30 per cent and temperature 29°C and below (Sundarababu *et al.*, 1983). A method has been developed to mass culture this fungus on a cheaper substrate like cassava chips and rice bran supplemented with waste fish meal extract or urea as a source of nitrogen in specially designed large aluminium vessels (Mohan and Pillai, 1982). Cattle dung pits or farmyard organic refuse heaps in farmers' homesteads can be inoculated with the fungal preparation at approximately 5×10^{11} spores per m^3 of the heap by thorough mixing. The fungal propagules established in the medium survived for longer periods and infected the grubs. Dangar *et al.* (1991) used still cheaper and easily available agricultural waste material like coconut water

Table 60.3: Growth (g dry wt/100 ml medium) and spore production ($\times 10^6$/ml) of *M. anisopliae* in different media on different days

Medium	*Growth (days)*				*Spore production (days)*			
	10	*20*	*30*	*Mean*	*10*	*20*	*30*	*Mean*
Autoclaved CW (pH 5.5)	0.73	1.00	1.46	1.06	5.55	24.25	34.68	21.49
Filter-sterile CW (pH 5.5)	0.65	0.83	1.45	0.98	10.75	27.18	41.03	26.32
Aseptically drawn out CW (pH 5.5)	0.50	0.97	1.56	1.04	9.56	29.74	46.66	28.65
Autoclaved CW (pH 6.5)	0.60	0.91	1.33	0.95	4.32	24.07	33.62	20.60
Potato dextrose broth (pH 6.5)	0.50	0.79	1.15	0.81	4.48	7.17	18.72	10.12
Mean	0.62	0.90	1.39	0.97	6.93	22.48	34.90	21.22
SE/plot				= 0.04				0.078
CV (%)				= 3.96				2.650
CD (P = 0.05) for medium				= 0.026				0.571
CD (P = 0.05) for days				= 0.200				0.442
CD (P = 0.05) for medium x days				= 0.045				0.089

(CW) from the copra making industry for mass production of the fungus. This medium supported better mycelial growth and sporulation of the fungus than the conventional potato and dextrose (Tables 60.3 and 60.4). This method can be adopted by the farmers themselves with easily available local resources. The fungal spores cultured can be applied to the breeding sites at approximately 10^{9-11} spores per m^3 of breeding material.

The virus disease of *O. rhinoceros* caused by baculovirus of *Oryctes* is documented as one of the most successful microbial control agents employed for the biosuppression of coconut rhinoceros beetle in several countries including South Pacific islands, Fiji, Mauritius, Seychelles and Papua New Guinea (Cattagirone, 1981). Recent studies revealed the occurrence of baculovirus disease in the natural population of beetles collected from Kerala, India (Mohan *et al.*, 1983). The viral infection resulted in reduction in the longevity of beetles by 40 per cent and total reduction in the fecundity of the beetles. Wherever the virus was introduced into the habitat of the pest an initial epizootic decimated the larval and beetle populations resulting in drastic reduction in larval population at the breeding sites leading to substantial reduction in pest incidence and crop damage. The easy and rapid transmission of the virus disease could maintain the pest population at lower levels for many years. This viral pathogen was successfully introduced in Minicoy, Lakshadweep in April 1983 and a significant reduction in pest population was obtained (Mohan *et al.*, 1989). The data collected during December 1988 revealed 7 per cent leaf damage, negligible spathe infestation and fresh incidence on spindles (only four to five cases per 2000 palms), as against 56.6, 31.1 and 39.2 per cent respectively, of the pre-release condition. Sixty-two per cent of the beetle population collected from different parts of the island revealed baculovirus disease incidence, as against none during the pre-release condition (Table 60.4).

Table 60.4: Performance of baculovirus at Minicoy, Lakshadweep

Date of survey	*Per cent infestation*			*Baculovirus disease incidence (%)*
	Leaf	*Spathe*	*Spindle*	
Pre-release				
Apr. 1983	56.6	31.1	39.2	0.0
Post-release				
Jan. 1984	44.9	6.4	5.0	50.0
Nov. 1984	20.4	2.3	5.1	25.9
Sep. 1985	17.5	1.6	9.2	43.3
May. 1986	10.0	0.5	1.2	50.0
Dec. 1988	7.0	Negligible*		62.0

* Only four to five cases recorded per 2000 palms.

Baculovirus of *Oryctes* was introduced to Androth, Lakshadweep in April 1988. Post-release observations recorded during January 1990 revealed that

the viral pathogen had established in the natural population of the pest and exerted a considerable degree of pest suppression and consequent reduction in crop damage (Table 60.5). Leaf damage had come down to 13.5 from 55 per cent, spathe damage to 3.2 from 7.3 per cent and fresh incidence on spindle to 5.9 from 23.5 per cent of the pre-release condition. The observations on the site occupancy of the pest in breeding places revealed that the grub population had come down from 80 to 5, pupae from 17.8 to 0.02 and adults from 2.1 to 0.3 per site (Table 60.6). The population of baculovirus-infected grubs with typical visual symptoms also had increased from zero to 11.4 per site.

Table 60.5: Performance of Oryctes baculovirus in Androth island of Lakshadweep

Date of survey	*Per cent infestation*			*Baculovirus disease incidence (%)*
	Leaf	*Spathe*	*Spindle*	
Pre-release				
Apr. 1988	55.0	7.3	23.5	0.0
Post-release				
Dec. 1988	43.0	3.0	15.7	35.6
Jan. 1990	13.5	3.2	5.9	60.6

Table 60.6: Site occupancy of the pest in breeding sites at Androth, Lakshadweep

Date of survey	*Total no. of sites*	*No. per site*			*Diseased grubs (visual symptoms) per site*
		Grubs	*Pupae*	*Adults*	
Pre-release					
Apr. 1988	50	80.1	17.8	2.1	0.0
Post-release					
Dec. 1988	45	7.4	0.1	0.6	0.5
Jan. 1990	58	5.4	0.02	0.3	11.4

Baculovirus was introduced to Andamans in May 1987. There was establishment of the pathogen in the natural population of the beetles which effected remarkable reduction in frond damage, spathe damage and crown infestation (Jacob, 1990). In the Maldives, the virus was totally absent and its introduction during 1984/1985 resulted in significant reduction of *O. rhinoceros* population (Zelazny *et al.*, 1989).

Release of the infected beetle is the most economical, effective and easy method for dissemination of the inoculum into the natural population of the beetles. Baculovirus of *Oryctes* could be one of the effective components in the integrated control programme.

Young and Longworth (1981) reported successful control of *O. rhinoceros* in Tonga for seven years after its first and only release in 1970, whereas, in Western Samoa, a resurgence of the pest was noticed at low levels of virus

incidence, four years after the viral epizootic. Subsequent re-release of a small number of diseased beetles brought about substantial reduction in pest population and crop damage (Marschall and Ioane, 1982).

In order to evaluate the impact of re-release of baculovirus in an already infected contiguous area an experiment was initiated at Chittillappilly, Thrissur district, Kerala, during July 1989.

After two years of re-release of baculovirus, there was a drastic decline in percentage of infested palms, leaf damage, spathe damage and fresh incidence on spindles (Table 60.7).

Table 60.7: Impact of re-release of baculovirus at Chittillappilly, Thrissur, Kerala

Date of survey	*Per cent infestation*			
	Palms	*Leaves*	*Spathes*	*Spindle*
Pre-release				
Jul. 1989	100	34.44	12.5	68.18
Post-release				
Feb. 1990	64.29	23.76	0	50.00
Jul. 1990	64.71	27.07	0	17.65
Mar. 1991	89.47	33.96	6.52	0.00
Jul. 1991	68.18	27.38	1.89	13.63

According to Zelazny *et al.* (1989) there was the possibility of development of resistance to baculovirus in population of *O. rhinoceros*. In Indonesia (North and South Sulawese), East Java, Philippines (South Luzon), Maldives etc. the conditions are more or less similar for the build up of populations of *O. rhinoceros*. Differences exist in the population level and there has been a negative correlation between the presence and prevalence of the virus and the damage by the beetle. The disease was prevalent in East Java and South Sulawese, but occurred rarely, probably suggesting the possibility of host resistance to the virus in these locations.

To overcome the problem of resistance it is necessary to use efficient strains of the pathogen against the pest. Screening of strains prevalent in different tracts would be beneficial for isolating quick acting virulent strains of the pathogen which could be utilised for biosuppression of the pest. More detailed studies on these lines are desirable.

OTHER METHODS

Use of attractant traps, metal vane traps or coconut cap traps treated with ethyl dihydro chrysanthemumate (chrislure) or commercially available ethyl chrysanthemumate (rhinolure), were found effective for collection and destruction of beetles in the South Pacific (Barber *et al.*, 1971; Bedford, 1973; Maddison *et al.*, 1973).

Vegetative barriers such as growing cover crops like *Pueraria javanica* restrict the feeding of the beetle on the crowns of palms, conceal the breeding

grounds and act as physical barriers to impede flight of the beetles from their breeding sites. This method was suggested as one of the effective and inexpensive methods to check the pest damage on young palms in Malaysia and Ivory Coast (Owen, 1961; Wood, 1969; Julia and Mariau, 1976). However, in areas where cattle dung, farmyard manure and other decaying organic debris form the major breeding material of the pest, this method may not be practicable.

Irradiation using gamma rays affected egg fertility (Hurpin, 1970). Chemosterilants such as derivatives of aziridin reduce the longevity and competitiveness of males as compared to those of the normal males (Hurpin, 1972) and juvenile hormone mimics such as methoprene affect the adult emergence (Dhondt *et al.,* 1976).

Under the IPM programme for the coconut rhinoceros beetle in the Pacific Islands, Zelazny *et al.* (1985) had envisaged:

1) Planting legumes as cover crops to conceal the potential breeding sites of the beetle.

2) Treatment of breeding places of the beetle with the entomopathogen *M. anisopliae.*

3) Promoting the spread of the virus by leaving some dead standing palms.

4) Increasing the prevalence of the virus by releasing virus infected beetles.

To sum up, maintenance of field sanitation, extraction of beetles during the peak period of pest abundance on the crowns of palms, mass multiplication and release of *M. anisopliae* to the breeding sites and re-release of baculovirus of *Oryctes* are some of the methods which can be adopted for the efficient management of rhinoceros beetle.

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DISCUSSION

T.P. Sreeharan: Exotic predators did not do well in Sri Lanka. Can the possible reasons be given?

G.B. Pillai: Exotic predator *Platymeris laevicollis* has been tried in several countries. Even though there was some degree of pest suppression, there was no build up of the predator in any of the release sites in India.

L. Diehl: What was the effect of the beetle control on yield of nuts?

G.B. Pillai: In one experiment, the yield was increased by five to eight nuts per palm per year by adoption of beetle control operations.

NEMATODE MANAGEMENT IN COCONUT AND COCONUT-BASED CROPPING SYSTEM

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ABSTRACT

Important nematode pests in coconut and coconut-based farming systems are the burrowing *(Radopholus similis)*, the root-knot *(Meloidogyne incognita)* and the lesion *(Pratylenchus coffeae)* nematodes. The burrowing nematode causes severe damage to coconut, arecanut, banana, black pepper, ginger and turmeric. Consequent on heavy root rotting, the plants exhibit loss of vigour, stunting, yellowing of leaves, delay in flowering and reduction in yield. Aerial and underground symptoms produced by other nematodes are discussed.

Measures suggested for developing an integrated nematode management in coconut and coconut-based farming system are the use of nematode-free planting material of coconut and intercrops; application of organic manure to the coconut basins, growing and incorporation of green manure crops in coconut basins, application of phorate and introduction of biocontrol agents like *Pasteuria penetrans*, *Paecilomyces lilacinus* and VAM to nursery potting mixture to reduce nematode population and for imparting resistance/tolerance to nematode infestation.

The coconut-based cropping systems that have been developed or evolved over many centuries on a low risk basis, are a combination of natural and farmer selections. Even though coconut cropping systems are known in various countries, very little information is available on nematode problems of coconut or of the component crops except for some exploratory surveys conducted (Orton Williams, 1980; Lamberti, 1980 and 1981) as well as investigations carried out in relation to major coconut diseases like lethal yellowing and kaincope disease (Govindankutty and Koshy, 1979). The present paper examines the nematode problems and their management in the coconut-based multispecies cropping systems on the west coast of South India.

Nematode Problems on Coconut and Component Crops

The important nematodes recorded in coconut-based farming systems in India are the burrowing (*Radopholus similis* Cobb, 1893; Throne, 1949), the

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root-knot (*Meloidogyne incognita* Kofoid and White, 1919; Chitwood, 1949) and the lesion (*Pratylenchus coffeae* Zimmermann, 1898; Filipjev and Schuurmans Steckhoven, 1941) nematodes. The cyst nematode (*Heterodera oryzicola* Rao and Jayaprakash, 1978) was recorded on banana. Coconut as well as the component crops like arecanut, banana, black pepper, ginger, turmeric, and tuber crops are susceptible to one or more species of these nematodes. During a detailed survey in coconut based cropping systems in Kerala and Karnataka States in India, widespread occurrence of *R. similis* on coconut, arecanut, banana, black pepper, ginger, turmeric and betal vine (Koshy *et al.*, 1978; Sundararaju *et al.*, 1979a; Koshy and Bridge, 1990) was recorded. *M. incognita* was recorded on black pepper, banana, ginger, turmeric, *subabul*, cacao, cardamom, pineapple and betelvine whereas the *P. coffeae* was recorded from roots of coffee, banana, ginger and turmeric (Table 61.1).

Table 61.1: Susceptibility of different crops to nematode infestation

Crops	*R. similis*	*M. incognita*	*P. coffeae*
INDIA			
Coconut	+++	–	+
Banana	+++	++	+
Black pepper	+++	+++	–
Cacao	–	+	–
Nutmeg	+	+	–
Cinnamon	–	–	–
Pineapple	–	+	–
Clove	+	+	–
Coffee	+	+	+++
Lemon	–	–	–
Subabul	–	+++	–
Tapioca	–	+	–
Elephant foot yam	–	+++	–
Taro	–	+	–
Papaya	–	+++	–
Ginger	++	+++	++
Turmeric	++	+++	++

Crops	*R. similis*	*Meloidogyne* sp.	*P. coffeae*	*P. brachyurus*
FIJI				
Banana	+	+	+	+
Coconut	–	+	+	+
Coffee	–	–	+	+
Ginger	+	+	+	–
Papaya	–	+	+	+

Contd.

Table 61.1 Contd.

Crops	*R. similis*	*Meloidogyne* sp.	*P. coffeae*	*P. brachyurus*
Pineapple	–	+	+	+
Tannia	–	+	+	–
Tapioca	–	+	–	+
Taro	+	+	+	+
Turmeric	+	+	–	+
Yam	+	+	+	+
KIRIBATI				
Banana	–	+	+	–
Coconut	–	–	–	–
Papaya	–	+	+	–
Pineapple	–	–	–	–
Tannia	–	+	–	–
Yam	–	+	–	–
NIUE				
Coconut	–	–	–	–
Papaya	–	+	+	–
Pineapple	–	+	+	–
Taro	–	+	–	–
Tapioca	–	–	+	–
Yam	–	+	+	–
WESTERN SAMOA				
Banana	+	+	+	–
Cacao	–	+	–	–
Coconut	+	+	+	–
Coffee	–	+	+	–
Cinnamon	–	–	–	+
Ginger	–	+	–	–
Papaya	–	+	–	–
Pepper	–	+	–	–
Pineapple	+	+	–	–
Tapioca	+	+	–	–
Taro	+	+	–	+
Yam	–	+	–	–
TONGO				
Cacao	–	–	–	+
Coconut	–	+	+	–
Coffee	–	–	–	–
Papaya	–	+	+	+
Pepper	–	+	+	+
Pineapple	–	–	–	+
Tannia	–	+	+	–
Tapioca	–	+	+	+
Taro	–	+	+	+
Yam	–	–	+	+

+ + + = Highly susceptible.
+ + = Moderately susceptible.
+ = Less susceptible.
– = Non-host.

Radopholus similis

Radopholus similis causes pepper yellows in Indonesia (Christie, 1957), spreading decline of citrus in Florida (DuCharme, 1954) and toppling disease of banana in all banana growing regions of the world (Blake, 1972) except in Israel (Minz *et al.*, 1960) and Taiwan (Huang, 1972).

Symptoms

The burrowing nematode infested coconut palms exhibit general yellowing and visible reduction in growth, vigour and yield. These above-ground symptoms are non-specific and the only definite method to identify an infested palm is to look for symptoms on fresh main roots during September to November. *Radopholus similis* on infestation produces small, elongate, orange coloured lesions on the young, succulent, creamy-white to light orange tender portions of roots of coconut, banana and black pepper. These lesions coalesce and cause extensive rotting of roots. Primary lesions also show cracking of epidermis under stereo-microscopic examination. The nematode also attacks the plumules, leaf bases and haustoria of coconut seedlings (Koshy and Sosamma, 1987). Unlike in coconut, the tip of lateral and tertiary roots on infestation become black in arecanut. The primary symptoms of *R. similis* infested or slow decline affected black pepper vines are the appearance of a few, pale yellow, dropping leaves. The number of such leaves gradually increases and within a year or two the entire foliage may become yellow, and lead to shedding of leaves, cessation of growth and die back symptoms. The tender creamy-white feeder roots show typical orange to purple coloured lesions. The root system exhibits extensive rotting with the main roots devoid of feeder roots. The symptoms are well pronounced when soil moisture is depleted during November to May. Infested ginger and turmeric plants exhibit stunting, reduced vigour and tillering and dry faster than healthy plants. Tips of young leaves become chlorotic and scorched. The infested ginger rhizomes exhibit small, shallow, sunken, water-soaked lesions. Infested turmeric rhizomes tend to lose their characteristic bright yellow colour and on cross-section show brown rotting (Sosamma *et al.*, 1979; Sundararaju *et al.*, 1979b).

Survival

The nematode is known to survive and multiply more in deep, well drained sandy loam soils but less in shallow, poorly drained clayey soils. The coconut isolate of *R. similis* was found to survive in host-free dry sandy soil for three months and in host-free wet soil for 15 months under greenhouse conditions. Active nematode populations could also be recovered from roots of felled palms for a period of six months (Sosamma and Koshy, 1986).

Dissemination

Nematode is disseminated mainly through the infested planting materials, floods, irrigation water, farm implements and bulk transport of soil.

Meloidogyne incognita

Black pepper and betelvine infested by both burrowing and root-knot nematodes show unthrifty growth and yellowing of leaves. The prominent symptoms of root-knot nematode infestation on black pepper are a gradual decline characterised by unthrifty growth and yellowing of leaves. Leaves of vines infested with *M. incognita* exhibit dense yellowish discolouration of the interveinal areas making the leaf veins quite prominent with a deep green colour, whereas leaves of the vines infested with *R. similis* show uniform pale or whitish yellow discolouration and typical dropping. Root system becomes heavily galled. In the variety Panniyur-1 the galls are smooth and bigger in size compared to the small galls with exposed egg masses giving a pitted rough appearance to roots of cv. Karimunda.

In ginger and turmeric the root-knot nematode causes galling and rotting of roots and underground rhizomes. Infested plants show stunted growth, yellowing, marginal and tip drying of leaves and reduced tillering. In turmeric, infested rhizomes tend to lose their bright yellow colour (Sukumaran and Sundararaju, 1986; Sukumaran *et al.*, 1989).

Pratylenchus coffeae

The lesion nematode-infested ginger and turmeric plants exhibit stunting, reduced vigour and tillering, and dry faster than healthy plants. The youngest leaves become chlorotic with scorched tips. The infested rhizomes exhibit small, shallow, sunken, water-soaked lesions. Infested turmeric rhizomes tend to lose their characteristic bright yellow colour and show brown rotting.

Economic Threshold Levels

The pathogenicity of *R. similis* was studied on coconut and other component crops. The threshold inoculum density required for causing significant reduction of various growth parameters on coconut was 100 nematodes in 625 cm^3 or 900 g soil under field conditions over a period of five years (Koshy and Sosamma, 1987). In black pepper, reduction in the growth and productivity of the vines were more marked in the vines inoculated with 10,000 and more *M. incognita* while *R. similis* even at 100 nematodes per vine caused significant reduction in all the growth characteristics (Ramana *et al.*, 1987). An inoculum level of 10 burrowing nematodes per vine caused foliar yellowing and defoliation after two years and an inoculum level of 100 nematodes per plant caused 29 per cent reduction in yield compared to 59 per cent reduction with an initial inoculum of 10,000 nematodes per plant after two years (Mohandas and Ramana, 1991). The effect of *R. similis* was studied on turmeric and found that an initial inoculum level of 10 nematodes caused 35 per cent reduction of rhizome weight after four months and 46 per cent reduction at the end of the season (Sosamma *et al.*, 1979). A reduction of 73.6 per cent of rhizome weight was recorded at an initial inoculum level of 10,000 nematodes per plant after a period of six months and an initial inoculum level of 10 nematodes per plant caused 39.9 per cent reduction in rhizome weight (Sundararaju *et al.*, 1979b).

INTEGRATED NEMATODE MANAGEMENT

Control of the burrowing nematode infestation on coconut with extensive root system is difficult, especially under the high density multispecies cropping system involving susceptible crops like banana, black pepper, ginger and turmeric.

Products of some crops such as banana, papaya, pineapple and betelvine are generally consumed without any processing or cooking. Application of nematicides to the root zone of one component crop can lead to deposition of residues in the produce of an adjoining crop as the roots of these crops are interwoven and the nematicides get carried through irrigation and rain water. Application of phorate at the rate of 10 g a.i./palm to coconut and 3 g a.i./vine to black pepper in June and September has been found beneficial in increasing yield. Application of phorate to banana at the rate of 3 g a.i./sucker at planting and 90 days after planting is beneficial for the control of burrowing and other nematodes besides banana aphid, root grub and rhizome weevil.

The cultural methods that are generally practised such as crop rotation, shifting of planting date, fallowing and flooding are only of limited use in coconut based farming systems, since most of the crops involved are perennial in nature. However, root-knot and burrowing nematode susceptible intercrops such as ginger, turmeric, papaya, elephant foot yam and Chinese potato may be avoided and if grown, planting sites may be changed every year. Growing nematode-resistant crops such as cacao, pineapple, cinnamon, clove, colocasia and tapioca should be preferred. Maximum care should be taken to avoid crop combinations that are susceptible to the same nematode species. Instead of root-knot susceptible *subabul (Leucaena leucocephala), Gliricidia maculata* may be grown on the borders and in the interspaces as a standard for black pepper and its leaves and tender twigs may be used for green manuring because of its known nematicidal properties. Green manure crops like *Crotalaria juncea* and *Pueraria javanica* may be grown in basins and interspaces and incorporated into the soil. Increased use of organic amendments like *neem* and *marotti (Hydnocarpus)* oil cakes, farmyard manure and mulching with weeds, grass, straw and dry leaves help in the build up of predatory nematodes and nematode parasiting fungi.

Sanitational methods such as opening planting pits, when the weather is dry and burning of trash in pits, paring of banana suckers and sun-drying them, solarising nursery beds and potting mixture are some of the easiest and less expensive methods which limit population build up of nematodes.

Host tissue environment is ideal for rapid multiplication of nematodes. Burrowing nematode infested seedlings of coconut and arecanut and rooted cuttings of black pepper do not establish easily and even if they get established initially they do not withstand the drought conditions and more than 50 per cent of them are lost in the first year itself. Seed rhizomes of ginger and turmeric should be raised in nematicide treated plots. Certified nematode free seed/planting material need to be made available as in the case of potato.

Recently biological control of plant parasitic nematodes is receiving greater attention. Some species of fungi and bacteria prevent nematode multiplication and even reduce the damage caused by nematodes. Very little work has been carried out in India on biological control of nematodes except for a few stray records of isolations of fungi. Studies were carried out at CPCRI, to find out the effect of VAM in imparting tolerance to *R. similis* and *M. incognita* infestation on plantation crops in different cropping systems. The effect of six species of VA mycorrhiza individually and in combination with root-knot nematode, *M. incognita* was studied on cardamom. The results revealed that the prior inoculation with VA mycorrhizal fungi, particularly *Glomus margarita* and *G. fasciculatum* were effective in ameliorating the deleterious effects of nematodes and in providing vigorous, healthy seedlings for transplantation in the field (Thomas *et al.,* 1989). Since the root-knot nematode is a serious problem on ginger, causing drastic reduction in rhizome yield (Charles, 1978) the individual and interactive effects of VA mycorrhiza, root-knot nematode *M. incognita* and *Pythium aphanidermatum* were studied on ginger. Inoculation with VA-mycorrhizae, particularly a mixture of *G. fasciculatum* and *G. multicauli* (100 spores) was effective in ameliorating the deleterious effects of nematode and a fungus *P. aphanidermatum* on ginger (Rohini Iyer and Sundararaju, 1990). The use of VA mycorrhiza *G. macrocarpum* as a biological control agent against root-knot nematode was also studied on *subabul* seedlings at CPCRI, Kasaragod. Prior inoculation with VA mycorrhiza *G. macrocarpum* (200 spores per 5 kg soil) was effective in ameliorating the deleterious effects of root-knot nematode on *subabul* (Sundararaju *et al.,* 1990). *Paecilomyces lilacinus* (Thom) Samson reduced the damaging effect of *R. similis* on betelvine when inoculated 25 days prior to nematode inoculation, whereas simultaneous inoculation of both the organisms or inoculation of the fungus 25 days after nematode inoculation was not effective in reducing the damage (Sosamma *et al.,* 1990). While it is not possible to achieve absolute control of plant parasitic nematodes or control to an economic level with biocontrol agents at field level, this method can be part of an integrated nematode management programme.

One of the most economical and effective ways to control nematodes is growing nematode resistant plant cultivars. In view of the importance, various crops grown in coconut based cropping systems were screened against root-knot and burrowing nematodes (Sosamma *et al.,* 1980; 1988; Sosamma, 1984; Mohandas and Ramana, 1983; Jacob and Kuriyan, 1979; Ramana and Mohandas, 1986; Mani *et al.,* 1987; Gunasekharan *et al.,* 1987; Chen *et al.,* 1986; Anonymous, 1987). A list of resistant/tolerant varieties/hybrids to the *R. similis* and *M. incognita* is given in Table 61.2. There are a number of varieties and hybrids in coconut, banana, black pepper, *subabul* and coffee that are either tolerant or resistant to the root-knot and burrowing nematodes. Based on the information available, a suitable crop combination for nematode infested areas is suggested (Table 61.3).

Table 61.2: Cultivars/varieties tolerant to burrowing and root-knot nematodes

Crops	*Burrowing nematode*		*Root-knot nematode*
	Cultivars	*Hybrids*	*Cultivars*
Coconut	Kenthali Klappawangi Java Tall	LO × Gangabondam COD × WCT MDY × Java Giant San Ramon × Gangabondam Java Giant × MDY	
Black pepper	–	–	CLT-P-812 Neyyatinkaramundi Jeerakamundi Karimunda Kudirugunda
Subabul	–	–	K-500, K-72
Banana	Palayamkodan Yelakkabale Njalipoovan		
Coffee	–	–	Robusta
Turmeric	–	–	5379-1-2, 5663-6-3, Kodur, Cheyapuspa, 5335-1-7, 5335-27, Ca-17/1, Cli-124/6 Cli-339, Armoor, Duggirala, Guntur-1 Guntur-9, Rajampet, Sugandham, Appalapadu

Table 61.3: Recommended crop combinations in coconut based HDMSCS with integrated nematode management in India for rainfed conditions

Crop combinations	*1*	*2*	*3*
1.	Coconut + pepper	Cacao	–
2.	Coconut + pepper	Pineapple	Banana
3.	Coconut + pepper	Nutmeg/clove/cinnamon	Banana
4.	Coconut + pepper	Nutmeg/clove/cinnamon	Yams/*Tannia*/cassava
5.	Coconut + pepper	Hybrid napier	–

Measures suggested for developing an integrated nematode management in coconut and coconut based farming systems are: (1) use of nematode free planting materials of coconut and intercrops, (2) use of tolerant/less susceptible cultivars or hybrids of coconut and other intercrops in infested areas, (3) application of 50 kg cowdung/farmyard manure, 2 kg *neem/marotti* oilcake and 25 kg green manure to the coconut basins, (4) growing of *C. juncea* in the basins and interspaces and its incorporation into soil at the flowering stage as

a green manure, (5) growing of *G. maculata* on the borders and in the interspaces as a standard for black pepper and use of its leaves and tender twigs for green manuring of coconut and black pepper, and (6) application of phorate at the rate of 10 g a.i./palm and 3 g a.i./vine in June and September for coconut and black pepper, respectively. For banana, phorate may be applied at the rate of 3 g a.i. per sucker at planting and 90 days after planting. In the case of ratoon crop, phorate may be applied at the same rate per hill twice a year, but care should be taken to avoid the application of phorate at and after flowering. Nematicides need not be applied separately to black pepper trailed on to coconut, if the standard is receiving nematicides already, and introduction of biocontrol agents like *P. penetrans, P. lilacinus* and VAM to nursery potting mixture and planting pits to reduce nematode population and for imparting resistance/tolerance to nematode infestation.

Developing a location specific integrated nematode management schedule depending upon the crops and nematodes involved, thereby keeping the nematode population below the threshold level to increase the income per unit area/input is the immediate need for coconut based farming system.

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DISCUSSION

M. de S. Liyanage: In Sri Lanka, *Pueraria* is raised as cover crop in coconut gardens. Do you think *Pueraria* can reduce nematode population?

P.K. Koshy: *Pueraria* leaves have no nematicidal properties. On the other hand, they are highly susceptible to root-knot nematode which reduces nodulation by Rhizobium.

T.P. Sreeharan: How can the residue problem be solved in mixed cropping when nematicide application has become necessary?

P.K. Koshy: Nematicides should not be applied after flowering. Phorate leaves no residue after 45 days in coconut, arecanut and banana at the recommended dosages.

RED RING DISEASE OF THE COCONUT PALM

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ABSTRACT

Red ring disease of the coconut palm, *Cocos nucifera* L. is incited by the plant parasitic nematode *Rhadinaphelenchus cocophilus*. Whereas the definitive host of the nematode is the coconut palm and other susceptible palm species, it is only vectored by the palm weevil, *Rhynchophorus palmarum* which develops in these palm species. The disease is confined to some West Indian Islands and to Latin American countries where the coconut palm is cultivated. The most characteristic symptom of the disease is a broad orange-red coloured band of nematode-laden necrotic tissue within the stem, leaves and roots of the affected palm. Juvenile palms between the ages of two and 10 years are most susceptible.

Management of the disease is effected through control of the insect vector using guard-baskets containing chunks of coconut tissue sprayed with 0.1 per cent lannate solution to attract and kill them, and by removal of the diseased trees after poisoning them with an effective weedicide, or by burning.

HISTORY OF RED RING DISEASE

The disease was first reported as occurring in Trinidad by Hart in 1905. Stockdale in 1906, thought that two different diseases were being confused since they both culminated in decay of the bud. One of these was red ring disease, then called root disease, and the other, bud rot initiated by *Phytophthora palmivora* Butl.

Nowell (1919) had found that a large number of roots examined from trees in Trinidad contained hundreds of nematodes of the same species. They were also present in the constant red ring found in trees in Grenada and also in the material collected in Trinidad by Rorer. Later he confirmed the absence of a causal fungus earlier reported by Rorer (1911). He noted that the nematodes of the same species previously observed elsewhere were constantly present in stems, leaves and roots. The name 'red ring disease' was then used by Nowell in 1919 and became the eventual name for the disease. The nematode was then

identified by Cobb as *Aphelenchus cocophilus* and is now known as *Rhadinaphelenchus cocophilus* (Cobb, 1919; Goodey, 1960).

DISTRIBUTION, CROP LOSS AND ORIGIN OF THE DISEASE

This nematode is also associated with a little leaf disease of coconut and oil palm in Surinam (Van Hoff and Seinhorst, 1962). Whereas the nematode is present in all the contiguous countries in South and Central America wherever coconuts are grown, it is not present in all the northern West Indian islands separated by water. In severely affected coconut zones, recorded losses can be as high as 60 per cent of the young palms and about 20 per cent of the mature ones.

It appears reasonable to assume a Latin American origin for red ring disease based on the following: (a) the disease is present only in the Latin American areas and only in those countries where the palm weevil, *Rhyncophorus palmarum*, the vector, is present; (b) *R. palmarum*, is the species of *Rhyncophorus* localised in the American continent though other members of the genus are present in South-east Asia with enough diversity to indicate this area as the origin of the genus; further, local 'red' variants of *R. palmarum* throughout Latin America repeat frequently the diverse colouration of the several species in South-east Asia—the insect has therefore migrated to and became isolated in Latin America, without transporting the red ring nematode which is absent from the Old World; (c) the nematode is known to be an obligatory parasite on coconut, oil palm and a few other genera of palms in Latin America only; and (d) an ectoparasitic form of the nematode in Latin America has been reported from Surinam. This form is associated with little-leaf disease of coconuts in the presence of the palm weevil as pest of the same palms. Experimental evidence has shown that these ectoparasitic forms can cause red ring disease when they are injected into the healthy palms.

The evidence strongly points to the obligate parasite *Rhadinaphelenchus cocophilus* as a variant of this ectoparasitic form capable naturally of multiplying in the coconut palm, causing disease and being carried by those palm weevils incapable genetically of removing them from their haemocoel. Notably, the palm weevil does not transmit the nematode to any other non-palm species in which it also develops such as sugar cane, papaya and pineapple. However, quarantine measures are strongly recommended outside Latin America to preclude this form of *R. cocophilus* entering new countries having other species of the palm weevil.

SYMPTOMS OF RED RING DISEASE

Coconut palms more than three-years-old are susceptible and those up to 10-years-old are more so. All the affected organs: roots, stems and petioles show a red band of discoloured tissue within the cortex. This ring is normally browner in many dwarf and hybrid varieties of coconut. In the tall varieties the colour is almost brick-red. Occasionally, trees more than 20-years-old do not

have the characteristic 5 cm wide band in the trunk, but instead, possess a central, solid cylinder of reddened tissue.

External symptoms are displayed by the leaves chronologically as they wilt, turn yellow from the tip of the leaflets to the base of the rachis, and then turn brown. Generally, leaf symptoms start on the lowest or oldest leaves close to the point of infection on the stem and then progress upward around the tree. Trees between the ages of three and 10 years die within two months. Older and heavy bearing trees shed all their fruits as the subtending leaves become infected. Occasionally, the crown of the tree falls off as a result of severe internal damage done by the larvae of the palm weevil which usually tunnel extensively during their development in the diseased crown. However, there is no bacterial decay of the heart leaves associated with these symptoms, nor is there necrosis of the inflorescence which dries out. Seedlings are not naturally affected by the disease.

No plausible explanation has ever been given for the normal position of the red ring in diseased stems. One suggestion was that aeration and water supply accounted for the inner limit of the red ring, and the hardness of the tissue, for the outer limit (Martyn, 1953). Generally, these internal symptoms are fully developed before external symptoms become visible. At first, discrete pink lesions appear in the stem and coalesce into a red band. Such primary lesions are the locations where the nematodes multiply. Nematodes present in the roots can enter the soil as the roots decompose.

Alternate Definitive Hosts

The following palms are known also to be naturally susceptible to the nematode, *Acrocomia aculeata* (gru gru), *A. intumescens, Attalea cohune* (cohune nut), *Cocos* sp., *Elaeis guineensis* (oil palm), *Mauritis flexosa, M. caribea* (cocorite), *M. mexicana, Maximiliana maripa, Oenocarpus distichus, Phoenix canariensis, P. dactylifera* (date palm), *Roystonea olearacea* (cabbage palm), *R. regia* (royal palm), *Sabal daucescens* (sabal palm).

TRANSMISSION OF THE RED RING NEMATODE

The exact nature of the association between the red ring nematode and the palm weevil was the object of much speculation over the years. Ashby (1921) supported Cobb's view that the palm weevil was the vector. Martyn in 1953, suggested that nematodes could be carried by fragments of diseased tissue attached to the hair on the body of the insect. Similar ideas, were entertained by Bain and Fedon of Venezuela and Hagley in Trinidad. However, Griffith (1968) demonstrated that the number of nematodes on the body surface of the palm weevil, either in frass or on the body hairs, could not, on their own consistently initiate infection in the healthy palm.

It has been acknowledged by many scientific workers that small quantities of the red ring nematodes survive in the body-cavity especially in tracheal, of all stages of some palm weevils which developed in red ring diseased coconut palms. Hagley (1965) had demonstrated that the incidence of red ring disease

could be positively correlated with weevil population density; however, later it was shown that significant reduction in weevil populations by insecticide reflected no corresponding effect on the control of red ring incidence in the short run. One, therefore, had to correlate the levels of significance with control measures. It was shown (Griffith, 1987) that in newly emerged insects, the nematodes, having been located in the trachea (73.1 per cent) and randomly dispersed in the haemocoel (10.2 per cent) were not disposed for transmission to healthy trees. The red ring nematode was non-propagative in the palm weevil. Moreover, since any developing larva in a diseased palm was expected to consume a modest 500 g of nematode infected tissue with over 1000 nematodes per g, the emerging palm weevils must have been able to destroy the large numbers of nematodes entering their haemocoel. Epidemological studies had shown that an infector plant only caused infection of one or two nearby plants yet transmission trials with palm weevil by many workers, such as, Blair, Fenwick, Hagley, and Martyn had always failed to produce disease in healthy susceptible trees. This was so even though the insects had newly emerged from diseased palms. There was need to find a consistent vector among the insect population. This related to the defence mechanism of the insect.

Transmission of the Nematode and Insect Defence Mechanism

In order to demonstrate any hidden segregative influence of the red ring nematode on the palm weevil population, as was possible with the 29/500 larvae which did not remove the nematode during their lifetime, it was argued that a significant extent of parasitisation could be utilised as a suitable index for discovering an unknown large volume of resident red ring nematode parasites within the adult insect which would be a certain vector.

On examination of the wild population, such smaller adult insects measuring less than 30 mm from the top of the head to the tip of the abdomen, as soon as they emerged, were laden with over 6000 nematodes, sometimes up to 10,000. These were disposed at the ovipositor of the female (or the aedeagus of the male) for injection into the coconut palm, when the female oviposited (Griffith, 1968). The genetics of the weevil population indicated (Griffith, 1987) that these were homozygous recessive for the ability to remove the nematode. Therefore, the potential vector population was 25 per cent. The red ring nematode had therefore segregated the palm weevil population into two sub-populations.

Effect of Nematode on Vectors — Vector Efficiency

The extent of parasitisation of the palm weevil vector by the nematode is critical and bears an essential correlation to the dispersal of the nematode. When laboratory-reared progeny of vector weevils are allowed to develop in diseased tissue, mortality is always high. As the larvae continue to feed, increasing quantities of nematodes accumulate in the body-cavity. The extent of their accumulation and feeding activities determine their effect on the longevity of the weevil larvae and rate of mortality of the emerging adult insect.

A positively correlated observation with hosting large numbers of the nematode is the reduction in the quantity of fat-body in the adult insect. Normal size non-vector palm weevils always have an abundance of fat-body. Vector insects have almost none. To some degree, this is related to the longevity of the adult insect in the field since the adults eat very little. Fecundity is always affected too. A non-vector female can oviposit between 200 and 400 eggs in the laboratory during 30 days. Many oviposit over 500 eggs. Very few vector insects oviposit more than 50 eggs with 20 the most frequently recorded quantity.

Thus, in addition to limiting of the size of the vector population by parasitisation, the reproductive potential of the survivors is affected through reduced fecundity. Further, many female vectors may oviposit unfertilised eggs, since mating might not be accomplished with the larger insects around. Thus, a female insect, although able to transmit the nematode may not give rise to progeny. Any further transmission therefore depends largely upon the attractiveness of the affected tree to palm weevils producing fertile eggs with the genetic requirements for susceptibility to the nematode. This replenishment of vectors comes from the homozygous recessive progeny resulting from the heterozygous parents in the population. The rate of spread of the nematode will correlate with the gene frequency of the recessive allele.

Environmental Factors Affecting the Disease

The larvae of the palm weevil often die when they are developing in a tree which is attacked by Cedros wilt disease subsequent to the contracting of red ring disease. It is known that the bacterium (*Micrococcus (agilis) roseus* Ali-Cohen) in Cedros wilt diseased palms produces the disease in affected palm weevils. Natural cannibalism in larvae of the palm weevil resulting from overcrowding often affects the number of emerging weevils. Some ground lizards also feed on the adult insects. The red ring nematodes die in the decomposing tissue of the diseased tree and an unidentified fungal parasite exists for the nematode.

Hagley (1963) reported that the heaviest losses due to red ring disease occurred at the end of the wet season and the first two to three months of the dry season, that is, between December and March in Trinidad. Thus, conditions in the environment must be right for the weevil population to increase and for an epidemic to begin — humidity being an important factor for adult weevil longevity. The palm weevil, on the other hand, can be a pest in its own right. For example, it is a pest of the coconut palm, the *grugru* palm and several others. Many of the host palms are wild in the forest and in other uncultivated areas of Latin America and may become a source of migrant insects to cultivated fields.

Application of Insecticides in Diseased Estates

When insecticides are applied to the leaf-axils of healthy trees in an estate with red ring disease, the following results were recorded: Mungia (1958) reported a reduction in the annual incidence of red ring disease from 10 to 1 per cent following large scale application of Endrin to the leaf-axils of healthy

palms. Hagley (1963) reported 31.4 per cent reduction by the use of Endrin at 50 to 70 day intervals. Fenwick (1967) obtained a similar reduction in the disease incidence. He obtained one-third reduction using Endrin and Agrocide 3 applied to the leaf-axils of healthy trees at monthly intervals. When these factors are applied jointly to the practice of large scale application of insecticides, the ratio between the number of diseased and healthy trees is the essential limiting factor in the economy of such endeavours. Therefore, as a necessary corollary from these observations, control measures should advisedly follow a pattern whereby early diseased trees must be destroyed. Early diseased trees were effectively poisoned with either Weedicide '100' (Maharaj, 1964) or Silvisar 510 (Hoyle, 1968). Such preparations caused the death of the nematodes and developing weevils. Most of the insects in trees with "broken necks", due to the tunnelling of larvae, escaped such poisons. However, estates which are free from disease have very few infected palm weevils. The converse is true with heavily infected fields.

Nematicide, Insecticide and Herbicide Treatments

Traps of guard baskets: The habitat of palm weevil in the coconut estate is normally the diseased coconut palm to which the insect is attracted for oviposition. Its life cycle in the coconut palm is known to average about 80 days from the laboratory and field development studies. Therefore, about 80 days after the tree becomes attractive and is visited by other palm weevils, a new population of adult insects would begin emerging from diseased trees. If fertile eggs of mated vector insects were oviposited initially in the healthy tree together with the inoculum of nematodes, and the diseased tree becomes attractive to other insects afterwards, vector weevils would have emerged first before the second general population developing in the attractive tree. This presents an important relationship to control and the timing for the use of insecticides.

After many insecticidal trials by early workers, Hagley applied insecticides at 70 and 50 days intervals but noted that different timings might have been more effective. Fenwick sprayed both at three-month intervals and at two-month intervals, among other timings, and did not accomplish any reduction in losses. The lack of response to these treatments in the short run indicated that vector insects emerged between sprays and infected the healthy trees.

Cultural Practices: Since the nematodes did not multiply in the insect nor survived for any appreciable time in the dead tree, the only known reservoir of inoculum was the diseased tree in which the vector palm weevils developed. Thus, the elimination of the diseased tree by burning or poisoning, as soon as red ring symptoms appeared, reduced significantly the available source of the pathogen and also controlled the population of the vectors.

Recently, control measures directed against the palm weevil have been developed using poisoned baits such as 'guard-baskets' containing chunks of diseased coconut tissue sprayed with 0.1 per cent lannate which attract and kill palm weevils already in coconut estates. These have been in use since 1970 throughout Latin America.

BIOLOGICAL CONTROL PROGRAMMES FOR THE PALM WEEVIL

Populations of palm weevils, *Rhyncophorus palmarum* L. are segregated into those which demonstrate a mechanism of resistance to certain nematodes and those which do not. Since the mechanism is genetically inherited, susceptible populations can be eliminated by the action of some entomopathogenic organism whereas resistant strains will not be. When this relates to vectors for the red ring nematode, the spread of the disease can be reduced by certain entomopathogens. However, the same entomophile may have no influence on the rest of the population which may continue to develop into pest proportions. Screening for biological control of the palm weevil would therefore comprise two dimensions: one, for pathogenicity to the insect species and the other for the differential status of the pathogen on the vector weevil sub-population. In this case, one will be comparing resistance in vectors and non-vectors.

With regard to entomopathogenic nematodes of the *Heterorhaditae, Steinernematidae,* and *Rhabditidae,* one is alerted to certain exigencies. The number of these nematodes which cycled in certain pests varied widely among insects and among the nematodes themselves (Morris *et al.*, 1990). It would appear that studies on the lipoid epicuticle of nematodes and its relationship to circulating lypases originating from the fat-body of certain insects could be emphasised. The organ is also known to be the site for proteins which exhibits bacterial activity in some insects (Faye and Wyatt, 1980). Some lypolitic enzyme substances present might be able to destroy the lipid barrier of the epicuticle and so make these organisms ineffective as controlling aspects for some palm weevils. This may relate to the mechanism of defence for *R. cocophilus*. These can cause different and independent segregation of insect populations.

In considering biological control of vectors for pathogens where economic sub-populations already exist, resistance to biological agents becomes a more critical factor. Such studies are in progress with the palm weevil.

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ROOT GRUBS OF COCONUT AND THEIR MANAGEMENT

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ABSTRACT

Four species of white grubs, namely, *Leucopholis coneophora* Burm, *L. burmeisteri* Brenske, *L. lepidophora* Blanchard and *Holotrichia serrata* (Fabricius) are known to cause damage to coconut roots in India. All *Leucopholis* species on coconut are reported only from the West Coast of India and the Western Ghats, whereas *H. serrata* is known to attack coconut in the plains of Peninsular India.

L. coneophora and *H. serrata* have a one year life cycle while *L. burmeisteri* and *L. lepidophora* have a two-year life cycle under field conditions. *H. serrata* adults become active immediately after the first rains in April in the South and their activity extends up to July end in North India. The adult activity in case of *L. coneophora,* starts in the month of May, *L. burmeisteri* in the latter part of May or early June and *L. lepidophora* in late July or early August.

The management of root grubs of coconut needs a thorough knowledge of the behaviour and biology of each species. An integrated management involving adult collection, cultural practices and timely application of insecticides will help to eradicate the pest from an infested garden.

INTRODUCTION

White grubs are considered as national pests not because of a single species like *Heliothis,* spread all over the country but because the root feeding larvae of more than 40 known pest species of white grubs are found from the Himalayas at an altitude of 10,000 ft. down to the coastal line, causing severe damage to several cultivated crops. Naturally coconut is not free from the ravages of white grubs (Veeresh, 1988).

Although coconut is affected by many Scarabaeidae including *Oryctes rhinoceros* (Dynastinae) (Menon and Pandalai, 1960; Kurian *et al.*, 1983), only four species of root feeding white grubs belonging to the subfamily Melolonthinae have been recorded from India, three of which belong to the genus *Leucopholis* and the other to *Holotrichia*.

Abraham and Kurian (1970) and Kurian and Koya (1974) reported a root feeding Rutelinae, *Anomala marginipennis* Arrow. However, the present authors have not come across this species in the Western Ghats or the coastal area during their extensive study for the last two decades. Being an extremely small species (adult size 14 to 16 mm), the larvae may not do a significant damage on the roots of coconut which are more than 10 mm in diameter unless they are in such large numbers. Besides, Arrow (1917) describes and reports this species as occurring only in Assam and the North-east India.

Distribution and Identification

The four species under discussion exhibit three distinct distribution patterns (Veeresh *et al.*, 1991). *Holotrichia serrata* (Fabricius), is a serious problem in the plains and occurs only in isolation in the Western Ghats. Among the three species of *Leucopholis, L. coneophora* Brenske is found in the coastal belt and also occurs in isolation in the Western Ghats. Whereas *L. burmeisteri* Brenske and *L. lepidophora* Blanchard overlap in their distribution in the hilly regions of the Western Ghats. Their ecological requirements seem to be similar, yet they have not been found occurring in the same place at the same time. All the three species of *Leucopholis* confine to heavy rainfall areas with lateritic, coastal-alluvial or sandy soils (Fig. 63.1).

Adults and larval description of all the above four species are available (Nirula *et al.*, 1952; Nirula, 1958; Sekhar, 1958; Veeresh, 1977; Nair and Daniel, 1982; Abraham, 1981; Veeresh *et al.*, 1982; Patil and Veeresh, 1981). A gist of identifying characters of the four species are provided in Table 63.1.

Biology and Behaviour

i) *Holotrichia serrata:* A number of workers have given an account of the biology and behaviour of *H. serrata.* But the major ones are of Veeresh (1977) and Raodeo *et al.* (1976). Adult emergence is at the onset of the first summer rains either in the last week of March or first week of April in Southern India and as we move towards the North, depending upon pre-monsoon showers, emergence may occur any time before July. This species has a number of adult hosts on which they settle soon after emergence, mate and feed at dusk, around 7.00 p.m. but they have decided preference for *neem Azadirachta indica*, if it is available in the vicinity. The weakness has been taken advantage of, collecting adults in large numbers as a means of control with success (Veeresh, 1974; Raodeo *et al.*, 1976).

The female adult continues to lay eggs for nearly four weeks, one to nine eggs per day singly, in an earthen cell at a depth of 5 to 15 cm. The eggs hatch in 10 to 15 days and the first instar larvae survive on dead organic matter in the first month. Subsequently, the second and third instars, go in search of roots. The larvae feed up to December–January, go little deeper 30 to 45 cm, spend a short quiescent period and pupate in an earthern cell. The pupal stage lasts for about two weeks and then transforms to an adult. But the adults remain within the pupal cell till the first summer rains occur, when they emerge.

Table 63.1: Distinguishing characters of the four species of white grub encountered in coconut gardens

Name	*H. serrata*	*L. coneophora*	*L. burmeisteri*	*L. lepidophora*
Adult characters	20–25 mm, reddish-brown concave head, thorax elytra with broad irregular punctations. Lateral margin of thorax serrated and elytra with stridulatory files.	20–30 mm, chestnut brown, body covered with pear-shaped scales. Parameres of the aedeagus widely separated.	30–38 mm, uniformly brown, densely covered with spine-like short white scales. Parameres of the aedeagus separated but close together.	28–38 mm, dark brown to black, covered with dirty yellow flat ovoid scales. Parameres of the aedeagus closely apposed and blunt distally.
Third instar larval characters	Antennal ring with 15–18 setae; anterior frontal setae 13–14; epizygum and zygum present; pro-plegmatia 15–18; maxillary stridulatory teeth 12–13; raster with 21–23 pali; length 40–47 mm (Veeresh, 1977).	10–11 setae first antennal segment with anterior frontal setae 24–31; plegmatia 16–20; epizygum poorly developed; max. stridulatory teeth 13–15; raster with 30–31 pali; length 43–47 mm (Sekhar, 1958; Nirula, 1959; Veeresh *et al.*, 1982).	First antennal segment with 6–7 setae; anterior frontal setae 14–16; proplegmatia absent; plegmatia 15–17; epizygum absent; max. stridulatory teeth 18–20; raster with 20–26 pali; length 48–55 mm (Patil and Veeresh, 1981; Veeresh *et al.*, 1982).	First antennal segment with 12–13 setae; anterior frontal setae 24–25; proplegmatia absent; plegmatia 24–28; epizygum absent; max. stridulatory teeth 16–19; raster with 19–20 pali; 48–52 mm long (Patil and Veeresh, 1981; Veeresh *et al.*, 1982).

ii) *Leucopholis* spp.: Adults of all the three species of *Leucopholis* are more or less similar in respect of their emergence, mating and feeding. The emergence dates differ among themselves. *Leucopholis coneophora* emerges after a couple of rains in May and June (Nirula, 1958; Sekhar, 1958; Abraham, 1981; Veeresh *et al.*, 1982; Veeresh *et al.*, 1985). *L. burmeisteri* requires further wetting of soil before it emerges in June. *L. lepidophora* emerges at the end of the wet season, in late July or early August. *L. coneophora* has a one year life cycle (Nirula, 1958; Abraham, 1981; Veeresh *et al.*, 1982), but *L. burmeisteri* and *L. lepidophora* have a two-year life cycle (unpublished results). Hence, they may often be found in overlapping generations.

Adult male and female attract each other and mate immediately after emergence, often a number of males attempting to mate with a single female. They continue to be active till midnight. After mating, the adult may fly out to the host plants, often several meters away and return back before dawn to the place of egg laying (a list of adult hosts is given in Table 63.2). They may lay eggs at any part of the coconut garden (Nirula, 1958). The larvae in the beginning feed on the organic matter and soon start feeding on the roots available in the immediate vicinity. Like any other root feeding white grubs, they are not quite specific to any particular roots as long as they get enough food, but prefer bigger roots or underground tubers to grass roots. Where there is no intercrop or weed, they soon find their way toward coconut roots. If intercrops like tuber crops, banana, fodder, grass, sugarcane etc. are available, the severity on coconut is reduced.

Table 63.2: Host plants of adults recorded under field conditions for the species of *Leucopholis* in Karnataka

Plant family	*Insect species*		
	L. coneophora	*L. burmeisteri*	*L. lepidophora*
Anacardiaceae	*Anacardium occidentale* L.	*Mangifera indica* L. *Poecileneuron indicum* Bedd.	*Mangifera indica* L.
Elaeagaceae	–	*Elaeagnum kolaga* Sch.	–
Fabaceae	–	–	*Acacia torta* (Roxb.) Craib
Moraceae	*Artocarpus heterophyllus* Lam. *Artocarpus hirsutum* Lam. *Ficus asperrima* Roxb. *Ficus* sp.	*Artocarpus heterophyllus* Lam. *Ficus asperrima* Roxb. *Ficus racemosa* L.	*Artocarpus heterophyllus* Lam. *Ficus asperrima* (Roxb.) *Ficus racemosa* L. *Holigarna ferruginea* March
Myrtaceae	*Syzygium zealanicum* (L.) DC.	*Psidium guajava* L. *Syzygium zealanicum* (L.) DC.	*Psidium guajava* *Syzygium zealanicum* (L.) DC.
Tiliaceae	–	*Grewia microcos* L. *Grewia* sp.	–

In some cases eggs of *L. coneophora* have been encountered up to a depth of 2 m in the coastal sand beds. Depending upon the water table and root zone, the vertical distribution of the larvae varies from 20 to 100 cm (Abraham, 1981; Nirula, 1958). Feeding is a continuous process under coconut ecosystem for six to 18 months depending upon the species.

Nature and Symptoms of Damage

No clear cut symptoms could be seen due to white grub damage except in young palms of less than three years of age which may wither if a large number of grubs attack. However, pale uniform yellowing of leaves, drooping of fronds, decrease in yield and button shedding are indirect symptoms on older palms (Nirula *et al.*, 1952; Nirula, 1955; 1958; Veeresh, 1983). A sure sign for the presence of root feeding white grubs is available while intercultivating and during weeding operations. The suspected gardens may be examined at random by digging the base of the palm to a depth of 30 cm. The root grubs are invariably found associated with roots.

Often the intercrops like tuber crops or vegetables grown in the garden indicate the presence of root grubs by their sudden death. When such plants are pulled out they easily come up and if the soil is dug a couple of inches below, the presence of root grubs can be noticed (Nirula, 1955; 1958; Veeresh, *et al.*, 1982).

After the pre-monsoon showers in the dust, the beetles make a buzzing noise while emerging which is another sign of the presence of white grubs.

Management of Coconut Root Grubs

a) *Natural Control*: Periodical intercultivations like digging, hoeing and ploughing will reduce the root grub population to a non-pest level. Several birds may pick up exposed grubs if they have access to the garden. The domestic fowls are of great help in this regard (Veeresh, 1980; 1988).

Several pathogens including *Bacillus popilliae, Beauveria brongniartii* and *Metarrhizium anisopliae* exercise great check under coconut ecosystem. *Bacillus popilliae* has been found very effective against *L. lepidophora* (Veeresh and Kumar, 1991).

b) *Non-chemical Methods*: Adult collection is one of the best, the cheapest and pollution free method if adopted diligently. Adult collection as a means of management needs a knowledge of biology and behaviour of the species, particularly at the time of emergence. Each species has its own time of emergence from the soil in the evening. This method has been found very successful in case of *H. serrata* which is very much attracted to adult host plant, the *neem* (*A. indica*) on which the adults congregate after emergence and can be easily collected and killed (Veeresh, 1974).

The three species of *Leucopholis* do not go directly to their host plants after emergence but attempt to copulate on the ground or short plants within the garden when they are easy to catch and kill. One has to keep watching after the onset of rains for the emergence of adults. A week's operation in the evening for an hour or two with proper light and enough people, can help

collect all the beetles. This method is found very effective in several arecanut and coconut gardens in the *malnad* region in Karnataka.

c) *Chemical Method*: A number of chemicals has been tested against coconut white grubs. Application of any soil insecticide three to four weeks after first emergence will give effective control as the young larvae after hatching would be easily killed by the insecticide. When once grubs go to root zone, no chemical will be effective against the grubs whatsoever method one adopts to incorporate the insecticide. Normally a basal application of any of the soil insecticides at the beginning of the monsoon during June–July as a prophylactic measure would ensure control of coconut root grubs.

d) *Integrated Method*: The integrated pest management approach would be the best solution, adopting adult collection, application of insecticides at the right time and cultural method to expose the grubs for natural enemies. If once the garden is cleared from root grubs, there is no possibility of occurrence of the pest for four to five years (Yadava, 1981; Veeresh, 1977; 1988).

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EMERGING PEST PROBLEMS IN COCONUT AND THEIR CONTROL

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ABSTRACT

The nature and extent of damage, alternate hosts, biology and control of pests newly emerging in the agroecosystem *Paradasynus rostratus* Dist. and two closely related genera *Amblypelta* occurring in Australia and Solomon Islands and *Psuedotheraptus* confined to east Africa have been discussed. From the present status of *P. rostratus* in Kerala, the need for doing intensive research on the management of the pest has been highlighted. The importance of scale insects, mealy bugs and mites emerging occasionally as serious pests in the coconut ecosystem of Kerala and the scope for containing the pests have also been discussed.

INTRODUCTION

Constantly changing cropping patterns, varieties of crops and agrotechniques cause instability in biotic and abiotic components of any agroecosystem. The pest status in the system also keeps fluctuating. Many major pests get relegated to the status of minor pests and the reverse trend also occurs frequently. In the coconut ecosystem of Kerala, the emergence of a coreid bug *Paradasynus rostratus* Stal as a pest is one such instance. This belongs to the tribe Dasynini of the family Coreidae and two genera belonging to the same tribe *Amblypelta* spp. of northern Australia and Solomon islands and *Psuedotheraptus* spp. of East Africa and Zanzibar islands have already gained notoreity as destructive pests of coconut. The type of injury caused by these bugs is identical though these bugs are geographically isolated from one another and systematically distinct. Besides these, linked with the plant protection measures adopted in the ecosystem and also due to changes in climatic factors, scale insects, mealy bugs and mites often emerge as new problems in coconut plantations. A brief review of the information available on these pests is presented in this paper.

***Amblypelta* spp.**

The 'variable and generally poor yield of coconut in Solomon island' was a puzzle to scientists during the first quarter of the twentieth century. The nut fall noticed was identified to be due to feeding of a coreid bug. The nature of injury caused by the bug and the detailed biology of the insect were reported by Lever (1933). The new insect which was earlier included under *Dasynus* was brought under the genus *Amblypelta* errected by Stal (1873) and the species was identified as *cocophaga* by China (1934).

The importance of the genus as a pest of coconut in Solomon islands prompted an extensive survey and a number of species were collected from Australia, New Guinea, Kai islands, Timor and Java, Bismarck Archipelago, Solomon islands, New Hebrides and New Caledonia. Brown (1958a) classified the then known specimens and erected 12 species and five subspecies under the genus. Among these, seven species/subspecies were identified as coconut pests, *A. cocophaga cocophaga* China, *A. cocophaga malaitensis* Brown, *A. lutescens lutescens* (Dist.) were noted as regular pests on coconut while *A. eristobalensis* Brown, *A. eostalis costalis* van Duzee *A. costalis runnellensis* Brown, frequenting the palm and causing nut fall and *A. gallegonis bougainvillensis* Brown rarely attacking the palm. Among these *A. cocophaga* alone had become a serious problem for coconut growers.

Nature of Damage

Philips (1940) reported his detailed observations on the nut fall. By enclosing the newly opened inflorescence with wire mesh cages which excluded *Amblypelta* he allowed in other smaller species of insects and through "nut fall induction tests involving the confinement of the third instar nymphs and adults of the insect on caged inflorescence", he established that the heavy nut fall observed in the island was caused by *A. cocophaga* and the yield of the crop could be substantially improved by preventing the damage. He also observed the polyphagous nature of the insect and opined that they might have migrated to the plantations from the bushes of adjoining forests.

Brown (1958b) observed that they feed on fruits, stem and petioles of plants and cause characteristic symptoms. On coconut the bug feeds on the soft tissue at the proximal part of the ovary reaching the same by piercing the calyx with the stylet. A brown scar appears around the feeding puncture which later elongated along the long axis of the fruit, causing nut fall if the attack is in early stages of growth (up to 10 weeks) and malformations at later stages (which extends up to seven months). In addition to discolouration a gummy exudation occurs from the scar and hence the symptom was also called 'gummy disease'. The nuts remaining on the bunches grow with distortion, splits and cracks. He observed that such nuts produce only 65 to 96 per cent of the copra produced by unattacked nuts. Two bugs per tree were found sufficient to cause severe damage to the plantation. In an infested garden 97 per cent of the fallen nuts showed typical damage caused by the bug (Philips, 1940).

Alternate Hosts

A striking fact about species of *Amblypelta* is the extreme polyphagous nature. *A. cocophaga* was reported to feed on 35 species of plants in 23 families predominantly of Euphorbiaceae (Brown, 1958b).

Biological Control

Brown (1959a; 1959b) reviewed the role of ants in regulating the population of *A. cocophaga* in Solomon islands. Of the four species of ants widely distributed in the island *Oceophylla smaragdina* (F) reduced the nut fall significantly while *Pheidole megacephala* (F) and *Iridomyrmex myrmecodiae* Emery gave no protection. *Anoplolepis longipes* (Jerd) which was not considered helpful was found as effective as *O. smaragdina* in Malaita. *Ochetomyrmix auropunctus* introduced into Solomon islands was found to reduce the nut damage (Macfarlane, 1988). Attempts to colonise useful colonies of ants generally proved unsuccessful at field level. Due to interspecific competition the ant population remains highly fluctuating, *O. smaragdina* often getting displaced by the colonisation of other non-beneficial species.

A reduvid, *Euagorus dorycus*, an egg parasite, *Anastatus* sp. and an entomogenous fungus had been reported on *A. cocophaga*. But they were not effective for biological control (Philips, 1940). *Trichopoda pennipes* (Tachinid) also failed to establish at field level (Brown, 1959b).

Psuedotheraptus sp.

Widespread damage of coconut was observed in British East Africa during the second quarter of the twentieth century (McDonald, 1925; Wilsford, 1925; 1926). Way (1951) indicated that the damage was caused by a coreid bug which was tentatively identified as *Theraptus*. Brown (1955) placed it under the new genus *Psuedotheraptus* since it had some characters of gonocerinni while *Theraptus* was a typical dasynine species.

Distribution

British East Africa (Kenya, Thanganyika) and islands of Zanzibar, Pamba and Mafia.

Nature of Damage

Detailed studies on the nature of damage, biology and population levels of the pest were made (Way, 1953). The later instars and adults of the bug pierced the immature and mature flowers and young nuts through the calyx and fed from the underlying soft tissue. The description of the symptoms was identical to that caused by *A. cocophaga*. Way observed that a single feeding puncture caused nut fall up to 12 weeks after the opening of the spadix while the older nut with a single puncture remained attached to the inflorescence and continued to grow. Nuts with 10 or more feeding punctures fell up to 16 weeks of age. As the nut increased in length the lesions formed beneath the bracts got pushed outwards and appeared as a ring of scars. He also noted that when the lesion extended to the endocarp the latter burst and the endosperm got

destroyed. When attacked later than the sixth month after opening of spadix the lesions on mature nuts appeared close to the calyx and the copra yield did not get reduced.

As in *A. cocophaga*, a population of two bugs/tree was found sufficient to cause heavy damage in plantations. From laboratory findings he estimated that a bug in its life time can cause 200 feeding punctures and a single puncture was sufficient to cause one nut to fall up to the twelfth week after the opening of the spadix. He observed that 40 to 70 per cent of five to 10-week-old nuts fell 'naturally' but in infested areas after the tenth week the nut fall continued and reached up to 90 per cent in the next three to four weeks.

Vanderplank (1959a) estimated that two-thirds of the potential crop in Zanzibar was being lost due to *P. wayi* incidence and the projected annual loss of revenue was £ 0.5 to 2 million.

Control

P. wayi was controlled to a limited extent by *O. longinoda* (Latr) (Way, 1951; 1953). Julia and Mariau (1978) observed that 60 per cent of the trees having *O. longinoda* colonies showed nut damage below 15 per cent only and he recommended the encouragement of the colonies for controlling the pest.

Lindane 0.4 per cent dust was proved effective in controlling *P. wayi* but it eliminated the useful predator *O. longinoda* from the palms and the treatment was followed by heavy outbreak of scale insects. Vanderplank (1959b) claimed that DDT, resin, diesel, kerosene mixture (DRDK) controlled the pest and boosted *O. longinoda* population since antagonistic species of ants like *Pheidole* sp., *Crematogaster, Paratrechina* were eliminated by the treatment.

Paradasynus rostratus

The first report of a coreid bug causing injury to coconut was made by Kurien *et al.* (1972). Its identity as *P. rostratus,* description of the nature of damage done, biology, morphology of immature stages and some preliminary observations on the distribution in Kerala were subsequently published (Kurian *et al.*, 1976; 1979).

Distribution and Host Plants

The insect was first collected from Bombay and identified as *Pendulinus rostratus* and was placed under a new genus *Paradasynus* raised by China (1934). It was reported to be present on coconut in all parts of Kerala along the west coast and Thirthahalli in Karnataka and on tamarind (*Tamarindus indica*) in Kerala and neighbouring parts of Tamil Nadu (Kurien *et al.*, 1979), on cashew at Trivandrum (Nair and Remamony, 1964). A recent survey in Kerala state (Visalakshi *et al.*, 1989) showed that the pest is not restricted to the coastal belt but also seen in high intensity in all the agro-climatic zones of the state. Its first report from Bombay indicates the possibility of this pest occurring towards North at least along the coastal belt.

The data (Table 64.1) show that the different hosts are not influencing the pace of development significantly. It may be an indication of its polyphagy and

adaptability to a wide range of hosts. The distribution of the pest in Kerala was found to be state-wide and the pest is serious as seen from the percentage of palms showing damaged nuts and percentage and intensity of damage to infested nuts observed. The agriculture extension units completely free from the pest were found to be around 15 per cent only. The incidence showed wide variations with the percentage of infested palms being highest in Wynad district (23.48) followed by Kasaragod and Trivandrum (4.82) (Visalakshi *et al.*, 1989).

Table 64.1: Biology of *P. rostratus* on different hosts

Stage of the insect	*Duration in days*		
	Coconut	*Cashew*	*Guava*
Egg	8–10	8–11	8–10
1st instar	4–5	3–6	3–0
2nd instar	5–7	3–8	9–2
3rd instar	4–6	4–6	4–9
4th instar	4–6	3–6	7–1
5th instar	8–10	8–10	4–5
Total duration	33–44	29–47	–
	(38.5)	(38.0)	(37)
Adult longevity	49–53	35–40	25–35

Nature and Extent of Damage

The damage caused by *P. rostratus* was identical with those caused by *A. cocophaga* and *P. wayi*. In the early stages, before fertilisation and soon after that, the ovary/nut dry up and remain within the calyx and attached to the spadix and gradually the whole inflorescence dry up. When the nuts at different growth stages were exposed to the attack of the third instar nymphs (Table 64.2) the nut fall remained high up to 140 days after nut set and some of the damaged nuts remained attached to the bunch till maturity. The fall continued in cages exposed to the bug up to the two-hundredth day after fruit set though the percentage was relatively low. In this respect the earlier observations on *P. wayi* and *A. cocophaga* that the nut fall ceases after the sixteenth week after the opening of the spadix did not agree with the damage done by *P. rostratus*. Apart from the nut fall, the crinkling and malformations of the nut significantly reduced the size of the nut and the yield of copra and oil. A quantification of such loss was done by Visalakshi *et al.* (1989). The area of pericarp damaged showed significant correlation with the weight of dehusked nut (0.264), volume of dehusked nut (0.224), weight of copra (0.300), weight of oil (0.350) and percentage of oil in copra (0.415).

Ecology

The seasonal occurrence of the pest as revealed from the number of nuts falling with feeding injury beneath the calyx is presented in Table 64.3. It is clearly seen that the population tends to increase from June in all the years

covered in the survey (1986 to 1989) and decline sharply from November. The percentage of infestation was positively correlated with rainfall (r = 0.44) and humidity (0.41) and negatively correlated with temperature (r = 0.53). The observations indicated that if chemical control is to be resorted to, it should be done most advantageously at the beginning of June and November.

Table 64.2: Susceptibility of coconut at different stages after fruit set to the attack of *P. rostratus*

Age of nuts at the time of exposure (days)	*No. of nuts/ bunch at the time of exposure*	*No. of nuts on bunches 2 MAR*		*Nut fall percentage*	*Damaged nuts on bunches (%)*
		Healthy	*Damaged*		
20	43	Nil	43	0	–
50	45	Nil	11	75.5	–
80	23	Nil	2	91.3	100
110	13	Nil	1	92.3	100
140	9	Nil	1	88.8	100
170	13	4	3	46.2	42.4
200	11	4	6	9.0	60.0

MAR = Months after release

Table 64.3: Seasonal occurrence of *P. rostratus* on coconut

Year	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun.*	*Jul.*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*
1985	–	–	–	–	–	27.7	24.2	48.3	47.6	40.6	23.3	19.2
1986	17.5	13.3	9.7	13.2	12.6	20.6	12.9	59.5	43.5	38.3	25.9	17.7
1987	14.9	5.8	5.4	9.5	13.1	8.2	9.7	52.6	46.7	43.5	19.7	4.4
1988	6.7	13.7	8.2	13.6	10.1	14.2	13.4	58.3	52.4	45.5	13.3	8.1
1989	3.0	1.3	0.6	17.1	6.9							

Per cent correlation between nuts damaged and rainfall −0.44*.
Per cent correlation between nuts damaged and relative humidity −0.41*.
Per cent correlation between nuts damaged and temperature −0.53*.
*Significant at 5 per cent level.

Chemical Control

The results of multinational trial and the pooled analysis revealed (Table 64.4) that carbaryl 0.2/0.1 per cent, BHC 0.2 per cent and endosulfan 0.1 per cent gave significant reduction in nut damage. When applied at different frequencies eight applications per year were found to be the best (Table 64.5). Though all treatments were significantly superior to control, a minimum of six rounds of treatments were found necessary for keeping the extent of damage around 20 per cent. In spite of the high expenditure for the treatments the net income showed that the technology was lucrative.

Present Status

In spite of the enormous amount of researches carried out on *Amblypelta* spp. and *P. wayi* and despite much information on the distribution, biology,

alternate hosts nature and extent of damage caused by the pests is known, effective control methods are still lacking. An extreme polyphagous nature of the pest and survival of sizeable portions of the population in the undergrowths in coconut plantations and on plants around the gardens limit the success of control measures.

Table 64.4: Comparative efficacy of different insectides for the control of *P. dasynus*

Treatments (insecticides)	*Mean per cent of damaged nuts*			
	Location I	*Location II*	*Location III*	*Pooled*
Carbaryl 0.2%	7.9(16.34)	9.8(18.24)	23.5(28.99)	13.1(21.19)
Carbaryl 0.1%	21.9(27.87)	15.6(23.25)	31.2(33.95)	22.6(29.36)
HCH 0.2%	14.8(22.64)	22.0(27.97)	22.9(28.55)	19.8(26.39)
HCH 0.1%	29.3(32.75)	35.8(36.73)	33.9(36.59)	33.0(35.03)
Endosulfan 0.1%	28.3(32.23)	21.9(27.88)	16.6(23.99)	22.2(28.03)
Endosulfan 0.05%	40.7(36.92)	36.3(37.08)	38.4(38.29)	38.5(38.33)
Control	52.2(46.17)	58.7(49.99)	67.6(55.31)	59.5(50.49)
CD at 5% level	(8.26)	(12.58)	(13.22)	(7.23)

Figures in parentheses are angular values.

Table 64.5: Frequency of application of insecticides required for the control of *P. rostratus*

Treatments	*Buttons infected (%)*	*Mature nuts infected (%)*	*Income/tree over control*
HCH 0.2% 8 times/year	5.83 (13.96)	13.34 (21.35)	206.00
HCH 0.2% 6 times/year	14.27 (22.12)	26.58 (30.94)	110.00
HCH 0.2% 4 times/year	16.99 (28.39)	29.08 (33.12)	130.00
Carbaryl 0.1% 8 times/year	10.63 (18.94)	14.44 (22.26)	131.00
Carbaryl 0.1% 6 times/year	22.02 (27.93)	25.25 (30.10)	70.00
Carbaryl 0.1% 4 times/year	29.27 (32.71)	34.68 (36.03)	120.00
HCH 10% dust 100 g/tree 8 times/year	7.64 (16.01)	11.14 (19.44)	118.00
HCH 10% dust 100 g/tree 6 times/year	18.15 (25.19)	19.03 (25.49)	99.00
HCH 10% dust 100 g/tree 4 times/year	24.66 (29.75)	32.33 (34.41)	93.00
Control	38.67 (38.41)	48.26 (43.99)	
CD at 5% level	(2.19)	(5.44)	

Figures given in parantheses are transformed values.

Though many biocontrol agents have been reported for tackling the exotic species, their efficacy at field level are not impressive. Effective predators or parasites have not been identified for tackling *P. rostratus* so far. Extensive research on biology, ecology and control of *P. rostratus* in India is an urgent necessity. It is a pest restricted to the Southern parts of India and it is likely to be confined to this region since its related genera are also restricted in distribution and flourishing as zoogeographically isolated genera.

Scale Insects

This group of pests represented by a number of species in India and all over the world emerge sporadically as a serious problem to coconut cultivation, particularly during summer months. *Aspidiotus destructor* Sign. is the most important among the scale insects in India.

***Aspidiotus destructor* Sign.**

It is a well-known pest of several crops mainly coconut and banana and is present in most tropical countries (diaspine coccid).

The insects feed on the underside of the leaves and when heavily populated they are seen on the upper surface as well as on the leaf, stem, flower, spikes and fruits though essentially a leaf destroying pest.

A number of useful parasites and predators have been reported on this insect. Taylor (1935) made an elaborate study of the biology and potentiality of the parasites and predators known till then. It included four aphilinids, namely, *Aphelinus chrysomphalli* Mercet., *Casca parvipennis* Gahan, *Aspidiotiphagous citrinus* Graw, and *Physcus vericornis* How. and four encyrtids, namely, *Camperiella unifasciata* Ishii., *Spaniopterus crucifer* Gahan., *Chiloneurinus microphagus* Meyr. and *Thonsoniella* sp.

The predators included were *Scymanus severini* Wsc., *Scymnus* sp., *Scymnus apiciflavus* Mots., *Pharellus minutissimus* Sic., *Aleurothrips fasciapennis* Frankl, *Cryptognatha nodiceps* Mishl., *C. simillima* Sic., *Azya trinitatis* Hshl., *Pentilia insidiosa* Muls. and *Scymnus aeinipennis*. The parasites reported recently include *A. chrysomphali* and *C. parvipennis* from Tamil Nadu (Jalaluddin and Mohanasundaram, 1989).

The predators reported were *Lindoram lophanthae* in New Hebrides giving 100 per cent mortality of the scale (Coherean, 1965) and *Cryptognatha noduceps* in Principi island—extremely successful in 1955 (Castel Branco, 1972); *Psuedoscymnus annomatum* and *Chilocoris nigritis* in New Hebrides (1981), *Tolsimia isonavi* in New Guinea (Chazean, 1981) and *Psuedoscymnus dwipakalpa* in Tamil Nadu and Andhra Pradesh, India (Ghorpade, 1977; Jalaluddin and Mohanasundaram, 1989).

The population of *A. destructor* in Tamil Nadu was found high from February to April and in June. It was effectively controlled by three rounds of fish oil soap (2.5 per cent), four rounds of fish oil soap (1.25 per cent), dimethoate 0.03 per cent or monocrotophos 0.04 per cent at weekly intervals (Jalaluddin *et al.*, 1991).

Lepidosaphes mcgregori Banks, an elongated hard scale, pinkish in colour, infest the upper surface of coconut leaves and tender coconuts. Leaves of outer whorls dry up when attacked. In severe outbreaks the inner whorls except tender ones were seen infested. Leaves first turn yellow and then dry up. It can be effectively controlled by spraying dimethoate (0.05 per cent) (Visalakshi *et al.*, 1982; Nair, 1989).

The other cocoids reported as minor pests of coconut are, the hard scales (*Aspidiotus ficus* Ash, *A. orientalis* Newst, *Pinnaspis aspidistrae* Sign), soft

scales (*Lecanium acutissimum* Gr., *L. lespesidum* Linn) and the waxy scales (*Ceroplastes actiniformis* Gr. and *Vinsonia stellifera,* Westw.) (Nair, 1975).

Mealy Bugs

This is a sporadic pest on coconut emerging due to climatic variations or as an aftermath of insecticidal applications, especially residual pesticides, for the control of other pests like *P. rostratus, Opisina arenosella* Walk etc.

1. *Pseudococcus longispinus* Targ.

This infests the heart leaves of coconut which gets deformed and stunted. On emergence, the midribs of the leaflets of the affected leaves appear waxy and twisted, as a result of which the leaves fail to open up properly. In rainy season the tender shoot starts decaying from the base. Occasionally the nymphs enter the unopened spathe through cracks and crevices and settle on the inflorescence even before its emergence. They infest the female flowers at a very early stage and prevent nut set. In severe incidence the whole spathe and the inflorescence dry up without opening. Monocrotophos and fenthion were found effective against the pest (Nair, 1989).

2. *Rhizaecus* sp.

It is prevalent in the sandy tracts in Kerala. The adults are cream coloured, subglobular, 2.4 mm long and 1.9 mm broad, smooth, with faint segmentation, enclosed within a loose jacket of white cottony felt. They are seen in groups attached to the side branches arising from main fibrous roots. The point of attachment gets discoloured turning brown in due course. The side roots gradually dry up. The infested plants, on severe infestation show yellowing and loss of vigour (Nair, 1989).

Pseudococcus cocotis Mask (Nair, 1989), *Palmiculator palmarum, Planocrocus lilacinous* and *Pseudococcus microadonidum* (Williams, 1981) are the minor mealy bug pests reported on coconut.

MITES

Among the mite pests of coconut the perianth mite, *Dolychotetranychus vandergooti* (Oudemans) is most destructive. It lives in the perianth region inside the prophylls. These mites are also seen on the soft portions of the nut covered by the perianth. They are orange coloured with typical elongated bodies. The infestation commencing at the early button stage causes discolouration of the button at the proximal end especially at the attachment of the nut to the peduncle and causes nut fall. Occasionally they are found on spathe and male flowers too. The population remains high from July to November (Sathiamma, 1985).

Seventeen species of mites listed by Ghai and Wadhi (1983), *Oligonychus iseilemae* (Hirst), *Tetranychus* sp., *T. ludeni Zacher* (Sathiamma, 1985; 1986), *O. tylus* Baker and Pritchard (Sha *et al.*, 1988). *Uracrobates* sp. (Remani and Haq, 1990), are leaf mites usually feeding on the lower surface of the leaflets. They suck sap and cause pale yellow specks which coalesce and result in

browning and subsequent drying of leaflets. Organophosphatic insecticides like quinalphos, monocrotophos, dimethoate and acaricides like dicofol have been reported effective in controlling the mites infesting coconut (Nair, 1989; Sarkar and Somchoudhury, 1988).

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DISCUSSION

M.A. Foale: Do you think that the *Paradasynus* could be confined to limited areas by manipulating the ant population as is done in Solomon Islands?

M. Mohandas: The advantage of encouraging ant population needs to be explored. Even in Solomon Islands this alone had not been proved as a perfect method of control for *Amblypelta*.

K.G. Unnikrishnan: Will application of fertiliser increase or decrease pest population?

M. Mohandas: The pest status of different species in an ecosystem is bound to be influenced by the quantity and type of fertilisers applied. Nitrogen gives a boost and potassium deters the build up of some species—but not all.

ROOT TRANSMISSION OF RED RING NEMATODE (*RHADINAPHELENCHUS COCOPHILUS*) IN COCONUT PLANTS

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ABSTRACT

The role of root transmission of red-ring nematode (*Rhadinaphelenchus cocophilus*) was investigated in a screen-house experiment. Transmission through root contact occurred in seven of 15 plants growing around artificially inoculated plants. In another experiment, every plant was contaminated when a suspension of nematode was placed on the mechanically damaged roots. The young seedlings did not develop the typical symptoms of red-ring nematode when planted to replace dead plants. It is suggested that seedling tissues are unsuitable for the multiplication of red-ring nematode.

This study was conducted to determine if direct transmission of red-ring nematode occurs through root contact and through cultivation practices. Also, the transmission to young seedlings and its susceptibility was investigated. All the work was conducted in a screen house, free from the presence of possible vectors.

MATERIALS AND METHODS

Root transmission test: Twenty healthy coconut plants of the variety Brazilian Tall were transplanted to a screen house in 1987. The work was done three years later when plants began to form the bole and became susceptible to the nematode (Ohler, 1984). Infective material consisted of red-ring nematodes obtained from infected tissue, by the methods described by Fenwick (1963). Five ml of suspension containing approximately 6000 nematodes were introduced into the base of the stem using a driller and a hypodermic syringe in five plants. The remaining 15 plants around the infected ones were observed if the leaves showed the gold colours (Fig. 65.1). When these symptoms were observed, the plant was dug up and sampled. The remaining plants were removed at the end of the experiment, 30 weeks later.

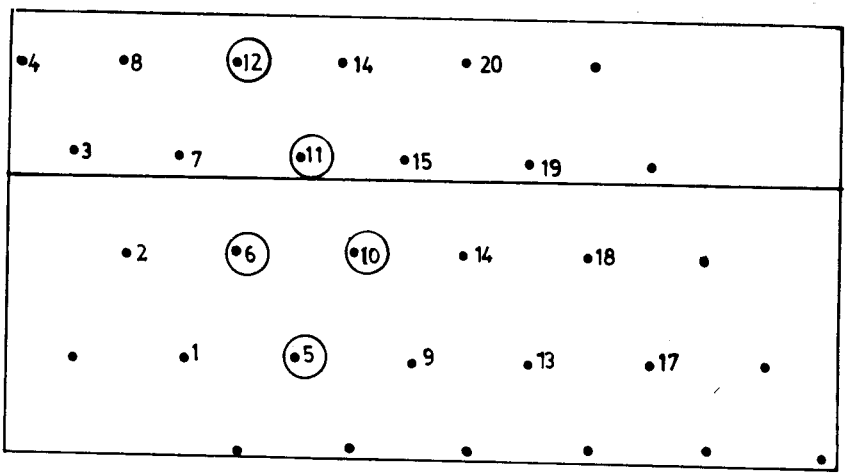

Fig. 65.1: Sketch map of 20 coconuts, showing location of the trees in the screen house. The plants 5, 6, 10, 11 and 12 were *mechanically* inoculated with *cocophilus.*

Cultivation test: In this trial, 12 coconut plants of the same variety and age were used. The roots of the palms were exposed with a hoe and a suspension of active nematodes (3000 nemas/l of water) was poured over the damaged roots. The soil around the plants was watered and kept moist for two days.

Seedling susceptibility: The experiment was conducted in order to establish if seedlings could replace infected plants without becoming contaminated. Immediately after the infected plant was taken out, a seven-month seedling of the Cameroon Red Dwarf variety was planted in the same hole, without chemical treatment. After one or two months the plant was removed and examined for the presence of the nematode. Ten seedlings were used in the experiment. The seedling susceptibility was further investigated by mechanical inoculation. Five ml of suspension, containing 3000 nematodes, was introduced into a hole made by a driller at the base of 20 plants and into the stem. In every test, the planting density was 294 trees/ha.

Sampling and processing: The examination for nematode presence was done in the laboratory. Pieces of 2 cm length of root tissue and pieces of tissue (50 g of weight) were taken and placed at different heights of the stem having the soil line as the starting point. In all cases the plants were observed for external symptoms and then removed. In the laboratory, samples were examined for nematodes following the standard procedure (Fenwick, 1963).

RESULTS

Root transmission: The five trees subjected to basal mechanical inoculation developed symptoms of leaf yellowing within seven weeks. Nematodes were observed in the root tissue, bole area and in the tissue 30 cm above the soil line, in every plant (Table 65.1). Nematodes were detected in seven of the 15 plants surrounding the five mechanically inoculated plants (Table 65.1). Nematodes

were detected in the non-inoculated plants 12 weeks after the first mechanical inoculation (plant number 14). It was found in the roots, bole area and 30 cm above the soil line. At 17 weeks the nematode was found only in the bottom part of plant number 2. In plant number 9, cut 21 weeks after the first inoculation, the nematode invasion had occurred throughout the whole stem (Table 65.1). After 30 weeks, leaf symptoms indicated that the plants were succumbing to red-ring disease. When the plants 13, 15 and 30 were cut and examined, nematode invasion had occurred throughout the stems and into the roots (Table 65.1). The number of nematodes per g of plant tissue varied from 381 to four nematodes. More nematodes were found in the mechanically inoculated plants than in the plants where the nematodes were acquired through contact.

Table 65.1: Number of active red-ring nematodes (*R. cocophilus*) transmitted by root contact of coconut tissue

Plant No.	*Weeks after inoculation (when plant was sampled)*	*Roots*	*5 cm**	*30 cm**	*60 cm**	*90 cm**
1	30	–	–	–	–	–
2	17	5	34	–	–	–
3	30	–	–	–	–	–
4	30	–	–	–	–	–
5**	7	156	376	136	7	–
6**	7	20	189	–	–	–
7	13	8	52	17	–	–
8	30	–	–	–	–	–
9	21	108	381	97	15	6
10**	7	18	71	183	97	–
11**	7	–	152	178	–	–
12**	7	23	189	–	–	–
13	30	51	78	41	23	65
14	12	23	12	–	–	–
15	30	–	4	4	4	80
16	12	4	–	–	–	–
17	30	–	–	–	–	–
18	30	–	–	–	–	–
19	30	–	–	–	–	–
20	30	19	82	19	47	75

*Plant height where the sample was taken.
**Plants artificially inoculated with nematode suspension.
–No nematodes were found.

Cultivation test: Twelve plants subjected to root damage and watered with nematode suspension developed symptoms within 80 days, by which time red-ring infection was well advanced and the oldest and lowest three leaves were all dead, and the other leaves were progressively yellowing. When these plants were cut and examined nematode invasion had occurred throughout the stems (Table 65.2).

Table 65.2: Presence of *R. cocophilus* in plants of coconut after cultivation (root damage) and watered with nematode suspension

Plant No.	*Days after treatment*	*Leaf yellowing*	*Roots*	*5 cm**	*30 cm**	*60 cm**	*90 cm**
21	80	–	+	+	+	–	–
22	88	–	+	+	+	+	+
23	89	+	+	+	+	+	–
24	90	+	+	+	+	+	+
25	90	+	+	+	+	+	+
26	90	+	+	+	+	+	+
27	92	+	+	+	+	+	+
28	92	+	+	+	+	+	+
29	92	+	+	+	+	+	+
30	92	+	+	+	+	+	+
31	92	+	+	+	+	+	+
32	92	+	+	+	+	+	+

*Plant height where sample was taken.

Seedling susceptibility: There was no manifestation of the disease symptoms in the seedlings used to replace the diseased plants (Table 65.3). No nematodes were detected in the roots, stem region or in the old seed. It seems unlikely that early infection occurs. Young seedlings mechanically inoculated did not develop the disease either.

Table 65.3: Presence of *R. cocophilus* on coconut seedlings planted replacing coconuts affected by red-ring nematode in the screen house

Plant replacing	*Days after planting*	*Old seed*	*Roots*	*Bole area*
N 21	30	6	–	–
N 22	30	–	–	–
N 23	30	–	–	–
N 24	30	–	–	–
N 25	30	–	–	–
N 26	60	–	–	–
N 27	60	–	–	–
N 28	60	–	–	–
N 29	60	–	–	–
N 30	60	–	–	–

– No active nematodes were detected.

DISCUSSION

The transmission throughout root contact among infected plants and healthy ones was identified in the experiment.

Work on this problem is made more difficult by the recommended density of tall coconuts of 143/ha. In the experiment a space of 3 m between plants was used. However, in a coconut plantation root contact occurs constantly. Menon

and Pandalai (1958) registered a length of 22 m of a single root. In addition, when replanting occurs, the common practice is to plant the new trees between the old rows making the space of 4 m among plants.

Schhiling and Van Dinther (1982) have shown that nematode population was found almost exclusively in the necrotic area of the red-ring. The number of nematode extracts varied from 0 to 4,833/g, with the average of 300/g. In this trial the number of nematodes was smaller and varied from 0 to 381. It may be explained by the young age of the plants used in the experiment. The number of active nematodes varied enormously in the samples and among the plants. However, on an average, mechanically infected plants showed symptoms first and had more nematodes than the plants that became infected through root contact. That was expected because the number of nematodes inoculated is probably higher (6,000) than when nematodes migrate from diseased plants to healthy ones.

Similarly, as in previous experiments with R.R.D. (Fenwick and Mohammed, 1964), seedlings are not successfully colonised and no nematodes were recovered from them. It is suggested that seedling tissues might have been unsuitable for the development of nematodes.

In conclusion, RRN can also be transmitted by other means than the insect vector. Therefore, the cultivation on rainy days should be avoided. The infected plants should be removed immediately, not allowing further root contact.

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DISCUSSION

Fred Opio: Have you quantified the extent of loss on farmers' fields?

D.R.N. Warwick: No, but this disease is very devastating and if the farmer does not control the insect vector and does not remove diseased plants from the field, he may lose all his crop.

H.C. Harries: Is red-ring always present as a symptom?

D.R.N. Warwick: No, you may have *R. cocophilus* infestation without the symptoms. I noticed one green dwarf plant dying in our station without the ring; but after many samples nematodes were found in the meristem area.

POPULATION ABUNDANCE OF *LEUCOPHOLIS CONEOPHORA* BURM. IN COCONUT GARDENS

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ABSTRACT

Population of different life stages of white grubs *Leucopholis coneophora* Burm., an important pest of the coconut palm at different depths of the soil and their seasonal intensity were studied for a period of three years. The beetle population and eggs were more at depths of 30 to 100 cm, first, second and third instars at 15 to 45 cm and pupal stages at 60 to 100 cm depth. The information gathered is of great significance in planning management schedules against white grubs.

INTRODUCTION

The white grub *Leucopholis coneophora* Burm. is one of the key pests of the coconut palm in the loamy sand soil tracts of Kerala and Karnataka, in India. Grubs of this melolonthid beetle feed on the soft tender apical portion of fresh roots. Continuous infestation by grubs in a garden results in general weakness of palms and reduction in yield. Management of this insect is a difficult task because the pest is soil inhabiting with a long life cycle. Soil application of insecticides and collection and destruction of adult beetles during the peak period of emergence are the most practicable methods for the management of the pest. With a view to developing effective schedules for pest management a study was undertaken to find out the seasonal intensity of population abundance of the life stages of *L. coneophora* at different depths of soil in coconut gardens.

MATERIALS AND METHODS

The population of different life stages of *L. coneophora* was assessed at fortnightly intervals at two locations at Thazhakkara and Vazhuvadi, Alappuzha

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District, Kerala from September 1977 to September 1980. At each location a pest-infested 0.50 ha coconut garden with loamy sand soil was identified, and 10 (1 m^3) sample pits were taken, 3 m away from the base of the palms. The soil in the pit was removed in layers and the same was passed through 20-inch mesh sieve to separate the life stages of the pest present. The number of adults, eggs, different instars of grubs and pupae present in layers of 0 to 15, 15 to 30, 30 to 45, 45 to 60 and 60 to 100 cm depths were recorded. Using these data the distribution of different life stages at different depths of soil and in different months was assessed.

RESULTS AND DISCUSSION

Table 66.1 shows the mean percentage of different life stages at different depths of soil observed at monthly intervals. Data relating to the seasonal distribution of life stages of *L. coneophora* are presented in Table 66.2.

Table 66.1: Distribution of life stages of *Leucopholis coneophora* in different depths of soil

Location	*Depth (cm)*	*Average percentage population of*					
		Adult	*Egg*	*Grub instar*			*Pupa*
				First	*Second*	*Third*	
Thazhakkara	0–15	2.2	3.6	22.0	17.8	9.5	0.0
	15–30	14.7	24.4	45.5	39.0	27.4	4.2
	30–45	26.5	32.9	19.8	28.8	25.5	19.3
	45–60	21.0	19.4	9.8	12.0	21.9	23.7
	60–100	35.4	19.5	2.8	3.2	15.7	52.7
Vazhuvadi	0–15	2.1	0.5	23.7	13.5	6.3	1.1
	15–30	14.5	11.2	34.6	37.3	27.3	8.1
	30–45	26.6	31.5	27.0	35.1	27.9	23.1
	45–60	23.7	14.9	12.0	8.3	22.9	28.0
	60–100	33.0	41.7	2.7	5.6	15.5	39.4

The beetle population at both the locations was low in the upper stratum of the soil at 0 to 15 and 15 to 30 cm. About 80 per cent of the population was at depths of 30 to 100 cm with the maximum at 60 to 100 cm depths. Beetles collected till the month of June were mostly from depths of 45 to 100 cm whereas a relatively higher proportion was obtained at 15 to 30 cm depths from June to August. The beetles collected till June might have been pre-emerged individuals, whereas the collection obtained from July onwards included the beetles which had emerged, mated and resettled for egg laying. The adults were seen in the soil from the second half of May to the end of August, but stray beetles were seen in April and September. With reference to the occurrence of beetle population in the soil, no distinct peak could be observed. In general, the population in the months of June and July was higher than the population in May and August.

Table 66.2: Seasonal distribution of different life stages of white grub *Leucopholis coneophora* in two locations in Alappuzha district (Kerala)

Life stages	*Location*	*Average population during the months of*																
		Apr.	*May*	*Jun.*	*Jul.*	*Aug.*	*Sep.*	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun.*	*Jul.*	*Aug.*
Adult	1	0	7	42	49	30	2											
	2	4	23	66	49	18	2											
Egg	1		27	216	334	223	0											
	2		126	370	222	252	95											
Grub – first	1		3	73	101	146	143	9										
instar	2		13	32	111	102	59	12										
Grub – second	1				20	41	106	52	14									
instar	2				13	33	44	35	17									
Grub – third	1							238	72	117	102	105	132	124	70	27	11	
instar	2							108	49	114	88	82	134	93	40	43	19	
Pupa	1												0	13	38	49	36	5
													11	37	45	96	23	2

Location 1 Thazhakkara.
2 Vazhuvadi.

The least number of eggs was found in 0 to 15 cm depth. A higher percentage of eggs was observed in depths of 60 to 100 cm during May and June. During the months of July to September, eggs were largely obtained from a depth of 15 to 60 cm. The eggs were generally seen from the second half of May onwards to the end of August. However, there was no distinct peak of occurrence of eggs in the field.

The highest percentage of first instar grubs was seen at depths of 15 to 30 cm and the least in the deepest layers of 60 to 100 cm. Although the eggs were seen in deeper strata, the first instar grubs were seen in fairly large numbers in the upper stratum of 15 to 30 cm, where coconut roots normally do not exist — obviously, the first instar depended on the roots of weeds and other intercrops as the source of food. First instar grubs were obtained from the second half of May to the beginning of October, but the higher level of population was recorded from the second half of June to the end of September, and second instar grubs were largely distributed at depths of 15 to 45 cm. The percentage of grubs seen at lower depths was very low. Generally, the top zone of 0 to 15 cm also had less population. In different months during the period of observation no definite trend in the depth-wise distribution of grubs could be determined. Second instar grubs were observed from the first half of July to the first half of November.

Third instar grubs were seen predominantly at depths of 15 to 30 cm during October to January and at depths of 45 to 60 cm after January. Moisture in the upper stratum would be higher during October to January due to the North-east monsoon. The influence of rainfall on the distribution of third instar grubs was evident by the trend in distribution from January onwards. During January, February and March higher percentage of grub population was observed in deeper depths of 30 to 100 cm. This might be due to the comparatively higher soil temperature and less moisture in the upper stratum of soil during the summer months. Downward migration of grubs of *L. coneophora* from the upper to the lower layers during the summer months was reported earlier also (Mathen *et al.*, 1964; Nirula, 1958). The third instar grubs were seen from the first half of October to the end of July of the succeeding year.

Pupae were observed largely at depths of 30 to 100 cm. The population of pupae observed in the higher stratum of 15 to 30 cm was mostly during the heavy monsoon period, June and July. The depth chosen for pupation appeared to be influenced by soil conditions.

Pupae were seen from the beginning of March till the end of August. But the number observed in March and August was relatively low and the regular period of occurrence of pupal stage can be treated as April to July.

The above studies have clearly brought out the pattern of distribution of the life stages of this important pest in different depths of soil as well as the seasonal intensity of the same. The information gathered is quite relevant in developing an integrated management schedule for the pest. Collection and destruction of beetles of *L. coneophora* is one of the important management methods to bring down the population. As is evident, beetles are abundant

during June and July and the above management method can be adopted during this period. Insecticidal application into soil is another method for pest suppression in the grub stage. In a separate study, Abraham (1983) has shown that the LD_{50} value for third instar grubs was nearly four times higher than that of second instar grubs. Hence, the control of grubs using insecticides during the first and second instar stages is more economical, effective and least hazardous. Insecticide application may therefore be adopted during June to September period. Attracting third instar grubs to the root zone of trap crops and control of them can be achieved after January when other crops are harvested. Using cassava as a trap crop is a possibility.

It is evident from the depth-wide distribution that pest population in the upper stratum of 0 to 15 cm is very low. Therefore, insecticidal application has to be deeper in the soil for making contact with the pest for effective control.

Ploughing or digging and exposing the grubs to predators like birds is a very effective natural control measure. Ploughing or digging to a depth of 30 cm or more would be beneficial in exposing the immature stages of the pest.

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DISCUSSION

P.A.C.R. Perera: Have you made any studies on the feeding habits of the adult beetles because it may be possible to control them by application of insecticides?

V.A. Abraham: Adults do not feed on any plant and do not congregate on alternate hosts prior to mating as seen in other species of root grubs. Hence, the suggested method of control is not possible with *L. coneophora*.

R. Mahindapala: How important is *Leucopholis* in Kerala and what is the economic damage caused by it?

V.A. Abraham: The pest is serious in localised pockets in soils with loamy sand texture. The economic damage has not been precisely estimated so far.

T.P. Sreeharan: Does the use of trap crop increase the pest population?

V.A. Abraham: Trap crop namely, cassava will attract the grubs to the root zone which can be collected and killed. Hence it will reduce the population of the pest.

D.C. Sastri: How physical and chemical properties of soil affect the distribution of larvae?

V.A. Abraham: Soil moisture and temperature influence the distribution at various stages. They prefer loamy sand type and the population in other soil types is very low. Excess moisture and dried condition are also not preferred by the insect.

SEASONAL ABUNDANCE OF THE COCONUT WHITE MITE AND ITS PREDATORS

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ABSTRACT

Oligonychus iseliemae (Hirst) (Acarina: Tetranychidae) infests seedlings and grown up coconut palms and inhabits the adaxial surface of the leaflets. They live in colonies and feeding by the immature stages and adults results in draining of the sap and consequent drying of the affected leaves. Severe damage was usually observed in coconut nurseries and just planted seedlings in the field.

O. iseilemae occurred in the field almost throughout the year. Mean population varied from 94 to 803 from January to June and from 4 to 93 during July to December. Among the meteorological factors, high temperature, low relative humidity and long hours of bright sunshine favoured the increase in mite population and rainfall effected a decline. The mite, insect and spider predators coexisted with *O. iseilemae* colony and brought about substantial reduction of the prey population. The dominant mite predators observed were *Amblyseius paraaerialis, A. eucalypticus, Cunaxa setirostris* and *Agistemus* sp.

INTRODUCTION

Mites often appear as minor pests on coconut palm, but occasional sporadic outbreaks can cause substantial damage to the palm. Among these, 12 species belong to the family Tetranychidae, six to Tenuipalpidae and one to Eriophydae (Ghai and Wadhi, 1983; Gupta, 1985; Kurian *et al.*, 1979; Mohanasundaram and Karuppuchamy, 1989 and Sathiamma, 1983; 1985; 1986; 1988). The recorded tetranychid mites on coconut foliage include *Oligonychus indicus* (Hirst), *O. modestus* Banks, *O. plegas* Baker and Pritchard, *O. pratensis* Banks, *O. tylus* Baker and Pritchard, *O. velascoi* Rimando, *Tetranychus fijiensis* (Hirst), *T. ludeni* Zacher, *T. neocaledonicus* Andre and two unidentified species of *Oligonychus* and *Tetranychus*.

The coconut white mite, *O. iseilemae* inhabits the adaxial surface of the coconut leaflets along the midrib in thin webbings. The infestation is mostly

observed on seedlings, but occurs in adult palms as well. The immature stages and adult mites suck sap from the leaflet resulting in the drying up of the affected portion. The damage and drying is often observed in the coconut nursery and transplanted coconut seedlings in the main field.

Studies were carried out at the Central Plantation Crops Research Institute, Regional Station, Kayangulam, Kerala, during 1985 and 1986 on the seasonal occurrence of *O. iseilemae* and the associated predators and the results are summarised in this paper.

MATERIALS AND METHODS

The seasonal variation in population of *O. iseilemae* was studied on 10 randomly selected, three- to four-year old coconut seedlings at the rate of two sample leaves per seedling, at fortnightly intervals, for a period of two years. Population of egg, larva, protonymph, deutonymph and adult mites present on each of the leaflets of the two leaves/seedling was counted and the mean population per leaf for every fortnight was converted to monthly data. Data on the predators associated with *O. iseilemae* population on the leaflet were recorded. Maximum and minimum temperatures, relative humidity, rainfall and sunshine were collected from the meteorological observatory of the Institute.

RESULTS AND DISCUSSION

Population of *O. iseilemae* occurred in the field during all months of the year (Fig. 67.1). High population (mean population being 94 to 803 per month) was observed during the period from January to June and low (4 to 93 per month) from July to December. The build up of the population commenced from January, gradually increased and reached its peak in May. Thereafter, it declined and reached a very low level in July and continued to maintain almost a low population till December. Predator fauna and weather parameters played a significant role in the build up/decline in population of *O. iseilemae*

The mite, insect and spider predators, particularly, species belonging to the families Phytoseiidae, Cunaxidae, Stigmaeidae, Coccinellidae, Cecidomyiidae and Clubionidae, coexisted with *O. iseilemae* colony, with the seasonal incidence almost coinciding with that of the prey population (Fig. 67.1). The dominant mite predators identified were *Amblyseius paraaerialis* Muma and *A. eucalypticus* Gupta (Phytoseiidae), *Cunaxa setirostris* Hermann (Cunaxidae) and *Agistemus* sp. (Stigmaeidae). The phytoseiid predators occurred in the field during all months of the year, except July, with maximum population during March to May period, when the prey population was also abundant. Maximum population of *C. setirostris* was present during March and May, with a peak in March. *Agistemus* sp. was also abundant during March. The predator population was either quite low or absent during the latter part of the year. The population of the insect predators was low during most months of the year, but

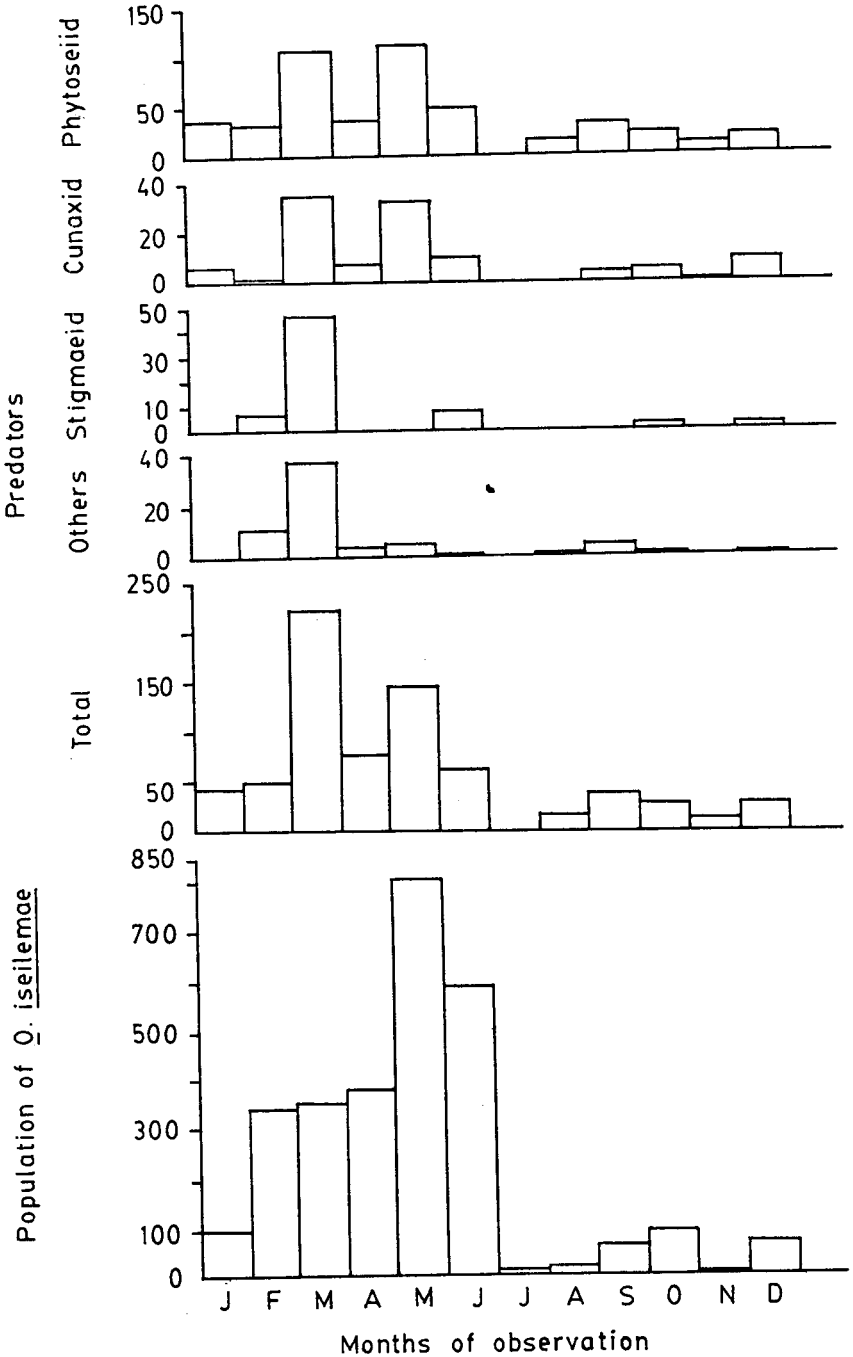

Fig. 67.1: Fluctuations in population density of *Oligonychus iseilemae* and the associated predators.

together with the spider predators they contributed effectively to the biosuppression of the population of *O. iseilemae*.

The incidence of the predators, particularly, the phytoseiid predators, followed a similar pattern as that of the prey population. With build up of *O. iseilemae* population in January, the predator fauna also multiplied in large numbers and reached the peak level in March and suppressed the rapid increase in the prey population. With the decline in population of the predators in April, the prey population increased numerically and reached the peak density in May. Again, the predator population also increased and effected a substantial reduction in prey population. With the decline in prey, during June and July only a low population of the predators survived in the field.

Considering the weather parameters (Fig. 67.2) higher maximum (31° to 34°C) and minimum (21° to 25°C) temperatures, low relative humidity (87 to 91 per cent) and longer hours of bright sunshine (176 to 283 hours) occurred during the months from January to May. During July to December low maximum (27° to 33°C) and minimum (21° to 24°C) temperatures, high relative humidity (93 to 94 per cent) and shorter sunshine hours (126 to 262 hours) was observed. Rainfall was high (165 to 443 mm) from May to November and low (19 to 115 mm) from January to April and December. Maximum rainfall occurred during May and July (296 and 443 mm, respectively). It was observed that high maximum temperature, low relative humidity and longest hours of bright sunshine favoured the incidence of spider mite fauna and maximum rainfall suppressed the population.

It was concluded from the studies that the predator fauna and weather factors were responsible for almost 71 per cent of the variations in population of *O. iseilemae*. A combined effect of the effective indigenous predators and the weather parameters maintained the spider mite population on coconut foliage at a low level, before attaining severe proportions and damaging the crop.

Similar observations on the coconut red mite *Raoiella indica* Hirst (Tenuipalpidae) also gave a positive correlation with temperature and bright sunshine hours and negative correlation with rainfall and relative humidity and mite population and these factors effected 69 per cent of the fluctuations in field population of *R. indica* (Nageshachandra and Channabasavanna, 1983).

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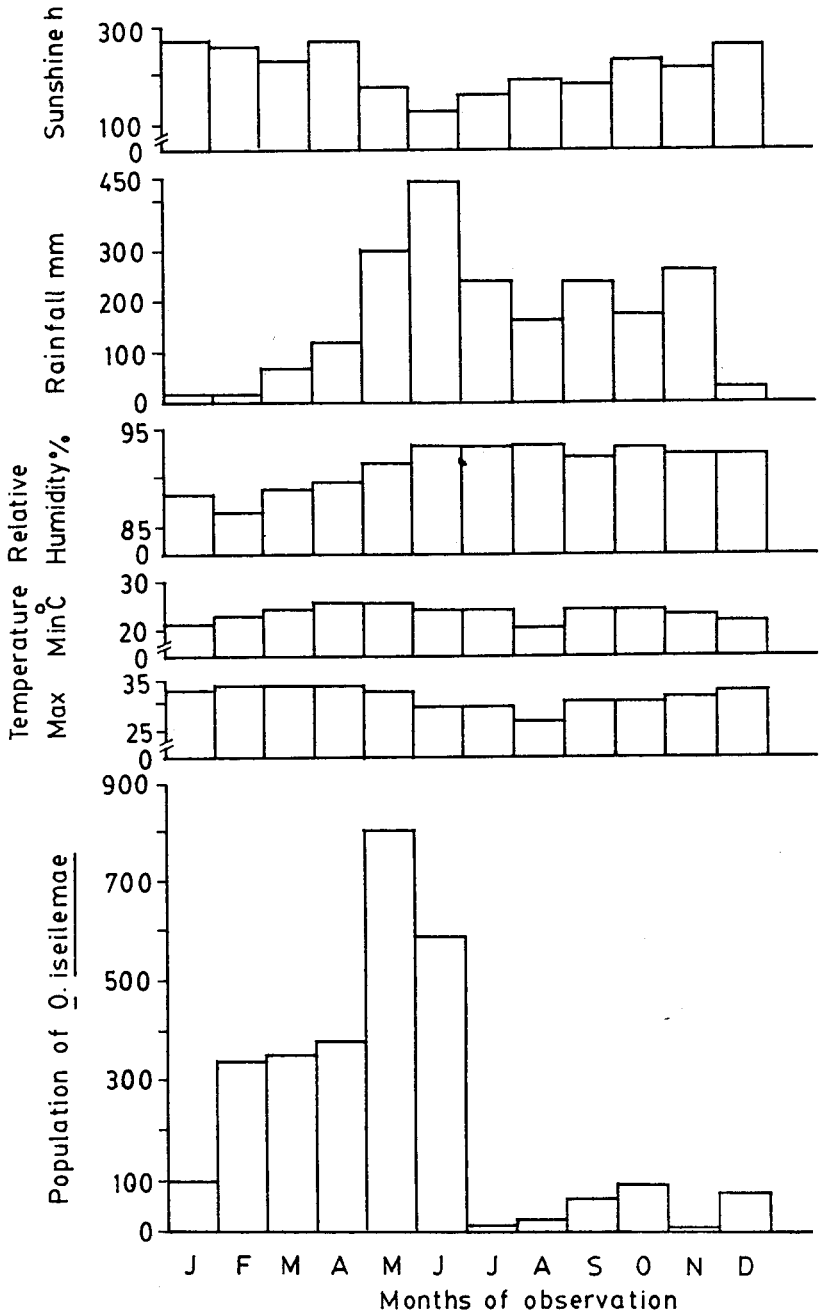

Fig. 67.2: Fluctuations in population density of *Oligonychus iseilemae* in relation to the meteorological factors.

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SEASONAL FLUCTUATIONS IN POPULATION DENSITY OF THE LACE BUG *STEPHANITIS TYPICA* (DISTANT) AND ITS PREDATOR *STETHOCONUS PRAEFECTUS* (DISTANT)

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The lace-bug *Stephanitis typica* (Distant) gained importance as a pest of the coconut palm and as a vector of the root (wilt) disease of coconut which is prevalent in Kerala. Vectoral role of *Stephanitis typica* was established by transmitting the pathogen (MLOs) to healthy coconut seedlings under insect-proof conditions in field cages by Mathen *et al.* (1990). Seasonal abundance of the pest was studied by Mathen *et al.* (1968). The role of the mirid bug *Stethoconus praefectus* as a predator of *S. typica* was reported and a brief description of the predator and its life history were furnished by Mathen *et al.* (1973).

Fluctuations in the population density of *S. typica* and its predator on young coconut seedlings below the age of three years were studied during the period of January 1990 to June 1991 in relation to meteorological factors.

Two plots each comprising 250 seedlings below the age group of three years were selected. The plots were divided into five subplots of 50 seedlings each. From each subplot 10 seedlings were selected at random each week to record populations of *S. typica* and its predator *S. praefectus*. Since the number of leaves in the young seedlings were few, the youngest single leaf was selected from seedlings having seven and less than seven leaves. In seedlings with eight to 12 leaves the two youngest leaves and those with 13 to 17 leaves the three youngest leaves and so on, were selected to record the observations. From the selected leaves, leaflets falling within 41 to 60 per cent from the base of petiole were observed and the total number of adults and nymphs of both *S. typica* and its predator were recorded. The estimated population of the pest was worked out by multiplying the total observed population with the factor 3.76

(Mathen *et al.*, 1973). Meteorological observations at CPCRI, Kayangulam were utilised for the study.

The population fluctuations of *S. typica* and its predator in plots I and II (Table 68.1) show more or less the same pattern. The nymphal population was observed to be higher than that of the adult for both the plots.

Table 68.1: Estimated population of *S. typica* and *S. praefectus* and per cent distribution in plots I and II.

Year/ month	PLOT I						PLOT II					
	S. typica				*Stethoconus*		*S. typica*				*Stethoconus*	
	Adult	%	*Nymph*	%	*Nos.*	%	*Adult*	%	*Nymph*	%	*Nos.*	%
1990												
Jan.	297	7.8	285	7.5	0	0.0	505	8.1	431	6.9	12	4.9
Feb.	157	4.1	189	5.0	8	14.8	174	2.8	269	4.3	19	7.0
Mar.	38	1.0	68	1.8	8	14.8	102	1.6	86	1.4	0	0.0
Apr.	62	1.6	181	4.8	0	0.0	36	0.6	91	1.5	0	0.0
May	83	2.2	153	4.0	0	0.0	110	1.8	197	3.2	0	0.0
Jun.	104	2.7	366	9.6	0	0.0	343	5.5	673	10.8	0	0.0
Jul.	91	2.4	225	5.9	19	35.2	294	4.7	627	10.0	158	64.8
Aug.	24	0.6	49	1.3	4	7.4	72	1.2	101	1.6	4	1.6
Sep.	49	1.3	55	1.4	0	0.0	101	1.6	157	2.5	0	0.0
Oct.	136	3.6	177	4.7	11	20.4	362	5.8	426	6.8	0	0.0
Nov.	179	4.7	300	7.9	0	0.0	307	4.9	494	7.9	17	7.0
Dec.	308	8.1	230	6.0	4	7.4	133	2.1	149	2.4	34	14.0
1991												
Jan.	131	2.9	260	5.7	34	26.2	97	1.1	67	0.8	50	11.2
Feb.	113	2.5	180	3.9	8	6.2	110	1.3	223	2.6	15	3.4
Mar.	178	3.9	320	7.0	0	0.0	427	5.0	608	7.1	0	0.0
Apr.	83	1.8	229	5.0	0	0.0	201	2.4	385	4.5	4	0.9
May	108	2.3	272	5.9	8	6.2	418	4.9	456	5.3	82	18.4
Jun.	143	3.1	281	6.1	15	11.5	457	5.4	813	9.5	72	16.1

The estimated average monthly populations of *S. typica* and its predator along with monthly average meteorological factors are presented in Table 68.2. The highest predator population was observed in July 1990 and January 1991. Temperature below 33°C favoured pest build up irrespective of wider diurnal variation. Temperature above 33°C may not affect pest build up provided the average variation between the maximum and minimum temperatures is narrow. Hours of bright sunshine influenced the population trend and fewer hours of sunshine were found to be related to higher peaks. The population build up showed a positive relation to rainfall, number of rainy days and relative humidity around 90 per cent and above. Dry spells seemed to be associated with low populations. The up and down trends in predator population were found to be closely related to prey population and the predator exercised a definite role in bringing down the prey population that had reached higher levels in spite of favourable meteorological parameters. A high predator population was

observed following peaks in *S. typica* populations in the month of February, June and December in 1990 and January, May and June 1991. The predator exercised a definite regulatory pressure on the pest population in spite of favourable meteorological factors in August and September, 1990 and April, 1991. Decline in prey population resulted in very low predator population.

Table 68.2: Population density of *S. typica* and *S. praefectus* in relation to meteorological data

Year/ month	*Per cent distribution S. typica*			*S. praefectus*	*Temperature average*		*Rainfall (mm)*	*No. of rainy days*	*RH*	*Hours of sunshine (%)*
	Adult	*Nymph*	*Total*		*Max.°C*	*Min.°C*				
1990										
Jan.	8.0	7.1	15.1	4.0	32.8	13.4	32.8	2	89	268.8
Feb.	3.3	4.6	7.9	9.1	34.3	15.3	4.4	1	91	283.8
Mar.	1.4	1.5	2.9	2.7	34.7	17.6	35.0	2	89	313.8
Apr.	1.0	2.7	3.7	0	34.3	18.9	83.0	5	89	255.4
May	1.9	3.5	5.4	0	31.4	17.7	657.7	21	95	142.8
Jun.	4.5	10.4	14.8	0	31.3	17.2	356.0	19	95	161.1
Jul.	3.8	8.5	12.3	14.3	30.1	16.1	585.0	26	95	130.1
Aug.	1.0	1.5	2.5	3.2	30.8	16.3	89.4	10	95	166.9
Sep.	1.5	2.1	3.6	0	31.4	16.4	79.2	4	93	237.0
Oct,	4.7	6.0	10.7	1.0	31.4	16.2	352.5	20	93	220.7
Nov.	4.9	7.9	12.8	1.3	32.4	15.6	42.7	3	93	278.6
Dec.	4.4	3.8	8.2	4.6	33.3	13.6	2.9	1	91	269.6
1991										
Jan.	1.8	2.5	4.3	16.2	33.4	16.5	0	0	91	294.6
Feb.	1.7	3.0	4.8	3.7	34.3	20.7	7.2	1	92	287.6
Mar.	4.6	7.1	10.7	0.0	34.9	24.0	20.0	4	92	295.1
Apr.	2.1	4.7	6.8	0.4	32.5	24.1	88.9	8	91	277.4
May	4.0	5.6	9.6	7.2	34.4	24.4	291.1	9	91	268.8
Jun.	4.6	8.4	12.9	5.2	30.7	23.3	1005.0	25	96	78.2

Mathen *et al.* (1968) observed that high temperature, low rainfall, low relative humidity and greater hours of sunshine favoured high population of *S. typica*. They observed a negative correlation with relative humidity and rainfall and positive correlation with temperature and sunshine. The period of study reported by Mathen *et al.* (1968) had heavy rainfall and very high relative humidity, above 95 per cent. The average maximum temperature recorded during the period was 34°C for one month under the entire period of study. Therefore, the conditions under which the above conclusions were made may not hold good in the present study. Therefore it is felt that studies on population for longer period may yield a realistic picture of the influence of different meteorological parameters on the population of *S. typica*.

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NATURAL OCCURRENCE OF CYTOPLASMIC POLYHEDROSIS VIRUS OF RED PALM WEEVIL IN KERALA

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The red palm weevil *Rhyncophorus ferrugineus* F. (Coleoptera: Curculionidae) is one of the serious pests inflicting heavy loss to coconut palms below five to 15 years of age. In coconut, red palm weevil infestation to an extent of 5 to 10 per cent has been reported. The natural enemies reported are some external parasitoids and predators (Nair, 1978) and the occurrence of microbial parasites has not been reported. This paper reports the results of a survey undertaken during 1983 to 1988 on the incidence of entomopathogens on red palm weevil in Trivandrum and in comparison with the endemic areas of Alleppey and Kottayam districts.

The coconut palms subjected to red palm weevil infestation and its entomopathogens were mostly below 15 years of age comprising an average number of 150 to 200 in all the places of Trivandrum, Alleppey and Kottayam. Badly infested palms beyond recovery stage were cut open and eggs, grubs, pupae and adults were collected and reared on fresh coconut petiole under laboratory conditions and observed for the microbial parasites. The different stages of red palm weevil infected with cytoplasmic polyhedrosis virus (CPV) were sorted out individually, kept in sterile glass vials and subjected to microbial analysis. The polyhedra were isolated by triturating the diseased mid-gut tissues in sterile distilled water and further purified by differential centrifugation. The semi-purified polyhedral inclusion bodies (PIBs) of CPV were subjected to pathogenecity tests and also by both light and electron microscopic studies. The disease was determined by visual examination of the body, midgut and Giemsa stained smears of mid-gut and body contents by light microscope. The average monthly percentage infestation of red palm weevil, the mortality percentage of CPV on grubs, pupae and adults and the cumulative percentage mortality of all the stages recorded from places of

Trivandrum, Alleppey and Kottayam during the period from August 1983 to March, 1988 are presented in Table 69.1.

Table 69.1: Natural incidence of cytoplasmic polyhedrosis on various stages of *Rhyncophorus ferrugineus* in different places of Trivandrum, Kottayam and Alleppey districts

Period	*Place*	*Average % infestation*	*% mortality of CPV incidence*			*Cumulative % mortality*
			Grubs	*Pupae*	*Adults*	
August 1983	Kalliyoor*	2.5	11.1	7.1	4.3	22.5
September 1983	Vellayani*	3.0	12.5	5.3	3.7	21.5
September 1983	Kumarakom**	9.6	2.6	–	–	2.6
October 1983	Palapur*	1.4	14.2	5.5	2.9	22.6
November 1983	Karamana*	2.5	12.5	4.7	5.0	22.2
December 1983	Muttacaud*	1.0	14.8	8.7	8.0	31.5
January 1984	Vellayani*	1.8	12.8	5.8	6.2	24.8
February 1984	Kalliyoor*	2.0	9.3	3.4	7.1	19.8
March 1984	Vellayani*	1.0	14.2	13.3	3.8	31.3
April 1984	Instructional Farm, Vellayani*	1.5	11.7	6.6	10.7	29.0
May 1984	Kalliyoor*	0.5	9.2	7.8	2.2	19.2
June 1984	Venganoor*	0.6	10.9	3.5	3.6	28.0
July 1984	Tiruvallam*	1.3	8.3	4.9	6.9	20.1
August 1984	Valiyathura*	1.2	12.2	2.2	9.0	23.4
September 1984	Karamana*	0.6	10.3	4.2	6.5	21.0
October 1984	Neyyattinkara*	1.6	14.2	3.7	5.7	23.6
November 1984	Kamukinkode*	2.6	11.1	4.1	8.3	23.5
December 1984	Palode*	0.8	5.2	7.6	2.0	14.8
January 1985	Vellayani*	2.0	13.3	5.7	4.0	23.0
February 1985	Kumarakom**	11.6	0.9	0.4	0.0	1.3
February 1985	Vijayapuram**	5.5	–	–	–	–
February 1985	Moncompu***	10.0	–	–	1.3	1.3
February 1985	Koorappadam**	10.0	0.9	–	0.9	1.8
February 1985	Pulinkunnu***	10.7	1.6	–	–	1.6
February 1985	Changanassery**	6.2	0.7	–	1.4	2.1
March 1985	Thiruvalla**	8.3	2.4	–	0.8	3.2
March 1985	Kumarakom**	12.0	1.2	–	–	1.2
April 1985	Vellayani*	1.5	6.6	7.1	10.2	23.9
May 1985	Karamana*	0.6	6.6	4.6	5.0	16.2
June 1985	Balaramapuram*	1.0	11.6	1.8	7.6	21.0
July 1985	Tiruvallam*	1.0	7.5	5.3	5.7	18.5
August 1985	Kalliyoor*	0.5	3.4	8.9	11.7	24.0
September 1985	Vizhinjam*	0.6	10.4	9.3	5.1	24.8
October 1985	Kottukal*	0.4	5.1	5.2	16.6	26.9
November 1985	Venganoor*	0.6	7.6	16.6	6.6	30.8
December 1985	Vellayani*	0.5	3.1	1.6	13.1	17.8
January 1986	Valiyathura*	0.5	4.3	2.2	13.9	20.4
February 1986	Neyyattinkara*	2.0	5.8	6.2	13.9	25.9
March 1986	Peringamala*	1.0	3.2	3.3	17.6	24.1
April 1986	Vellayani*	0.4	3.2	3.3	17.2	23.7
May 1986	Neyyattinkara*	0.5	10.0	5.5	8.8	24.3
June 1986	Peringamala*	0.6	5.2	8.3	6.0	19.5
July 1986	Vellayani*	1.0	6.4	3.4	7.1	16.9

Contd.

Table 69.1 contd.

Period	Place	Average % infestation	% mortality of CPV incidence			Cumulative % mortality
			Grubs	Pupae	Adults	
August 1986	Tiruvallam*	0.3	7.2	7.8	10.6	25.6
September 1986	Pachalloor*	1.0	4.6	10.0	6.6	21.2
October 1986	Kalliyoor*	1.3	15.9	8.1	5.8	29.8
November 1986	Karamana*	0.5	4.7	11.6	3.7	20.0
December 1986	Valiyathura*	2.0	13.3	3.8	8.0	25.1
January 1987	Vellayani*	0.4	10.0	3.7	15.4	29.1
February 1987	Balaramapuram*	0.6	2.5	2.5	5.2	10.2
March 1987	Neyyattinkara*	0.5	1.9	3.9	8.6	14.4
April 1987	Valiyathura*	0.7	6.6	2.3	7.1	16.0
May 1987	Peringamala*	0.5	9.2	1.0	4.1	14.3
June 1987	Tiruvallam*	0.4	7.1	5.1	5.3	17.5
July 1987	Karamana*	0.4	7.6	3.3	3.4	14.3
August 1987	Kalliyoor*	0.8	3.4	5.3	3.7	12.4
September 1987	Vellayani*	1.0	5.0	7.0	3.7	15.7
October 1987	Neyyattinkara*	1.0	9.7	3.0	4.8	17.5
November 1987	Venganoor*	1.4	8.0	8.6	4.7	21.3
December 1987	Vizhinjam*	0.4	10.0	4.5	6.6	21.1
January 1989	Balaramapuram*	0.4	8.6	2.3	4.8	15.7
February 1989	Thiruvallam*	1.4	4.1	4.3	9.9	18.3
March 1989	Kalliyoor*	0.5	6.1	1.6	8.3	16.0

*Trivandrum district
**Kottayam district
***Alleppey district

The field diseased cytoplasmic polyhedrosis virus (CPV) grubs of red palm weevil showed retarded development, cessation of feeding, comparatively swollen head and marked constriction on the anterior abdominal region of the body than healthy insect. Similar CPV expressions have been recorded on cabbage loopar, *Trichoplusia ni* (Vail and Hall, 1967). The hind gut became everted due to blocking of the alimentary canal and continuous effort of the grubs to void the polyhedral inclusion bodies (PIBs) in large numbers. In an advanced stage of the disease the PIBs are seen oozed out in large quantities through the rectum. The cuticle is leathery, tough and not easily ruptured. When the cadavers of second and third stage grubs were kept in sterile distilled water, there was no disintegration of tissues and the shape of the body was intact after three years of preservation at 4°C. The diseased grubs which pupated were crinkled and malignant in appearance. The less infected pupae did not emerge into adults and the adults emerged were either smaller or distorted and possessed crinkled wings and died in 10 to 15 days unlike the healthy ones that lived for 60 to 110 days. The eggs laid by the diseased female adults did not hatch.

The diseased eggs when triturated in sterile distilled water under light microscope revealed thousands of PIBs. The excreta given out by diseased adults of both male and female yielded large quantity of PIBs. The infected

grubs when dissected, showed the mid-gut as milky white. The numerous PIBs present in the tissue are visible under light microscope. The infected tissues are found to be devoid of fat body. The purified PIBs were determined as cytoplasmic polyhedrosis virus by light and electron microscope. The PIBs readily stained with 5 per cent Giemsa stain. The PIBs were regularly hexagonal having a pitted appearance. The virions are spherical, with surface projections.

The natural incidence of CPV on grubs, pupae and adults of red palm weevil from different places of Trivandrum to that of endemic areas of Alleppey and Kottayam is presented in Table 69.1. The infestation of the pest is felt throughout the period in varying intensities in all the places during the period of observation.

The observation on the red palm weevil infestation and the prevalence of CPV incidence on the field collected stages in the endemic areas of Alleppey and Kottayam revealed that a high incidence of the pest (116 per cent) is due to the negligible influence of CPV (1.3 per cent) during February 1985. But, in places of Trivandrum district, there was less incidence of red palm weevil infestation (0.3 per cent, August 1986—Tiruvallam) with a high level of cumulative infection of grubs, pupae and adults by CPV (25.6 per cent, August 1986—Tiruvallam). Thus there is high correlation of the pest incidence with respect to the occurrence of CPV in all the places observed. Further, the palms observed in the endemic areas having low-lying topography succumbed to high pest infestation (Kumarakom 11.6 per cent, Moncompu 10 per cent and Pulinkunnu 10.7 per cent) when compared to elevated areas namely, Vijayapuram (5.5 per cent) and Changanassery (6.2 per cent). This is in consonance with the observations recorded in places of Trivandrum district wherein, low-lying areas and rice fields converted into coconut plantations suffered more due to red palm weevil infestation (Kalliyoor 2.5 per cent, Vellayani 2 per cent) than elevated areas (Kottukal 0.4 per cent, Peringamala 0.3 per cent and Palode 0.8 per cent).

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INFECTION OF RED PALM WEEVIL BY MICROBIAL PATHOGENS

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The red palm weevil *(Rhynchophorus ferrugineus* F.) is a tissue borer pest of the coconut palm. The pest infestation is detectable only when palms are about to die due to damage of internal tissues. Curative chemical treatments are not very effective, particularly at later stages of infestation. Though an earwig, a predator on eggs and early instar grubs of the pest was recorded (Abraham and Kurian, 1973), it exerts only a meagre control of the pest due to its polyphagous nature and difficulty to reach the pest within the palm tissues. Recently a cytoplasmic polyhedrosis virus (Gopinadhan *et al.*, 1990) has been reported. But, applicability of the same under field conditions is not known. Natural occurrence of bacterial and efficient viral pathogens, if any, for using them for biocontrol is investigated.

Field-collected grubs, pupae and adults of red palm weevil which showed abnormality were used for isolation of different pathogens. Tissues were processed and observed under both LM and TEM.

Haemolymph of the surface-sterlised grubs was collected, diluted (10 g) serially and aliquots from 10 and 10^2 were inoculated in different microbiological media to cover the entire range of microbes. Cultural, morphological staining, physiological and biochemical characters were studied for the pure cultures of bacteria. Pathogenicity of the isolates was checked in terms of LD_{50} by inoculating 10–10^{10} bacteria (intrahaemocoelic) and 10–10^{15} bacteria (*per os*) to each of the 10 grubs for each concentration.

The major symptoms and post-mortem changes are furnished in Table 70.1. The symptoms are typical for bacterial infection known for various bacterial diseases of insects (Burges and Hussy, 1971; Steinhaus, 1963). Among different bacterial isolates (Table 70.2), the coryneform bacteria are more important pathogens because of their LD_{50} values (10^3–10^8) were minimum and were constantly associated with the disease. Any bacterium having LD_{50}

value between 10^3 and 10^8 is expected to become a pathogen (Burges and Hussy, 1971). Following the coryneform group, *Bacillus* spp. (Table 70.1) were isolated most of the time along with the former. So, it could be expected that coryneform bacteria are the primary cause of the bacterial infection and *Bacillus* spp. are opportunistic invaders accentuating death of the grubs. Though uncommon, *Corynebacterium* spp. and *Arthrobacter* spp. of coryneform group are known insect pathogens (Burges, 1981). Secondary role of *Bacillus* spp. is evident from their high LD_{50} values (Table 70.1) and non-occurrence of known pathogens like *B. thuringiensis, B. lentimorbus* and *B. popilliae*. The other bacterial isolates (Table 70.1) which are common inhabitants of the gut were occasionally obtained and their high LD_{50} values (Table 70.1) suggest that they are of non-pathogenic type.

Table 70.1: Morphological and behavioural characters of diseased grubs of red palm weevil

Characters	*Observations*
Behavioural	Sluggishness, refusal to feed.
Morphological	Rough and tough skin, accumulation of fluid in the haemocoel, yellowing of fat, diarrhoea, dilation of gut, thickening of gut wall, whitish appearance of gut.
Post-mortem	Softening, blackening and putrefaction.

Table 70.2: Bacterial isolates from diseased grubs of red palm weevil and their LD_{50} values

Organism	*LD_{50} values*	
	Per os	*Intrahaemocoelie*
Coryneform group*	10^8–10^{11}	10^3–10^8
Bacillus spp.**	$\geq 10^{12}$	$\geq 10^8$
Serratia spp., *Proteus* spp.		
Pseudomonas spp.		
Micrococcus spp.	≥ 10	$\geq 10^9$
Lactobacillus spp.		

*Based on 90 out of 158 isolates.
**Based on 30 out of 45 isolates.

The histopathological changes (Table 70.3) are evident for a nuclear viral infection of the pest. Similar symptoms of other nuclear infections by

Table 70.3: Histopathological characters of different tissues and characters of virus-like structures

Tissue	*Histopathology*	*Virus structure*
Fore, mid-gut and hind gut, fat body and nerve tissue.	Nuclear hypertrophy, fragmentation of chromatin, vacuolisation in nucleus and cytoplasm.	Two types, hexagonal isodiametric with central core and capsid, and 7.8–13.7 nm (attached to nuclear membrane) and 0.30–0.33 μ in diameter.

entomoviruses are well documented (Burges, 1981; Burges and Hussy, 1971; Steinhaus, 1963). Presence of virus-like particles (Table 70.3) within the infected cells confirms the view.

However, sequence of development of the disease, possibility of simultaneous infection by virus and bacteria like that of flachire/gattine of *Bombyx mori* and the exact role of individual organisms requires further investigation.

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BIOLOGY AND CONTROL OF *RATTUS RATTUS WROUGHTONI* HINTON, A PEST OF COCONUT IN INDIA

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ABSTRACT

The biology and control aspects of *Rattus rattus wroughtoni* were studied in coconut gardens around Kasaragod. Among the eight different species of rodents that harboured in the plantations, *R.r. wroughtoni* was the most predominant (45 per cent) one. This rat caused 14 to 20 per cent damage to tender coconuts. The intensity of damage was more during summer and early monsoon (April to June) and less during post-monsoon (August to October). The mean persistence of individuals in the population was four months. Poison baiting with warfarin, fumarin or bromadiolone gave good control of the pest.

R.r. wroughtoni is the most predominant rodent pest in the coconut and cocoa plantations of Kerala and Karnataka and also of Maharashtra. Detailed studies were initiated at the Central Plantation Crops Research Institute, Kasaragod on the biology and control of this pest as the information available was scanty. The present paper summarises the results obtained in the past one decade.

1. Species Composition

In coconut plantations eight different species of rodents were observed to coexist (Advani, 1984). Among them *R.r. wroughtoni* was the most predominant one (45 per cent) followed by the field mouse *Mus booduga* (31 per cent). Other rodents found in association with these animals were the tree mouse, *Vandeleuria oleracea* (12 per cent); the Western Ghats squirrel, *Funambulus tristriatus* (7 per cent); *R.r. rufescens* (4 per cent) and the Indian gerbil, *Tatera indica* (1 per cent). The burrows of the lesser bandicoot *Bandicota bengalensis* and the larger bandicoot, *Bandicota indica* were also found in certain gardens (Table 71.1). The *R.r. wroughtoni* lived mostly on the tree canopy whereas *M. booduga* remained on the ground, thus minimising competition for food and shelter.

Table 71.1: Relative abundance and spatial preferences of rodents* in coconut gardens (N = 465)

Species	*Number trapped*	*Spatial preferences of individuals*	
		Ground	*Above ground*
R.r. wroughtoni	214(46.0)	37(17.3)	177(82.7)
M. booduga	145(31.2)	145(100.0)	0
R.r. rufescens	17(3.7)	4(23.5)	13(76.5)
F. tristriatus	32(6.9)	3(9.4)	29(90.6)
V. oleracea	55(11.8)	1(1.8)	54(98.2)
T. indica	2(0.4)	2(100.0)	0

Figures in parentheses are per cent values.
*Burrows of *B. bengalensis* and *B. indica* were observed in certain gardens.

2. Damage Intensity

Monthly observations carried out for three years in a coconut plantation of 165 yielding palms revealed considerable variation in damage from month to month. The intensity of damage was more during summer and early monsoon (April to June) and less during post-monsoon (August to October) periods (Fig. 71.1). The damage intensity varied from 14.3 per cent during 1988 to 20.4 per cent during 1990. Advani (1984) has reported that the damage intensity to coconut was more in coconut-cocoa mixed cropping systems (28.5 per cent) than in coconut monocrop system (21 per cent).

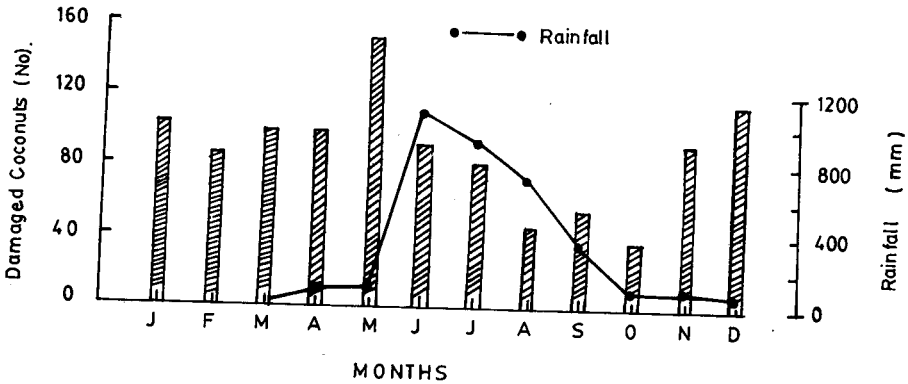

Fig. 71.1: Number of tender coconuts damaged by rats in 165 palms in different months (Mean of three years).

3. Population Structure and Movement Patterns

3.1. Sex ratio: In the natural population of *R.r. wroughtoni* the female rats significantly ($P < 0.001$) outnumbered male rats by 1.0: 0.87 (Bhat *et al.*, 1987). However, during the months of March, July and August, the number of male rats trapped was more than the females. This was attributed to the presence of more number of pregnant females during these months which restricts their movement.

3.2. Body weight distribution: In general, the male rats were significantly ($P < 0.001$) heavier and bigger than the female rats (Bhat *et al.*, 1987). The body weight in male rats varied from 20 to 190 g and in female rats 20 to 176 g. Nearly 46 per cent of male rats weighed > 100 g whereas only 29 per cent of the female rats attained that weight (Table 71.2).

Table 71.2: Body weight distribution in *R.r. wroughtoni*

Weight group (g)	*Sample size*	*Number*		*Females %*	$X^2(1)$	*P value*
		Males	*Females*			
<41	189	61	128	67.7	23.7	0.001
41–60	420	158	262	62.4	25.7	0.001
61–80	428	160	268	62.6	27.2	0.001
81–100	625	283	342	54.7	5.6	0.05
101–120	495	263	232	47.0	1.9	NS
121–140	273	166	107	39.2	13.6	0.001
>140	209	140	69	33.0	24.1	0.001

3.3. Home ranges: The movement of *R.r. wroughtoni* in coconut plantations was observed by capture, mark, release and recapture technique (Blair, 1940). The home ranges of four male and three female rats, recaptured for 10 or more times within the study area were plotted in the map and the area covered calculated. It was found that the male rats covered an area of 1160 sq m (787.5 to 1687.5 sq m) whereas the female rats covered only 932.8 sq m (843.7 to 998.5 sq m). The home ranges were highly overlapping and up to seven individuals were observed to visit one trap point. In coconut-cocoa mixed cropping system the home ranges of *R.r. wroughtoni* were observed to be smaller (661.6 sq m for males and 557.8 sq m for females) than in coconut pure crop.

4. Breeding Behaviour

4.1. Breeding season: In the natural population, *R.r. wroughtoni* was observed to breed throughout the year but with two peaks. One peak during February–March (early summer) and the other during July–August (monsoon). The breeding was lowest during summer (April to early part of June).

4.2. Ovulation rate and litter size: In *R.r. wroughtoni* the ovulation rate based on *corpora lutea* count varied from one to nine (5.26 ± 0.16). However, the litter size based on embryo count varied from one to eight (4.49 ± 0.10).

4.3. Post-natal development: The newly born young ones of *R.r. wroughtoni* weighed 2.5 to 2.9 g and measured 35 to 40 mm. The length of the tail was shorter than the head and the body. During the first week of post-natal development the pinnae unfolded and incisors erupted. Eyes opened during the third week. Tail length surpassed the head and body length during the fifth week. The young ones weaned during the thirty-sixth day of development when they weighed around 15.2 g (Advani, 1984).

4.4. Juvenile emergence and adult persistence: Young ones of *R.r. wroughtoni* came out of their nests when they were 20 to 30 g weight. Such juveniles became

adults within two to three months of their emergence. In nature, nearly 50 per cent of the rats did not persist in the population for more than four months and none after 12 months (Bhat, 1988).

5. Control Methods

5.1. Trapping: Among the two common 'live' traps namely, the wooden and the Sherman, the former was found to capture significantly more number of rats (Bhat and Sujatha, 1987).

5.2. Bait preference: About 25 baits and their combinations were screened in the laboratory to find out the most preferred bait for *R.r. wroughtoni*. It was found that the sweetened (2 per cent) whole grains of rice was ideal to prepare poison baits for the control of this pest. Addition of oils and dried fish decreased the acceptance (Bhat and Sujatha, 1989 a).

5.3. Poison baiting

5.3.1. *Multiple dose anticoagulants*: To begin with, the two common multiple dose anticoagulants, namely, warfarin and fumarin were evaluated against *R.r. wroughtoni* (Bhat and Sujatha, 1989 b). Studies revealed that there was no significant difference in the toxicity between these poisons (LFP_{50} around four days for both) to *R.r. wroughtoni* (Table 71.3) but fumarin mixed baits were accepted significantly more than warfarin mixed ones (Table 71.4).

Table 71.3: Toxicity of warfarin and fumarin (0.025 per cent) to *R.r. wroughtoni*

Days of exposure	*Mortality (%)*		*Lethal dose(mg/kg)*		*Days to death*	
	Warfarin	*Fumarin*	*Warfarin*	*Fumarin*	*Warfarin*	*Fumarin*
3	20.0	20.0	6.7 ± 1.47	5.5 ± 0.73	4.7 ± 0.33	4.3 ± 0.67
4	46.7	53.3	7.7 ± 0.91	8.7 ± 0.67	7.6 ± 1.91	6.1 ± 0.40
6	73.3	73.3	11.1 ± 0.90	9.7 ± 1.18	5.7 ± 0.38	5.2 ± 0.35
8	86.7	80.0	6.7 ± 0.65	8.4 ± 0.92	5.3 ± 0.29	6.9 ± 0.36
10	93.3	93.3	8.1 ± 0.67	11.3 ± 1.63	6.2 ± 0.39	8.5 ± 1.30
12	100.0	93.3	8.5 ± 1.08	11.5 ± 1.47	6.9 ± 0.75	9.0 ± 0.92
14	–	100.0	–	11.6 ± 1.70	–	8.7 ± 1.05

Table 71.4: Relative acceptability of poison baits by *R.r. wroughtoni*

Treatments	*Consumption (g/kg) of baits*			*t value at P <0.01*
	Warfarin	*Fumarin*	*Plain*	
Warfarin versus Fuamrin	12.68 ± 2.34 (12.3%)	90.34 ± 5.43 (87.7%)	–	12.55
Warfarin versus Plain	30.83 ± 6.65 (30.0%)	–	71.96 ± 6.45 (70.0%)	4.91
Fumarin versus Plain	–	28.91 ± 3.22 (38.0%)	47.13 ± 3.92 (62.0%)	3.29

Based on the bait preferences of *R.r. wroughtoni* the following ingredients were suggested to prepare the poison bait in wax cake form:

Broken rice: 12 parts;
Jaggery: 1 part;
Paraffin wax: 6 parts; and
Warfarin/Fumarin (0.5 per cent powder): 1 part.

First, the paraffin wax is melted in a vessel. Rice, jaggery and poison are mixed in a tray of 2.5 cm deep. The molten wax is then poured over that mixture, mixed properly and spread evenly on the tray and pressed well. Once the smooth surface is formed the slightly hardened mixture is cut into blocks of 4.5 × 3.0 × 2.5 cm. The bait is kept overnight for cooling. Next morning the blocks are ready for baiting.

Field trials were conducted using warfarin and fumarin (0.025 per cent) wax blocks to control *R.r. wroughtoni* in coconut gardens (Bhat and Sujatha, 1988). The infestations of *R.r. wroughtoni* were completely controlled by applying warfarin/fumarin wax blocks on the crown of coconut palms three times at an interval of three days at the rate of 105 g, 70 g and 35 g baits per palm on 30 palms per ha (Table 71.5).

Table 71.5: Field evaluation of warfarin and fumarin against *R.r. wroughtoni* in coconut

Times of baiting	*Poisons used*	*Trap index and number of damaged nuts*		*% of reduction*
		Pre-control	*Post-control*	
Once	Warfarin	22.52(63.5)	10.78(29.5)	52.13(53.5)
	Fumarin	24.19(48.0)	11.79(23.0)	51.26(52.1)
	Control	24.72(21.0)	28.57(18.0)	−15.57(14.3)
Twice	Warfarin	23.48(23.5)	6.86(7.0)	70.78(70.2)
	Fumarin	25.72(22.5)	7.44(7.0)	71.07(68.9)
	Control	28.57(18.0)	22.73(20.0)	20.44(−11.1)
Thrice	Warfarin	30.12(21.5)	2.05(Nil)	93.19(100.0)
	Fumarin	34.35(27.5)	2.04(Nil)	94.06(100.0)
	Control	22.73(20.0)	27.27(24.0)	−19.97(−20.0)

Figures in parentheses are number of damaged nuts.

5.3.2. *Single dose anticoagulants:* Among the three promising single dose anticoagulants namely, brodifacoum, bromadiolone and flocoumafen, the first one was found to be more toxic than the other two. However, since only bromadiolone is registered in India, more detailed studies were conducted with that poison to control *R.r. wroughtoni* in coconut gardens.

The rats did not exhibit any bait shyness when exposed to bromadiolone baits (Bhat and Sujatha, 1991). One day exposure to the poison bait (0.005 per cent) resulted in 93 per cent mortality and two days exposure resulted in cent per cent mortality. The days to death varied from three to 13 (Table 71.6).

In the field trial, one time application of bromadiolone (0.005 per cent) wax blocks on the crown of rat infested coconut palm (30 palms per ha) reduced the damage by 79.6 per cent. Two times application of poison baits at an interval of 12 days has completely controlled the damage.

Table 71.6: Toxicity of bromadiolone to *R.r. wroughtoni*

A. No-choice feeding (N = 30)

Exposure (days)	*Poison consumed (mg/kg)*	*Mortality (%)*	*Days to death*
One	6.03(2.0–10.0)	93.3	5.28(3–13)
Two	11.63(3.4–19.1)	100.0	5.80(3–10)

B. Choice feeding (N = 10)

Exposure	*Bait consumption (g/animal/day)*		*Preference*		*Mortality (%)*
	Plain	*Poison*	*Plain*	*Poison*	
One	3.30	2.30	40.0	40.0	60.0
Two	2.75	3.74	50.0	40.0	70.0
Three	3.85	2.05	40.0	40.0	100.0

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DISEASE MANAGEMENT

Chairman	R. Mahindapala
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FUNGAL DISEASES OF COCONUT IN THE WORLD

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ABSTRACT

A wide array of fungi attack coconut palm causing different degrees of losses. Among these, a few fungi are causative agents of important diseases inflicting either death of the palm or gradual decline in vigour and/or yield. The diseases are described under: (1) major diseases, (2) diseases which are likely to become major in future, and (3) minor diseases. The important diseases described are bud rot, basal stem rot, stem bleeding, lethal bole rot, leaf rot etc. The paper also gives an account of the world distribution of important fungal diseases and losses caused by them. The symptomatology, etiology, epidemiology and disease management of major diseases are described in brief. The future lines of work are also outlined at the end. A coordinated approach in research on coconut diseases on a regional basis should receive attention so that there is free exchange of information and expertise between these countries. Investigations on disease management including reaction of varieties to important diseases of coconut should be a priority in the research programmes of different coconut research institutes.

INTRODUCTION

Coconut cultivation runs the risk of being affected by various diseases in many parts of the world. A wide array of fungi attack different parts of coconut namely, crown, stem or root. Among the 173 fungal species reported from coconut (Joseph and Radha, 1979 b), only a few cause serious disease problems and are difficult to control effectively. Joseph and Radha (1979 a) had attempted earlier to enlist the species of fungi and fungal diseases recorded on coconut. Only important fungal diseases on coconut are discussed in this paper.

In India, bud rot, Thanjavur wilt (Basal stem rot or Ganoderma wilt), leaf rot and stem bleeding are important coconut diseases of fungal etiology. In Indonesia, *Phytophthora* rots, stem bleeding and leaf spots are responsible for losses in hybrid coconuts (Sitepu and Darwis, 1989). There are many types of

leaf spots reported from different parts of the world and are of less importance. The losses caused by some important fungal diseases of coconut are presented in Table 72.1.

Table 72.1: Loss due to important fungal diseases of coconut

Disease	*Causative organism*	*Country*	*Loss/incidence*	*Reference*
Bud rot	*Phytophthora palmivora*	India	0.1–10%	Radha and Joseph (1974)
		Jamaica	2.5%	Nowell (1925)
		Philippines	6.7%	Rillo and Paloma (1989)
		Indonesia	50% (in hybrids)	Sitepu and Darwis (1989)
		Ivory Coast	50%	Quillec *et al.* (1984)
		Sri Lanka	Not wide-spread	Mahindapala (1989)
Basal stem rot	*Ganoderma lucidum* *G. applanatum*	India (Tamil Nadu)	2.6–13.5%	Rethinam (1984)
	G. boninense	Sri Lanka	Not a major disease	Mahindapala (1989)
Stem bleeding	*Thielaviopsis paradoxa*	Indonesia	Not serious	Sitepu and Darwis (1989)
		India*	8.8%	Anonymous (1990)
Leaf rot	*Bipolaris halodes*	India	Upto 70%	Radha *et al.* (1962)
	B. incurvata	Papua New Guinea	Seedlings affected	Gallasch (1974)
Lethal bole rot	*Marasmiellus cocophilus*	Kenya	20–30% incidence in nurseries	Bock *et al.* (1970)
	M. inoderma	Tanzania Solomon Is. Malaysia		Jackson and Firman (1979)

*Limited survey in Kannur and Kasaragod districts in Kerala.

The fungal diseases are described under three major heads namely, (i) major diseases, (ii) diseases which are likely to become major in future, and (iii) minor diseases. In the first category bud rot, basal stem rot and stem bleeding are included while in the second category leaf rot and lethal bole rot are discussed. Different categories of leaf spot, fruit rot, thread blight, etc. are included in minor diseases.

MAJOR FUNGAL DISEASES

Bud Rot

The disease is the common killer disease of coconut reported from many coconut growing countries, and was first reported from Grand Cayman (West Indies) in 1834 (Tucker, 1926). Subsequently the disease was reported from Cuba, India, the Philippines, Jamaica, East Africa, Fiji, Papua New Guinea, Sri Lanka etc.

The disease is sporadic in nature though outbreaks of epidemics are also not uncommon (Radha and Joseph, 1983). Losses up to 2.5 per cent have been reported in Jamaica (Nowell,1925), while Radha and Joseph (1974) reported

0.1 to 10 per cent in various states of India. Occasional heavy incidence (35 to 40 per cent) also has been observed in Kerala and Karnataka by these authors.

Symptomatology: The first externally visible symptom is the withering of the spear leaf which subsequently turns brown and bends. In course of time, the younger leaves closer to the spindle also show similar symptoms. The internal tissues show discolouration, assuming pale pink colour with a brown border (Quillec *et al.*, 1984). The base of the spindle is rotten and can be detached with a gentle pull. It emits a foul smell. One by one, the inner leaves also fall away leaving only mature leaves in the lower whorl at the trunk apex. The palm ultimately succumbs to the disease (Menon and Pandalai, 1958).

The pathogen: Butler (1906) and Shaw and Sundararaman (1914) reported the causal organism as *Phytophthora palmivora* Butl.; *P. faberi* Maubl. was found to be the causal agent in the Philippines (Reinking, 1919); *P. heveae* in Ivory Coast and French Polynesia (Franquivelle *et al.*, 1989; Quillec and Renard, 1984); while *P. parasitica* was found to be the causal agent in Costa Rica and *P. nicotianae* in Indonesia (de Nuce de Lamothe, 1988; Coffey *et al.*, 1990). These pathogens also cause lesions on nuts resulting in nut fall, quite independent of bud rot. Steer and Coates-Beckford (1990) reported that *P. katsurae* and *Thielaviopsis paradoxa* also caused bud rot in wound-inoculated seedlings. Joseph and Radha (1975) and Quillec *et al.* (1984) observed from inoculation studies that other fungal species like *Fusarium* spp. or bacteria like *Erwinia, Pseudomonas* or *Xanthomonas* are only secondary saprophytic colonisers. Inoculation with sporangial suspension of *P. palmivora* could induce bud rot symptoms in both the laboratory and in the field in two- to six-year-old seedlings (Joseph and Radha, 1975). Thomas *et al.* (1947) observed presence of both 'plus' and 'minus' strains of the pathogen which on pairing produced oospores. Kumar and Hegde (1987) however, found that the coconut isolates belonged to A_2 mating types.

Epidemiology: Radha and Joseph (1974) reported that relative humidity and rainfall are more related to fungal infection and disease development. It took a minimum of five weeks for manifestation of symptoms on artificial inoculation (Radha and Joseph, 1974). Rillo and Paloma (1989) found that in the Philippines higher incidence of *Phytophthora* was always preceded by higher rainfall during the previous months. The disease was found to be mainly confined to young palms below 25 years (Quillec *et al.*, 1984).

The fungus was found to survive in the frond bases or basal part of the crown (Menon and Pandalai, 1958; Radha and Joseph, 1974) or in roots (Harris *et al.*, 1984). The fungus was found to infect arecanut, oil palm, rubber, jack, cacao, cardamom, *Washingtonia* etc. on cross-inoculation (Das and Cheeran, 1986).

Disease management: Curative measures could save the palm if the disease is diagnosed in the early stages. The appropriate period would be the stage when the spindle has just started showing symptoms of withering. Menon and Pandalai (1958) and Peiris (1962) have described in detail the method of removal of the infected tissues, application of Bordeaux paste etc. Care should be taken while using copper fungicides on dwarf palms, since phytotoxic

symptoms have been observed in some dwarfs (Schut, 1975). The authors have found that Dithane M-45 can be used effectively in such cases. Other fungicides advocated earlier against bud rot disease include phenyl mercury urea applied in the form of powder or pellets in leaf axils (Peiris, 1962) or Demosan spray (Radha and Joseph, 1974), or stem injection or root infusion of Aliette or Ridomil or phosphorous acid (Coffey *et al.*, 1990). However, these are quite expensive. Mahindapala (1989) suggested use of copper fungicide mixed with coir dust taken in muslin cloth and kept in axils for the control. One of us (KKNN) has observed that Dithane M-45 mixed with saw dust and taken in a perforated polythene sachet can be kept in leaf axils of dwarf seedlings, resulting in effective control of the disease. Ohler (1984) suggested that measures like improved drainage, wide spacing and weed control would help in reducing the relative humidity resulting in an indirect prevention of disease incidence.

Quillec *et al.* (1984) observed that hybrids were less sensitive to the disease than West African Tall. However, Brahmana and Kelana (1988) found dwarf palms more sensitive while others were highly tolerant. Rillo and Paloma (1989) found that *Phytophthora* incidence was higher in Cameroon Red Dwarf, MYD etc. as compared to Catigan, MYD × WAT etc. Bennett *et al.* (1986) found that Nias Yellow Dwarf were highly susceptible. Since Nias Dwarfs have never been reported to suffer from *Phytophthora* rots in their land of origin Nias Island, North Sumatra, the authors opined that in studying resistant characteristics environmental conditions should be taken into consideration. Coffey *et al.* (1990) reported that in Indonesia dwarf selections such as Jombang and Raja appeared to be more resistant to nut fall in inoculation trials.

Basal Stem Rot

Basal stem rot is one of the destructive diseases of coconut occurring in various coconut growing regions of the world. The disease is known as Ganoderma wilt in Andhra Pradesh, *Anabe* in Karnataka (Venkatarayan, 1936; Rao and Rao, 1966) and as Thanjavur wilt in Tamil Nadu (Vijayan and Natarajan, 1972). Peries (1974) reported the disease from Sri Lanka as 'basal stem rot'. Nambiar and Rethinam (1987) reported the disease in some pockets of Kerala also. Bhaskaran and Ramanathan (1984) found that the disease incidence ranged from 0.6 per cent to 4.9 per cent in Tamil Nadu. In severely affected gardens in Thanjavur district of Tamil Nadu, the disease incidence was as high as 31.4 per cent (Bhaskaran *et al.*, 1984).

Symptomatology: Though the root system is affected first, the visible symptom is seen in the crown as wilting of leaflets. The outer whorl of leaves turn yellowish, then gradually become brown and droop to form a skirt around the trunk apex. In course of time the apex of the trunk shows tapering with the advancement of the disease, and the stem base shows bleeding symptoms. The tissues beneath the lesions are decayed and this decay can be traced into the bole region. The drooped leaves fall off one by one leaving only a few leaves at the apex. The crown is easily blown off by wind (Bhaskaran *et al.*, 1982). At the

base of the affected palms, sporophores of *Ganoderma* spp. appear, generally after the death of the palm (Bhaskaran *et al.*, 1989). Usually it takes six months to two years for the affected palms to die (Rethinam, 1984).

The pathogen: In India, *Ganoderma lucidum* was reported to be the causative agent of the disease (Rao and Rao, 1966). However, later reports (Bhaskaran *et al.*, 1989) show that *G. applanatum* is also involved. Peries *et al.* (1975) on the other hand reported *G. boninense* as the causal agent of basal stem rot in Sri Lanka. However, the pathogenicity still remains to be established by artificial inoculation.

Epidemiology: Rao and Rao (1966) reported less incidence of the disease in heavy soils of Andhra Pradesh, probably due to their high moisture retention capacity. Peries *et al.* (1975) also found that the disease progressed rapidly in dry areas, the destruction of the palm being faster (six to 30 months) in areas receiving less rainfall (1000 mm) as compared to areas receiving 2000 mm rainfall (up to six years). Lewin *et al.* (1983) reported that soil moisture stress during the summer predisposed the palms to infection. A positive correlation between mean maximum temperature and the number of bleeding palms has been observed by Jagannathan and Ramasamy (1975). Vijayan and Natarajan (1972) reported that trees in the age group of 10 to 30 years were more susceptible. The disease spread was from a central point towards outside and the linear spread was found to be influenced by low rainfall and relative humidity (Ramapandu *et al.*, 1980).

Early detection: Since diagnosis of the disease at a very early stage is essential for taking up effective control measures, some work has been done in this line. Colorimetric methods (Natarajan *et al.*, 1986) or methods employing physiological parameters like transpiration rate and stomatal diffusive resistance (Vijayaraghavan *et al.*, 1987) have given encouraging results. Diagnostic method using fluorescent antibody technique developed against Ganoderma disease in arecanut (Reddy and Ananthanarayanan, 1984) is being employed in coconut also (Anonymous, 1991).

Disease management: Destruction of the bole of the diseased palm and isolation of healthy palms was suggested by Briton-Jones (1940) and Nambiar and Rethinam (1987), while Peries *et al.* (1975) recommended removal of the affected tissues and applying fungicides. Ploughing and flood irrigation should be avoided to prevent the spread of infective propagules. Irrigation may be provided through drip or channel. Application of *neem* cake at 5 kg per palm was found to be beneficial in inhibiting the disease (Bhaskaran *et al.*, 1988). The use of *Trichoderma* spp. for the biological control of the pathogen has been reported (Bhaskaran *et al.*, 1989). Among the fungicides, Aureofungin-sol and calixin have been reported to give very encouraging results.

Stem Bleeding Disease

The disease was first reported from Sri Lanka (Petch, 1906) and later from India, the Philippines, Malaysia, Trinidad, Fiji, Indonesia etc. The disease has been found to occur in all soil types, but more in laterite and sandy soils. Serious infection was found to lead to reduced yield (Nambiar and Sastry,

1988). In Indonesia stem bleeding causes severe damage to PB-121 hybrid and affects yield (Kartika *et al.*, 1984).

Symptomatology: As the very name of the disease indicates, the characteristic symptom is the presence of bleeding patches on the stem. In the initial stage, dark brown small lesions develop at the base of the trunk, which gradually progress upwards. A dark reddish-brown liquid exudes from the longitudinal growth cracks on the stem. These lesions may coalesce to form larger lesions. The exudate dries up in course of time to form black encrustations with underlying tissues being disintegrated and fibrous. This process is fast in young palms. As a result of the degradation, cavities are formed on the trunk. The leaves also show gradual yellowing in the outer whorl, rather prematurely, then droop and dry up. The trunk gradually tapers towards the apex and the crown size is reduced. Crown symptoms are more pronounced during the summer season. Mathew *et al.* (1989) described a method of indexing the disease severity.

The pathogen: *Thielaviopsis paradoxa* (de Seynes) von Hohnel has been reported to be the pathogen involved in the disease (Briton-Jones, 1940; Nambiar *et al.*, 1986; Sitepu and Darvis, 1989). Though *Phomopsis cocoina* Cke (Punith) and *Schizophyllum commune* Fr. have been recorded from affected stems, their pathogenicity could not be established (Lily 1984a; 1984b). *T. paradoxa* was also isolated from nuts showing gummosis and splitting (Nambiar, unpubl.). Inoculation studies showed that infection by the fungus was faster on the trunk during wet and cooler months (July to November) when high humidity and moderate temperature prevail (Nambiar *et al.*, 1989). The optimum temperature for mycelial growth was found to be 28°C (Milanes and Herrera, 1986) while Nishitha Naik (1990) found that it was 30°C. Anil Kumar and Nambiar (1990) reported the effect of certain physical and chemical factors on spore germination. An efficient method of isolation of the fungus from coconut stem tissues and soil was also reported by these authors (Anil Kumar and Nambiar, 1991).

Epidemiology: The fungus is a weak pathogen and enters the trunk through a wound or growth cracks (Briton-Jones, 1940). Splits are known to develop on the stem after sudden heavy rains preceded by prolonged dry period (Ohler, 1984) or after heavy manuring (Briton-Jones, 1940) or trash burning Nambiar and Sastry, 1988). Salgado (1942) and Sulladmath *et al.* (1980) suggested that poor drainage, imbalanced mineral nutrition or other physiological disorders might be other predisposing factors. Though Potty and Radhakrishnan (1978) found that increased levels of P caused increased disease incidence, Mathew and Ramanandan (1980) could not observe any significant difference in the major nutrient content between healthy and diseased palms. Nor could they find any relation between disease and soil pH or electrical conductivity. In Indonesia, chlorine deficiency is reported to be associated with the disease and correction of this deficiency was found to prevent the disease (Van Uexkull, 1985). Nagarajan (1985) reported that excessive salinity with high sodium during summer was associated with the disease. Radhakrishnan (1987) reported maximum symptoms under natural conditions in July and the least in summer months. Nambiar *et al.* (1989) observed from inoculation trials maximum infection during July to November.

Disease Management: Till recently, the control measures adopted by the farmers were mainly phytosanitation and application of hot coal tar or Bordeaux paste to the affected patch on the trunk from where the dead and decayed tissues have been removed by chiselling. Root feeding or drenching carbendazim or tridemorph were found effective recently in controlling the disease (Nambiar and Sastry, 1988; Radhakrishnan, 1990). Summer irrigation may be provided to reduce prolonged moisture stress. Along with normally recommended organics and fertilisers, *neem* cake may be added at the rate of 5 kg per palm to increase soil microflora including *Trichoderma* spp. which inhibits the growth of the pathogen *in vitro* (Gowda and Nambiar, 1991) and in detached frond tissues (Usman, 1988; Sanal Kumar, 1990).

OTHER IMPORTANT DISEASES

Leaf rot and lethal bole rot are two diseases of coconut now observed sporadically, often causing serious economic losses.

Leaf Rot Disease

Leaf rot disease was reported (Menon and Nair, 1948) to be present in Southern Kerala during the last century itself. Palms affected by root (wilt) disease were found to be generally superimposed by this fungal disease (Radha and Lal, 1968). The yield loss in root (wilt) affected palms is mainly due to incidence of leaf rot (Radha *et al.,* 1962). In Papua New Guinea, Gallasch (1979) observed a similar foliar disease and called it the leaf spot disease. Nursery seedlings and young palms have been found to be affected by this fungal disease (Ferreira and Leal, 1987). Era and Celino (1972) observed severe incidence of the disease in Laguna plantations. Recently the disease has been reported in the exotic collections of World Coconut Germplasm Centre in the Andamans (Rao, 1988 a).

The symptomatology has been described in detail in a recent review by Joseph and Rawther (1991). Reddish-brown minute sunken spots and water soaked lesions appear on the spindle and tender leaves. The lesions enlarge and soft rot develops gradually. The tips of leaflets and margins become decayed. The rotting subsequently spread extensively within the spindle and tender leaves. The successively emerging spindles are also attacked by leaf rot. These affected tissues break off when dried and are blown off by wind leaving only the midrib giving a fan-like appearance to the affected leaves. When the attack is on the older leaves, the symptoms appear as leaf spots rather than leaf rots. Fungi like *Helminthosporim halodes* = *Bipolaris halodes* (Drechs) Shoemaker, *Gloeosporium* sp., *Gliocladium roseum, Curvularia* sp., *Diplodia* sp., *Pestalotia* sp., and *Fusarium* sp. were isolated (Menon and Nair, 1948). Menon and Nair (1951) in elaborate pathogenicity trials found that *H. halodes* is the most virulent pathogen among the fungi tested and the rest are only secondary parasites aggravating the rotting initiated by *H. halodes*. Radha and Lal (1968) reported the presence of *H. halodes* from Kasaragod, a root (wilt)-free area.

Nadakal (1965) found *Panagrolaimus* sp., a nematode on leaf tissues of palms affected by diseases including leaf rot.

The disease incidence is favoured by high humidity and low temperature (Menon and Nair, 1951; Radha *et al.,* 1961). They also found that while nitrogenous fertilisers in high dose are favourable for the disease incidence, potassic fertilisers increased the resistance of palms. George and Samraj (1966) suggested boron deficiency as a factor responsible for the disease development since coconut palms affected by leaf rot responded favourably to boric acid application. However, Radha (1965) could not observe such alleviation of symptoms when boron was applied. Lily (1963) reported that the tender most leaf was highly susceptible.

Nair and Radha (1959) and Radha (1961) found that regular manuring and spraying with copper fungicides checked the disease. While Gregory (1960) found aerial spraying of oil based copper fungicides useful in controlling the disease, Samraj *et al.* (1966) could get only contradictory results. Gallasch (1979) advocated spraying with Duter 0.04 per cent concentration. Spraying of leaves sequentially with Bordeaux mixture 1 per cent, Dithane M-45 0.3 per cent and Fytolan 0.5 per cent at quarterly intervals, after removing all severely affected leaves was found to reduce further incidence of the disease in affected palms (Anonymous, 1982).

Lethal Bole Rot

The disease was first noticed in Kenya and Tanzania and was reported to reach epidemic proportions in several areas along the coasts of these countries (Bock *et al.,* 1970). Later Jackson and Firman (1979) reported the disease from Solomon Islands and Holliday (1980) from Madagascar. The disease mainly affects young palms in the field or seedlings in the nursery. A survey conducted in Kenya and Tanzania between 1967 and 1969 showed that 5 to 20 per cent of palms were dead due to the disease.

The characteristic diagnostic symptom of the disease is the presence of a dry, reddish-brown rot at the base of the bole. Around the decay, there is a distinctive yellowish margin, 0.5 to 1.0 cm wide. The symptoms are more pronounced in two- to four-year-old seedlings. In seedlings, the presence of white mycelium was noted in cavities in the area of rot. However, in mature palms, mycelial colonisation proceeds rather slowly. The crown shows symptoms of general wilt and the leaves turn yellowish. In older palms, the outer whorl of leaves droop leaving an erect tuft of wilted, drying leaves. In the nursery the infected seedlings produce short leaves which unfold before emerging fully. A foul odour is emitted from the inner whorl of leaves as a result of soft rot in the tissues.

The causal fungus is *Marasmiellus cocophilus* (Pegler) (Bock *et al.,* 1970). Sporophores occur on exposed roots and leaf bases at ground level in seedlings. The coconut debris in the soil is also colonised by the fungus. Bock *et al.* (1970) found that the fungus gained access only through wounds in the roots. *Marasmiellus* spp. have been known to cause preemergence shoot rot of coconuts in Malaysia (Tey and Chan, 1980) and in Solomon Islands (Jackson

and Firman, 1982). The important species are *M. inoderma, M. palmivorus, M. cocophilus, M. albofuscus, M. crinisequi* and *M. semiustus. M. inoderma* colonises on the husk, infects the embryo and invades the cavity (Jackson and Firman, 1979). *M. palmivorus* was found to attack germinating nuts in Malaysia causing 20 to 30 per cent losses (Tey and Chan, 1980).

Dipping seednuts, after partial husking at the top, for 15 minutes in 250 ppm phenyl mercury acetate was recommended to control preemergence root rot (Jackson and Firman, 1982). Strict quarantine measures are to be followed to prevent transportation of affected seeds/seedlings to healthy areas/countries. Nuiati variety was reported to be resistant to *M. inoderma*.

FUNGAL DISEASES OF MINOR IMPORTANCE

Grey Leaf Spot

The disease also known as leaf blight is widespread in all coconut growing countries. It was reported from Cuba (Horne, 1908) and from British Guyana. The disease was later reported from Malaysia, New Hebrides, Sri Lanka, India, Trinidad, Nigeria etc. (Menon and Pandalai, 1958; Obazee and Ikozun, 1985).

Symptoms develop on leaflets of the outer whorl of leaves as minute yellow oval spots encircled by a grey brown margin. Many such spots may coalesce to form larger patches. The centre of the spots becomes greyish-white. The leaves in advanced stages of disease present a blighted appearance and hence the name leaf blight.

The disease is caused by a fungus *Pestalotiopsis palmarum* (Cooke) Stey. This is a weak pathogen. Fernando and Mahindapala (1977) could not establish the pathogenicity of the fungus in inoculation experiments. Brown (1975) found that the fungus appears as black minute specks. Many other species of *Pestalotiopsis* have been reported to be associated with leaf spot (Brown, 1973). Abad and Magat (1977) opined that the disease incidence indicated poor nutritional status of affected palms. Alonzo and Palomar (1980) reported that potassium deficiency increased the blight.

Application of balanced fertiliser, provision of adequate shade in the nurseries, and prophylactic spraying with Bordeaux mixture have been recommended by many workers to control the disease (Menon and Pandalai, 1958; Briton-Jones, 1940). Regular application of potassium chloride was reported to reduce the disease incidence (Abad *et al.*, 1978 a). Alonzo and Palomar (1980) reported that application of sea water or sea weed salt reduced leaf spot in seedlings. Das and Mahanta (1985) found that carbendazim, thiabendazole and thiram inhibited the growth of the pathogen. Abad *et al.* (1978 b) reported that 'Catigar' variety showed consistent tolerance to the disease. In Indonesia, Khina-1, Khina-3, Markham Tall etc. are considered to have low susceptibility to this disease (Sitepu and Darwis, 1985 a). Rao (1988 b) found that cultivar 'Katchal' grown in the Andamans was more tolerant compared to other cultivars.

Fruit Rot

Fruit rot or nut fall was recorded from India (Sundararaman and Ramakrishnan, 1924), Malaysia (Turner, 1965), Colombia (Sanchez Potes, 1966), and Indonesia (Bennett *et al.*, 1986). The disease is characterised by rotting of immature nuts during the rainy season, resulting in nut fall. Water soaked lesions develop at the stalk end of nuts. These lesions turn brown and become sunken due to decay of underlying tissues. The rot extends into the husk sometimes deep into the endosperm cavity of the shell which has not hardened.

The disease is caused by *Phytophthora palmivora*. Bennett *et al.* (1986) found in inoculation trials that the rate of lesion growth was inversely proportional to the age of nuts. The pathogen also causes bud rot. The disease can be effectively prevented by prophylactic spray with Bordeaux mixture 1 per cent during the pre-monsoon period.

Sulladmath and Shantappa (1979) recorded immature nut fall in Karnataka in India caused by another fungus *Botryosphaeria rhodina* (Berk and Curt.) V. Arx. In Brazil, Almeida Jr. and Aquino (1978) reported fruit rot caused by *Colletotrichum gloeosporioides* Penz. The disease mainly affects harvested fruits, causing 1.5 to 41 per cent incidence. The affected fruits are desiccated and deformed showing longitudinal fissures. *Colletotrichum* spp. are known to cause nut splitting in Kenya (cited by Menon and Pandalai, 1958). In India, *C. cingulata* and *C. paucisetum* are known to cause leaf spot (Johnston, 1965).

Petiole Disease/Petiole Rot

The disease was first recorded from Sri Lanka (Stockdale, 1907; Gadd, 1920) and later from Malaysia, Papua New Guinea and New Caledonia. Recently, Sulladmath and Ponnappa (1978) recorded the disease from Karnataka state, India.

Dark, chocolate brown, irregular or circular lesions appear on the adaxial surface of the petiole. Isolated raised blisters also appear. Two or more lesions merge to form larger ones. The affected petioles break at the point of the lesions and broken dry fronds hang down. The disease is caused by *Anthostomella cylindrospora* Booth and Shaw and *A. fusispora* Booth and Shaw (Booth and Shaw, 1967). Sivanesan *et al.* (1976) described *Leiosphaerella longispora* from lesions on the coconut petioles which collapsed due to drought in Papua New Guinea. In Jamaica, Ashby (1920) isolated *Phytophthora* sp. from lesions on the petiole showing 'leaf stalk rot' symptoms. The authors have isolated *P. palmivora* and *Thielaviopsis paradoxa* from such affected petioles of coconut in some areas of Kerala and Karnataka.

Leaf Spots

Many types of leaf spot diseases have been described to affect coconut leaves. They are *Alternaria* leaf spot (Rao and Subramanyan, 1975), *Curvularia* leaf spot (Chan, 1974) *Exosporium* leaf spots (Mitra, 1929), oval leaf spot (Stevens, 1932) etc. *Alternaria* leaf spot first described from Andhra Pradesh (Rao and Subramanyan, 1975) is generally seen on one to three-year-old

coconut seedlings as black round or oval spots. The causal agent is *Alternaria alternata* (Fr) Keissler. Recently this fungus has been noticed in some coconut gardens in Kerala. Mishra (1987) recorded *A. tenuissima* from affected leaves. Radha and Menon (1954) reported *Curvularia* sp. from leaves of root (wilt) affected palms. Chan (1974) isolated *C. maculans* from the lesions on leaves in Malaysia. The disease is serious in seedlings grown under shade and spreads rapidly under high humid conditions (Tey and Chan, 1980). Chan (1974) found that spraying the affected seedlings with captan or Difolatan controlled *Curvularia* leaf spot. *Exosporium* leaf spot is caused by *E. durum* (Johnston, 1965) and *E. palmivorum* (Mitra, 1929). Jet black wart like fructifications are seen on the affected leaf surface. The disease occurs on palms under neglect. Oval leaf spot has been reported from Philippines, Samoa, Papua New Guinea and Indonesia, Malaysia, New Caledonia, Solomon Islands and Tongo (Johnston, 1965). The disease is characterised by small oval spots, dark tan in colour, and is caused by *Epicoccum cocos* Stevens. Infection occurs through insect injuries. Rao and Renukumar (1989) reported a leaf spot disease caused by *Cercospora apii* Fr. occurring on seedlings in South Andamans. Sooty mould caused by *Capnodium footi* or *Aithalodema setosum* have been reported from the Philippines, Malaysia, Solomon Islands, etc. (Johnston, 1965). Sooty mould can be controlled by spraying an emulsion consisting of soap, kerosene and water (225 g soap, 4.5 l water and 9 l kerosene) and the emulsion is diluted to 1:9 water while spraying.

White Thread Blight

This disease has been recorded from Papua New Guinea, Sri Lanka, Fiji, New Hebrides and New Britain. The disease is characterised by the appearance of large circular necrotic patches on the upper surface of leaflets of older leaves. White mycelial threads are seen on the under-surface of leaflets, along the midrib and the affected tissues are killed. The disease is caused by *Corticium penicillatum* Petch. Tey and Chan (1980) found that *Corticium* sp. caused leaf blotch in seedlings in Malaysia. Avoiding overcrowding in the garden, pruning severely affected leaves and spraying Bordeaux mixture helped to control the disease (Douglas, 1965).

Post-Harvest Diseases

The important fungi attacking copra are *Aspergillus niger, A. glaucus, A. flavus, A. fumigatus* and *A. ochraceous* (Ward, 1937), *Ceratostomella adiposum* (Thompson, 1933), *Botryodiplodia theobromae* and *Rhizopus oryzae* (Rao *et al.*, 1971), *Penicillium frequentas* (Nair and Nathan, 1971), *Endosporostilbe* sp. (Patil and Kelkar, 1975), *Penicillium citrinum* (Susamma and Menon, 1983), *Tabutia cocoicola* (Sivanesan, 1979) and *Drechslera hawaiiensis* (Sharma *et al.*, 1985). Fernandez (1988) reported fungi viz., *Thielaviopsis, Cephalosporium, Microsporium, Botrytis* and *Fusarium* from the thin layers external to the endocarp. *Thielaviopsis paradoxa* has been recently noticed in copra and the shell of coconut in India (Nambiar, unpubl.). Susamma *et al.* (1980) found that monsoon periods favoured the development of fungi on copra. Moisture

content of above 5 per cent in copra permitted fungal invasion (Pusposindjojo and Christensen 1977). Susamma and Menon (1983) reported that copra having 5 per cent moisture and kept in gunny bags lined with polythene sheet remained moderately free of infection.

CONCLUSION

In a perennial tree crop like coconut, disease control is difficult. In the case of basal stem rot, by the time the disease is diagnosed, often the disease would have advanced into the last stage when adoption of curative measures may not have yielded the desired results. Under such circumstances, a method for early diagnosis of the disease would have to be evolved. A beginning has been made in this line at this Institute using fluorescent antibody technique. The relationship between *Ganoderma* spp. occurring in different palms will have to be studied using serological methods and also based on the protein band difference.

Methods to apply systemic fungicides easily into the palm trunk through stem injectors or as encapsulated chemicals placed in bore holes in the trunk can be developed.

There should be strict quarantine regulations not only between countries, but within a country also. Transport of planting materials from diseased areas to the healthy areas should be prevented by law as also by educating the farmers.

In a crop like coconut, which is committed to the land for a long duration, use of resistant varieties against diseases is likely to be the most promising way of tackling them and hence should receive priority. This is especially necessary when the cost of inputs including that of fungicides is increasing day by day. It is a happy augury that work in this line is in progress in India to develop tolerant varieties to coconut diseases.

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DISCUSSION

P.A.C.R. Perera: What were the fungicides used in the root feeding technique and indicate whether the roots used were cut roots or uncut roots?

K.K.N. Nambiar: Calixin and Bavistin were used separately and individually. Young roots, both uncut roots with root cap intact and cut roots can be used.

M.R. Sharma: Are there any residues when fungicides are used?

K.K.N. Nambiar: No residue of Calixin or Bavistin is found in nut water of treated coconut palms.

ROOT (WILT) DISEASE OF COCONUT— CURRENT STATUS

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ABSTRACT

Root (wilt) disease of coconut reported over a century ago in Kerala, South India, is a non-lethal but declining malady. The annual loss due to the disease is estimated to be about 968 million nuts. The cause of the disease remained uncertain till recently. Recent studies have conclusively ruled out involvement of biological agents, nutritional and physiological factors as disease incitant(s). Identification of a phloem bound mollicute, its insect vector and the evidences accrued in favour of the mycoplasmal etiology are discussed.

INTRODUCTION

Coconut root (wilt) disease has been the subject matter of a number of treatise in the past (Jayasankar and Bavappa, 1986; Nair *et al.,* 1991). The scope of this paper is to give an overview on the current status of the etiology of the disease. Root (wilt) disease was first reported after the great floods of 1882 in three independent locations, each about 50 km apart in the erstwhile state of Travancore (Butler, 1908; Kunjan Pillai, 1911; Varghese, 1934). Since then it has spread from the original foci of infection. According to a survey conducted during 1984/85, the disease is prevalent in more or less a contiguous manner in 0.41 million ha in the eight southern districts of Kerala (Anonymous, 1985). It is also noticed in few isolated pockets in the northern districts of the state (Radha *et al.,* 1985) and in the bordering districts of Tamil Nadu. The intensity of the disease in the contiguous diseased tract ranged between 1.52 per cent in Thiruvananthapuram district and 75.63 per cent in Kottayam district. The annual loss due to the disease is estimated to be about 968 million nuts. The disease is non-lethal but debilitating and palms of all age groups are affected. Delayed flowering and reduction in yield are observed in palms contracting the disease in the pre-bearing age (Ramadasan *et al.,* 1971). The disease occurs in

all major soil types. However, the spread is faster in sandy, sandy loam, alluvial and in heavy textured clayey soils than in laterites. The disease incidence is relatively higher in water logged low lying areas adjacent to rivers and canals and in *Kari* soils (Pillai *et al.,* 1973).

Symptoms

The most consistent and diagnostic symptom of the disease is the characteristic ribbing of leaflets termed flaccidity (Radha and Lal, 1972). Foliar yellowing and marginal necrosis are the other associated symptoms (Fig. 73.1). Yellowing is virtually absent in young palms where flaccidity is the only symptom (Radha and Lal, 1972). George and Radha (1973) developed an indexing system for quantifying the disease, giving due weightage to intensity and frequency of occurrence of these three major symptoms.

Fig. 73.1: Coconut palm showing flaccidity and necrosis of leaflets.

Rotting of roots was once considered as a major symptom (Butler, 1908; Menon and Nair, 1949; Menon and Pandalai, 1959; Michael, 1964). However, this could not be substantiated in later studies (Nagaraj and Menon, 1955; Lal, 1969; Joseph and Jayasankar, 1981). Drying up of spathe and necrosis of spikelets extending from tip downwards in tender unopened inflorescence was noticed in certain cases (Menon and Pandalai, 1959; Maramorosch, 1964). A high percentage of pollen produced was either sterile or with low viability (Varkey and Davis, 1960). Similarly, meiotic irregularities were also observed in diseased palms (Nambiar and Prasannakumari, 1964). Abnormal shedding of female flowers and immature nuts and lack of ability to produce female flowers significantly affected the palms' productivity (Varghese 1934; Menon and Pandalai, 1959). Kernel of nuts from diseased palms does not dry normally and remains flexible (Menon and Nair, 1951; Maramorosch, 1964).

Leaf rot disease caused by certain fungi occurs superimposed on about 30 per cent of the root (wilt) affected palms bringing about a rapid decline in yield (Anonymous, 1989a). However, this could be controlled to a greater extent with sequential spraying of fungicides (Anonymous, 1986).

Diagnosis

Field identification of diseased palms is by and large through visual symptoms. The need for a reliable diagnostic test, preferably one which could detect the disease status before the expression of foliar symptoms, led to exploring of several tests (Sasikala *et al.,* 1991). A sero-diagnostic test (Solomon *et al.,* 1983) and a physiological test (Rajagopal and Amma, 1989) based on differential stomatal resistance have been found to be reliable. With these tests, the disease condition could be diagnosed six to 24 months before the expression of foliar symptoms (Rajagopal *et al.,* 1988b).

ETIOLOGY

Biological agents

Etiology of the disease remained an enigma until recently. A number of biological agents such as fungi, bacteria and nematodes were reported to be associated with the disease. However, pathogenicity studies with these organisms singly and in combination failed to reproduce the symptoms of the disease, thereby, ruling out their involvement in disease causation (Joseph and Lily, 1991; Jayasankar and George, 1991; Sosamma and Koshy, 1991).

Physiological Factors and Nutrients

Physiological and biochemical changes observed in diseased palms are indicative of a pathogen altered host metabolism than of a physiological disorder (Mathew *et al.,* 1991). Similarly, an extensive analysis of soil and leaf tissues of palms in healthy and diseased tracts and various fertiliser trials conducted clearly ruled out the involvement of any major or micronutrients in the incidence of the disease (Cecil and Amma, 1991).

Virus

Association of a submicroscopic agent possibly a virus or virus-like agent was postulated by a number of workers (Nagaraj and Menon, 1956; Shanta and Menon, 1961; Holmes, 1965; Summanwar *et al.,* 1969; Maramorosch and Konda, 1977). However, no virus could either be isolated or consistently observed in tissues of diseased palms (Solomon and Sasikala, 1981). Polyacrylamide gel electrophoretic analysis of isolated nucleic acids from diseased palms also excluded the association of any viroid type pathogen with the disease (Randles and Hatta, 1980).

Mycoplasma-like Organisms (MLOs)

Comparative histopathological studies on tissues of healthy and diseased palms revealed structural alterations such as disorganisation and degeneration of vascular tissues, increased chromophily and necrotic obliteration in the latter (Govindankutty and Vellaichamy, 1983). These observations prompted detailed ultrastructural studies of the vascular tissues. Electron microscopic examination of juvenile tissues like submeristem, petiole of developing leaves, rachilla of unopened inflorescence and root tips of diseased palms showed the presence of a phloem bound mollicute—the mycoplasma-like organism (MLO) (Solomon *et al.,* 1983). These prokaryotes are bound by a trilamellar unit membrane and contain DNA strands and ribosomes (Fig. 73.2). Pleomorphic forms varying from circular to oval and occasionally beaded or filamentous ones are also observed. The coccoid forms are in the size range of 250 to 400 nm. They are found in increasing numbers in the 'sink' region. Degenerated or moribund forms are often observed in mature tissues (Solomon *et al.,* 1987). Constant association of the organism with the disease

Fig. 73.2: Mycoplasma-like organisms in sieve tubes of tender petiole from root (wilt) diseased coconut palm.

has since been established with the finding of MLOs in tissues of 70 diseased palms and their absence in 50 healthy palms studied. Intracellular presence of the organism, their absence in healthy palms and the structural changes observed further adduced to its etiological role. Interestingly, none of the other biological agents reported associated with the disease could be observed in the vascular tissues of the palms studied.

Histological staining techniques for visualising MLOs under optical microscope have also been standardised. Free hand sections of tender rachilla and roots of diseased palms subjected to Dienes' staining exhibited abnormal bluish colouration in sieve tubes. Tissues of healthy palms were devoid of such staining sites. Similarly, fixed tissues sectioned and stained with fluorochrome, 4,6-diamidino-2 phenyl indole 2 HCl (DAPI) and Hoechst 33258 showed fluorescing areas in the sieve cells suggestive of the accumulation of DNA in extra-nuclear sites indicating the presence of MLOs (Solomon *et al.*, 1987). Such positive reactions are more frequent in junctions of vascular bridges and also close to the sieve plate.

Elucidation of the constant association of MLOs with the disease warranted identification of the insect vector. Lace bug—*Stephanitis typica* Distant (Tingidae)—being the single major group of insect on coconut and based on transmission experiments was presumed to be the vector of the disease (Nagaraj and Menon, 1956; Shanta *et al.*, 1964). Since MLOs are generally transmitted by leaf hoppers, plant hoppers and in a few instances by psyllids, the vector role of lace bugs needed reinvestigation. A record of insects on coconut in India did not include any belonging to the conventional mycoplasma transmitting group—Auchenorhyncha. An inventory of all insects of transmission importance was made through various trapping aids (sticky, rotary flight, suction and light traps) supplemented with direct observation of over 200 seedlings for a period of two years. This led to the identification of a leaf hopper, *Sophonia greeni* (Distant) and a plant hopper, *Proutista moesta* (Westwood) (Rajan and Mathen, 1984; 1985). A rapid survey of representative gardens in eight districts where the disease occurs contiguously revealed that the disease does not exist independent of these three insects.

A study of the feeding habit of lace bug by cold immobilisation of stylet fixed *in situ* in coconut pinnae followed by serial sectioning revealed its termination in phloem, thereby indicating the phloem feeding nature (Mathen *et al.*, 1988). The potential of these putative insects to acquire MLOs while feeding on diseased palms was further studied. MLOs were observed in salivary glands and brain tissues of lace bugs offered acquisition and incubation period (A + I) of 18 to 23 days on diseased palms. Lace bugs from disease free areas and insects offering A + I less than 18 days were found to be free of the organism (Mathen *et al.*, 1987). Recently, the MLOs have also been located in plant hoppers given A + I of over 37 days (Anonymous, 1990).

Insect Transmission

The vector role of lace bug was studied in a transmission experiment. Eight West Coast Tall, two-year-old coconut seedlings obtained from a disease

free area and planted in methyl bromide fumigated soil held in field tanks of 1.8 × 1.8 × x 1.2 m and protected with slanting insect proof cages of 3.7 m were used for the experiment (Fig. 73.3). Four of the seedlings were inoculated with lace bugs offered five days acquisition feeding on diseased palms and insects offered 18 days A + I as detailed in Table 73.1. Four uninoculated plants grown in insect proof cages were maintained as control. Nine months after the first inoculation, three out of four seedlings showed strong positive serological reaction and faint reaction in the fourth indicating disease contraction. Similar results were also obtained in Dienes' and fluorescence staining. EM observation of the root tissues confirmed the presence of MLOs in all four seedlings between nine and 27 months after the first inoculation. Flaccidity of leaflets, the decisive and diagnostic symptom of the disease, was evident in two of the seedlings by the seventeenth month. None of the uninoculated control seedlings either exhibited visual symptoms or showed the presence of MLOs (Mathen *et al.,* 1990).

Table 73.1: Number of lace bugs inoculated on experimental coconut seedlings in field cages numbered 3, 4, 9 and 10

Date	*5 days' acquisition*				*Total*	*5 days' acquisition plus 13 days' incubation*				*Total*
31 Dec 1985	184	180	180	174	718					
31 Mar 1986	200	196	202	180	778					
30 Jun 1986	631	637	639	664	2571					
Total	1015	1013	1021	1018	4067					
30 Sep 1986						626	621	616	595	2458
31 Dec 1986						427	431	434	458	1750
31 Mar 1987						90	76	80	76	322
Total						1143	1128	1130	1129	4530
30 Jun 1987	100	101	106	97	404					
30 Sep 1987	278	285	257	287	1107					
30 Nov 1987	–	705	–	706	1411					
Total	378	1091	363	1090	2922					
Grand total	1393	2104	1384	2108	6989					

Apart from the direct evidence emerging out of the transmission experiment, a number of indirect evidences have also accrued in support of the vector role of lace bug. They are found colonising in increasing number towards the inner leaves of the crown where active forms of the organism are generally found (Mathen *et al.,* 1969). The number of lace bugs on diseased palms is found to be four times the number in healthy palms (Mathen, 1982). After monitoring of lace bug population for two years in about 700 juvenile palms, Mathen (1985) reported a direct linear correlation between the number of insects colonising the palms and a fresh incidence of disease. Field

experiments are in progress to see whether the control of aerial insects can regulate the fresh incidence of disease.

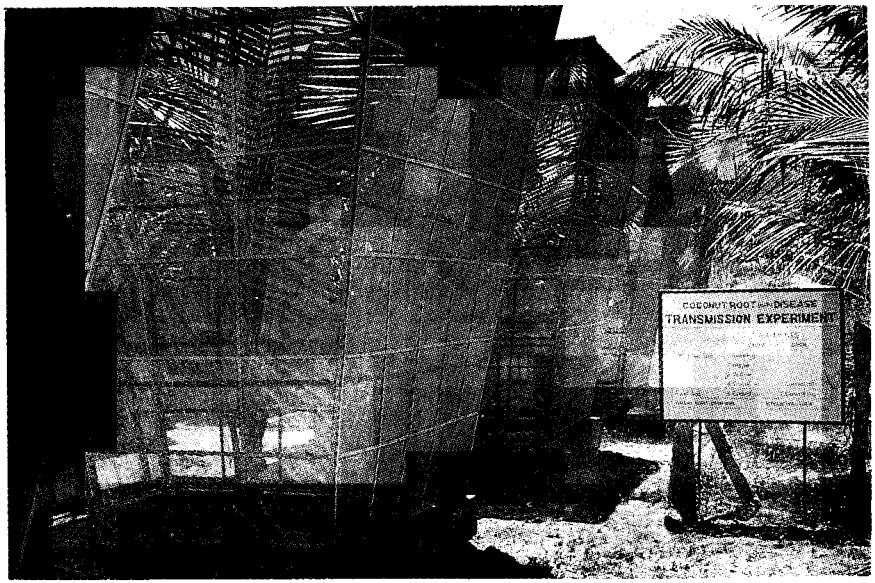

Fig. 73.3: Insect proof cages for transmission experiment.

Dodder Transmission

Experimental transmission with dodder species was also performed. The conventional dodder, *Cuscuta* species although established on coconut foliage did not develop intimate haustorial connection. *Cassytha filiformis*, a member of Lauraceae established strong vascular connections on coconut pinnae. Dodder laurels established on field palms were bridged to potted periwinkles in nylon netted cages. Within three weeks of haustorial connections, the periwinkle exhibited chlorotic spots in the interveinal areas and at vein endings of fully opened leaves. Ultrathin sections of the leaves of diseased source palm, connecting dodder, laurel and recipient periwinkle showed the presence of MLOs. The organism could also be serially transmitted from periwinkle to periwinkle (Sasikala *et al.*, 1988).

Culturing

Although transmission through insect and dodder have been achieved, culturing of MLO is still considered to be vital to fulfil the requirements of Koch's postulate. Mycoplasma being confined to phloem, a medium simulating the physicochemical environment of the phloem may be necessary for culturing of the organism. Phloem sap as such or supplemented with serum has been found to be an ideal medium for culturing of fastidious organisms such as *Acholeplasma laidlawii, Mycoplasma fermentans, Spiroplasma citri*, and *Phytomonas davidi* (Eden-Green and Waters, 1982; McCoy, 1976; 1977; 1978). Rajagopal *et al.* (1988a) standardised a method for aseptic collection of vascular

sap in ice-packed vacuum flask and analysed the constituents of the sap. The vascular sap from apparently healthy palms supplemented with serum was utilised for *in vitro* culturing of the organism. In addition over 40 different media with various combinations of nutrients and other cultural conditions were used for culturing of the organism from tissues of diseased palms, symptomatic periwinkle and infective lace bug. Culturing in chick embryos was also tried. However, the organism could not be cultivated (Anonymous, 1989b). Currently, the possibilities of long-term maintenance of the organism in explants of diseased palms and selected organs of infective lace bugs are being explored. Preliminary studies indicate that the mollicutes could be maintained in tissue cultured explants for six to eight weeks (Anonymous, 1989b).

Chemotherapy

Since MLOs are not amenable to culturing *in vitro*, differential chemotherapy is universally advocated as the best tool to provide circumstantial evidence for the mycoplasmal etiology of a disease. To ensure that the antibiotic reaches the target site in an unaltered state within a reasonable period, a number of injection devices were tried. An indigenously fabricated pneumatic pressure injector was found ideal for the purpose (Pillai and Raju, 1985). The antibiotic reached the foliage within 24 h of its application and traces of the chemical persisted up to 12 weeks as confirmed by bioassay using *Bacillus cereus* sub sp. *mycoides* as the test organism. Results of a field trial with four concentrations of oxytetracycline hydrochloride (OTC), a single concentration of Penicillin and distilled water control clearly indicated remission of symptoms in palms treated with 3 g and 6 g ai of OTC. Contrastingly, palms in both Penicillin and distilled water controls deteriorated over the pre-treatment condition (Pillai *et al.*, 1991). Although field application of OTC cannot be recommended either for the control of the disease or as a prophylactic measure, the results have nevertheless given convincing evidence to the mycoplasma etiology of the disease.

Screening of Coconut Germplasm

Field evaluation of 45 cultivars and 62 hybrid combinations in progress since 1972 indicated that none of the cultivars/hybrids is resistant to the disease. However, the hybrid Chowghat Orange Dwarf (COD) × West Coast Tall (WCT) under ideal management yielded a higher number of nuts compared to WCT of identical age in the initial years of production (Anonymous, 1986).

Breeding for Disease Resistance

An intensive survey in the heavily diseased area (hot spot) has been conducted to locate disease free high-yielding palms above the age of 35 years. Palms finally selected after subjecting to serological and physiological tests are being used as parents in the breeding programme.

Twenty-four exotic accessions from South Pacific Ocean Islands have been planted in the World Coconut Germplasm Centre at Sipighat in the Andamans for producing *inter se* and selfed nuts for screening against the disease.

Future Thrust

1) Assessing the vector role of plant hopper through transmission experiment under controlled condition.

2) Intensifying the breeding programme to evolve identical plant type resistant/tolerant to disease.

3) Developing DNA hybridisation probes for detection of MLOs infection and integrated management of diseased gardens to obtain optimum yield.

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DISCUSSION

P. Rethinam: Can you indicate the number of diseased palms tested for MLOs and for the protozoan flagellate studies?

J.J. Solomon: Seventy diseased palms and 50 healthy palms were examined for MLOs. The palms sampled were from different locations, intensities of disease and age groups. For protozoan flagellates six palms each in early, middle and advanced stages of disease were examined.

Carlos Oropeza: Have you tried MLO transmission from *Catharanthus roseus* to coconut?

J.J. Solomon: No. We have not so far tried MLO transmission from *Catharanthus roseus* to coconut. However, we are planning to do transmission studies between diseased coconut to healthy coconuts and from *Catharanthus* to coconut.

H.C. Harries: Is it possible for viroid or virus infection to predispose palms to MLO infection which they might otherwise resist?

J.J. Solomon: Possible association of viroids with coconut root(wilt) disease was investigated in collaboration with Dr. J.W. Randles of Australia. PAGE analysis of isolated nucleic acids and molecular hybridisation techniques have ruled out the involvement of viroids with the disease. EM examination of purified samples and thin sections of various plant parts have ruled out the involvement of viruses with the disease. Hence the question of predisposition of palms to MLO infection by viroid or virus does not arise.

MANAGEMENT OF COCONUT ROOT (WILT) DISEASE

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ABSTRACT

Coconut root (wilt) disease responds well to the management practices if the disease is in the early to middle stages. In the absence of a definite chemical control measure, a two-pronged approach was made namely to live with the disease in the heavily infested areas of southern Kerala and contain the disease in the mildly affected areas of northern Kerala and border districts of Tamil Nadu adjoining Kerala.

Integrated management increased nut yield from 28 to 51 nuts/palm/year within three years in mildly affected area and 23.4 nuts/palm/year on an average in disease affected area. Irrigation coupled with fertilizer application, plant protection measures and mixed cropping increased the yield of disease affected coconut garden from 17.6 to 46.0 nuts/palm/year.

In the mildly infected areas, the removal of disease affected palms irrespective of yield, continuous monitoring and removal helped to maintain almost disease free condition.

INTRODUCTION

Coconut root (wilt) disease reported over a century ago in Kerala is a slow debilitating disease but not lethal. Typical foliar symptoms of the disease are wilting and drooping of leaves, flaccidity, ribbing, yellowing and necrosis, coupled with shedding of buttons and immature nuts and reduction in the size and number of leaves. Often leaf rot caused by *Bipolaris halodes* is also associated with the disease which hastens the deterioration of the palms. Having established the mycoplasmal etiology, the possibility of sustaining the health and yield of the diseased palms is by adoption of integrated management practices.

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ORIGIN, DISTRIBUTION AND LOSS DUE TO ROOT (WILT) DISEASE

The root (wilt) disease of coconut has been known to be present in Southern Kerala and first reported from Erattupetta area of Meenachil Taluk in Kottayam District (Butler, 1908; Pillai, 1911). It is believed to have been significantly manifested since the great floods of 1882 (Menon and Pandalai, 1958). The disease which appeared more or less simultaneously in Thiruvalla and Kartikappally in Alleppey District began to spread to adjoining areas also (Varghese, 1934) and spread to about 24,000 ha of plantations in Meenachil, Thiruvalla, Kayangulam and Alleppey (Butler, 1908; Pillai, 1911). Varghese (1934) traced the occurrence of disease up to Cochin in the north and Kottarakara in the south. Pillai *et al.* (1973) reported contiguous distribution of disease in six districts, namely, Trivandrum, Quilon, Alleppey, Kottayam, Ernakulam and Trichur of Kerala State. A comprehensive survey was undertaken jointly by CPCRI, Agricultural Department and other agencies in 1984/85 to assess the extent and loss (Anonymous, 1985). This survey indicated prevalence of the disease in 4,10,000 ha in a contiguous manner in eight southern districts of Kerala. The intensity of the disease in both bearing and non-bearing categories of the palms was highest in Kottayam district (75.6 per cent) followed by Alleppey (70.7 per cent), Pathanamthitta (38.2 per cent), Ernakulam (34.5 per cent), Idukki (34.2 per cent) and Quilon (28.6 per cent). In the districts of Trichur and Thiruvananthapuram the percentage of disease incidence was 2.6 and 1.5, respectively (Fig. 74.1). It is also estimated that annual loss is about 968 million nuts. The loss in husk per nut of diseased palm was around 25.8 per cent and that of copra and oil per nut was 9 and 11.3 per cent respectively. The loss in revenue by sale of leaves is to the tune of 60 per cent.

The survey also revealed the sparse occurrence of the disease in some isolated pockets in the northern parts of Kerala, namely, Palghat, Malappuram, Kozhikode, Cannanore and Wynad far away from the contiguously diseased area bordered by Karuvannur river and Amballur-Varandarapalli road in Trichur district and adjoining districts of Tamil Nadu (Rethinam *et al.*, 1982; Radha *et al.*, 1981; Anonymous, 1986).

MANAGEMENT OF ROOT (WILT) DISEASE

Root (wilt) disease of coconut caused by Mycoplasma-like Organisms (MLO) has no definite control measures. However, the bearing palms which are in the initial to middle stages of disease intensity respond well to the management practices. Similarly, eradication in the mildly affected areas of Nadathara (Kerala) and Vallam (Senkottai) indicated that these areas are free from disease. Based on these evidences, the strategy developed to combat the disease is adoption of integrated management practices in the heavily affected contiguous tracts and removing the foci of infection in mildly affected areas by eradication of all diseased palms.

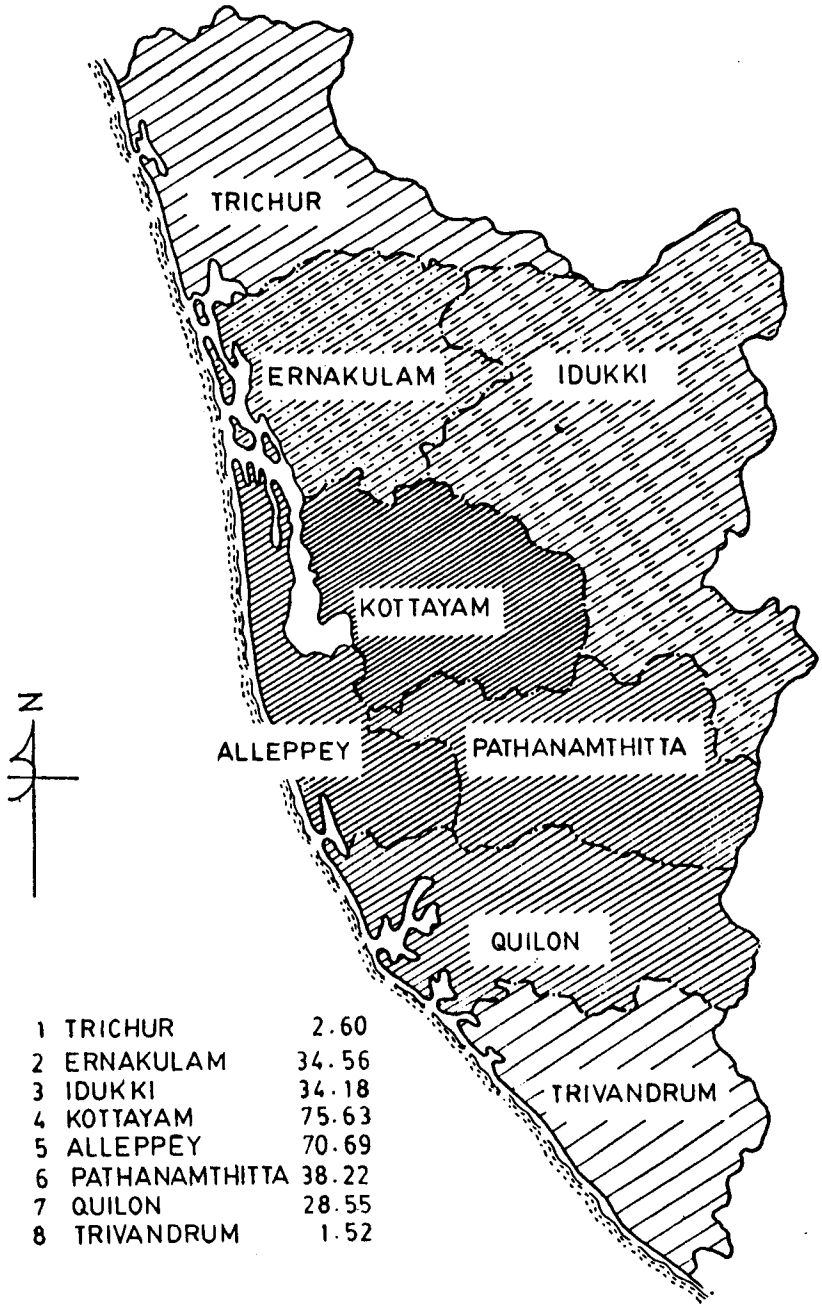

Fig. 74.1: Intensity of incidence of coconut root (wilt) disease in the contiguously affected districts of Kerala state.

Management Technologies

Managing the disease for sustained productivity of the palms has been well established (Sahasranaman *et al.,* 1964; Menon and Nayar, 1978; Sahasranaman *et al.,* 1983; Muralidharan *et al.,* 1986; Rajagopal *et al.,* 1987).

Mixed Farming: Cultivation of forage grasses in the interspaces of diseased coconut plantations and maintenance of milch cows enabled recycling of cattle manure and other organic wastes in the plantation. Adoption of these practices resulted in a decrease in foliar yellowing and increase in nut yield by 26.1 per cent (Table 74.1) over a period of five years (1976 to 1980) (Sahasranaman *et al.,* 1983). The response was higher in the disease early palms and lowest in disease advanced palms. In addition, there was increase in the soil organic carbon, exchangeable calcium, magnesium, potassium and soil microbial activity (Anonymous, 1986).

Table 74.1: Effect of mixed farming on nut yield of root (wilt) affected palms

Disease index	*Pre-treatment yield*		*Post-treatment yield*		*Increase over pre-treatment (%)*		*Estimated net response due to mixed farming (%)*
	Control	*Treat.*	*Control*	*Treat.*	*Control*	*Treat.*	
0–10	58.3	50.3	62.4	68.4	7.0	36.0	29.0
11–25	31.1	33.7	29.2	42.3	−6.1	25.5	31.6
26–50	20.9	22.5	18.1	24.5	13.4	8.9	22.3
> 51	19.5	19.0	21.4	23.7	9.8	24.7	14.9
Mean	30.5	31.4	29.9	39.6	−2.0	26.1	28.1

Intercropping and Mixed Cropping: Intercropping and mixed cropping in root (wilt) affected gardens exert some ameliorating effect on the disease affected palms and on increasing the yields. Intercropping with cassava, elephant foot yam and greater yam for five years in 16-year old coconut gardens gave an overall increase in the nut yield to the extent of 5, 15 and 8 per cent, respectively (Menon and Nayar, 1978). However, in a cassava plot the disease intensity was on the increase (indices increased from 32.1 to 37.3) whereas in others it was on the decrease (37.0 to 33.3). A similar study with cassava, elephant foot yam, colocasia, greater yam, ginger and turmeric did not reveal any adverse effect on disease index or yield of palms (Antony, 1983). Intercropping systems increased the mycorrhizal status of root (wilt) affected coconut palms (Thomas, 1988).

Mixed cropping with cocoa under single and double hedge systems increased the yield of coconut by 27.1 and 35 per cent, respectively without any deterioration in the disease intensity of palms under rainfed conditions (Nair *et al.,* 1975). In an experiment, conducted in the farmers' fields for a period of five years under irrigated conditions with the recommended doses of fertilisers to both the crops, the yield of coconut increased from an average of 17.6 to 46 nuts/palms/year. Similarly, Sahasranaman *et al.* (1983) reported that the nut yield of coconut in a root (wilt) affected garden increased by 27 to 35 per cent

as a result of coconut-cocoa mixed cropping. Mixed cropping with hybrid Napier enhanced the total bacteria, nitrogen fixing bacteria and phosphate solubilising bacteria (Potty *et al.*, 1977).

Basin Management with Green Manure: Eight species of leguminous green manure crops were raised in coconut basins in the farmers' fields to evaluate their efficiency in enriching soil organic matter and biological activity. The highest green manure yield of 43.4 kg/basin was obtained from *Pueraria phaseoloides*. On an average the three green manure crops, namely, *Pueraria phaseoloides, Mimosa invisa* and *Calapagonium mucunoides* yielded 19.45, 17.00 and 14.71 kg green manure respectively in a period of four months. There was a significant increase in microbial population as also in the activities of soil enzymes, namely, dehydrogenase, urease and phosphatase (Thomas, 1987).

Nutrient requirement for West Coast Tall (WCT) and West Coast Tall × Chowghat Orange Dwarf palms: In a freshly replanted plot of WCT and COD × WCT hybrid, the application of 500 g MgO per palm along with 500 : 300 : 1000 g N, P_2O_5 and K_2O/palm/year was optimum under rainfed conditions. Regular application of fertilisers since planting reduced the incidence of disease and increased yield (Cecil, 1981; Amma *et al.*, 1983). Cecil and Amma (1991) while reviewing the nutrition of coconut in the root (wilt) affected area had indicated that the foliar yellowing is not due to any major nutrient deficiency but can be corrected with the foliar application of magnesium sulphate as 2 per cent solution. No other nutrient deficiency was associated with the disease. The nutrient management practices adopted in the cultivators' fields during 1982 to 1984 gave encouraging results (Table 74.2). The yield increase was more in diseased early palms and was much less in diseased advanced palms.

Table 74.2: Response due to management practices on the yield of coconut in cultivators' fields (rainfed)

Disease index	*No. of palms observed*		*Yield at start of expt. (nuts per palm) 1982*	*Estimated yield for 1984 (nuts per palm)*	*Response % increase*
	1982	*1984*			
Apparently healthy (< 10%)	114	90	29.1	49.3	69.4
Disease early (11–50%)	66	82	18.9	30.2	59.8
Disease advanced (> 50%)	9	12	8.5	9.4	10.6
Total	188	184	4643.6	7028.8	51.4
General mean			24.7	38.2	

Varietal difference: A comparative evaluation of WCT and COD × WCT in the root (wilt) affected areas under unirrigated conditions indicated that the hybrid, COD × WCT came to the bearing stage early and the disease intensity was less (Table 74.3). The performance of COD × WCT up to the eleventh year gave clear indications that this hybrid with adequate management from

field planting can perform better than the local tall (Cecil, 1981; Amma *et al.*, 1983).

Table 74.3: Comparative performance of COD × WCT and WCT in root (wilt) affected area with respect to yield and disease incidence

Year after planting	*Disease incidence %*		*Nut yield/palm*	
	COD × WCT	*WCT*	*COD × WCT*	*WCT*
Fourth	1.8	2.2	–	–
Fifth	3.6	4.3	55.9	–
Sixth	5.0	8.8	100.9	–
Seventh	5.0	22.5	75.9	16.8
Eighth	8.9	29.3	91.1	39.6
Ninth	22.1	35.5	105.0	49.4
Tenth	22.8	42.6	61.9	44.8
Eleventh	40.9	50.7	103.4	62.9
Twelfth	41.1	62.2	26.6*	52.1
Cumulative yield/palm up to the twelfth year			620.7	265.6

*Mean yield in 1984 after the unprecedented drought in 1982–83.

Water Management: Studies conducted at the farmers' fields have indicated that irrigation of the palms with 250 l of water/palm/week during January to May with normal application of fertilisers and plant protection chemicals resulted in an overall improvement of the conditions of the palms with increased nut yield ranging from 64 to 200 per cent. There was reduction in the flaccidity, yellowing, leaf rot and necrosis to the tune of 51, 60, 40 and 45 per cent, respectively and an increase in the overall photosynthetic activity by 53.3 per cent (Rajagopal *et al.*, 1987).

Leaf rot control: Sequential application of Bordeaux mixture 1 per cent, Dithane M. 45, 0.3 per cent and Fytolon 0.5 per cent gave an effective control (87.8 per cent) of leaf rot which is normally superimposed on root (wilt) affected palms (Thomas Joseph and Rawther, 1991).

Integrated Management: An integrated management practice consisting of eradication of diseased advance and unproductive palms as also young palms that have taken up the disease prior to flowering, application of balanced fertilisers, farmyard manure, control of leaf rot and growing intercrops and mixed crops were tried in the farmers' fields both under irrigated and rainfed conditions in the diseased tract and the results are presented in Tables 74.4 and 74.5. Average increases of 23.4 nuts/palm under rainfed and 17.2 nuts under irrigated conditions were obtained (Muralidharan *et al.*, 1991). A large scale demonstration in mildly affected areas of Trichur district revealed an increase of yield from 20.2 nuts during 1981–82 to 49.2 nuts/palm/year during 1984 due to the adoption of integrated management practices (Anonymous, 1986).

Table 74.4: Effect of integrated management practices on yield of root (wilt) affected palms (rainfed)

Disease index	*Yield (nuts/palm/year)*				*Increase in nut yield over control*	
	Pre-expt.		*Post-expt.*		*Number*	*%*
	Control	*Treat.*	*Control*	*Treat.*		
0–10	40.8	43.5	51.3	30.9	29.6	57.7
11–25	29.9	26.4	35.5	64.3	28.8	81.1
26–50	18.7	17.7	21.2	29.6	8.4	39.6
> 51	9.7	8.0	9.4	11.4	2.0	17.5
Mean	33.4	32.6	41.0	65.3	24.3	59.3

Table 74.5: Effect of integrated management practices on yield of root (wilt) affected palms (irrigated)

Disease index	*Yield (nuts/palm/year)*				*Increase in nut yield over control*	
	Pre-expt.		*Post-expt.*		*Number*	*%*
	Control	*Treat.*	*Control*	*Treat.*		
0–10	52.4	54.4	58.2	72.1	14.0	24.1
11–25	27.5	32.6	35.5	61.5	26.0	73.0
26–50	13.3	18.6	21.5	25.1	3.0	17.0
> 51	9.8	10.2	10.4	7.8	−2.6	25.0
Mean	35.8	43.6	45.1	62.3	17.2	36.0

Containing the Disease by Eradication in Mildly Affected Areas

Eradication of disease affected palms to contain the disease within the contiguously infected geographic limit has been successful (Anonymous, 1986). Uprooting and burning of diseased trees in Vallam village of Senkottai, Tamil Nadu in 1971 prevented the recurrence of disease (Anonymous, 1986) and this was confirmed again in 1991. Based on this encouraging result an attempt was made to create a buffer zone in the sparsely affected areas between Chalakudi river and Karuvannur river in Trichur district by eradicating 28,000 diseased palms and also to contain the disease within the geographical zone. An attempt was also made in 10 villages north of Karuvanoor river and Amballur — Varandarappalli road at the border of buffer zone (Fig. 74.2). A total of 730 palms in 341 gardens were confirmed to be diseased and were eradicated after spraying carbaryl (0.05 per cent) to suppress *Stephanitis typica*, the insect vector, before cutting the palms. The leaves, boles and root were burnt *in situ*. Replanting was done with elite seedlings after applying 10 g Temik G to the pit. Continuous monitoring was done by survey and eradication in this area. Subsequently areas beyond the buffer zone were also surveyed and eradicated. The results indicated that where continuous monitoring was done the recurrence was almost nil (Radha *et al.*, 1981; Rethinam *et al.*, 1982) (Table 74.6).

Table 74.6: Effect of eradication of diseased palms on recurrence of disease

State, district and village	*Year of eradication*	*Number of*		*Recurrence in 1984*	
		Gardens	*Palms*	*Gardens*	*Palms*
Tamil Nadu					
Sencottai	1971	1	3	Nil	Nil
Kerala					
Trichur Distt.					
1. Nadathara	1973	1	1	Nil	Nil
2. Varandarappalli	1979	78	175	5	8
3. Amballur	1979	43	66	Nil	Nil
4. Kallur	1979	5	9	Nil	Nil
5. Arattupuzha	1979	2	9	Nil	Nil
6. Inchemudi	1979	2	3	Nil	Nil
7. Kurumbilavu	1979	5	8	Nil	Nil
8. Keezhupailikare	1979	17	24	Nil	Nil
9. Urakam	1979	4	9	Nil	Nil
10. Nemmenikkare	1981	13	37	Nil	Nil
11. Vellachira	1981	2	2	Nil	Nil
Palghat Distt.	1980–82	11	27	Nil	Nil
Malappuram Distt.	1980–82	3	3	Nil	Nil
Kozhikode Distt.	1980–82	30	48	Nil	Nil

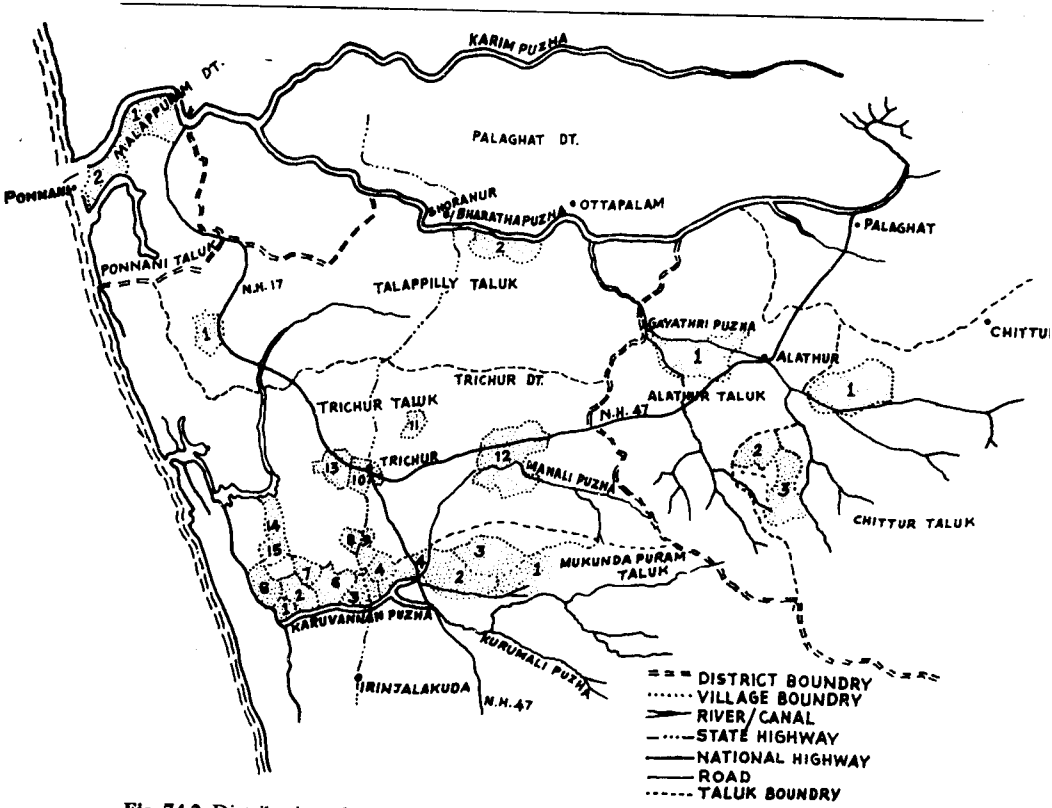

Fig. 74.2: Distribution of root (wilt) disease affected villages in parts of Trichur, Malappuram and Palghat districts — 1982.

Similarly, in 24 villages away from the belt area where 100 diseased palms were removed from 40 gardens, there has been no recurrence so far. This attempt had helped to keep the northern Kerala nearly free from the disease except in pockets of Cannanore district where eradication could not be completed and a few cases of recurrence and new incidence had occurred. A resurvey made in June 1991 after a lapse of five years has indicated that 3,202 diseased palms are still to be removed in the belt area. This indicates the need to constantly monitor the mildly affected area to keep it free from disease.

CONCLUSIONS

Integrated management practices, consisting of removal of diseased advanced old and diseased juvenile palms; adoption of packages like application of fertiliser 500, 300, 1000 g N, P_2O_5, K_2O and 500 g MgO coupled with 50 kg farmyard manure/palm/year in two splits; irrigation during dry months (January to May); proper drainage; leaf-rot control with sequential spraying; raising intercrop and mixed crop; and restructuring the canopy of the existing trees to provide adequate light to the coconut, are recommended to increase the productivity of palms in severely affected eight southern districts. Eradication of diseased palms irrespective of yield and continuous monitoring coupled with adoption of the above-said management practices are suggested for the mildly affected areas for containing the disease and increasing the productivity. A permanent solution can be possible if a resistant/tolerant variety is available. These management strategies will definitely go a long way in increasing the production and productivity of coconut in Kerala though the only permanent solution will be evolving disease tolerant coconut varieties.

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FIELD RESISTANCE OF COCONUTS TO "LIXAS" AND LEAF BLIGHT IN BRAZIL

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ABSTRACT

In Brazil, a foliar disease complex is increasingly recognised as the major constraint to coconut improvement. Two fungi called *Catacauma torrendiella* Batista and *Coccostroma palmicola* (Speg) von Arx and Muller, causal organisms of "lixa pequena" and "lixa grande", respectively, provoke wart-like symptoms. *Botryodiplodia* sp. appears as a secondary parasite causing rapid necrosis of the leaf tissue. The objective of this work was to evaluate the field reaction of eight coconut tall varieties during the vegetative stage. Ten plants of the varieties West African Tall (WAT), Tonga Tall (TGT), Rennell Tall (RLT), Vanuatu Tall (VTT), Malayan Tall (MLT), Polynesian Tall (PYT), Rotuma Tall (RTT) and Brazilian Tall were utilised. Although no variety was resistant, the PYT, RTT and TGT varieties showed the best performance under the conditions studied.

INTRODUCTION

Coconut is the predominant crop in the coast of North-eastern Brazil. This region is responsible for 92 per cent of all coconut grown in the country. On an average, the coconut production is 3,377 fruits/ha (Cuenca, 1989), consequence of irregular rainfall distribution, low yielding varieties and the attack by a number of insect pests and diseases. Another cause for the low productivity is the unsuitable soil conditions. Savin and Christoi (1965) concluded that 74 per cent of the Brazilian coconuts were deficient in nitrogen, whereas 68 per cent were potassium deficient. In another work, Sobral (1989) demonstrated that in the state of Sergipe, 82.8 per cent of leaf samples collected were N and P deficient and in 65.7 per cent of the samples, potassium was below the value taken as reference for the critical level.

Three foliar diseases are responsible for the enormous losses in different coconut growing regions of Brazil. "Lixa pequena" or small verrucosis, caused

by *Catacauma torrendiella* Batista, was described in 1948 (Batista, 1948). The first symptoms of this disease are small black, charcoal-like fruiting bodies formed superficially. This formation, known as stroma is either found isolated, in lines, or in a diamond shape on the leaflets and midribs. Eventually, the plant tissue around the stromata forms brown, necrotic lesions, which enlarge to about 15 × 2 cm. Numerous brown areas coalesce, the leaflets become necrotic and the whole leaf collapses. "Lixa pequena" occurs mainly in areas not located near the sea-shore, and it is well spread in the different coconut regions (Franco, 1965; Oliveira *et al.*, 1984 and Renard, 1990).

"Lixa grande" also known as large verrucosis is caused by *Coccostroma palmicola* (Speg) von Arx and Muller. The stromata of this fungus are brown, larger and more superficial than the previous fungus described. This fungus, appears to be more prevalent than *C. torrendiella* in the drier areas and does not occur in the northern region of the country (Renard, 1982).

Leaf blight disease was first described by Franco (1975) in the state of Sergipe. It was observed that the lower leaves become brown and died prematurely leaving coconut bunches without support. Leaf browning spreads from the tip to the base (the symptom develops in a so-called "V" information); and there is no transition area from the brown tissue to the green area. In the north-east in general, leaf lesions are associated with *Botryodiplodia* sp. In the north, it is common to find *Botryosphaeria* sp. on the leaf lesion. This fungus does not infect the plant without previous abrasion of the leaf tissue. Ram (1989) demonstrated that the high incidence of leaf blight is correlated with the increase of temperature and decrease of relative humidity. It is suggested that three fungi are responsible for the reduction in assimilating leaf area and consequently for the low production of coconut in Brazil. Evaluation of coconut accessions for their tolerance "Lixas" and leaf blight is reported in this paper.

MATERIAL AND METHODS

The experiment was conducted in the germplasm collection consisting of tall accessions in Neopolis county, state of Sergipe. The density of the plantation is 160 trees/ha.

The plant material consisting of West African Tall (WAT), Tonga Tall (TGT), Rennell Tall (RLT), Vanuatu Tall (VTT), Malayan Tall (MLT), Polynesian Tall (PYT), and Rotuma Tall (RTT) was obtained from the Institut de Recherche pour les Huiles et Oleagineux (I.R.H.O.). Seeds from the Brazilian Tall variety (BrT. PF) also included in the experiment, were collected in the "Praia do Forte" Beach in the state of Bahia.

The experimental plantation was established in 1985 in a zone most affected by 'lixas' and leaf blight. Ten plants of each variety were chosen at random and each plant was considered as one replication, in a completely randomised design. The data were recorded on a monthly basis for three years, starting in January 1988. The 'lixas' were evaluated by counting the number of stromata in one leaflet from the six lower leaves. For the leaf blight, a disease

index was used, based on the work of Amaral (1969). The disease index was calculated by the following equation:

$$DI = \frac{n_1+2n_2+3n_3}{3N}$$

DI = Disease index.
N = $n_0 + n_1 + n_2 + n_3$ = total number of leaves
n_0 = healthy leaves.
n_1 = leaves with lesions smaller than 50 cm on the rachis.
n_2 = leaves with lesions between 50 and 100 cm.
n_3 = lesions longer than 100 cm.

RESULTS AND DISCUSSION

The average number of stromata of "lixa pequena" is shown in Fig. 75.1. Polynesian Tall (PYT), Rotuma Tall (RTT) and Tonga Tall (TGT) were less affected by this fungus than the other varieties. Brazilian Tall (BRT) was the most susceptible in the first year of observation and continued to be one of the most susceptible. With the exception of BRT the incidence of disease is higher as the plant age increases.

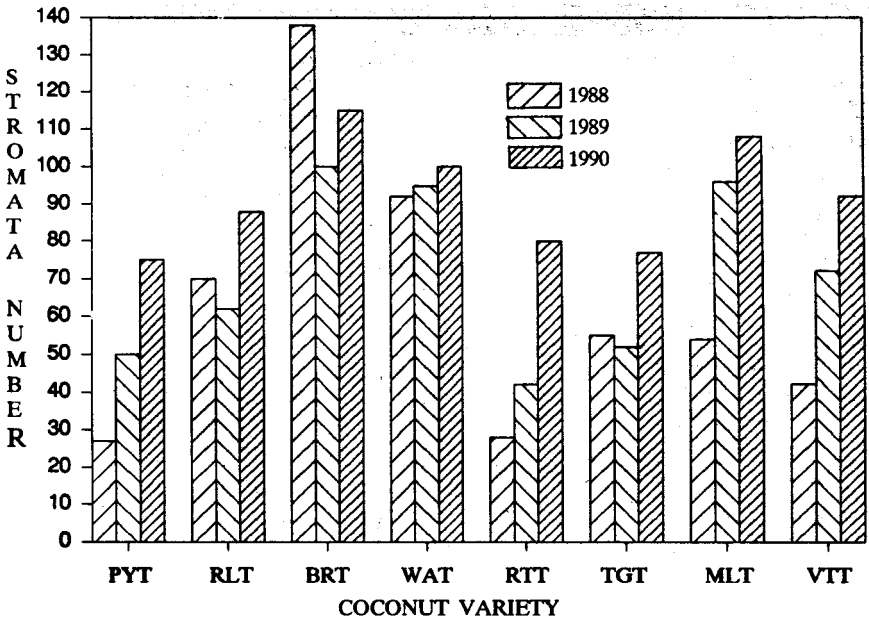

Fig. 75.1: Average number of stromata of "lixa pequena" caused by *Catacauma torrendiella* Batista on coconut leaves. Values are averages of 12-month observations, on Neopolis, SE.

In relation to *C. palmicola,* again the Polynesian Tall (PYT) was the least affected, followed by Rotuma Tall (RTT) and Tonga Tall (TGT) (Fig. 75.2). BRT and WAT were the most susceptible averaging a larger number of stromata.

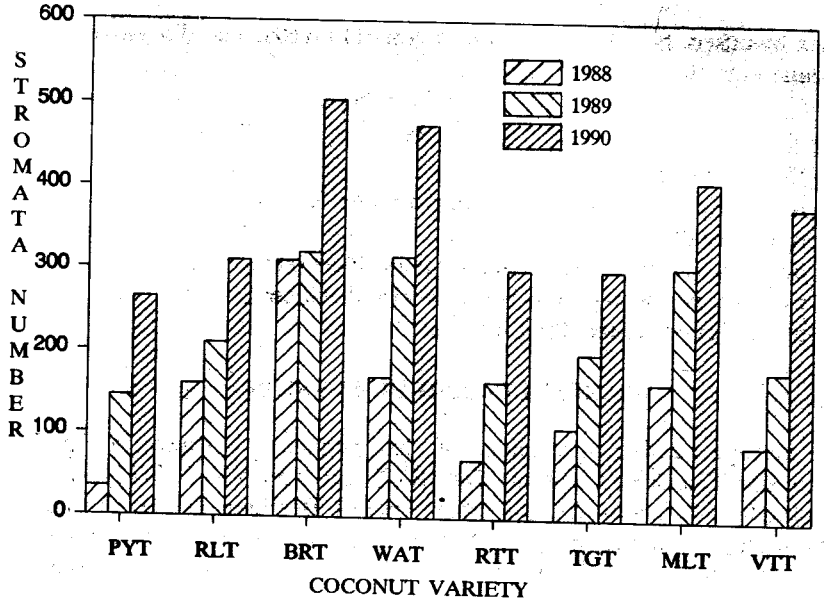

Fig. 75.2: Average number of stromata of "lixa grande" caused by *Coccostroma palmicola* (Speg) von Arx & Müller on coconut leaves. Values are averages of 12-month observations, on Neópolis, SE.

The disease index utilised to evaluate the leaf blight again indicated that PYT, RTT and TGT populations were less susceptible to the disease and BRT and WAT were highly affected by the disease (Fig. 75.3). Harries (1981)

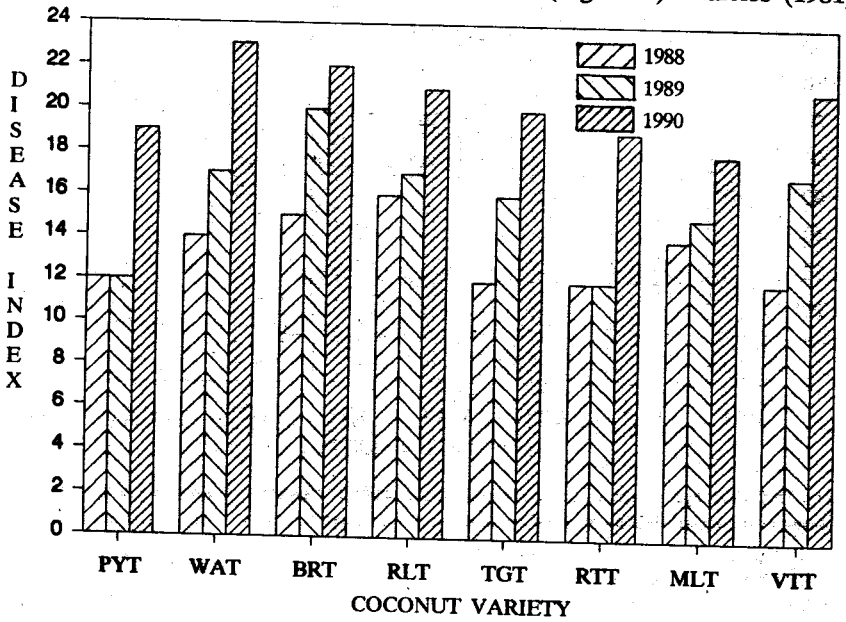

Fig. 75.3: Disease index average of coconut leaf blight (*Lasiodiplodia* sp.) Values are averages of 12-month observations, on Neopolis, SE.

indicated that Polynesian Tall is a highly variable population as a result of introgression between Niu Kafa and Niu Vai types. It is also suggested that the greater heterogenicity of introgressed types may allow superior selections to be made for breeding purposes. It is expected that for disease resistance a selection of this variety will also be useful.

Although none of the Tall accessions was found resistant to 'Lixas' and leaf blight, comparative tolerance of Polynesian Tall, Tonga Tall and Rotuma Tall is encouraging.

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DISCUSSION

K.K.N. Nambiar: What is the yield loss due to leaf blight?

D.R.N. Warwick: It causes an approximate loss of 5 per cent of yield in the state of Sergipe.

TATIPAKA DISEASE OF COCONUT— CURRENT STATUS

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ABSTRACT

Andhra Pradesh stands fourth in coconut production in India with an area of 48,900 ha. The central delta of the river Godavari 'Konaseema' consisting of 60 per cent of the area under coconut in the state is the chief producer catering to the seed-nut requirements of Andhra Pradesh and north-eastern states. In this region a slow debilitating disease made its appearance after the 1949 cyclone and named as 'Tatipaka' disease after the village in which it was first noticed. The disease occurs in Srikakulam, West Godavari, Krishna and Guntur districts. The disease is characterised by pale green foliage, reduction in number and size of leaves, abnormal bending of fronds, translucent chlorotic spots on leaflets, fasciation of leaflets, production of bunches with either a mixture of normal and atrophied nuts or only atrophied nuts. The mature normal nuts of diseased trees have soft mesocarp. Tapering of stem below the crown and rotting of roots are also associated.

The diseased trees become completely barren in due course. All the diseased palms may not express the symptoms fully and palms differ in expression of symptoms. The disease is mostly confined to black alluvial soils. It spreads very slowly at a rate of 3.5 per cent over a period of five years and is sporadic in nature. Preliminary studies on the etiology of the disease did not indicate any association of fungi or bacteria. Subsequent studies through light-fluorescent and electron microscopy revealed the association of mycoplasma like organisms with the disease. Several experiments carried out earlier to control the disease by chemicals and ameliorative methods failed to show any effect. However later studies involving tetracycline hydrochloride through root feeding resulted in some improvement. An intensive survey conducted during 1985 to 1990 revealed 8,179 palms to be Tatipaka diseased. Eradication of these palms is in progress.

INTRODUCTION

"Tatipaka disease" of coconut is confined to Srikakulam, West Godavari, Krishna and Guntur districts of Andhra Pradesh in India. The disease took its

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name from the village in which it was first observed in 1952 after the devastating cyclone of 1949 (Rao *et al.,* 1956). Coconut production in the disease endemic area of East Godavari district, which comprises more than 60 per cent of the state's area under coconut, is adversely affected by this debilitating disease. There are reports of incidence of this disease from other coconut growing districts also (Subbaiah and Rao, 1963; Rethinam *et al.,* 1989).

Symptoms

The disease is observed mostly on palms in the age group of 20 to 60 years. Young palms below 20 years of age are rarely affected. Common symptoms of the disease are:

a) Reduction in the number and size of roots; extensive root rot; and root regeneration is greatly affected resulting in a slow decline of the diseased palm.

b) Reduction in the number and size of leaves; the leaves become light green and turn yellowish with a green tinge; chlorotic spots develop on leaflets; in some cases leaflets of some leaves adhere together without normal splitting; and the fronds bend in the middle giving a bow-like appearance.

c) Spathes are very small with very few rachillae; the bunches contain a mixture of normal and atrophied nuts; and in extreme cases palms become barren.

d) Production of nuts is reduced with the progress of the disease; development of nut is not normal; it becomes round with soft mesocarp which could be felt by pressing with the thumb; and with the advancement of disease the nuts become shrivelled and atrophied which do not contain water, copra and shell.

e) Under severe diseased condition, trunk below the crown tapers abruptly.

As a result of the disease, size of the crown is reduced with pale green foliage. With the advancement of disease the palm sheds leaves leading to a "slow decline".

The presence of a combination of commonly observed symptoms only should be reckoned for the identification of a diseased palm. The set of symptoms may vary slightly from palm to palm (Rao, 1966; Ramapandu and Rajamannar, 1981). The prominent symptoms common to all diseased palms are reduction in leaf number and size, round nuts with soft mesocarp and/or atrophied nuts and pale green foliage with a general reduction in crown size.

Distribution and Spread

Though the disease was earlier reported to occur in Godavari central delta of East Godavari district only, a survey conducted in the other coconut growing districts revealed that the disease is prevalent in West Godavari, Srikakulam, Guntur and Krishna districts also. A recent survey (Narasimhachari *et al.,* 1991) in the Godavari central delta showed that the disease has spread to 85 out of 201 villages.

In earlier surveys the disease was mostly found distributed in black alluvial soils. Later it was found more or less evenly distributed in heavy and light soils also.

Etiology

Preliminary studies indicated that the disease is not associated with any fungal or bacterial pathogen. Attempts to transmit the disease through saps and purification indicated the non-viral nature of the disease (Ramapandu and Rajamannar, 1981; Rajamannar *et al.*, 1984).

Electron microscopic examination of disease samples at Waite Institute, Australia revealed the presence of mycoplasma-like bodies in addition to rod shaped virus particles, cytoplasmic crystalline inclusion like structures and rare inclusions looking like parallel arrays of virus particles in different samples. Further investigations through electron microscopy revealed the association of MLOs with this disease. Light microscopy using Dienes' stain and fluorescent microscopy using aniline blue as fluorochrome, of sections of rachillae of diseased palms corroborated the findings of electron microscopy.

Management of Tatipaka Disease Affected Palm/Garden

The trials undertaken to control and/or manage the disease were based on the symptomatology of the disease. Most of the initial efforts were aimed at ameliorating the condition of diseased palm based on the presumption that manures, fertilisers and micronutrients might invigorate the diseased palms.

Root regeneration in an infected palm by making rings of 3 cm width above the bole and heaping a mixture of river sand and farm yard manure and/or river silt around the rings made no perceptible difference in the condition of palm. However, this practice checked further deterioration of the diseased palm. Application of zinc sulphate at the rate of 2 kg/palm twice in one year and subsequently at the rate of 1 kg/palm/year increased the zinc, iron, calcium and potash contents in the leaves and reduced disease intensity of diseased palms.

Several fungicides, namely, Vitavax, Kasumin, methyl benzimidazole carbamate (MBC), Benlate; antibiotics, namely, Agrimycin 100, Aureofungin sol, tetracycline hydrochloride; antiviral compounds (AVC—white and yellow); hormones, namely, G.A., N.A.A., I.A.A., and I.B.A.; and other chemicals like ascorbic acid and catechol were found ineffective in controlling the disease. A slight remission of symptoms was observed in diseased palms treated with tetracycline hydrochloride 3 and 6 g/palm administered through root feeding. This observation again strengthens the MLO etiology of Tatipaka disease.

At present investigations on management of Tatipaka disease affected coconut gardens by a package of practices involving removal of diseased palms and application of river silt, *neem* cake, normal recommended dose of N, P, K, magnesium sulphate and boron are underway.

Screening for resistance

The dwarf cultivar, *Gangabondam* was noticed to be free from the disease even in the areas where a very high incidence of disease on local tall (East Coast Tall) was noticed. This fact came to light during the recent survey conducted to mark all diseased palms with a view to removing them.

Tatipaka Disease Eradication Programme

Since there is no known method of cure for MLO diseases, the option left is containing the disease spread by eradication of diseased palms. With this objective the entire central delta of river Godavari in East Godavari district, where the disease is endemic, was surveyed to locate the diseased palms on a palm to palm basis. A total of 8,179 palms were affected by the disease. These disease affected palms were marked to facilitate easy identification by farmers. The farmers were advised to remove and destroy the disease affected palms. The programme of eradication is in progress under the supervision of the State Department of Horticulture.

Future Line of Work

1) Complete eradication of disease affected palms.

2) Monitoring the area for fresh incidence of disease where eradication was completed.

3) Developing serodiagnostic techniques for the disease.

4) Transmission tests with insects and dodder.

5) Quick screening procedures for germplasm.

6) Enumeration of Gangabondam population in Godavari central delta.

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DISCUSSION

V.V. Long: 1) What is the difference between Tatipaka and Cadang-Cadang as the first symptoms of diseased palms?

2) Do you think that the two diseases have the same causal organism?

M. Rajamannar: 1) In cadang-cadang, chlorotic mottling is seen, while in Tatipaka translucent chlorotic spots and/or streaks which are conspicuous are seen. The crown in general shows yellowing, reduction in leaf size and leaf number as characteristic symptoms of Tatipaka disease.

2) The two diseases have different causal organisms. Cadang-Cadang is caused by a viroid and Tatipaka disease is caused by MLOs.

E.V.V. Bhaskara Rao (comments): In this paper, Gangabondam is indicated to be relatively more tolerant to Tatipaka. Earlier reports of Malayan Yellow Dwarf and Chowghat Green Dwarf reaction against lethal yellowing and root (wilt) disease point out that dwarfing genes could be one of the components of tolerance. This needs further investigation.

H.C. Harries (comments): The three colour forms of the Malayan Dwarf are highly resistant to lethal yellowing in Jamaica, but give a different response to lethal disease in Tanzania. It is unlikely that the same gene for resistance will work against every disease. But it is worth including dwarf genotypes in all disease resistance breeding programmes.

DETECTION OF LETHAL YELLOWING MYCOPLASMA-LIKE ORGANISMS BY DNA PROBES IN PALMS OF YUCATAN MEXICO

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ABSTRACT

Lethal yellowing (LY) mycoplasma-like organisms (MLO) were detected in *Cocos nucifera* L. (coconut) palms of Yucatán by radiolabelled cloned DNA probes. LY143 and LYD9 probes containing DNA fragments from a Florida LY MLO hybridised at moderate stringency with nucleic acids extracted from six Yucatán LY-diseased but not healthy palms. These results suggested similarities between the LY MLO form Yucatán, Mexico and the LY MLO from Florida, U.S.A. They also provide a diagnostic tool for LY MLO detection.

INTRODUCTION

Lethal yellowing (LY) is a devastating disease of *Cocos nucifera* L and at least 30 other palm species (Thomas and Norris, 1980). LY represents the most single threat to worldwide coconut production (Harries, 1978). 'Caribbean' LY is currently affecting the Yucatán Peninsula of Mexico and threatens to spread to other geographic regions of México and Central America. The LY agent, is a mycoplasma-like organism (MLO) presumed to be transmitted by the palm plant hopper *Myndus crudus* Van Duzee when feeding from the palm phloem (Howard, 1983).

The LY agent, like other MLOs, is unculturable, so detection of the LY MLO and disease diagnosis has been indirectly determined by antibiotic treatment (McCoy, 1972) and transmission electron microscopy (TEM) (Parthasarathy, 1973; Cardeña *et al.,* 1991). Although TEM has been used to confirm the presence of the 'Caribbean' LY MLO in coconut palms of the

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Caribbean area, it cannot be considered a quick and precise procedure. Also, MLOs are too small to be resolved by light microscopy (McCoy, 1979). Therefore the major drawback to obtaining etiological and epidemiological information concerning LY has been the lack of a rapid, sensitive and specific means for pathogen detection and disease diagnosis. Worldwide, little is known about the ecology and distribution of MLOs associated with LY.

A recent research effort dealing with plant MLOs is the use of recombinant DNA technology for the detection and diagnosis of this important group of plant pathogen (Kirkpatrick *et al.*, 1990). Cloned random fragments of MLO DNA used as probes have permitted up-to-date: (a) to detect several MLOs in their plant and insect hosts (Kirkpatrick *et al.*, 1990), and (b) to distinguish MLOs from one another (Davis *et al.*, 1990), and (c) to provide information concerning genetic interrelatedness among MLOs from various hosts and geographic regions (Lee and Davis, 1988). DNA hybridisation probes for detection of the MLO associated with LY disease of Florida palms have recently been developed (Harrison *et al.*, 1991a). The purpose of this study was to determine whether these newly developed probes detect MLOs associated with LY diseased palms of Yucatán.

MATERIALS AND METHODS

Plant Material

Palm apical bud tissue was collected from six naturally infected *Cocos nucifera* L. palms of the Atlantic Tall variety displaying mid-foliar symptoms indicative of LY disease. Disease characteristics of palms and sample collection dates are shown in Table 77.1. Site location is shown in Fig. 77.1.

Table 77.1: Characteristics of diseased and healthy coconut palms used as sources for DNA extraction. Sample collection date, age, disease grade, location and variety are indicated

Sample ID	*Date 1991*	*Age (yrs)*	*LY Grade (*)*	*Location*	*Variety*
1	June 22	8	5	San Crisanto	Hybrid
2	June 22	12	5	San Crisanto	Hybrid
3	June 22	10	5	San Crisanto	A. Tall
4	June 25	8	5	San Crisanto	A. Tall
5	June 25	1	CONTROL	Campeche(**)	A. Tall
6	April 30	12	4	San Bruno	A. Tall
7	May 20	8	4	Chicxulub	A. Tall

*As described by McCoy (1979).
**This location is an area where LY is not currently present (240 Km from Merida, Yucatán).
A. Tall = Atlantic Tall.
Hybrid = A. Tall × [A. Tall × Dwarf].

DNA Extractions

Palm apical buds were collected and immature leaf bases were removed and immediately frozen in liquid nitrogen. DNA was extracted within 48 hours

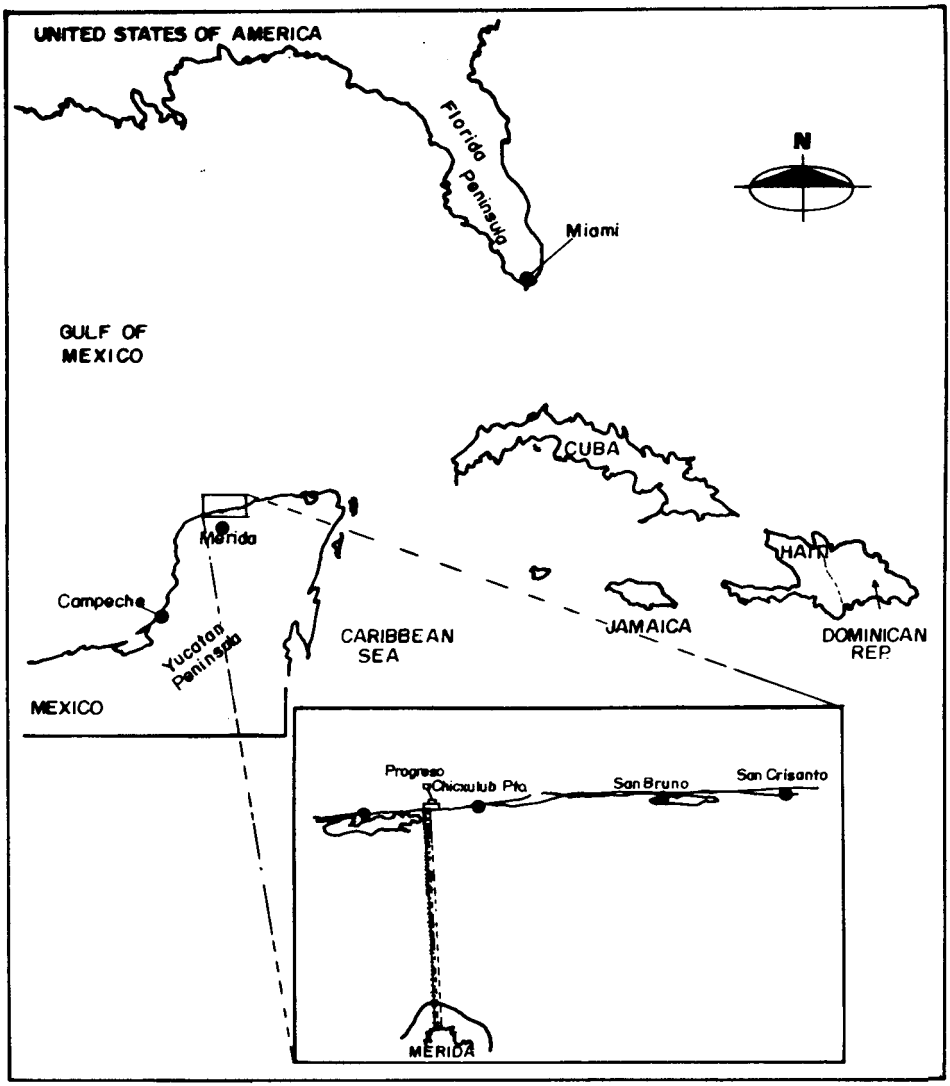

Fig. 77.1: Location of San Bruno, Chicxulub and San Crisanto sampling sites of Yucatan palms. Geographic location of Yucatan and Florida peninsulas.

from collection—3 g of each frozen sample was then pulverised in liquid nitrogen to the consistency of powder. Fifteen ml of DNA extraction buffer (Harrison *et al.*, 1991b) (100 mM TRIS, 50 mM EDTA, and 500 mM NaCl, pH 8.0) was added to the powder while still in the mortar and the slurry transferred to a 40 ml polypropylene tube. Each sample was incubated for 10 minutes at 68° C. After addition of 35 μl of B-mercaptoethanol, 100 μl of SDS 20 per cent, and 6 ml of sodium acetate 3.0 M to the lysate, the mixture was chilled on ice

for 30 minutes and centrifuged at 25,000 × g for 20 minutes at 4°C to pellet the insoluble precipitates. The aqueous supernatant liquid was filtered through two layers of facial tissue into a clean sterile 40 ml centrifuge tube. A further 10 ml of room temperature isopropanol was added. Tubes were incubated overnight at 0°C, then centrifuged at 20,000 × g for 15 minutes to pellet the nucleic acids. The supernatant was discarded and the nucleic acid pellet was washed with 100 per cent ethanol. The suspension was transferred to an eppendorf tube and centrifuged at 20,000 g for five minutes. Nucleic acid pellets were air dried and stored at 4°C.

DNA Visualisation

DNA pellets of each sample were resuspended in 250 μl of TE buffer and electrophoresed. An aliquot of each DNA sample in the gel was visualised by staining it with ethidium bromide.

DNA Hybridisation

Nucleic acid pellet was resuspended in 100 μl of TE Buffer (0.01 mM EDTA + 10 mM TRIS, pH 8.0); 10 μl of each sample (that is, 2 μg of DNA) was applied to duplicate on nitrocellulose membranes. Membranes were baked at 80°C and air dried in vacuo for one hour. DNA samples were denatured according to a colony hybridisation procedure. Essentially, the blots were wetted with 6X SCC by placing the membrane on to filter paper soaked with this buffer for five minutes. The membranes were transferred to a second filter paper soaked with a solution of 0.5 N NaOH, 1.5 M NaCl for five minutes (denaturing step), and then to a third filter paper soaked with a solution of 1.5 M NaCl, 0.5 M Tris (pH 7.4), for five minutes. Membranes were transferred to a fourth filter soaked with 2X SSC for two minutes, then air dried and baked at 80°C for one hour. Denatured DNA samples from different plant material were kindly provided by Dr. Harrison of the University of Florida. Pigeon pea witches' broom mycoplasma-like organism from Florida (WB MLO), healthy *Veitchia merillii* Florida palm, lethal yellowing *Veitchia merillii* Florida palm, healthy coconut Florida palm and lethal yellowing coconut palm were also applied on nitrocellulose membranes for comparison with our DNA palm samples.

Prehybridisation of membranes was done at 68°C overnight according to manufacturer's instructions. For hybridisations, this solution was replaced with a similar solution also containing the denatured radiolabelled LYI43 or LYD9 probes (Harrison *et al.*, 1991a). Hybridisation with labelled probes was performed for 16 hours at 68°C, after which membranes were subjected to moderate stringency wash conditions consisting of two washes in 2X SSC, 0.1 per cent SDS at 25°C (30 minutes each wash), one was in 0.2X SSC, 0.1 per cent SDS at 25°C (30 minutes). Membranes were then sealed in plastic wrap and exposed to X-Omat AR diagnostic film (Eastman Kodak, Rochester, NY) with an intensifier screen (Lightening Plus, Du Pont, Newark, DE). Autoradiography was performed at −75°C for 60 hours.

RESULTS

DNA Visualisation

Gel staining with ethidium bromide showed DNA present in each of the six Yucatán palm samples including the control, although the DNA content of all samples was relatively low (ca 100 $\mu g/\mu l$).

DNA Hybridisation

Hybridisation results at moderate stringency between probes LYI43 and LYD9 were similar. Results are shown in Table 77.2. For simple interpretation we used a numerical scale to indicate the order of samples relative to their hybridisation signal intensity. For example, No. 1 DNA sample from an LY-affected *Veitchia merillii* palm from Florida with the strongest hybridisation signal was given the value of 1. DNA palm sample No. 2 of Yucatán had the weakest signal and was given the value of 5. A picture of the autoradiogram for LYI43 probe is shown in Fig. 77.2. All palm DNA samples of Yucatan had a positive hybridisation except the healthy controls. When comparing with Florida palms, only the LY infected *Veitchia* and coconut had a positive hybridisation. DNA samples from two healthy palm species of Florida and from one MLO witches' broom diseased plant had a negative hybridisation.

When comparing signal intensity between geographic region, four LY diseased coconut palms of Yucatán had a similar or stronger signal than the LY diseased coconut palm of Florida.

Table 77.2: Hybridisation signal and relative signal intensity of Yucatán and Florida palm samples

Sample ID	*Hybridisation signal*	*Relative signal intensity*
Yucatán samples		
1	+	2
2	(+) (weak)	5
3	+	3
4	+	4
5 (control)	–	–
6	+	2
7	+	3
Florida samples		
Pigeon pea WB MLO	–	–
Healthy *Veitchia*	–	–
LY *Veitchia*	+	1
Healthy coconut	–	–
LY coconut	+	3

WB MLO = Witches' broom mycoplasma-like organism.

Discussion

Although limited quantities of DNA were tested from each Yucatán palm sample, the DNA was of sufficient quality for hybridisation. All DNA extracted

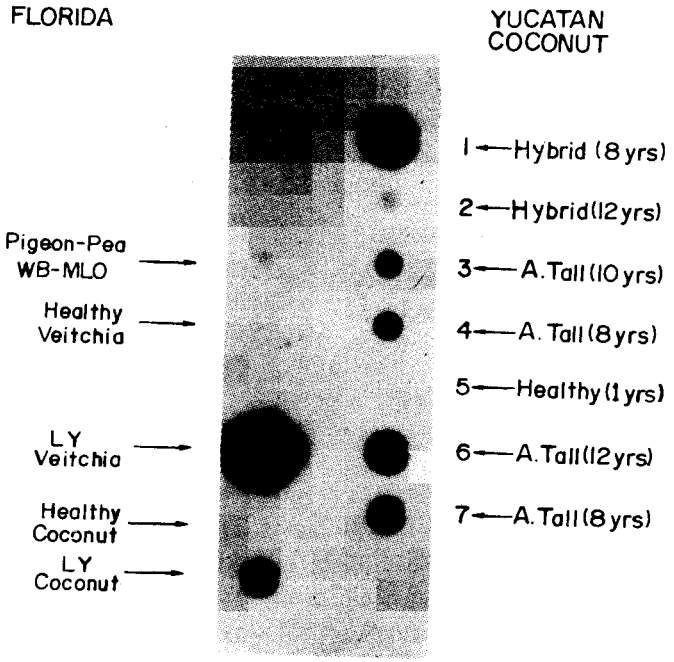

Fig. 77.2: Dot blot hybridisation of various DNAs with a cloned fragment of ^{32}P-labelled LY MLO DNA (probe LYI43). 1, 2, 3, 4, 6 and 7 DNA from LY-diseased coconut palms of Yucatan. 5, DNA from a healthy coconut palm of Yucatán.

form LY diseased palms of Yucatan gave a positive result hybridisation signal with both LY probes. In spite of these positive results it is imperative to overcome problems for DNA extraction procedures in order that we are able to extract sufficient high quality DNA for further studies.

LYI43 and LYD9 probes were cloned and identified as chromosomal DNA fragments of the MLO associated with LY disease of *Veitchia merillii* in Florida. This could explain the fact that the hybridisation signal from the LY *Veitchia merillii* sample was the strongest from all positive hybridisation signals.

Positive hybridisation signals of all Yucatán diseased palms suggested that MLOs associated with LY diseased coconut palms of Yucatán are genetically similar, perhaps identical to MLOs associated with LY disease of Florida palms. However, more detailed studies will be required to determine the extent of this similarity.

Although both geographic regions compared in this study are from 'Caribbean' LY region, it is obvious that these DNA probes provide a powerful research tool to determine if differences in coconut varietal susceptibility and epidemiology between 'Caribbean' and 'African' LY is because different MLOs have developed in each continent. The negative hybridisation signal for the chromosomal DNA MLO associated with witches' broom disease of *pigeon pea* determined that the DNA probes we tested were specific for chromosomal DNA MLO associated with LY of palms. This initial study

clearly demonstrates the utility of cloned probes developed from the Florida LY MLO as a diagnostic tool for detection of MLOs associated with LY of coconut palms in the Yucatán of Mexico.

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DISCUSSION

J.J. Solomon: Do you think that *Myndus crudus* is the vector of the disease in Yucatàn?

C. Oropeza: It has not been demonstrated, but *M. crudus* has been detected in populations of coconut in Yucatàn.

V. Rajagopal: How does the DNA probe method compare with the earlier diagnostic methods of stomatal resistance and leaf water potential?

C. Oropeza: As far as we are concerned both parameters were somehow suggested as diagnostic tools but never used as such. But in any case, changes in these parameters come about as a result of not only pathological conditions but also environmental changes. Therefore as diagnostic tools they would lack selectivity. DNA probes in contrast can selectively detect MLO-DNA.

D.C. Sastri: Are the DNA restrictions from pure MLO-DNA? What is the size of DNA restriction fragments labelled and used as probes and how many probes are used?

C. Oropeza: They were obtained from MLO-DNA isolated from plant DNA by density gradient centrifugation. The size ranges from 1.2 to 4.1 kbp. A single probe identified as LY 143 was used. The sample is collected as an explant and DNA is extracted from it in the laboratory.

IMPACT OF ROOT (WILT) DISEASE ON THE YIELD OF YOUNG COCONUT PALMS

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ABSTRACT

When young West Coast Tall palms under regular fertiliser management contracted the disease during the pre-bearing period, the onset of bearing was found to be delayed. While about 90 per cent of the healthy palms flowered by the end of the eighth year, it was only around 70 per cent in palms which contracted disease during the pre-bearing stage. About 18 per cent of these diseased palms did not flower even up to the thirteenth year. Decline in yield was faster in palms which became diseased in later years. In general, about 45 per cent decline in yield was observed in diseased palms, during the course of 10 years, compared to the yield of healthy palms, while in palms which were diseased during the initial years, this loss was to the extent of 68 per cent.

In Dwarf × Tall palms though the occurrence of disease was at a slower rate the increase in the disease index was higher compared to that in WCT palms. The diseased Dwarf × Tall palms, in general were giving about 60 per cent lower yields, compared to the healthy palms.

INTRODUCTION

In the past, many attempts have been made to study the impact of root (wilt) disease on the yield of coconuts. Ramadasan *et al.* (1971) have observed that in palms which contracted the disease before the commencement of bearing, flowering was often delayed indefinitely and the yield of such palms was also drastically affected. Jose Abraham *et al.* (1987) reported significant negative correlation between yield and intensity of disease (disease index). They also reported an average reduction of 0.5 nut per index value, under cultivators' conditions, while it was 1.3 nuts per index for the younger palms under well managed farm conditions. The impact of root (wilt) disease on the time taken for flowering, trends in yield during the initial years of bearing for healthy and

diseased palms, the regression between disease intensity and yield and the loss in yield in two fertiliser trials conducted at CPCRI Regional Station, Kayangulam are presented.

MATERIALS AND METHODS

Two fertiliser trials were conducted at CPCRI Regional Station, Kayangulam, Kerala in soils of loamy sand type, under rainfed condition, receiving regular plant protection measures and cultural operations. Experiment No. 1 was initiated in 1970 on 648 newly planted West Coast Tall seedlings, to study the effect of N, P, K, Ca and Mg on the root (wilt) disease of coconut. The design adopted was split-plot, with 27 main plot treatments as the factorial combinations of three levels each N, P and K, in 24-tree plots, in a 3^3 confounded factorial arrangement, and the subplot treatments as factorial combinations of two levels each of Ca and Mg. Experiment No. 2 was laid out in 1972 using 324 newly planted D × T hybrid seedlings, to study the performance of these hybrids in root (wilt) disease affected area, under different fertiliser levels. There were 18 treatments, consisting of three levels of NPK × two levels of Ca × three levels of Mg.

Observations on the time taken for flowering, flowering leaf axil number (for Experiment No. 1 only), incidence of disease and its intensity, yield of nuts etc., recorded regularly were utilised for this study. The intensity of disease was measured using the method suggested by George and Radha (1973).

The palms which contracted disease in different years were considered separately to study the impact of the disease on the time taken for flowering. While studying the trend in yield for the initial years, the data for 1984 were omitted, in view of the fact that the same was adversely affected by the unprecedented drought of 1983. Both linear and quadratic models were tried, to work out the relationship between the age of the palm and the yield. The loss in yield due to the initiation of disease in different years was also worked out for the cumulative yield data for the tenth, twelfth and the fourteenth years. The relationship between disease intensity and yield was studied, by grouping the palms based on the intensity, and fitting linear regression models.

In Experiment No. 1, replanted seedlings have been excluded for recording flowering behaviour and yield was recorded in only 534 palms which had survived till the end of 1984. Similarly, in the case of D × T palms, 315 have been considered for flowering details, and 310 for yield studies, out of a total of 324 seedlings planted.

RESULTS AND DISCUSSIONS

a) Flowering in Relation to Initiation of Disease

Symptoms of root (wilt) disease were visible from the fourth year of planting, in both West Coast Tall (WCT) and D × T palms. By the end of the twelfth year, 62 per cent of the West Coast Tall palms and 39 per cent of the D × T palms had contracted disease. Cumulative figures for the percentage of

palms which came to flowering and palms which contracted disease in different years are presented in Table 78.1. In the case of West Coast Tall palms, flowering started by the fifth year while in D × T palms, flowering was earlier and 87 per cent had come to flowering by the fifth year. All the D × T palms had flowered by the eighth year, whereas it was only 90 per cent in West Coast Tall. Treatment with Mg was found to slightly favour early flowering. At the same time, the incidence of disease was also more in Mg treated palms.

Table 78.1: Progress in flowering and initiation of disease in West Coast Tall (planted: 1970) and D × T (planted: 1972) — cumulative percentage figures

Age of the palm (years)	*Flowering*		*Initiation of disease*	
	WCT (n = 633)	*D × T (n = 315)*	*WCT (n = 633)*	*D × T (n = 315)*
3	–	7.6	–	–
4	–	61.9	2.8	1.9
5	11.1	87.0	4.4	2.9
6	45.7	92.7	9.0	4.1
7	79.0	95.2	22.7	4.1
8	90.4	100.0	27.5	7.0
9	95.1	–	34.8	19.7
10	96.8	–	41.7	21.0
11	97.8	–	49.9	39.0
12	97.9	–	62.1	39.4
13	97.9	–	69.7	–

In West Coast Tall palms, the percentage of palms which flowered till the end of the sixth year, did not differ significantly between healthy and diseased palms. The delay in flowering was conspicuous in the latter years only.

In general, flowering was found to be delayed, when palms contracted the disease during the pre-bearing period. Ramadasan *et al.* (1971) had also reported similar results. According to Cecil *et al.* (1984) when young palm contracted the disease before flowering, the onset of bearing was delayed by about 12 months.

b) Occurrence of Disease and its Intensity Over the Years

Both West Coast Tall and D × T palms started showing symptoms of disease from the fourth year onwards (Table 78.2). By the end of the thirteenth year, nearly 70 per cent of the West Coast Tall palms had contracted the disease. In the case of D × T, 39 per cent of the palms were diseased by the twelfth year. A clear linear trend was visible in the cumulative percentage of palms diseased at different years. Regression studies showed that during this period, every year, 7.7 per cent of the West Coast Tall palms and 5.1 per cent of the D × T palms were diseased, under the prevailing management conditions.

Increase in intensity of the disease index in palms which contracted disease during different years is given in Table 78.3. Regression analysis

Table 78.2: Increase in the intensity of disease index in palms which contracted disease during different years

Variety	*Age (years) at initiation of disease*	*No. of palms*	*Mean disease index*		*Regression of disease index on age*	R^2
			I year	*1984*		
WCT	4	16	27.2	43.3	1.32**	0.71
	5	7	25.9	41.1	1.32**	0.59
	6	24	25.1	38.5	1.17**	0.46
	7	52	20.2	36.2	1.56**	0.53
	8	20	30.3	33.7	1.20**	0.64
D x T	4	5	16.0	33.2	1.86**	0.92
	5	2	21.7	32.3	1.54**	0.98
	6	3	22.7	33.1	1.13**	0.61

**Significant at P = 0.01.

Table 78.3: Yield curves for initial years of bearing (1976 to 1983)

Age (years) at initiation of disease	*Mg treat-ment*	$Y = a + bx$			$Y = a + bx + cx^2$			
		a	*b*	R^2	*a*	*b*	*c*	R^2
a) WCT								
3, 4, 5	0	−28.8	4.22**	0.89	−8.3	−0.37	0.24	0.91
	1	−21.0	5.40**	0.66	−96.6	22.31	−0.89	0.74
	P	−25.3	4.73**	0.85	−46.6	9.48	−0.25	0.86
6, 7	0	−19.5	3.99**	0.89	−58.9	12.81**	−0.46	0.94
	1	−21.7	5.36**	0.79	−109.6	25.02**	−1.03	0.90
	P	−20.7	4.80**	0.83	−89.1	20.09**	−0.80	0.92
8, 9, 10	0	−16.2	4.08**	0.60	−142.4	32.28**	−1.48**	0.91
	1	1.3	3.24	0.26	−197.8	47.77**	−2.34**	0.80
	P	−7.6	3.68	0.43	−169.7	39.90**	−1.91	0.88
11, 12, 13	0	−44.6	8.95**	0.79	−201.6	44.05**	−1.85**	0.92
	1	−23.9	8.34**	0.55	−333.1	77.44**	−3.64**	0.96
	P	−35.2	8.67	0.69	−260.7	59.06**	−2.65**	0.94
Healthy	0	−56.2	10.25**	0.90	−151.3	31.60**	−1.12	0.95
	1	−51.7	12.07**	0.82	−250.8	56.57**	−2.34**	0.94
	P	−53.9	11.23**	0.87	−202.7	44.47**	−1.75**	0.96
b) D x T								
4, 5, 6		−4.2	2.27	0.20	30.4	7.92	0.68	0.27
8		53.0	−1.09	0.01	−57.3	31.31	−2.16	0.13
9		61.2	0.54	0.001	−309.5	109.60	−7.27	0.78
11		27.1	5.58	0.19	−202.8	73.23	−4.51	0.65
Healthy		−8.2	12.55	0.56	−180.8	63.38	−3.39	0.73

**Significant at P = 0.01.
x : age (years) after field planting.
Mg treatment — O: Mg_0; 1:Mg_1.
Y : expected yield at age x.
P = Pooled.

showed that the increase in the disease score was linear, and the rate of increase was found to be about 1.3 points every year. In the case of D × T palms, the initial score was found to be slightly less at 20 points only, but was later increasing at the rate of 1.5 to 1.8 points every year. The marginal differences observed for the regression coefficients (rate of increase) were perhaps due to the varying number of years for which the data have been considered.

c) Trend in the Yield During the Initial Years

The tall variety of coconut palm normally begins to bear in five- to seven-years after planting and thereafter it takes another five- to six-years to reach the stage of full productivity (Menon and Pandalai, 1958). In this study, the yield data for the first 13 years after field planting alone have been considered for West Coast Tall and 11 years for D × T palms. During this period, the yield of palms is expected to show a rising trend. In the linear regression model $y = a + bx$, the coefficient of x ("b") measures the slope of the line or the growth rate. In healthy West Coast Tall palms, the yield of nuts was increasing at the rate of 11.2 nuts per palm per year, during the period under reference, whereas in palms which contracted disease during the seventh year or earlier, the rate of increase was only 4.8 nuts per year. Compared to this, in palms which became diseased after initiation of flowering, the growth rate was 8.7 nuts. In the case of palms which contracted disease during the eighth to the tenth year, the linear regression line was not found to give a good fit. This was because the yield started declining by the tenth year, due to the initiation of disease during this period. Irrespective of the year of incidence of disease, palms receiving Mg treatment were found to show a higher rate of increase in yield, compared to that of the palms not receiving Mg treatment.

In the case of D × T palms, the year to year fluctuations in yield were more and no clear linear trend was seen for the yield in the initial years. However, in general terms it can be stated that in healthy palms the yield was increasing at the rate of 12.6 nuts, whereas in palms which contracted disease earlier, the rate of increase was less (2.5 nuts).

Since the yield of palms is affected once they contract the disease, an attempt was also made to describe the yield trend during the initial years by using a curvilinear regression model of the form $y = a + bx + cx^2$, where x is the age of the palm and y is the expected yield. In all cases, a better fit was observed, than in the linear model, as evidenced by the high R^2 values (Table 78.3). The increase in R^2 values was substantial in the case of palms which contracted disease in the eighth year or later. It is seen from the empirical relationships presented in Table 78.3 that though the rate of increase in yield was low in palms which contracted disease during the pre-bearing period, the rate of decline in yield was more rapid in palms which contracted disease in later years.

d) Loss in Yield

It was clearly seen that the palms which contracted disease during the later years, the cumulative yield was less, compared to that of healthy palms (Table

78.4). Magnitude of the loss was found to gradually come down, as the age at initiation of disease was increasing.

Though the D × T palms were giving higher yields, in relative terms, the loss in yield was comparable with that of West Coast Tall palms.

Table 78.4: Cumulative yield of nuts and loss in yield due to initiation of disease at different periods

Age (years) at initiation of disease	*No. of palms*	*10th year*		*12th year*		*14th year*	
		Cum. yield	*Loss (%)*	*Cum. yield*	*Loss (%)*	*Cum. yield*	*Loss (%)*
a) *WCT*							
3, 4, 5	23	57.8	68.5	122.8	64.0	188.7	61.2
6, 7	76	90.5	50.6	160.3	52.9	227.2	53.4
8, 9, 10	92	120.2	34.4	186.5	45.3	242.8	50.2
11, 12, 13	171	180.1	1.7	315.5	7.4	422.2	13.4
Healthy	172	183.3		340.7		487.3	
b) *D x T*							
4, 5, 6	10	65.2	88.3	103.3	85.7		
8	9	312.1	44.1	374.5	48.3		
9	40	488.2	12.6	525.9	27.4		
11	56	475.9	14.8	568.6	21.5		
Healthy	190	558.5		724.2			

e) Relationship Between Disease Intensity and Yield

A steady decline in yield was observed with increase in the intensity of disease, in all the years (Table 78.5). The linear regression model showed that the yield was declining at the rate of 10 to 13 nuts, in the different years, for every 10-point increase in disease index. In the years of high yield, the rate of decline was also found to be high. The diseased West Coast Tall palms were found to give, in general, about 45 per cent lesser yield compared to the healthy palms.

Similar results were obtained for D × T palms also. The average yield of palms ranged from 28 to 100 nuts during this period. The rate of decline in yield was also found to be higher, compared to West Coast Tall, and it ranged from six to 27 nuts in the different years. The annual loss in yield due to disease was around 60 per cent in the different years.

Jose Abraham *et al.* (1987) had also reported similar results. According to them, in cultivators' gardens, where the mean yield was around 25 nuts only, the rate of decline in yield was five nuts for every 10 point increase in index. Under well managed conditions, with an average yield of 53 nuts, this rate of decline was up to 13 nuts.

From the foregoing discussion it is clear that in palms which have contracted disease during the early years after planting, the flowering is not only delayed, but the yield of nuts is also affected. In addition to loss in yield, Cecil *et al.* (1984) have also reported that the disease caused about 12 per cent

reduction in copra weight per nut. Disease was also reported to reduce the percentage of plaitable leaves, the weights of whole nut, husked nut and husk, and oil content (Anonymous, 1985).

Table 78.5: Frequency distribution of palms on the basis of disease intensity and regression of yield on disease index

Disease index class	*1982*		*1983*		*1984*	
	No. of palms	*Mean yield*	*No. of palms*	*Mean yield*	*No. of palms*	*Mean yield*
a) *West Coast Tall*						
0	231	71.8	181	81.8	183	64.0
11–20	20	56.7	35	75.4	40	59.4
21–30	85	52.7	94	61.8	102	48.7
31–40	95	40.9	107	49.7	84	30.1
41–50	77	28.1	78	28.3	83	23.5
> 50	26	11.8	39	9.6	42	14.5
Tot. Dis.	303	39.5	353	46.3	351	35.4
		(45.0)		(43.4)		(44.7)
Pooled	534	53.6	534	58.3	534	45.1
Regression equation	$y = 75.4 - 1.07x$ $R^2 = 0.97$		$y = 91.1 - 1.34x$ $R^2 = 0.93$		$y = 69.0 - 0.97x$ $R^2 = 0.94$	
b) *D x T*						
0	247	72.9	191	128.9	191	36.8
11–20	19	43.3	40	56.7	22	11.4
21–30	29	27.9	59	58.6	68	17.5
31–40	15	21.3	20	38.2	24	7.6
41–50	0	–	0	–	5	11.4
Total Dis.	63	31.0	119	54.5	119	14.1
		(57.5)		(57.7)		(61.7)
Pooled	310	64.4	310	100.3	310	28.1
	$y = 72.0 - 1.66x$ $R^2 = 0.99$		$y = 121.5 - 2.74x$ $R^2 = 0.92$		$y = 31.2 - 0.60x$ $R^2 = 0.71$	

Note: Figures in the parantheses denote the loss in yield (%) due to disease.
x : mean disease index. y : mean yield of nuts.

ACKNOWLEDGEMENT

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IN VITRO INHIBITION OF *THIELAVIOPSIS PARADOXA* BY MYCOFLORA FROM COCONUT BASIN

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Stem bleeding, an important debilitating disease of coconut is caused by *Thielaviopsis paradoxa* (de Seynes) Von Hohnel, a soil-borne weak pathogen. Soil environment offers scope for manipulation and can be made use of in managing the disease by enriching the mycoflora antagonistic to *T. paradoxa*. The present study was taken up with a view to identifying potential biocontrol agents against *T. paradoxa* in the coconut basin.

Soil samples representing 0 to 25 cm depth were collected separately at 60 days intervals from the root zones of stem bleeding affected West Coast Tall (WCT) coconut palms under various treatments. The soil samples were air dried, sieved and plated (0.5 g) on soil extract agar by soil plate method (Warcup, 1950).

Three replicates were maintained for each sample. The colonies as and when appeared were transferred to fresh potato dextrose agar (PDA) slants. The fungi were identified and used for *in vitro* interaction studies against a virulent isolate of *T. paradoxa*. Discs of 5 mm diameter cut from the periphery of 48-hour old cultures of candidate fungi and *T. paradoxa* were used for interaction studies by the "direct opposition method" of Webber and Hedger (1986). Simultaneous and sequential (A and B) inoculation techniques were followed. In sequence-A, *T. paradoxa* was inoculated 12 hours before the candidate fungus and in sequence-B, candidate fungus was inoculated 12 hours before *T. paradoxa*. In simultaneous type, discs of both candidate fungus and *T. paradoxa* were placed at the same time. In all these cases, a distance of 3.5 cm was maintained between the discs on PDA medium and the petridishes were incubated at 27 ± 2°C and were examined at 24 hour intervals. Observations included the growth of *T. paradoxa* towards the test fungus and *vice versa* and

also in the opposite direction as check. The measurements were used for finding out the percentage of inhibition of *T. paradoxa* by candidate fungi.

Observations recorded after 24 hours (Table 79.1) of inoculation showed that *Trichoderma viride*—isolate 2 exhibited maximum percentage of inhibition (42.8) in sequence-B type of inoculation compared to simultaneous (20) and sequence-A (10) inoculation. This could be due to the fact that candidate antagonistic fungus obtained additional time to establish itself and to get ready in defence to face the pathogen. Among the species of *Trichoderma* recognised as antagonists against *Ceratocystis* sp. and *T. paradoxa, T. viride* is the best (Webber and Hedger, 1986; Gowda, 1987). The present findings also confirm this observation. *Rhizopus stolonifer, Thielavia terricola, T. koningii, T. viride*—isolate 1 and *T. viride*—isolate 2 inhibited *T. paradoxa* population after 15 days of observation. All these types of interactions were included in the 'O' type interaction category. Information in respect of *R. stolonifer, T. terricola* and *T. koningii* are being recorded for the first time.

Table 79.1: Percentage inhibition of *T. paradoxa* (24 hours after inoculation) (mean of three replications)

Fungi tested	*Sequence - A inoculation*	*Simultaneous inoculation*	*Sequence - B inoculation*
Trichoderma viride –2	10.0	20.0	42.8
T. viride —*1*	10.0	19.0	33.3
Rhizopus stolonifer	9.0	14.2	28.5
Trichoderma koningii	4.7	9.0	20.0
Thielavia terricola	*	*	*

* *Thielavia terricola* showed inhibitory effect only after 48 hours. At this time, *T. paradoxa* growth covered the control (check) side so that the percentage of inhibition could not be measured.

After 15 days of observation, *Aspergillus fumigatus, A. terreus* and *Fusarium solani* exhibited mutual inhibition with *T. paradoxa* and were designated as 'MC' type of interaction. The remaining five fungi, namely, *Paecilomyces* sp., *Absidia* sp., *Penicillium pinophilum, Gongronella butleri* and *Cunninghamella elegans* freely intermingled with *T. paradoxa* and were included in the 'I' type interaction category.

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CHEMICAL CONTROL OF STEM BLEEDING DISEASE OF COCONUT

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Stem bleeding disease of coconut caused by *Thielaviopsis paradoxa* is widely prevalent in coconut growing states in India. The pathogen has been reported to be very sensitive to two systemic fungicides, namely, carbendazim (Bavistin) and tridemorph (Calixin) under *in vitro* conditions (Anonymous, 1988). The objectives of the present studies were to study: (i) suitable systemic fungicides for the control of the disease, (ii) the translocation and persistence of these chemicals in coconut, and (iii) the effect of these fungicides on potential antagonists of stem bleeding pathogen.

Field control trials involving Bavistin and Calixin applied through different methods were taken up in stem bleeding affected gardens to evolve an effective control schedule for this disease. The methods of application consisted of root feeding, stem injection, band application and soil drenching. Bavistin and Calixin were applied to the diseased palms thrice a year (January, June and October) through root feeding and stem injection (100 ml of 2 per cent or 5 per cent solution/palm in each case), band application (20 ml of 10 per cent solution/palm applied after chipping bark tissues) and soil drenching (40 l of 0.1 per cent solution/basin). The observations on lesion size, stem tapering and yield recorded before (1989) and after (1991) the experiment were used in calculating the disease index (Mathew *et al.*, 1989). It was observed that treatments with 100 ml of 5 per cent Bavistin/palm through root feeding and 100 ml of 5 per cent Calixin/palm through stem injection were better in reducing the rate of spread of the lesion on the stem. The mean disease indices at the end of the experiment were 7.38 and 7.00 in plots treated with Bavistin and Calixin, respectively compared to 14.94 in control plots. Yields of the palms treated with Bavistin 5 per cent (root feeding) and Calixin 5 per cent (stem injection) increased from 26 nuts/palm/year to 55 and 18 to 50, respectively.

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The study on translocation and persistence of the two test fungicides in coconut stem was undertaken using 30 year-old palms. The fungicides were applied through root feeding. Bavistin at the rate of 0.5 g/palm and 10 g/palm dissolved in 100 ml of 0.5 N HCl and Calixin at the rate of 2 ml/palm, 5 ml/palm and 10 ml/palm in 100 ml water were used for the study. Stem tissue samples were collected from 1, 2 and 3 m heights of the treated palms at regular intervals and assayed for residues using bioassay method (Anonymous, 1988; 1991). Nut water samples from four-, six- and 10-month-old nuts from the palms were also assayed similarly. The residues of carbendazim were detected only on the feeding side of the trunk up to 2 m height for a period of 180 days when Bavistin was applied at the rate of 10 g/palm. Tridemorph residues were detected from both feeding and opposite sides up to 3 m height for a period of 45 days in the palms treated with Calixin at all three concentrations (2, 5 and 10 ml/palm). Thus it is evident that tridemorph is comparatively more mobile in coconut stem than carbendazim. No detectable levels of residues of these two fungicides were found in the nut water samples of the treated palms.

The effect of carbendazim and tridemorph at different concentrations on the growth of *Trichoderma viride* and *T. harzianum* on PDA was studied using poisoned food technique. Carbendazim was found to be fungicidal to *T. harzianum* and fungistatic to *T. viride* at 1000 ppm whereas tridemorph was fungistatic to both these fungi even at 5000 ppm. Hence it is safe to use tridemorph for soil drenching at 1000 ppm.

Taking all the above factors into consideration, tridemorph (Calixin) is a better fungicide for use in the integrated disease management of stem bleeding disease of coconut.

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EARLY DETECTION OF *GANODERMA* INFECTION IN COCONUT AND ARECANUT

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Detection of 'root rot' or *anabe* disease infection in its early stages is difficult in coconut because of the time lag between infection and expression of visible symptoms. At present, the disease is diagnosed only on the basis of visual symptoms like yellowing of leaves, wilting and in advanced stages gummosis at the basal portion of the trunk. This often results in difficulty in adopting control measures at the appropriate time. As such, the necessity for detecting the disease in its early stages was felt. Kumar (1970) has, outlined some of the techniques for obtaining antigen specific antibody for detecting plant pathogenic fungus.

The culture of *Ganoderma* used in the study was isolated from infected roots of coconut palms and was grown for 40 to 45 days in Waksman's liquid medium at room temperature (28 ± 2°). The mycelium was retained by filtering and dried at 40°C and 600 to 700 mg of mycelium was ground in 15 to 20 ml physiological saline (PBS) and filtered through seitz filter. The filtrate was made up to 20 ml and this formed the antigen. Two ml of antigen was emulsified with equal volume of Freund's complete adjuvant (Difco) and injected intramuscularly thrice a week in 1.5 to 2 kg albino rabbits. The rabbits were bled after 12 days of last injection when the agglutination of the serum was at its maximum. The serum was separated by slow speed centrifugation (7000 rpm). Equal volume of antiserum + 0.15 m NaCl were mixed and to it, saturated solution of ammonium sulphate (3.2N) pH 7.0 was added drop by drop in quantity equivalent to the total volume of the mixture. The suspension was centrifuged at 6000 to 8000 rpm for 15 to 20 minutes. The resultant precipitate of antibodies was dissolved in 2 ml tris-HCl buffer (pH 7.2) and reprecipitated until the precipitate was absolutely white. Then the pH of the

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solution was raised to 8.5 with 0.5 m carbonate-bi-carbonate buffer (pH 9.0) before stirring it with Fluorescein Isothiocyanate (FITC) which was added to the solution at the rate of 50 mg per g of protein for four to five hours. The preparation was then eluted with Tris HCl buffer on the sephadex G-25 column to remove unconjugated dye.

Root sections of disease affected, apparently healthy and healthy coconut palms were cut and were flooded with one to two drops of FITC conjugated antiserum and left in the moist chamber for three to four hours at room temperature. After draining the unconjugated antiserum, the sections were washed with Tris-HCl buffer and mounted on buffered glycerin and examined under fluorescence microscope. The root sections of healthy palms showed pale green fluorescence in the xylem and phloem cells. However, the apparently healthy and diseased root sections showed additional apple green fluorescence in the xylem and phloem cells. No such intense green fluorescence areas could be made out in the xylem and phloem cells of healthy root sections. Kumar *et al.* (1975) observed apple green fluorescent dots in the greening affected citrus leaf sections when they were stained with FITC conjugated antiserum. Out of the samples examined 60 to 62 per cent of the root samples showed *Ganoderma* infection and the rest were found to be healthy (Table 81.1). The first report on the use of fluorescent antibody technique for detection of plant pathogenic fungi is by Beno and Allen (1964) on *Puccinia sorghi* and on *Polyporus tomentosis* by Kumar and Patton (1964). Price (1970) could successfully stain conidia of *Spherotheca pannosa* in a mixture of conidia and the fungus.

Table 81.1: No. of root samples examined for *Ganoderma* infection

Host	*Total No. of samples examined*	*No. of root samples showing disease infection*	*No. of root samples that did not carry the infection (healthy)*
1. Coconut	50	31	19
2. Arecanut	50	30	20
Total	100	61	39

The work described here was carried out as a necessity to investigate the disease infection in question, as the routine cultural methods failed to detect the fungus. Since the causal organism has a long incubation period, a technique of this nature which is very sensitive in detecting root infections by *Ganoderma* even before visible symptoms can appear, will be very much helpful to adopt disease control measures.

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STUDIES ON THE PHYSIOLOGY OF *COCOS NUCIFERA* PALMS AFFECTED BY LETHAL YELLOWING IN MEXICO

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ABSTRACT

Coconut (*Cocos nucifera*) affected by lethal yellowing showed a progressive decrease in noon stomatal conductance as the disease develops. This decrease was observed in fully developed young, middle aged and old leaves. Conductance dropped to a minimum in early stages of the disease, before leaves started showing yellowing. HPLC analysis of leaf pigments showed a decrease in the content of carotenoids and chlorophylls, but the rate of decrease was greater for chlorophylls. No qualitative differences were evident between the pigments of asymptomatic and diseased palms. The photosynthetic rate was found to decrease as the disease develops. This decrease appears after stomatal conductance drops and before any important changes in pigment contents are observed. Water potential and its components were measured and no changes were observed in the early stages of the disease. Amino acid content in leaf increased whereas protein content decreased in advanced stages of the disease. Abscissic acid content in leaf and the capacity of leaf tissue to form ethylene were found to increase in the early stages of the disease. Some of the symptoms of the disease were reproduced by treatment with an ethylene releasing agent. The results are discussed in view of the idea that as part of the mode of action of the causal agent to lethal yellowing there is a hormonal imbalance which in turn promotes other physiological alterations.

INTRODUCTION

Lethal yellowing (LY) is a devastating disease which affects palms and has been associated with mycoplasmalike organisms (Beakbane *et al.*, 1972; Heinze *et al.*, 1972; Plavsic-Banjac *et al.*, 1972). Palms affected by LY die within months (Dabek, 1974; 1975; Grylls and Hunt. 1971) and once the disease appears in a certain area, it may spread rapidly. Diseased coconut palms show symptoms such as premature nut fall, inflorescence necrosis, leaf yellowing and

root damage. Initially, older leaves and inflorescences are affected and as the disease progresses the younger structures are also affected. Previous studies have shown that LY diseased palms had lower noon stomatal conductances and a greater stomatal closure (Eskafi *et al.*, 1986). This in turn may affect other functions such as water transport and photosynthesis. Xylem transport has been already shown to be strongly reduced in palms with LY (Eskafi *et al.*, 1986). Dabek and Hunt (1976) reported evidence suggesting alterations in the contents of gibberelins, cytokinins and auxins in diseased palms. The authors proposed that a hormonal imbalance could be associated with the appearance of symptoms. This paper reports a study on physiological alterations of coconut palms with LY and evaluates the hypothesis that at least some of the symptoms result from hormonal imbalance.

MATERIALS AND METHODS

Biological material: *Cocos nucifera* Atlantic Tall variety about 12 years old from locations in Yucatan, Mexico. Palms with different stages of development of the disease were studied according to the classification reported by McCoy (1983). Asymptomatic palms (0), palms showing symptoms are then rated as 2–9 as the disease progresses. Results presented are the averages of the analysis of individual palms. For each study at least three to five palms were analysed.

Stomatal conductance: Calculated as the inverse of stomatal difussive resistance which was recorded *in situ* in the abaxial surface of intact fronds with a steady state porometer LICOR 1600.

Water potential: Determined *in situ* with a pressure chamber PMS Ins. Co. Pinnae were cut close to the base. The cut end was wrapped in a polythene bag and placed immediately into the chamber.

Photosynthetic rates: Measured *in situ* in intact fronds using portable LICOR LI-6200 photosynthesis system.

Pigment analysis: Acetone extracts of leaf tissue were analysed by HPLC using a C_{18}reverse phase column and gradient elution, methanol in water from 15 to 100 per cent in 15 minutes.

Abscisic acid analysis: Lyophilised tissue was extracted and analysed by radioimmunoassay according to Quarrie *et al.* (1988).

Ethylene formation in leaf discs: Discs (9 mm) were placed in a buffered solution (pH 6) containing 1—aminocyclopropane-1-carboxylic acid within sealed vials. Gas samples were taken from the atmosphere within the vials and analysed by gas chromatography using a Porapak 80/100 column.

Amino acid determination: Leaf tissue was extracted with water and the extracts washed with chloroform. The free amino acid content was measured according to Cocking and Yemm (1954). Arginine analysis was carried out by TLC/densitometry as reported by Oropeza and Sánchez (1990).

Protein determination: Leaf tissue was extracted with 10 per cent TCA. After centrifugation the proteins are recovered from the pellet with a buffered solution (pH 6.8) and measured according to Lowry *et al.* (1951) as modified by Markwell *et al.* (1978).

Exogenous ethylene treatment: Plants were applied at the stem with a 25 per cent solution of the ethylene-releasing agent ethrell through a hole provided with an adaptor to take a syringe.

Antibiotic treatment: Coconut palms at stage 2 (McCoy, 1972), were treated at the stem with 2 g (in 30 ml H_2O) of either penicillin-G or oxytetracycline-HCl through a hole provided with an adaptor to take a syringe.

RESULTS

Stomatal behaviour: Stomatal conductance (Gs) in asymptomatic coconut palms showed a diurnal fluctuation (Fig. 82.1) from 4 cm s^{-1} (day) to 0 cm s^{-1} (night). As the disease developed Gs decreased during the day and in stages 4 and 6 remained close to 0 cm s^{-1} during most of the day. Figure 82.2 shows the change in noon conductance as the disease progresses. Noon Gs was measured in fronds at the top, the middle and at the base of the canopy of diseased palms and in all cases it was nearly 0 cms^{-1}.

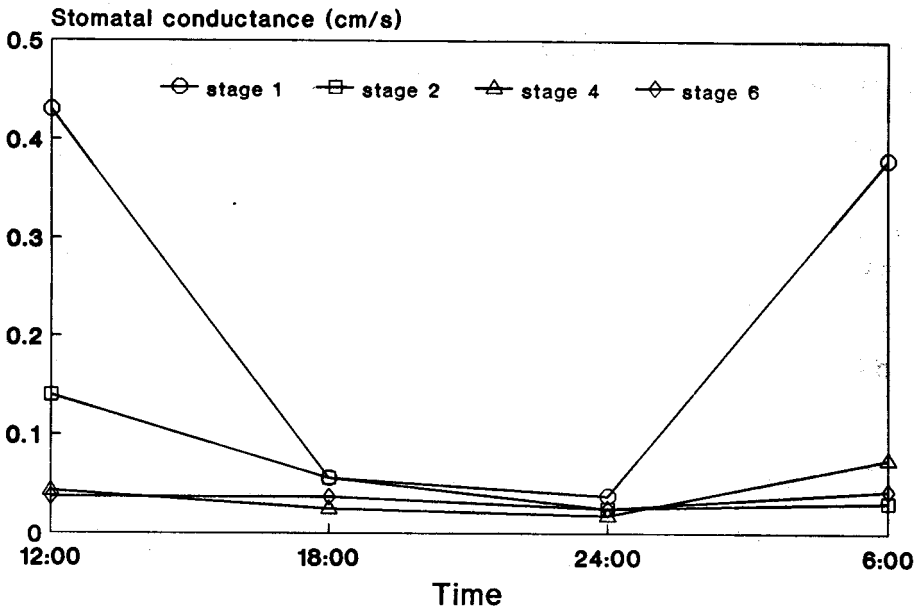

Fig. 82.1: Diurnal stomatal conductance in coconut palms at different stages of LY development.

Antibiotic treatment: Diseased palms treated with penicillin-G developed symptoms similar to untreated diseased palms, whereas those treated with oxytetracycline-HCl not only stopped the development of symptoms but also showed remission, as previously reported by McCoy (1972). In penicillin-G treated palms Gs was found to drop as low as in untreated palms, whereas in those treated with oxytetracycline-HCl it was about three times greater (Fig. 82.3).

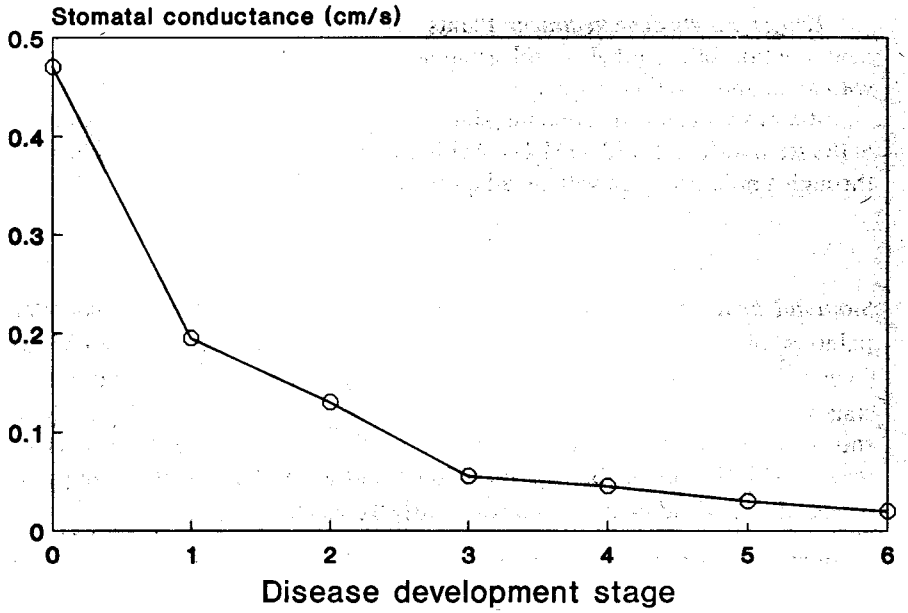

Fig. 82.2: Noon stomatal conductance in coconut palms at different stages of LY development.

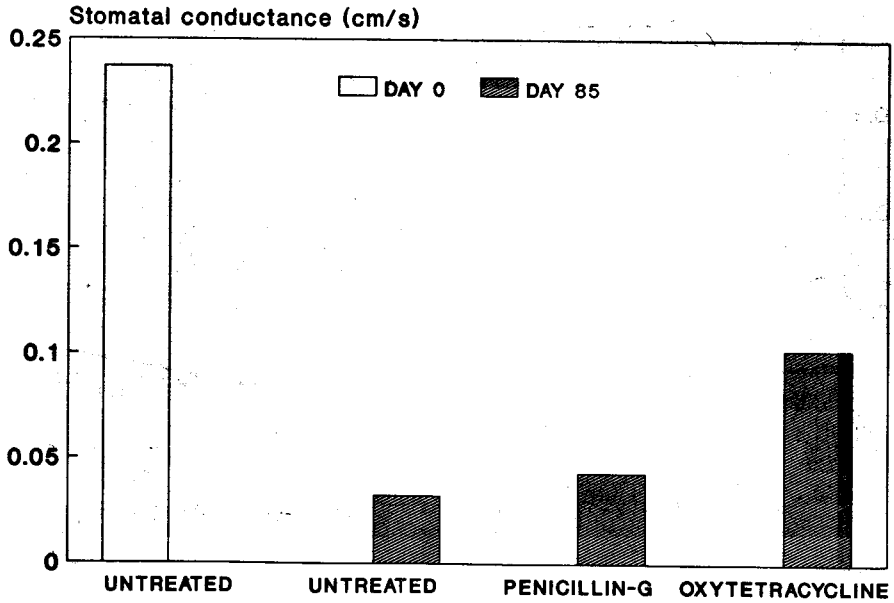

Fig. 82.3: Effect of antibiotics on the stomatal conductance in coconut palms at different stages of LY development.

Photosynthesis: The photosynthetic rate of asymptomatic palms was about 9 μmol m^{-2} s^{-1}. In the early stages of the disease (1 and 2) the rate did not show significant changes, whereas at stage 4 it dropped to 0 μmol m^{-2} s^{-1}.

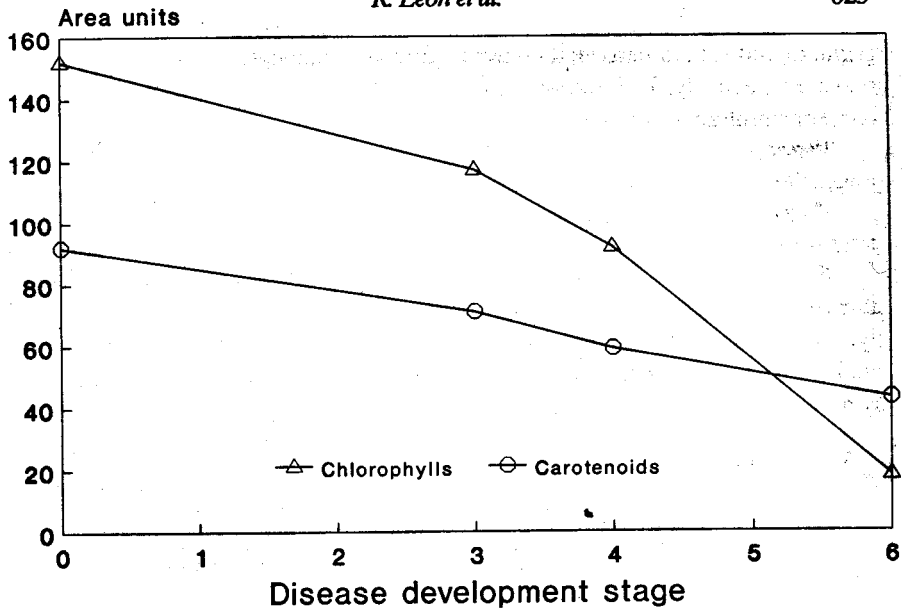

Fig. 82.4: Leaf pigment content in coconut palms at different stages of LY development. Results expressed per dry weight.

Pigments: Chromatography analysis of leaf pigments showed no qualitative differences between asymptomatic and diseased palms. Total contents of both chlorophylls and carotenoids decreased steadily as the disease progressed (Fig. 82.4). However, chlorophyll content decreased more rapidly.

Amino acid and protein contents: Arginine, total amino acid and protein contents of leaves did not change significantly in stages 0–3. Afterwards,

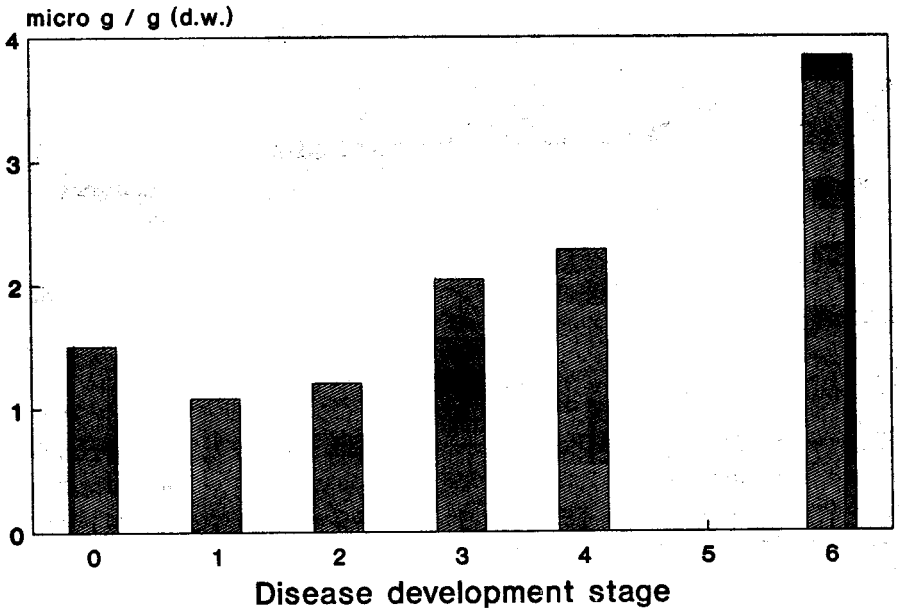

Fig. 82.5: Leaf ABA content in coconut palms at different stages of LY development.

arginine and total amino acid contents increased steadily up to five and three times, respectively. This could be the result of protein hydrolysis since protein content simultaneously decreased four times.

Water potential: No change occurred in water potential of leaves in early stages 0–4. Then, it decreased from −1.2 to −2 MPa at stage 5.

Abscisic acid (ABA) content: Leaf content did not show an increase at stages 0–2. Then, it increased up to two times at stage 6 (Fig. 82.5).

Ethylene formation in leaf discs: The ability of leaf discs to form ethylene increased in the early stages of the disease showing a peak at 1–2 (Fig. 82.6). Symptomless palms which developed symptoms within the length of the analysis had a greater ability to form ethylene than those which did not develop symptoms.

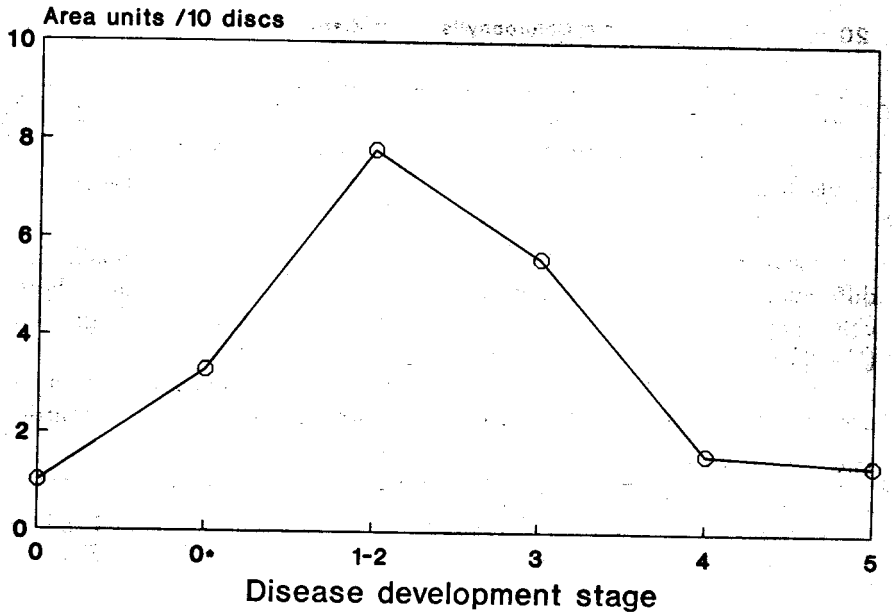

Fig. 82.6: Formation of ethylene by leaf discs from coconut palms at different stages of LY development. (*) Denotes asymptomatic palms which showed symptoms within four weeks after sampling.

Ethrel treatment: Symptomless palms treated with ethrel developed some LY symptoms. They showed nut fall and yellowing of basal leaves.

DISCUSSION

The results presented here show that coconut palms with LY had a lower noon stomatal conductance than symptomless palms confirming previous reports (Eskafi *et al.*, 1986). This occurred in all fronds across the canopy. The plants progressively lost their diurnal fluctuation and therefore as early as at stages 2–3 stomatal closure was spread from the base to the top of the canopy. This altered stomatal behaviour must be severely affecting other plant functions,

which in turn, may result in the appearance of other symptoms. Eskafi *et al.*, (1986) have already reported that water transport is strongly affected in palms with LY. The authors concluded that this was the result of stomatal closure. Also, as shown here, photosynthesis was strongly affected. Although the loss of leaf pigments could also affect the photosynthetic rate, this loss occurred more slowly than the decrease in stomatal conductance. On the other hand, even though enzymatic limitations cannot be ruled out, they are unlikely to be important during the early stages of the disease. No change in leaf protein content was observed during the early stages, which suggests no changes in at least the enzyme RUBP carboxylase, a major leaf protein constituent and a pace limiting factor for photosynthesis. Therefore, our results support stomatal closure as the main cause for the decrease in the photosynthetic rate. Furthermore, that stomatal closure is a central event leading to the appearance of other symptoms is supported by the effect of oxytetracycline treatment, stopping symptom development while reducing the drop in stomatal conductance.

At least some of the symptoms, such as stomatal closure, nut fall and leaf senescence could be explained by a hormonal imbalance. Fruit drop has been shown to be controlled by ethylene (Sexton *et al.*, 1985) and senescence by ethylene (Matoo and Aharoni, 1988) and ABA (Nooden, 1988). Stomatal closure could be promoted by ABA but also by a drop in leaf water potential (Zhang *et al.*, 1987). Our results showed no changes in the leaf water potential during the early stages of the disease. In contrast, the leaf ABA content increased from the early stages. However, at stages 1–2 there was no apparent increase in ABA content. Therefore, an increase in leaf ABA content could only partially explain the drop in stomatal conductance. Whether there are other factors (for example, changes in other growth regulators) causing LY stomatal closure or, as in the case of water stress-induced stomatal closure in *Commelina communis* (Zhang *et al.*, 1987), the occurrence of a epidermis-localised ABA increase, remains to be determined. On the other hand, the increase in ABA content started earlier than the chlorophyll and protein loss, characteristic symptoms of leaf senescence. Therefore, ABA (in addition to ethylene — see below) could be mediating the LY-induced leaf senescence. An involvement of ethylene in the development of the disease is suggested by the effects of ethrell treatment, promoting the occurrence of LY characteristic symptoms (nut fall and leaf yellowing) and by the greater ability of diseased leaf discs to form ethylene, which started to increase earlier than nut fall and leaf senescence.

The results presented here are consistent with the idea that as part of the mode of action of the causal agent of LY, there is a hormonal imbalance which promotes physiological changes. Some of these, such as stomatal closure, may be central to the development of the disease, altering functions such as water transport and photosynthesis. Some of the changes, for instance protein loss and increased availability of amino acids (including arginine, which may be involved in the susceptibility to LY, McCoy, 1983), may favour the growth of the causal agent and further decay of the diseased palm.

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FOLIAR YELLOWING AND ROOT ROT IN COCONUT SEEDLINGS CAUSED BY *PHYTOPHTHORA* SP.

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The establishment and subsequent growth of coconut seedlings transplanted in the field depends upon the site and drainage, especially in the areas prone to water logging. Association of root rot of coconut with *Rhizoctonia bataticola* (Menon and Nair, 1952) and *Phytophthora palmivora* (Harris *et al.*, 1984) and *Radopholus similis* (Mathen *et al.*, 1970) is known. Severe foliar yellowing and death of four- to five-year-old seedlings was noticed in water logged areas at Keechery village in Kannur district of Kerala during 1976, and in subsequent years. The root system of affected seedlings showed a varying degree of root rot.

The roots in the early stage of infection were washed thoroughly and plated on potato dextrose agar (PDA) and also Pimaricin-Vancomycin PCNB-Hymexazol (PVPH) medium (Tsao and Guy, 1977). *Fusarium* sp. and also *Phytophthora* sp. were isolated on PDA and *Phytophthora* sp. alone was isolated from PVPH medium. Isolate of *Phytophthora* sp. produced fluffy growth on carrot agar medium and abundant sporulation in water under continuous light. *Fusarium* sp. produced good growth and sporulation on PDA. Four-month old coconut sprouts (WCT) were transplanted into cement tubs of 75 cm diameter filled with nursery mixture of 3:1:1 (soil, sand, FYM). When the seedlings were about six months old, potted plants were inoculated with 250 ml of mycelial suspension of *Phytophthora* sp. and *Fusarium* sp. separately at the rate of six plants per isolate. The plants were given regular irrigation and were incubated for two months after inoculation.

The sprouts were pulled out two months after inoculation and observed for symptoms. Typical root rot symptoms were noticed in sprouts inoculated with *Phytophthora* sp. and mild foliar yellowing was noticed. However seedling

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death did not occur. There was a conspicuous absence of infection in *Fusarium* inoculated sprouts, thereby implying its non-pathogenic nature.

Though *Phytophthora* sp. could not cause death of the seedlings during the period of observation, typical foliar yellowing due to root rot was observed. Water logging under field conditions might have accentuated the root rot leading to death of the seedlings. Recent observations in the area showed poor bearing and foliar yellowing in coconut to varying degrees.

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HARVEST AND POST HARVEST TECHNOLOGY

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COCONUT BASED INDUSTRY IN INDIA

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ABSTRACT

About 55 per cent of 9,200 million coconuts produced is consumed in India in the raw form and only 35 per cent is converted to copra for subsequent oil milling. The rest is used for seed production, tender nuts, desiccated coconut etc. Copra production is done by traditional methods of sun-drying mostly as household and cottage scale activities throughout Kerala state. Though oil milling is done mechanically using rotaries and expellers, it is also a small scale enterprise barring a few large units. Coconut oil production has been stagnating around 0.2 million t, but has shown an upward trend during the last couple of years. Except a small quantity of desiccated coconut (7000 t/year) no other value added products of commercial significance are made from the fresh kernel. Coir sector employs about 0.4 million people producing about 0.2 million t of coir products and is the only coconut product which earns foreign exchange (Rs. 470 million). About 300,000 coconut palms are tapped mostly for fermented toddy which also constitute an important activity of economic importance and employment potential. Though coconut palm finds varied uses, its potential is not exploited for want of resources for technology upgradation and product diversification.

INTRODUCTION

Coconut in India is cultivated only in 0.35 per cent of the land area, but the demand for coconut products is spread over the entire country. The per capita availability of coconut is a meagre 10 nuts for India as compared to 225, 145 and 55 nuts for the Philippines, Sri Lanka and Indonesia, respectively. Low availability and high demand coupled with protected market favours high prices of coconut products in India. Added to this, violent fluctuations in the prices of coconut products have imposed great constraints on the development. Coconut industry in India therefore has not been a growth oriented one. The uneconomic size of the holdings could further explain the problems associated with the coconut industry. With a total production of about 9,200 million nuts (1989–90) coconut culture and industry sustains nearly 10 million people in gainful employment. Coconut contributes six to seven per cent to the

edible oil pool, besides being the only source of lauric fat in the country. The estimated annual value of coconut palm products in the country is over Rs. 36,000 million; export earnings being less than Rs. 500 million from coir products only.

Major economic activities based on coconut, are copra processing and oil milling, coir processing and toddy tapping. With about 2.5 million people engaged in the culture and processing of coconut in Kerala, the economic prosperity of the state is closely linked with the fluctuating fortunes of coconut industry.

Production and Growth

Both area and production of coconut showed a moderate increase in the country from 1950 to 1980. During this period, while the area under coconut increased from 0.60 to 1.0 million ha, production increased from 3,300 to 5,600 million nuts with an average annual growth of 2.5 per cent. However, the last decade witnessed a phenomenal increase in total production and area. While the area increased by 50 per cent, the production registered an impressive 65 per cent (5,600 to 9,200 million nuts). The growth was particularly remarkable during the last three years of the decade when the production shot up by about 3000 million nuts. During the last decade, particularly in the latter half, productivity also showed an upward trend, after stagnation for a long period. There has been a regional imbalance in the growth and productivity among coconut growing states. There has been a shift from the traditional coconut growing state of Kerala to Tamil Nadu. In area, production and productivity Tamil Nadu exhibited remarkable growth trend with an annual yield of 10,000 nuts/ha, almost double the productivity of Kerala. Better agricultural practices, irrigation and absence of major diseases could be the reasons for the success of coconut culture in Tamil Nadu.

Utilisation

Of the total coconut available in India, about 55 per cent go for the domestic consumption in the raw form. Another 40 per cent is used for copra, desiccated coconut, seeds etc. and the remaining 5 per cent is consumed as tender nuts for water. Maximum consumption of raw nuts is in the state of Kerala, with 200 to 300 nuts per household per year.

Of the 40 per cent nuts available for copra making, roughly 34 per cent is converted into milling copra and 6 per cent into edible copra. A small percentage of mature nuts (6 per cent) is converted into edible copra, which finds use in areas where fresh nuts are not available. About 1.6 per cent of the mature nuts are processed for desiccated coconut.

The milling copra is finally subjected to oil milling to produce coconut oil. About 2,950 million nuts (33 per cent) were processed into copra for further oil milling and produced 290,000 t of oil in 1989–90. Only 30 per cent of the oil is used for edible purpose. The remaining is utilised for non-edible uses in toiletries, cosmetics, soap making etc. The break up of utilisation of coconut as percentage, has remained more or less the same for the last several years. Coconut oil being the only commercially available lauric fat in the country, its

utilisation in the non-edible sector is bound to increase as the demand for toiletry, soap etc. goes up with population growth.

Commercial Products

Conversion of coconut into copra and coconut oil is the major processing activity developed in India. Except husk, no other by-products are processed commercially.

Edible Copra

Copra that is consumed directly and is not meant for oil milling is called edible copra. It is made in the ball form and in the cup form.

Ball copra is made by sorting fully matured unhusked nuts for a period of eight to 12 months on a raised platform usually made of bamboos inside a shed. During this period the water gets absorbed into the kernel which eventually dries up and gets loosened from the shell.

Edible copra is also made from fully mature nuts in the form of cups. For cup copra the quality standards are based on grades by traditional methods and are known in Kerala markets by 'Rajpur', 'Malathi', 'Dilpasant' and 'White'. Moisture content should not be more than 7 per cent. Production of edible copra is about 50,000 t per year and fetches a premium price over milling copra.

Milling Copra

Production of milling copra and oil milling are the major commercial activities based on coconut. Kerala accounts for 95 per cent of copra produced in the country. About 65 per cent of the nuts produced in Kerala are converted into copra. The trend is similar in Lakshadweep and the Andaman and Nicobar Islands. Production of copra therefore fluctuates with the total nut production in Kerala State.

Copra processing is a widespread activity employing more than 20,000 persons in about 10,000 units spread throughout rural Kerala. Copra making is a simple process involving dehusking, splitting the nuts into two halves and sun-drying. It takes about four to seven days depending on sunshine to dry copra to the desired moisture level. Improved drying methods to reduce the duration of drying are not popular yet due to economic reasons. Indirect smoke dryers that make use of husk and shell as fuel could bring down the drying time to 36 hours for capacities ranging from 100 to 1000 nuts. Dryers are slowly finding acceptance.

Quality copra is produced in Kerala, Lakshadweep and the Andaman and Nicobar Islands. In Kerala, about 6,800 nuts are required to produce 1 t of copra, whereas 8000 to 9000 nuts are required in other states. In the Philippines 4,500 nuts yield 1 t copra and it is 5000 nuts in Indonesia and Sri Lanka. Again, the reasons for this could be a smaller size of nuts which is the varietal characteristic of West Coast Tall variety widely grown in Kerala.

Oil Milling

Though copra production is concentrated in Kerala, oil milling is done in other states also due to the fact that the machineries used for copra milling are

common for other oilseeds that are produced in those states. Only about 50 per cent of the copra produced in Kerala is crushed locally leaving the remaining for interstate trading. The other states involved in copra milling are Maharashtra, West Bengal, Tamil Nadu, Andhra Pradesh, Karnataka etc.

Expellers are used for comparatively large scale milling. Usually two expellers constitute one unit, in order to facilitate two-stage crushing for maximum oil recovery. The steps involved are: copra drying, cleaning, cutting or disintegration, conditioning, feeding the expeller, first extraction, second extraction, oil filtration and oil storage. Extraction of oil in the expeller takes place within a perforated steel cage by means of a steel shaft with spiral worms driven by a geared motor. As the copra is carried from one end to the other end of the expeller, it is progressively subjected to increasing pressure resulting in expression of oil through the perforations. The residual cake is expelled through the end of the expeller having a cone assembly. Usually two-stage pressing is practised. In the first pressing at lower pressure about 50 per cent of the oil is expelled. The residual cake obtained is conditioned and passed through the second expeller adjusted at a higher pressure. The extraction efficiency by this way could be 95 to 97 per cent. The crushing capacity could vary from 3 to 100 t per day depending on the number of units installed. Larger mills are equipped with facilities for mechanical handling, steam heating (conditioning) etc. The oil collected in the tanks is pumped to filter press to obtain clear oil.

Power driven *'chekkus'* or rotaries are popular for lower capacity operations and are more decentralised. In principle they are similar to the traditional *'chekkus'* but both the pestle and mortar are made of iron and are spinning in opposite directions, powered by an electric motor. Rotaries are worked in pairs and the capacity of the rotary mill may vary from 2 to 3 quintal of copra per day. The dried copra is cut into pieces and fed to the rotary mill. About 1 kg of gum acacia is used for every quintal of copra to facilitate the extraction of oil and to bind the cake. The oil obtained is kept in settling tanks for a few days to permit settlement of fine particles and dirt by gravity. The extraction efficiency is about 90 to 92 per cent, which is slightly lower than that of an expeller.

Compared to expellers, rotaries require less capital investment, are easy to maintain and more amenable to lower capacities. The average product recovery is 62.5 kg oil and 35 kg cake for rotary mill and 64 kg oil and 32 kg cake for expeller mill from 100 kg copra. However, the basis adopted in all the mills for fixing the purchase price of milling copra is the extraction of 62.5 kg oil and 35 kg cake from 100 kg copra. The difference is treated as a process loss.

In India, the installed capacity for copra crushing is about 1000 t per 8 hours; equally distributed between expellers and rotaries. Considering two-shift operations and 300 working days per year the annual installed capacity is around 6 lakh t copra. The production of copra being around 4 lakh t as the maximum in the recent years, the overall capacity utilisation is not more than 60 per cent assuming that these mills are exclusively used for copra crushing. The distribution of the milling units indicates that most of the rotaries for

copra crushing are located in Kerala whereas more expellers are used in other states for the purpose.

Solvent extraction is employed only for copra cake to recover the residual oil. However bulk of the coconut cake is marketed for direct use as cattle feed leaving only a small quantity for solvent extraction. It is estimated that, of the 1.25 lakh t of cake available, not more than 40,000 t are used for solvent extraction, yielding about 3000 t of oil per year.

Quality of Copra and Oil

Compared to other edible oils, coconut oil is more prone to quality deterioration due to short and medium chain fatty acids content of coconut oil. FFA content of the oil is the main criteria for fixing the price, and every point rise in the FFA content results in price reduction. Drying copra to a moisture content less than 6 per cent and regulating the moisture content of the oil below 0.2 per cent level prevents quality deterioration during storage and handling. There are quality standards for coconut oil as prescribed by the Bureau of Indian Standards (BIS) and AGMARK. Coconut oil for edible purpose should meet the statutory requirements of Prevention of Food Adulteration Act (PFA).

FRESH KERNEL BASED PRODUCTS AND PRODUCT DIVERSIFICATION

Except for copra making, oil milling and coir manufacture, no other coconut based industries have developed in the country. Desiccated coconut and coconut cream made from fresh kernel have a good market potential.

In India, desiccated coconut industry is still in its infancy with an annual production of about 7000 tons. Of the 40 units in the country 30 are located in some regions of Karnataka state. The desiccated coconut units are small with capacities varying from 0.5 to 3 tons per hour. The process starts with mature green nuts. The shell is chipped off manually so as to obtain the fresh meat in the form of a ball. The brown testa is removed by paring to get the white meat. All these operations are done with the water inside. It is then split to remove the water and the white kernel is shredded in a hammer mill. The wet gratings are dried in an electric dryer to a moisture content of less than 3 per cent. The use of desiccated coconut is confined to confectionery and bakery products, and therefore the present market is small in India.

Regional Research Laboratory (CSIR), Trivandrum, has developed an improved process for canned coconut cream. This process involves extraction of coconut milk from the fresh kernel, emulsification in the presence of food additives followed by hot filling in cans and sterilisation using a rotary retort. All the equipments have been designed and fabricated indigenously. A demonstration plant to process 1000 nuts per 8 hours has been commissioned in Cochin with financial assistance from the Coconut Development Board. The canned coconut cream has a keeping quality of one year with quality parameters superior to similar products available abroad.

Another process developed by RRL is for the production of partially defatted coconut gratings and high grade coconut oil from fresh nuts. Two units based on this technology have been commissioned in Kerala and Tamil Nadu.

Coconut water is a waste product in copra processing and desiccated coconut industries. Attempts have been made to convert the water to some useful products like bottled coconut water and vinegar. A process for bottled coconut water for soft drink has been developed by RRL, Trivandrum, but the technology has not yet been utilised for commercial production.

Toddy Production

Toddy, a sugar containing juice obtained by tapping the unopened spadix of the coconut palm is a product of commercial significance, after copra, oil and coir. Toddy tapping, processing and distribution is a well organised sector in Kerala. The yield of toddy may vary from 0.5 to 3 litres per day per palm depending on the age and variety of the palm, season, etc. The duration of tapping also varies from six to eight months in a year yielding 100 to 300 litres per palm per year. Toddy is fermented to an alcoholic beverage with an ethyl alcohol content of 5 to 7 per cent. It is estimated that in Kerala alone about 300,000 coconut palms are tapped. Fermented toddy is a low alcoholic drink with substantial amount of minerals and B-complex vitamins and is a cheaper substitute for beer and other hard liquors. The natural fermentation is prevented by applying calcium hydroxide in the receptacle. The sweet toddy contains 14 to 18 per cent sugars and is dehydrated to make jaggery. Jaggery production is highly labour and energy intensive and therefore is not economical compared to fermented toddy. The estimated production of toddy at present in India is around 100 million litres per year worth about Rs. 400 million.

Coir

Coir is an important commercial product from coconut, next to copra. Husk forms about 35 to 45 per cent of the ripe coconut by weight. Fibre from the husk is extracted on a commercial scale by natural retting (golden yellow fibre) and mechanical processes (brown fibre). Seventy-five per cent of the coir production in India is from Kerala mostly by the natural retting process. Tamil Nadu, Karnataka and Andhra Pradesh account for the remaining. The products from these states are mostly brown fibre through mechanical processing. The actual production of coir for the year is only 200,000 tons, about 60 per cent of the production potential. The white coir industry in Kerala comprises 84,000 retting and fibre extraction units; 95,000 spinning units; 4,400 manufacturing units..These units are widely dispersed throughout the coastal belt of Kerala. A vast majority of them are tiny cottage household units. Barring a few factory type units and powerloom factories, the manufacturing sector also is dominated by small scale household units. There are about 650 brown coir units located in Tamil Nadu, Karnataka and Andhra Pradesh which are mere organised small scale units. In Kerala alone the coir industry is

estimated to employ 400,000 people, and it is a highly labour intensive sector with low wages.

The major domestic market at present is for coir yarn and coir rope (80 per cent). Rubberised coir products, in which curled coir is used (mattresses, pillows, cushions, air filters, packing materials, etc.) is another important item of domestic consumption. Rubberised coir sector has about 30 units in India and is a fast growing sector. Other coir products like coir matting and mats also have a major market share. An organised marketing strategy is needed to exploit the domestic market for coir.

Coir industry in India used to be export oriented and coir products are the only item from coconut exported from the country. Three decades ago about 75,000 t of coir goods (75 to 80 per cent of the production) were exported. But of late, it has dwindled and has been stagnating around 30,000 t. Increasing competition from synthetic yarn is responsible for this trend. The main market for coir and coir products in the EEC countries that account for 66 per cent of the total export and the total export earnings for 1990–91 was Rs. 472.5 million.

Shell Products

The estimated annual availability of coconut shell is about 1.0 million t. Except for small quantities of shell powder, charcoal etc. the shell is not utilised for any marketable commercial products. Almost the entire shell is used as fuel. It is possible to mobilise at least 30 per cent of the available shell in the country provided there is a steady demand for conversion to value added products like shell powder and activated carbon. Shell powder is produced in small quantities, but low yield at the desired particle size makes its economically less attractive. Pulverisers available now may have to be modified for powdering the shell and to maximise yield. Shell powder with uniform particle size is used as fillers in plastic industry, and as the starting material for making activated carbon. Activated carbon from coconut shell is not produced in the country. Activated carbon making technology has not been standardised indigenously for industrial scale production. One unit based on foreign technology is being established at the Export Promotion Zone, Cochin. Activated carbon from coconut shell is of superior quality and finds extensive use in pollution control, edible oil refining, gas masks, etc.

CONSUMPTION PATTERN OF COCONUT PRODUCTS AND DEMAND PROJECTIONS

Coconut oil is the second largest sector next to raw nuts. Production of coconut oil has been stagnating around 200,000 to 250,000 t for the last several years. More than 50 per cent is consumed for toiletry uses and about 20 per cent for soap making leaving only 30 per cent for edible purposes. In the toiletry and soap sectors, coconut oil is preferred and the demand is likely to go up with population growth and improvement in the standard of living. The average per capita consumption of coconut oil in Kerala is about 3 kg/year. Potential market expansion therefore is in the toiletry and soap sector where coconut oil

will be still preferred for quality consideration even with a premium over other oils.

The consumption of tender nut is growing at a faster rate in states like Karnataka and Andhra Pradesh, where raw nuts are used in the household and copra processing has not picked up. The internal consumption of coir products has shown an increase in the last few years. As such the overall demand for coconut products during the rest of the decade is expected to grow at about 5 per cent per annum. The projected production by the year 2000 is 14,000 million nuts which may still be short of domestic demands for coconut products.

CONCLUSION

Coconut production has shown an upward trend in the recent years. However, the industries based on coconut have been confined to copra processing, oil milling and coir products, mostly following traditional methods. Coconut being small holders crop and the processing being highly decentralised, application of modern technology has not taken place to improve the product quality and to diversify products. Consequently the economic prosperity of both farmers and processors is linked to the ups and downs of coconut oil causing instability to coconut based economy of many states. Upgradation of existing techniques of copra processing and price stability to coconut oil are important considerations. Utilisation of by-products and their value addition would improve the returns significantly. New products from kernel such as coconut cream and desiccated coconut and their popularisation would also go a long way in building a viable coconut industry and in improving the economic prospects of coconut cultivation in the country.

COCONUT BASED INDUSTRY IN SRI LANKA

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ABSTRACT

Sri Lanka is the fourth largest coconut producing country in the world, with an average yield of about 2.5 billion coconuts. Seventy-five per cent of the crop comes from small scale farms of less than 8 ha in extent, while the large plantations or estates contribute only 25 per cent to the annual crop.

Out of the total annual yield, a quantity of about 1.5 billion nuts is used as fresh coconuts for domestic cooking purposes, while the balance 1 billion, is available for industrial processing. A large number of coconut-based industries, numbering over 3000, located in the principal growing areas, are engaged in the manufacture of a range of kernel and non-kernel products, meant for domestic use, as well as for export. The annual foreign exchange earned from the export of coconut products exceeds SL Rs. 3 billion.

The vast majority of the processing units are family owned and owner-managed and are of small and medium scale operations. These small and medium scale processing operations offer great logistical and comparative advantages in that they use low-cost, labour intensive, traditional technologies; small quantities of surplus coconuts available from small scale farms within a particular growing area are processed within the same area and the products are distributed either for consumption or for further value addition within the same area. Regular operation of these processing units enables coconut farmers within the area to obtain reasonable farm gate price for their produce. They provide regular employment to people in the area and the cost of production in these small/medium scale processing units is much lower than in large-scale operations.

These factors have contributed to the proliferation of small and medium scale processing units and they form the core of the coconut based industrial sector. However, small scale operations using labour intensive, traditional technology are deemed inadequate to cope with increasing quality standards of some of the coconut products manufactured particularly for export.

Hence in the case of some of the products, there has been a recent trend to shift from small scale manufacture to medium and large scale operation, using modern and appropriate technology.

INTRODUCTION

Coconut is one of the major commercial crops grown in Sri Lanka. Coconut cultivation accounts for the second largest land usage and about 25 per cent of the total arable land in the country. The total extent under coconut cultivation is 1,028,562 acres and is concentrated mainly in the wet and intermediate wet zones of the island. Over the years, the extent under coconut cultivation had tended to show a marginal decline, owing to increasing use of coconut land for urbanisation, industry and housing programmes. Coconut farms are largely under private ownership and the vast majority of them are small holdings of less than 20 acres in extent. The distribution of coconut farms by size classification is given in Table 85.1.

Table 85.1: Distribution of coconut small holdings and estates by size classes

Size class of holdings*	*Number of holdings*	*Area (acres)*	*Bearing** area (acres)*
< 2 acres	405,289	231,412	203,996
2 < 3 acres	100,563	106,583	89,110
3 < 4 acres	63,587	78,218	64,979
4 < 5 acres	38,266	57,810	48,600
5 < 7 acres	45,685	87,752	73,659
7 < 10 acres	22,860	63,181	55,742
10 < 20 acres	17,290	97,779	88,234
> 20 acres	4,628	51,395	46,801
Total (Small holdings)	698, 168	773, 730	671,091
		Estate Sector	
20 to 29 acres	2,225	42,889	36,874
30 to 49 acres	1,787	52,136	46,127
50 to 99 acres	1,432	63,703	57,985
100 acres	836	96,104	84,014
Total (Estate sector)	6,280	254,832	225,000
Sri Lanka	704,448	1,028,562	896,091

Note: *Extent of the land area.
**Based on the number of coconut trees on the land.
Source: Census of Agriculture 1982. Department of Census and Statistics.

The total annual production of coconut varies between 2000 and 3000 million nuts out of which a quantity of 1500 and 1800 million nuts or 60 per cent, equivalent to 90 nuts per head per annum, is used in fresh form for the extraction of coconut milk — a widely used ingredient in all domestic cooking. The remaining 40 per cent of the crop is used as raw material by a large number of agro-based industries, for the manufacture of a range of products, including by-products, semi-finished products and finished products, such as desiccated coconut (DC), coconut cream, coconut oil, vinegar, coconut treacle, jaggery, coir fibre, fibre products, shell charcoal and activated carbon, some of which

are meant primarily for export. The pattern of utilisation of the annual crop for processing of the major products, in an average year, is given in Table 85.2.

Table 85.2: Pattern of utilisation of coconut crop for processing

Product	*Utilisation (in million nuts)*	
Desiccated coconut	375	
Copra/coconut oil	560	
Brown fibre and product	600	(husks)
White fibre	50	(husks)
Shell charcoal	400	(whole shells)
Activated carbon	715	(whole shells)

A large number of enterprises, scattered throughout the principal growing areas are engaged in the manufacture and trading of coconut products. The total annual turnover of the coconut-based industrial sector exceeds Rs. 5000 million. Coconut products constitute a valuable source of foreign exchange, with an annual earning potential of over Rs. 3 billion. The export revenues earned from the major coconut products manufactured and exported during the past five-year period is given in Table 85.3.

Table 85.3: Export revenues earned from major coconut products (Rs. '000)

Year	*Kernel products*	*Fibre and yarn*	*Fibre finished products*	*Shell products*	*Other by-products*	*Total*
1985	2,432,540	443,780	117,846	234,509	26,470	3,255,145
1986	1,816,640	565,490	159,690	263,390	33,610	2,838,820
1987	1,566,840	531,910	242,550	347,070	52,810	2,741,180
1988	986,670	503,530	262,910	404,370	23,590	2,181,070
1989	2,070,650	785,671	328,060	643,146	68,480	3,896,047

Source: Coconut Development Authority, Sri Lanka.

Extent of the Coconut-based Industrial Sector

The coconut based industrial sector comprises a well organised formal sector and a large informal sector. The formal sector for the most part, comprises the export-oriented industries dominated by family-owned and managed, small and medium scale processing units while the informal sector is made up mostly of cottage industries and backyard industries, engaged in the manufacture of products and by-products, primarily for the domestic market.

A profile of the coconut-based industries in the formal sector is furnished in Table 85.4.

The informal sector comprises a prolific number of very small scale industries engaged in the manufacture of the following products:

Copra
Coconut oil
Vinegar

Coconut treacle
Jaggery
White fibre
Coir products

Table 85.4: Coconut-based industries

Product	*No. of units*	*Market outlets for products*
Copra	402	Domestic and export
Coconut oil	125	Domestic and export
Desiccated coconut	58	Export
Coconut cream/powder	02	Export
Brown fibre	450	Domestic and export
White fibre	10	Domestic and export
Coir products	125	Domestic and export
Shell charcoal	200	Domestic and export
Activated carbon	04	Export

General Characteristics of the Coconut-based Industries

The small and medium scale industrial units in the coconut processing sector, have the following general characteristics:

i) They are family-owned and have typical owner-manager style of management.

ii) The technology used in almost all the products, is traditional, based on low cost, locally manufactured machinery and equipment and high content of labour.

iii) The capital investment involved is low, which gives these units the flexibility to cut down or completely stop production operations, according to market conditions and raw material availability.

iv) The cost of production in the small/medium processing units is relatively lower (than in large scale production units).

Copra Processing Industry

In terms of the number of industrial units and industrial utilisation of coconut, copra processing is perhaps the largest single industrial operation in the coconut processing sector. Over 2000 processing units, both in the formal and informal sectors and with capacities from 250 nuts to 50,000 nuts per batch, are engaged in the manufacture of copra. The estimated total installed capacity is over 250,000 tonnes per annum.

The traditional method of copra drying in Sri Lanka, is a multi-stage process and comprises:

a) An initial stage of sun-drying where the halves of the split nuts are arranged on a barbeque and exposed to the sun for a period of eight to 10 hours, followed by:

b) A series of hot air curings, with intermittent cooling, in an open kiln. During each hot air curing, a draught of hot air is made to flow through the bed

of kernels laid on a wooden platform, housed in a simple, well ventilated building structure. Well dried coconut shell is used as fuel. A diagrammatic sketch of a standard Sri Lanka copra kiln, with a capacity to cure 2000 coconuts per day is given in Fig. 85.1 below.

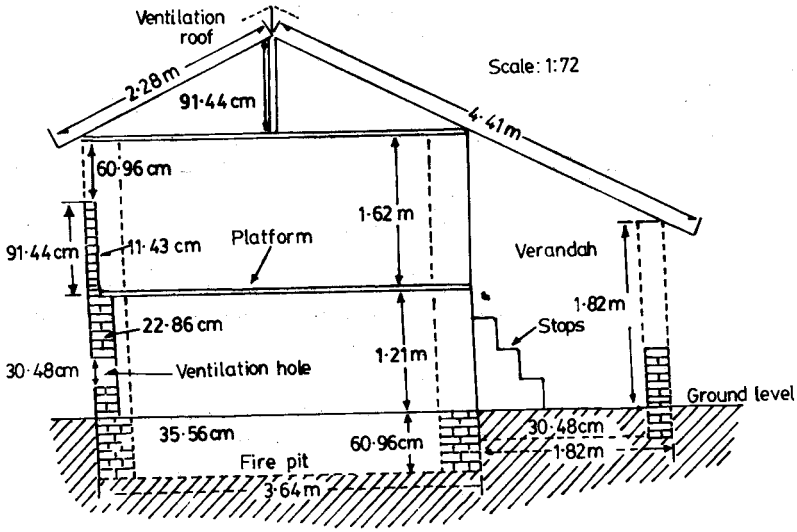

Fig. 85.1: Diagrammatic sketch of a standard Sri Lanka copra kiln.

The annual production of copra in an average year is about 150,000 tonnes. Industrially processed copra is classified into eight grades, according to the quality of the product, namely:

i) White edible grade
ii) Edible grade
iii) Milling superior grades 1, 2 and 3
iv) Milling ordinary grades 1, 2 and 3.

White edible and edible grades are high quality products meant primarily for export. The composition in terms of the proportion of milling superior and milling ordinary grade products in a batch of copra processed in an average kiln would vary, depending on the processing conditions adopted. On an average, about 4,900 coconuts are required for the manufacture of one tonne of copra.

Coconut Oil Milling Industry

An estimated 175 to 200 oil mills with capacities ranging from half tonne to 50 tonnes of oil per day, are engaged in the manufacture of coconut oil. The estimated total installed capacity in the oil milling industry is about 175,000 tonnes per annum.

In the coconut oil milling process, the raw material (copra) is first subject to a pre-treatment process consisting of:

a) disintegration into small pieces of about 0.4 cm to 0.8 cm, and
b) exposure of the cut meat to dry heat or steam.

Extraction of oil from pre-treated copra is carried out using standard expellers. While the larger oil mills generally use a combination of "low pressure" expellers followed by "high pressure" expellers, in extracting oil from copra, the smaller mills generally use only a single press operation using "low pressure" expellers, resulting in a high residual oil content in the *poonac*.

The typical oil contents in the *poonac* in single and double press operations, are given below:

Processing method	*% Residual oil in poonac*
Single press	12.30
Double press	10.75

Coconut oil manufactured in the average oil mill conforms to the quality standards of No. 1 edible grade and requires no further refining. About 100,000 tonnes of coconut oil is produced in an average year, out of which a quantity of about 60,000 tonnes is used domestically for both edible and industrial purposes, while the balance 40,000 tonnes is available for export (subject to export prices being favourable). About 50,000 tonnes of *poonac* is generated as a by-product of the oil milling industry and is used almost totally in the domestic livestock feed industry—8000 coconuts are required for the manufacture of 1 tonne of coconut oil and 0.5 tonne of *poonac*.

Desiccated Coconut Industry

Desiccated coconut is manufactured in 58 factories, out of which 56 are small and medium scale, traditional processing units, while the remaining two are large scale modern plants. The individual capacities of the small and medium scale processing units range from 2.5 to 10 tonnes per day. The capacity of each of the modern, large scale plants is 20 to 24 tonnes per day. Together, they have an installed capacity of about 75,000 tonnes per annum.

The technology used in traditional factories is simple and comprises initial stages of material preparation (de-shelling, removal of brown testa paring), followed by washing of the kernel in clear water. Pasteurisation using hot water, disintegration, drying, cooling, sieving and packing. The modern large scale mills too use basically the same process technology, but the process operation is mechanised and automated and is a continuous one unlike in the traditional process, which is a batch operation.

The quality of desiccated coconut manufactured both in the traditional plants as well as in the two modern plants, conform to high standards stipulated by the international buyers. The average annual production of desiccated coconut in Sri Lanka is about 50,000 tonnes for which 7000 coconuts are required to manufacture 1 tonne of desiccated coconut.

Brown Fibre Milling Industry

Forty per cent of the husks available is used in the manufacture of coir fibre. Over 450 processing units located within the principal growing areas are engaged in the manufacture of brown fibre. These units have processing capacities ranging from 2,500 husks to 30,000 husks per day. The total installed

capacity of the brown fibre industry is about 150,000 tonnes per year. All the above processing units, use traditional technology in extracting fibre from the husks. The process comprises an initial period of retting where brown husks are kept soaked in water for three to four weeks, followed by mechanical separation of the fibres. In the latter process operation, the husk segments are held against a revolving drum with steel spike projections on its rim — known as the "Sri Lanka drum". The spikes tear away much of the short fibres and pith leaving the medium and long fibres. The resulting hank of medium and long fibres with remaining short fibres and pith are then held against a second revolving drum also rimmed with steel spikes, but arranged differently on the rim known as the 'cleaner' drum, to remove all short fibre and pith and yield long-stapled bristle fibre. The mixture of short fibres and pith is passed through a cleaning machine comprising a revolving screen of wire mesh, to remove very short fibres and pith, yielding a product (which after drying and proper packing) is popularly known in the trade as 'mattress' fibre.

Manufacture of White Fibre

A number of industries have been established recently, for the manufacture of white fibre using a mechanised process. So far about 10 such processing units have been set up both within the traditional coconut belt and outside it. The combined annual capacity of these processing units is about 3000 t of white fibre.

Green husks are sent through a husk crusher, soaked in water and are then fed into a de-fibring machine, where the long strands of bristle fibre are separated from short fibres and pith. The mixture of short fibres and pith is sent through a turbo-cleaner, which separates the mattress fibre from the pith. The resulting fibre is washed in clean fresh water to remove tannins and retaining the natural white colour. A set of machinery and equipment required for the above process costs approximately about U.S. $ 25,000.

Coir Products Manufacture

Brown as well as white fibre is extensively used by a large number of industries engaged in the manufacture of a range of coir products, meant both for export and for local use. The number of established factories manufacturing some of the principal coir products mostly for export is as follows:

Product	*Number of units*
Coir brushes	75
Coir mats and matting	06
Rubberised coir mattresses	05
Coir twine	05

A significant increase has been recorded during the past few years, in the volume of finished coir products exported from Sri Lanka. Thus, the total volume of coir brushes exported in 1985 was 21 million pieces, while in 1989 the volume rose to 52 million pieces. Similarly, in other coir products too, substantial increases in export volumes have been achieved.

Machinery and equipment used in the manufacture of products such as coir mats and matting, rubberised coir mattresses and coir twine are mostly imported, while in the case of products such as coir brushes, locally manufactured machinery and equipment of simple design and construction are used.

Coconut Shell Charcoal

Coconut shell charcoal is manufactured in over 200 units located mostly within the main growing areas. Carbonisation of coconut shell is carried out using the traditional "pit method". Charcoal kilns used in carbonisation of coconut shell range from simple (unlined) pits dug in hard soil, to pits lined with fire bricks. These pits have capacities ranging from 0.5 t of charcoal to 2 t of charcoal per batch. The total installed capacity of the charcoal manufacturing units is about 50,000 t. Using the 'pit' process 20,000 whole shells are required to manufacture one tonne of shell charcoal. About 60,000 to 70,000 t of shell charcoal are produced in an average year.

Activated Carbon

There are four medium scale activated carbon plants located in the principal growing areas. Each plant has an annual capacity of about 5000 t. All plants use high technology in processing shell charcoal into activated carbon. Each producer manufactures products to meet specific end-user requirements and has specific marketing arrangements.

The quantity of activated carbon manufactured for export has steadily increased over the years. Thus in 1980 Sri Lanka exported only 710 t, while the quantity exported in 1989 exceeded 11,000 t. 3.3 tonnes of shell charcoal or the equivalent of 65,000 whole shells are required for the manufacture of one tonne of activated carbon.

The Informal Processing Sector

The informal processing sector is large and diversified and comprises mainly of cottage industries located both within and outside the principal growing areas. The most prolific activity in the informal processing sector is the small scale manufacture of copra and oil milling. A very large number of small scale copra kilns, with capacities to cure a few hundred coconuts at a time, are located throughout the coconut growing areas. Surplus coconuts from home gardens and very small coconut farms, are processed into copra, using coconut shell as the heat source. Copra manufactured in these small kilns is generally of low quality.

Complementary to the small scale copra kilns are small scale oil milling units, a large number of which are located at the village level. The basic machinery used in these units comprises small copra grinders and mini-expellers, the latter having capacities ranging from 500 to 750 kg of oil per day. The quality of oil produced in these oil milling units, commensurate with the quality of copra used, is low. The oil is used both for domestic purposes as well as for small scale industrial purposes, such as, soap making. Manufacturer of coconut treacle and jaggery are two other intensive, cottage-level activities

within the main growing areas. These products are used almost exclusively for domestic consumption.

Manufacture of white fibre is a prolific small scale activity along the southern coastal belt of the country. Green husks are retted in brackish water for a period of up to six months and are then beaten manually with wooden mallets to separate the fibre. A fine network of collectors, dealers and retting pit owners operate within the southern coastal region, where fibre processing had been one of the key small scale industries. White fibre is used mainly in making coir yarn using both hand-spinning and wheel-spinning. A large number of complementary processing units exist almost side by side with the white fibre manufacturing units, for conversion of the fibre into yarn, which in turn is used by a large number of other industries engaged in the manufacture of a range of coir products such as, rugs, mats and carpets.

Trends within the Coconut Processing Sector

The small and medium scale industries in the processing sector, face certain common problems, such as:

a) increasing difficulties in finding and retaining skilled workers;
b) escalation of the cost of production; and
c) stringent standards of quality demanded by foreign buyers.

In meeting the above challenges the different subsectors of the processing industry have adopted different strategies and certain distinct trends could be seen to be emerging.

Thus in the case of products such as desiccated coconut, the small scale hatch process operation appears to be inadequate in ensuring the high standards of quality demanded by foreign buyers and therefore there is a trend to move up from small scale batch operations to medium and large scale continuous production systems, with higher degree of uniformity and quality of the product.

In the case of coconut oil manufacture, the trend is clearly to retain the small and medium scale manufacture in preference to large scale operations. This is primarily due to the fact that copra is available mostly in small parcels matching the production capacities of small scale plants and also due to the fact that the cost of production in small scale operations is much lower than in large plants. In brown fibre production where lack of skilled workers is the crucial problem, production units have tended to remain small. The trend to remain as small production units is also seen in products such as shell charcoal and coir fibre products.

DISCUSSION

P.O. Thomas: What is the method of de-shelling and output/person if manual labour is used?

H.A. Tillekeratne: De-shelling in Sri Lanka is done manually using a hatchet and the output is nearly 2000 nuts/day.

WASTE HEAT RECOVERY TECHNOLOGY FOR KERNEL PROCESSING

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ABSTRACT

Equipment for recovering and using the heat evolved during coconut shell charcoal manufacture has been developed by the Natural Resources Institute.

Commercial and experimental Waste Heat Units (WHUs) are being operated in Sri Lanka to supply heat for drying desiccated coconut, manufacturing copra, and for a new process which produces high quality coconut oil directly from fresh coconuts.

Advantages of using WHU technology over traditional procedures for manufacturing these products are several:

i) Environmental — Conventional coconut shell charcoal production generates obnoxious fumes which are environmentally damaging and often place limits on the choice of site of operation. These fumes are virtually eliminated with a WHU.

ii) Improved quality charcoal — Charcoal produced by a WHU is superior to that manufactured by traditional methods and is found to be ideal for activated carbon manufacture.

iii) Better copra — The use of a WHU for copra manufacture allows the drying cycle to be more closely controlled, avoiding overheating, casehardening or charring. Free fatty acid levels are lower, and polycyclic aromatic hydrocarbon deposition on the coconut meat, an inevitable consequence of direct smoke drying, is also considerably reduced.

iv) Improved quality coconut oil — Freshly grated coconut meat is dried using the heat output of a WHU and immediately pressed. Problems with high free fatty acid or poor colour and flavour of the oil are avoided since the copra stage is bypassed.

INTRODUCTION

The traditional pit method of charcoal production yields approximately 30 per cent of the dry weight of the shells used as feedstock. The charcoal produced is of variable quality and is often contaminated with extraneous matter and soil.

During this process 50 per cent of the gross heat content of the shells is lost to the surroundings. Moreover, large volumes of obnoxious smoke are evolved and, in many countries, the use of pits for charcoal making is, for environmental reasons, restricted to areas remote from human habitation. Charcoal manufacture therefore has to be carried out away from the kernel processing facilities where the shells are generated and this frequently entails transport for some distance.

The coconut shell carbonisation with waste heat recovery unit (WHU), which has been developed by The Natural Resources Institute (NRI), reduces the smoke problem to a few minutes per day and produces clean, good quality charcoal. The gas evolved during the carbonisation is burned in a furnace and the heat is recovered. Systems and equipment have been devised by NRI to enable this heat to be used in the coconut processing industry, substituting for imported fossil fuels, coconut husk or locally felled wood.

The two major industrial uses of coconuts, copra and desiccated coconut manufacture, both use considerable quantities of heat to reduce the moisture content of wet kernel, at about 50 per cent to a level sufficiently low (3 per cent for DC, 8 per cent for copra) to prevent mould growth and hydrolytic deterioration of the coconut oil.

WHU technology has been commercialised in the coconut industry of Sri Lanka through a collaborative programme between NRI and the Sri Lanka Coconut Development Authority, partially financed from the United Kingdom Overseas Aid programme.

Inadequate copra drying techniques are the basic source of most quality problems encountered in copra and coconut oil. If drying is delayed for too long a period after splitting, or the copra is insufficiently dried, growth of mould and bacteria on the coconut meat cause hydrolytic breakdown of the coconut oil, poor colour, together with the possible production of mycotoxins. If direct smoke driers are employed, polycyclic aromatic hydrocarbons are deposited on the coconut meat.

Uncontrolled heating can lead to case-hardening or charring. High free fatty acid, colour, and polycyclic aromatic hydrocarbon levels in the coconut oil cause losses during refining, and high mycotoxin levels reduce the value and acceptability of the copra cake.

This paper presents the results of work carried out in Sri Lanka on the application of WHU technology for copra drying and for a new process which produces high quality oil directly from fresh coconut meat, bypassing the copra stage entirely.

MATERIALS AND METHODS

Description of WHU

Waste heat recovery technology was developed at two scales of batch operation: a standard unit of 1.5 tons of shell capacity, and a scaled-up version processing 3.4 tons of shell. This paper deals with the former scale of operation only.

The standard system (Figure 86.1) consists of a vertical cylindrical metal kiln (1) (made from 9.5 to 10 mm thick mild steel sheets) connected to a burner/furnace fitted with an exhaust gas fan. The fan induces combustion and draws secondary air into the furnace system. Approximate capacity of the unit is 8 m^3. Two hatches (2) and (3) are provided: one at the top of the kiln for loading shells and the other near the base of the kiln for discharging the charcoal. The top hatch is fitted with a thin mild steel bursting disc which will rupture in the unlikely event of the gas in the kiln exploding. A large horizontal lid (4) is located at the top of the kiln and can be swung over the burst disc by a pulley mechanism (5) operated from ground level. The main kiln body is designed to withstand over twice the theoretical pressure build-up in the event of the stoichiometric gas/air mixture spontaneously combusting in the kiln.

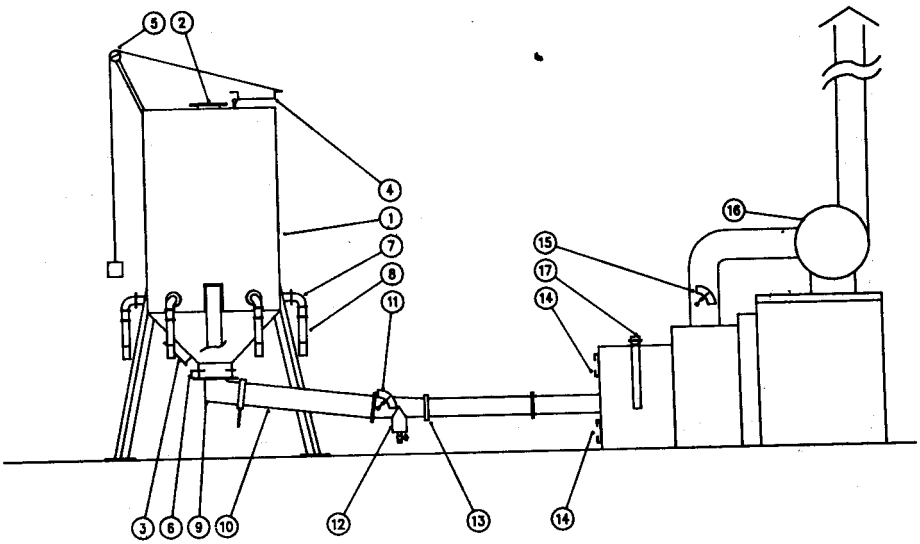

Fig. 86.1: Standard waste heat unit/heat exchanger system. See text for explanation of numbers.

The charcoal produced is supported by removable rods (6) that form a grid over the gas outlet port. Six air inlet ports (7) are equally spaced around the circumference of the kiln for lighting the charge. The metal pipes which protrude into the charge are fitted with cast iron sheaths to protect the ends of the pipes from the high combustion temperatures experienced at these points. The air inlet ports are flanged so that right-angled bend pipes, fitted with dampers for fine control of the flow of air into the kiln, can be swung into position after lighting. The inlets to the bends are fitted with perforated plates (8) so that they will direct any 'blowback' downwards and contain the flame or hot char which may be ejected.

The gas outlet is located at the base of the kiln (9) and is connected to the burner by a pipe (10) via a damper (11), a condensation trap (12) and a flame trap (13). The damper's function is to control the "kiln gas" flow to the furnace. The main control after start-up is maintained by setting the damper air inlets to

the furnace (14) and adjusting the flue damper (15) in the exhaust gas fan (16) line.

The gases are drawn into the furnace with combustion air and ignited by two cast iron (or ceramic) thimbles (17) which hold hot glowing charcoal which serves as a pilot light. The furnace and shell side of the heat exchanger are fitted with explosion doors which open at approximately 14 kg/m^2 of pressure. The hot combustion gases are used to heat air, via the heat exchanger, for drying purposes.

RESULTS

WHU Technology for Copra Production

The usual method of producing copra in Sri Lanka consumes approximately 50 per cent of the shells available from the coconuts, leaving 50 per cent for sale or as a raw material for carbonisation to charcoal.

An experimental/commercial copra facility was designed by NRI and constructed in Sri Lanka during 1989, to produce high quality copra using the heat generated from two sequentially operated standard WHUs. The system carbonised all the coconut shells associated with the copra manufactured and was self-sufficient in its thermal requirements when operated continuously.

The facility consisted of two WHUs, with a common furnace and heat exchanger system connected to a drying system. The drying system comprised a building which housed two deep drying beds, three conditioning bins, a storage area, and a working area for removing the shell from the partially dry kernel. A coconut splitting area was also provided outside.

Hot air obtained from the heat exchanger was passed through halved coconuts which were loaded into the drying bins. After drying for one day the shells were removed from the kernel (for subsequent carbonisation) and the kernel was loaded into the conditioning bins for final drying to a moisture content of between 4 and 6 per cent. The throughput of the facility was 20,000 coconuts per day with an output of approximately 3.2 tons of copra and 1 ton of charcoal.

Trials confirmed that high quality copra could be produced by the facility. Samples were found to be low in their content of free fatty acid, polycyclic aromatic hydrocarbons and aflatoxin. The charcoal was similarly of high quality and ideal for activated carbon manufacture.

The system requires a high degree of management and organisation to ensure continuous operation. Its widespread adoption is therefore unlikely and would probably be limited to estates, where feedstock can be closely organised and suitable overall management of the facility would exist. The financial aspects of operation would need to be carefully examined before the technology is introduced at any particular location.

WHU Technology for Coconut Oil Production

In copra crushing mills in Sri Lanka, the copra is cut into small pieces using a hammer mill, and passed through a wood fired or oil fired semi-automatic

dryer, where it is dried to a moisture content of between 4 and 6 per cent. It is then fed into the conditioner, where it is warmed (sometimes with the injection of steam) and augered into an expeller screw press. Depending on the mill, the copra is pressed either once or twice. Under good operating conditions over 94 per cent of the oil in the copra can be extracted with a single pass through the expeller.

In the trial system, the standard wood fired furnace was replaced by the WHU and the hot combustion gases passed through the tubes of the heat exchanger. Ambient air was drawn through and blown into the semi-automatic dryer via a centrifugal fan. The semi-automatic dryer consisted of a chamber fitted with perforated trays through which chopped fresh coconut meat was passed. The material cascaded downwards, counter-currently to the flow of drying air, which entered at approximately 110° to 120°C.

The output of the dryer operating on chopped fresh coconut kernel with a moisture content of 45 per cent, was between 120 and 160 kg/hour of dried coconut meat at approximately 4 per cent moisture content. The dried coconut meat was passed directly into the expeller and pressed as usual. In a commercial system, two WHUs would be operated in tandem, and, to maintain the throughput of the expeller, additional dryers would be required.

Copra production is bypassed in this procedure, and the coconut oil and "copra cake" are effectively produced, directly from fresh coconut kernel; their quality is therefore high, with a low content of free fatty acid, and free of aflatoxin, and polycyclic aromatic hydrocarbons.

DISCUSSION

The work of NRI in Sri Lanka has shown that Waste Heat Recovery technology can be applied to the three major coconut processing industries, desiccated coconut, copra and coconut oil production. There is considerable scope for the application of WHU technology to dual fuel boilers to provide process heat for the coconut industry in other countries. Widespread adoption of WHU technology for heat generation in these industries can assist in reducing deforestation or imports, increasing the yield of more consistent quality charcoal, and improving the quality of copra, coconut oil and cake. It also serves to give the processor a greater degree of energy self-sufficiency. Commercial and financial viability of the system in any given situation, will depend on a variety of local factors, and therefore each case will need to be assessed on a site specific basis.

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DISCUSSION

P.K. Das: a) What is the investment cost of a Waste Heat Unit (WHU)?

b) Could the technology be made available to the private sector in India?

c) How does the cost of producing oil from copra compare with that manufactured from fresh coconut kernel using the WHU technology?

Breag: a) The cost of a WHU in Sri Lanka in 1989 was approximately Rs. 125,000 (Sri Lankan Rupees) for a 1.5 ton shell capacity unit. A large version with a shell capacity of 3.2 tons was also developed and the cost was approximately twice that of the 1.5 ton capacity unit. These costs apply to Sri Lanka. In Indonesia and the Philippines the cost of the 1.5 ton capacity unit was estimated to be approximately twice that of the units manufactured in Sri Lanka.

b) The Natural Resources Institute (NRI) is prepared to introduce the technology to the coconut industry in India: but this will need to be carried out through a "collaborative technology transfer package" — providing of course that funding for such a project can be found.

c) As explained above, the cost of manufacture of oil from copra and that from fresh kernels using the WHU technology will need to be compared. Here again oil production would depend on a number of factors, such as, equipment, labour, electricity, fuel and feedstock costs. The best course of action would, in my view, be initially to assess the scope for the application of the technology and simultaneously to carry out a techno-economic evaluation of the WHU system for oil production in India. This will answer many of the questions you have raised and help to decide on whether the technology is suitable for application in the Indian coconut industry.

UTILISATION OF COCONUT WOOD: PROSPECTS AND PROBLEMS

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ABSTRACT

A large scale coconut replanting programme is envisioned to replace old and senile palms with hybrid and high yielding varieties of coconut as a positive approach to the problem of low palm productivity. Readily available coconut wood resource from senile palms in the Asia and Pacific regions consisting of 11 coconut producing countries was estimated at 164.38 million m^3 millable logs with the Philippines and Indonesia accounting for more than 70 per cent of the total log volume.

Coconut wood utilisation would not only provide a system of proper trunk disposal for phytosanitary measures at replanting time but would also give additional income to the coconut farmers, make available cheap construction material and would generate employment opportunities for people living in the rural areas.

Technologies on saw milling, machining, drying and preservation have been developed on coconut wood through R and D efforts to produce a range of potential industrial end products. These include, among others, coconut wood furniture, treated service poles and posts, and various building components.

Technical problems in the effective utilisation of coconut wood were identified as saw milling, machining, finishing, structural application and limitation in the size of sawn lumber.

While considerable advancement on coconut wood utilisation which R and D has been made, what remains to be done is the effective application of technologies from these research undertakings.

INTRODUCTION

The coconut growing countries of the Asian and Pacific regions share the common problem of declining palm productivity due to, among other things, increasing proportion of old and unproductive palms. Hence, as a positive approach to the problem of low productivity, a comprehensive replanting programme using precocious high-yielding varieties should be undertaken.

Replanting should be phased in order that the entire coconut plantation is covered in approximately 40 years, at which time the replanting cycle shall start all over again, hence a continuous programme (Mendoza, 1979).

The felling of large number of senile palms creates a problem by the physical presence of the felled trunks which at best impedes replanting and subsequent control operations, and at worst constitutes ideal breeding sites for the extremely destructive rhinoceros beetles. The research work on coconut wood utilisation carried out in the Philippines and elsewhere demonstrated that, with the use of appropriate technology, coconut wood has a great potential for commercial use both in house/building construction materials and in high value exportable wood products for decorative as well as novelties and utility purposes (Palomar and Siopongco, 1989).

R AND D REVIEW ON COCONUT WOOD UTILISATION

Properties of Coconut Wood

The anatomical structure of the coconut palm differs from the conventional tree. The coconut being a monocot has no vascular cambium, hence, its trunk once formed does not increase in diameter with age (McQuire, 1979).

In cross-section the stem has three distinct zones, namely: the dermal, sub-dermal and the central zones. The dermal zone is the most peripheral portion just below the cortex, the sub-dermal is a transitory zone between the dermal and the central regions, and the central zone represents the core.

Its main anatomical elements include the fibrovascular bundles, fibrous bundles and ground tissue. The fibrovascular bundles consist of phloem, xylem, axial parenchyma and thick-walled schlerenchyma fibres which serve as the major mechanical support of the palm trunk. The fibrous bundles, consisting of narrow fibre elements with no vascular tissue, are scattered in the ground tissue and their number per unit area decreases from the centre to the cortex of the stem. The ground tissue is parenchymatous and the thickness of its cell wall decreases from cortex to the inner zone of the central cylinder.

The physical properties of coconut wood depend largely on its density, moisture content and shrinkage. Its basic density decreases with the increasing height of the stem and it increases from the core to the cortex at any given height. In addition, the basic density at a particular height increases with age of the palm. Overall, the basic density ranges from 110 kg/m^3 at the top core portion to 850 kg/m^3 at the bottom dermal portion of an old coconut stem.

The moisture content is negatively correlated with the basic density, that is, moisture content decreases with increasing basic density and *vice versa*. The amount of moisture in coconut stem increases with an increasing stem height but decreases from the core to the cortex. The moisture content ranges from 50 per cent at the bottom dermal portion to 140 per cent at the top core portion of the stem.

The dimensional stability of wood is determined by its shrinkage or swelling which accompanies a decrease or increase in moisture content below fibre saturation point. Shrinkage or swelling causes drying defects such as checks or

splits. Unlike conventional wood where tangential shrinkage is almost twice the radial shrinkage, the tangential and radial shrinkages of coconut wood are not significantly different.

The mechanical properties of coconut wood, which defines its end use, are positively correlated with the basic density. As a result, coconut wood is classified according to the following basic density groups:

Classification	*Basic density range*
High density wood (dermal)	600 kg/m^3 and above
Medium density wood (sub-dermal)	400–599 kg/m^3
Low density wood (core)	Below 400 kg/m^3

Table 87.1 presents the mechanical and related properties of the three density groups of coconut wood based on green and dry samples. All values of the strength properties increase with increasing basic density. Except for impact bending, the values of the other mechanical properties of coconut wood at 12 per cent moisture content are significantly higher than in green condition. The strength properties of high density wood compare favourably with Apitong (*Dipterocarpus grandiflorus*), white lauan (*Pentacme contorta*) and Bagtikan (*Parashorea plicata*) which are commonly used as structural materials for building construction. The medium density coconut wood is comparable to white lauan in terms of modulus of rupture, stress at proportional limit and maximum crushing strength but it is slightly inferior in respect of the rest of the properties. In contrast, the low density coconut wood cannot compare with these wood species, hence, it should be used only for non-load bearing structures.

Table 87.1: Mechanical and related properties of coconut wood.

		Static bending			*Compression parallel to grain*		*Compression perpendicular to grain*	
Basic density (kg/m^3)	*Moisture content (%)*	*Modulus of elasticity (MPa)*	*Modulus of rupture (MPa)*	*Stress at proportional limit (MPa)*	*Modulus of elasticity (MPa)*	*Maximum crushing strength (MPa)*	*Stress at proportional limitt (MPa)*	*Impact bending (N)*
600 and	57	10857	86	51.6	7988	49	8.3	20.2
above	12	11414	104	61.7	9747	57	9.0	20.1
400 to	107	6880	53	30.4	5151	31	2.8	18.3
599	12	7116	63	38.4	5282	38	3.4	10.1
250 to	240	3100	26	13.1	2287	15	1.3	8.4
399	12	3633	33	15.4	2914	19	1.7	9.0

Coconut wood is comparable to Philippine hardwood/softwood and bamboos as far as holocellulose, lignin and pentosan contents are concerned. However, it contains higher ash than conventional Philippine woods. The proximate chemical compositions of coconut wood are as follows: Holocellulose-60 per cent: Lignin-25 per cent and Pentosan-22.9 per cent.

Saw Milling

In sawing coconut logs, the hard dermal and the medium sub-dermal portions are the important and valuable materials to recover.

A sawing pattern should be employed to segregate the three density groups of sawn coconut lumber. The round method of sawing assures that the hard, medium and soft lumbers are separately sawn (Penamora, 1983).

The first cut is a thin slab followed by a cut of 25 mm or 50 mm thick hard material depending on the diameter of the log. Then the log is turned either 90° or 180° following the same sequence of cutting until the hard portion is recovered. Similar sawing is done after each turn ensuring that the medium and soft portions are extracted separately.

Grading can be done visually based on the physical defects and colour of newly sawn lumber. However, mechanical grading can also be employed by determining the basic specific gravity or the stiffness of the lumber immediately after sawing.

The problems of sawing coconut trunks are similar to those encountered by saw millers when sawing high density species of tropical hardwood. These difficulties can be minimised, if not totally solved by knowing the properties of the coconut stem and using the hard facing materials on the saw teeth.

Experience has shown that the butt portion of the coconut stem is the one most likely to cause sawing difficulties particularly with a large diameter saw. Since the coconut log diameter is small with very high density on its periphery, the saw tends to go out of the saw line and the conventional saw easily becomes blunt. In addition, considerable amounts of fine substance similar to sand granules and pieces of small pebbles are present in the bark which contribute to the rapid dulling of saw teeth during the sawing operations. For these reasons, it is necessary to apply hard facing materials on the saw teeth on either circular or band-saw blades.

The hard facing of saw teeth can be done either by applying stellite metal on the saw teeth with oxy-acetylene welding equipment or by brazing tungsten carbide teeth into the face of the saw teeth. The former method can be applied easily to both circular and band-saw blades either manually or with stellite tipping machines while the latter is only applicable to circular saws.

Grinding or sharpening of stellite teeth can be done with a range of grinding wheels. For field operation using mobile circular saw mill, the manually operated jockey grinder has been found effective.

The tungsten carbide saw requires expensive impregnated diamond wheels for sharpening. The skill required to sharpen and replace tungsten carbide tips is much greater than the stellite teeth. In addition, there is a danger of damaging the sensitive tungsten carbide tips during sharpening and tensioning. However, a well-maintained tungsten carbide saw will retain its sharp cutting edge much longer than the stellite saw.

The existing saw mills being used in sawing conventional wood can be employed economically to saw coconut trunks if the necessary training and equipment to apply stellite to the saw teeth are provided. A stellite tipping machine together with the side and top grinders are important components of

the saw shop to obtain maximum efficiency of the stellite teeth. Hence, the success of sawing coconut trunks using a band saw depends much on the preparation and maintenance of the cutting blades.

Drying

Freshly-sawn coconut wood contains water by as much as one-third to one-half of its total weight. Except for a very few uses such as in marine piling, green materials are not advisable to use particularly for furnitures, panels, internal wood works and flooring. The wood has to undergo seasoning process to minimise, if not avoid, problems in its utilisation.

Generally, different species of wood have marked variations in their drying characteristics. Coconut wood exhibits varying wood structures that influence its drying behaviour. The differences in wood density across the stem coupled with variable green moisture contents present problems in drying. The very high moisture content of the soft central portion of the trunk is related to its susceptibility to collapse. On the other hand, the peripheral high density wood is more prone to surface checks and tends to develop twist.

The common drying methods include air drying under shed, forced air and kiln drying. Air drying is the simplest and most economical method of moisture removal from the wood. The sawn lumber are fillet-stacked under a shed or exposed outside protecting the top layers from direct sunlight or rain. The drying rate depends mainly on the prevailing humidity and temperature in a particular locality. Depending on the existing weather conditions, 25 mm and 50 mm boards take four to 11 weeks and 16 to 21 weeks, respectively, for air drying to attain equilibrium moisture contents of 17 to 19 per cent (Laxamana and Tamayo, 1978).

Forced air drying involves the use of blower where air under atmospheric or heated condition is forced to pass once or circulated through a stack of sawn lumber. This process accelerates the removal of free moisture from the wood even under relatively low temperature. At an average atmospheric air temperature of 25°C and air velocity of 3.5 m per second, 25 mm and 50 mm boards can be dried to an equilibrium moisture content in 22 days and 40 days, respectively.

Kiln drying is the process of exposing green or partially air-dried sawn lumber which are fillet-stacked in an enclosed chamber. The kiln is either heated by steam, electricity or through the product of combustion of wood or gas. The humidity, temperature and air circulation are controlled in the drying chamber, hence, the boards are dried to any moisture level within a short period.

Based on kiln drying experiment, the 25 mm coconut boards can be dried from green moisture content to the final moisture content of 13 per cent in 14 days by employing initial dry bulb temperature of 45°C and wet bulb temperature of 40°C to the final dry bulb temperature of 50°C and wet bulb temperature of 37°C. The 50 mm boards can be dried to 16 per cent final moisture content in 19 days with temperature range of 48 to 55°C dry bulb temperature and 39 to 45°C wet bulb temperature.

Machining

Coconut wood furnitures and other finished wood products are gaining nation-wide acceptance. However, secondary processing of coconut wood is not an easy task unless effective machining techniques are applied (Penamora, 1983). Technically, the principal limiting factor is the adverse and difficult working properties of the wood which result in rapid dulling and blunting of wood working tools.

Machining is the process of cutting and dressing wood into the desired shapes and sizes by various wood working machineries. The processes include rip and cross cutting, planing, turning, boring and sanding. The machines necessary for commercial production of coconut wood products include radial arm saw, tilting arbour saw, narrow band saw, planer, jointer, lathe, boring and mortising machine and sander.

Finishing

Finishing refers to the application of transparent or semi-transparent liquid coating to enhance the natural beauty of the grain, colour and figure of wood products. Good quality finish for coconut wood requires the preparation of the surface by sanding to remove the knife marks and to produce a smooth surface.

The schedules for finishing coconut wood products are influenced by the kind of coating materials to be used, individual skill, appropriate working methods and the wood substrate which refers to the density of the wood.

Coating involves sequence application of stain, filler, sealer and top coating materials such as lacquer, polyurethane, polyester and oil finish. Usually, two or more coats of finishes are applied to coconut wood to improve the appearance and quality of wood products.

Preservation

Coconut wood belongs to the non-durable group of timber. When used in situations favourable to attack by decay fungi and wood boring insects, the hard dermal portion of the trunk will last only for a period of one to two years. The soft inner portion will deteriorate in a few months when left exposed to the weather.

Its low natural durability requires preservative treatment to ensure that the wood is used within a reasonable service life. Coconut wood should be properly treated to protect it against attack of wood destroying organisms specially when used in ground contact and exposed to the weather.

The wood preservatives used for treating coconut wood fall into two general types, namely: oil-borne, such as creosote, pentachlorophenol, cuprinol and solignum; and, water-borne salts which are applied as water solutions. The standard wood preservatives used in water solution include chromated copper arsenate with trade names as Green salt, Tanalith, Boliden K-33 and Wolman CCA.

The treatment processes of wood are generally composed of two methods: the pressure and non-pressure processes. The former method, in which wood is impregnated in an enclosed cylinder under pressure, requires high capital investment and skilled technicians to operate the plant. The latter, which varies

according to procedures and equipment used, is easily adopted in the rural areas due to its simplicity in operation and low cost capital outlay. In general, the non-pressure process provides inferior control of preservative retention and penetration than the pressure process. The non-pressure process includes brushing or spraying, dipping, steeping, dip diffusion and hot and cold bath.

The recommended treating processes are presented in Table 87.2. The treatment schedules of the different processes have been established for coconut wood through a series of experiments and field and service tests of treated materials.

Uses of Coconut Wood

The structural use of coconut wood depends mainly on its density. The high density materials should be used in building components, such as, posts, floors, floor joists, purlins and other load bearing structures. The medium density boards can be effectively used for walling, horizontal studs, ceiling joists and door/window frames. As a rule, coconut wood with density below 400 kg/m^3 should not be used as structural framing materials. However, they can be utilised in the internal parts of a building, such as the ceiling and wall lining in the form of boards and shingles.

Coconut wood can be a promising material for the manufacture of furniture, novelties and other handicraft due to its beautiful grain and attractive natural appearance. The hard portion, although it can be used for furniture, imposes some limitation on the density requirement for ideal furniture. The problem can be overcome by adopting a suitable design that requires small sized components without sacrificing the strength requirement. The medium density wood is undoubtedly a good material for furniture and novelties including handicrafts as this is more or less the required density range in manufacturing furniture.

Coconut trunks for poles, piles and fence posts are perishable in untreated condition. They are easily destroyed by termites, marine borers and decay fungi (Palomar, 1989). The long lasting utilisation of coconut wood used in ground contact and exposed conditions is influenced by a successful preservative treatment.

High value coconut wood products which include furniture, decorative interior walls, parquet floors, various novelties and curio items are equally, if not more than, comparable to conventional wood species commonly used in the furniture industry as far as appearance is concerned. Hence, with effective product promotion, quality furniture and other high value coconut wood products can have a potential share not only in the domestic but also in the world markets.

PROSPECTS FOR COCONUT WOOD UTILISATION

In the past, the wood using industry depended heavily on conventional wood as the source of raw material for housing, furniture and other finished wood products. As a result of massive reliance on the traditional wood species, the industry faces a problem brought about by the scarcity and prohibitive cost of conventional wood.

Table 87.2: Recommended treating processes for coconut timber

Service condition	*Preservative and concentration*	*Processes and treating schedule*	*Timber condition*	*Retention (kg/m³)*
Ground contact (poles/posts)	CCA 4–6%	Pressure: 1st vacuum, 45 minutes; Pressure, 120 minutes; 2nd vacuum, 10 minutes.	Dry	14–20
	Creosote - bunker oil: 70:30 mixture	Pressure: 1st vacuum, 1 to 1–1/2 hours; Pressure, 2 to 3 hours; Temp., 160° to 180° F; 2nd vacuum, 1 hour.	Dry	160–192
	Creosote - bunker oil: 70:30 mixture	Hot and cold bath: 8 to 10 hours heating and overnight cooling	Dry	128–192
Outdoor, not in contact with ground (sign boards, benches, roof shingles etc.)	CCA 2–3%	Pressure: 1st vacuum, 30 minutes, Pressure, 60 minutes, 2nd vacuum, 10 minutes.	Dry	7–12
	Copper sulphate, 3%; arsenic pentoxide plus sodium dichromate, 3%	Double diffusion: 1st soaking in 3% copper sulphate for 2 to 3 days and 2nd soaking in 3% arsenic pentoxide plus sodium dichromate for 3 days.	Green	7–12
Indoor, not in contact with ground (beam, rafters, jambs, etc.)	PCP: 5% in oil; cuprinol or solignum: ready mixed.	Dipping/brushing: Dip for 3 to 5 minutes, or brush for 3 coatings.	Dry	1.8–2.0
	CCA: 2%	Steeping/dipping/brushing: Dip for 10 to 20 minutes or brush for 3 coatings.	Dry	0.5–0.8
	Timbor: 20–30%	Dip diffusion: Dip for 2 to 3 minutes, block-stack and cover with polythene sheet for 4 to 6 weeks.	Green	8–10

There is, therefore, an urgent need to look for lesser-known indigenous wood materials that could be a good substitute for commercially-known wood species to overcome the inadequate supply of logs and at the same time help conserving our remaining forest resources. One such raw material that would be locally available in many parts of the coconut producing countries is the coconut tree.

The growing number of old and senile palms requires the launching of a large scale replanting programme. Table 87.3 shows the estimated available wood resources in 11 coconut producing countries indicating the area under coconut, percentage of ageing palms and the volume of millable logs and sawn lumber.

Table 87.3: Estimated available wood resource in coconut producing countries

Country	[1]*Area under coconut ('000 ha)*	[2]*Percentage of ageing palms*	[3]*Volume of millable logs ('000 m³)*	[4]*Volume of sawn lumber ('000 m³)*
India	1,155.0	5.3	4,591.1	1,377.3
Indonesia	3,012.0	20.0	45,180.0	13,554.0
Malaysia	349.0	60.0	15,705.0	4,711.5
Papua New Guinea	241.0	30.0	5,422.5	1,626.8
Philippines	3,217.0	30.0	72,382.5	21,714.8
Solomon Islands	62.0	50.0	2,325.0	697.5
Sri Lanka	419.0	20.0	6,285.0	1,885.5
Thailand	281.0	35.0	7,376.3	2,212.9
Tonga	36.0	40.0	1,080.0	324.0
Vanuatu	69.0	45.0	2,328.8	698.6
Western Samoa	42.0	54.0	1,701.0	510.3
Total	8,883.0		164,377.2	49,313.2

[1] Source: APCC Statistical Yearbook 1984.
[2] Source: Country Statement, Proceedings Coconut Wood 1979.
[3] Estimated at 100 trees per ha with log volume of 0.75 m^3 per tree.
[4] Estimated at 30 per cent sawn lumber recovery.

The coconut growing countries listed above account for a total of more than 8.88 million ha planted with coconut. On the basis of country statements made during the Coconut Wood Utilisation Seminar held on October 22–27, 1979 at the Philippines, the estimated percentage of ageing palms range from 5.3 to 60 per cent with India and Malaysia having the lowest and highest proportion of old palms, respectively. The Philippines which accounts for the biggest area under coconut has 30 per cent senile trees while Indonesia which comes next in terms of coconut area has 20 per cent ageing palms. The rest of the coconut producing countries particularly the South Pacific regions have 40 to 54 per cent senile trees.

Based on the volume of millable logs, a total of about 164.38 million m^3 of round timber would be readily available for economic utilisation producing approximately 49.31 million m^3 of sawn coconut lumber. Of this volume, the Philippines and Indonesia account for 21.71 million and 13.55 million m^3 of sawn lumber, respectively, or a combined wood resource of 35.26 m^3 which represents more than 70 per cent of the expected total lumber production of the coconut producing countries.

In the Philippines alone following the 40-year cycle replanting programme, an annual supply of 8 million trees representing 1.8 million m^3 of sawn

lumber would be realised for economic utilisation. If the lumber will be used for the national shelter programme, about 38,160 three bedroom houses can be constructed yearly or roughly 1.5 million houses for the 40-year cycle coconut replanting programme.

PROBLEMS IN COCONUT WOOD UTILISATION AND HOW TO OVERCOME THEM

Experience shows that saw milling is the most difficult aspect in the processing of coconut wood. In order to effectively and efficiently convert coconut trunks into lumber, the saw should be correctly levelled and tensioned in addition to the technology of using either stellite or tungsten carbide tips as saw teeth. For best result, it is therefore essential to ensure that the saw blades are properly maintained. To do this, only experienced saw doctors should be employed in saw milling coconut trunks.

A problem related to structural application of coconut wood is the difficulty of nailing and subsequently splitting of high density wood near the ends of the boards. Pre-drilling is recommended prior to driving the nails.

Good finished products such as cabinet joinery and parquet floors are subjected to considerable sanding prior to the application of finishings. The use of mechanical sander instead of manual sanding facilitates finishing the surface of the wood.

The small diameter of coconut stem limits the size of sawn lumber, hence optimum width and thickness of boards that are recovered are 25 mm and 50 mm, respectively. For structures requiring bigger sizes of lumber, glue lamination of the wood to the desired dimensions solves this particular problem.

TECHNOLOGY TRANSFER

While considerable advancement of coconut wood research and development has been made in recent years, what remains to be done is the effective dissemination as well as appropriate application of the technologies obtained from these research studies.

The Timber Utilisation Division of the PCA's Zamboanga Research Centre offers on-the-job training in all aspects of coconut wood technology for both public and private parties who are interested to venture in coconut wood processing and utilisation (Kandeel, 1983). This project avails of the facilities and technology developed at the Centre.

Ultimately, the effective application of technology on coconut wood processing and utilisation will not only provide cheap and locally available construction materials but will also help to generate job opportunities in the rural areas and at the same time provide added income for the coconut farmers during the large scale coconut replanting programme.

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STUDIES ON THE COMPOSITION AND STORAGE OF COCONUT AND COCONUT PRODUCTS

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Coconut palm is one of the important sources of vegetable oil in the country and copra is one of the rich materials for vegetable oil extraction. Studies conducted at Jawaharlal Nehru Technological University, Institute of Chemical Technology, Anantapur on post-harvest technology of coconut are summarised below:

The keeping quality of copra as well as its yield and quality of oil largely depends on the procedure that is followed for processing and method of storage. For safe storage the moisture content of copra should be at 5 per cent or less. A moisture content of more than 6 per cent affects the quality of copra as well as the oil extracted. Partially deteriorated copra due to mould attack gives an abnormally high oil content compared to the outer layers.

Treatment of fresh coconuts with chemicals like sodium hydroxide, sodium carbonate, sodium chloride and glacial acetic acid results in apparently 7 to 10 per cent of higher copra than untreated control.

Coconut oil in storage is liable to a type of rancidity known as ketone or perfume rancidity. The cause of rancidity has been attributed to the presence of pencilium and aspergillus which promote β-oxidation of saturated acids. The raw edible grade coconut oil can be stored under ambient room condition for a period of one year without appreciable change in its light, colour, sweet odour, peroxide value and iodine value.

The dark colour of the solvent-extracted coconut oil can be reduced by pre-treatment with aqueous solution of oxalic acid, citric or tartaric acids. The resultant oil has good property of bleachability resulting in light coloured water/white oil when bleached with activated earth and carbon. The characteristic seed aroma of the oil is retained when treated with oxalic acid and other organic acids whereas the aroma is lost in alkali treatment and when

reverted in earth bleaching method. If oil is meant for non-edible purposes, oxalic acid is used for pre-treatment whereas citric or tartaric acids are used if the material is for edible purpose.

Red/brown coconut oil obtained from inferior grade copra had dark colour, strong rancid odour and high free fatty acid contents.

Bleaching oil with higher quantities of earth and carbon is very effective but the loss of oil is high. The degree of bleaching is the same in brown/red coconut oil pre-treated with phosphoric or citric or oxalic acids. Hydrogen peroxide is seen to be the most effective reagent in removing the colour of the oil.

The fresh coconut kernel contains about 4 to 4.5 per cent of protein and when the coconuts are processed into copra and oil the major portion of the original protein passes on to the coconut meal, which is the residual product after oil extraction. Partially de-oiled copra gratings and dessicated coconuts can be used as value added products for confections, preparation of sweetmeats and spice powders.

AFLATOXIN B_1 IN COPRA, A POTENTIAL THREAT TO CONSUMERS

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Copra is generally found to be contaminated by microorganisms during processing and storage under natural conditions, especially during rainy season. Among the fungal contaminants, *Aspergillus flavus* Link ex Fries has been found to liberate aflatoxin B_1, a potent toxin in appreciable quantities. This paper summarises the results of experiments conducted in this regard at the College of Agriculture, Vellayani, from 1974 to 1977.

Samples of copra were collected at bimonthly intervals for one year and were assayed for aflatoxin B_1 (Walt King *et al.*, 1968). The biological effects of *A. flavus* infected copra on small animals and birds were also studied. Pieces of copra were artificially inoculated with *A. flavus* in bulk and stored under saturated humidity conditions at room temperature of 28 to 30°C for 10 days. The inoculated copra was then finely powdered and made into pellets, autoclaved and used for feeding trials. A representative sample was also assayed for aflatoxin B_1.

A group of 37 one-day-old ducklings were maintained and force-fed with infected copra in addition to standard ration. Daily observations on casualties and weight of the surviving birds at the end of the experimental period was recorded. On the 30th day they were stunned to death. Liver and kidney of all the dead and killed birds were subjected to histopathological studies. Similar studies were conducted with small animals like rabbits and rats.

The data on seasonal variations in aflatoxin B_1 production in copra showed peak values in samples collected during March–April, May–June and July–August. One of the samples recorded a value of 2 ppm. In all other cases the concentration was above 1 ppm.

The studies on the mortality of ducklings during the experimental period revealed the following facts. Out of a total of 37 ducklings used for the trial, 28 ducklings died within the first eight days, three between eight and 20 days

and one between 20 and 30 days. Only five ducklings survived the experimental period.

HISTOPATHOLOGICAL STUDIES

Liver

Birds that died within seven days showed necrobiotic changes while proliferation of the bile duct with or without fibrotic changes was clear on birds which died later. The survived birds also showed necrosis, bile duct proliferation and hepatic fibrosis. Hepatic cell regeneration was also noticed. Pseudolobulation was present in some cases. The changes in the hepatic cells manifested as hydropic and fatty degenerations gave a moth eaten appearance to the parenchyma. The fat vacuoles in the hepatic cells were either single large or numerous small ones. These cells with degenerative changes were seen along with individual hepatic cells which had become necrotic. The onset of fibroblastic reaction was evident after seven days. Early manifestations were in the portal areas and later the fibroblasts were seen to be extending in between the hepatic cords. In those that died within 15 days, a slight collagen deposition was seen. Later by the thirtieth day, thick strands of fibrous tissues were seen around individual lobules.

Kidney

Kidney of ducklings that died during the first eight days showed necrosis and degeneration of tubular epithelial cells. The average weight gain of the birds in the treatment group was also significantly lower than those of the control group.

Similar results were observed with small animals also. The death of the experimental birds and animals indicated the existence of toxin at high levels in the copra samples administered. The LD_{50} of aflatoxin has been estimated to vary from 17.3 to 28.2 μg for a duckling weighing 50 g (Nesbitt *et al.*, 1962). In the present study also one g of copra infected by *A. flavus* produced very high mortality among ducklings and induced histopathological changes similar to the administration of purified preparations at LD_{50} levels. The poor weight gain in aflatoxin fed birds can be due to impaired protein synthesis. Sporn *et al.* (1966) have reported changes in RNA synthesis following aflatoxin treatment. This is due to the effect of aflatoxin on nuclear RNA synthesis. Because of the effects of aflatoxin on nuclear RNA synthesis it could be assumed that cytoplasmic RNA is also altered. Butler (1966) has also recorded acute liver injury in one-day-old ducklings. Bile duct proliferation also reached a maximum in three days and then regressed with subsequent repair of their parenchyma. The minimum concentration of aflatoxin B_1 required to produce bile duct proliferation is reported as 0.04 mg/kg based on administration of five equal doses. The pattern of mortality and the nature of bile duct proliferation corroborated the analytical results of high aflatoxin content in copra.

Studies on the production of aflatoxin during different periods of the year revealed its presence in samples collected from March to August. This is

attributed to the abundant growth and sporulation of *A. flavus* on the substratum facilitated by the moisture content and the congenial atmospheric conditions (Philip *et al.*, 1980). Aflatoxin producing strains of *A. flavus* are also widely distributed in nature under tropical conditions. With sufficient moisture they grow on food materials which are improperly handled or stored.

The presence of toxin producing strains like *A. flavus* in copra is of great practical significance since their presence beyond a certain level will definitely inflict injury to human beings and animals which are consuming the products, namely, coconut oil and coconut oil cake. The report of de Iomg *et al.* (1964) that milk of cows fed with aflatoxin contaminated feed focuses the importance of providing feed free of aflatoxin to milch animals. The recognition of the carcinogenic activity of aflatoxins causes public health problems also. Direct evidences that aflatoxin causes diseases in human beings is difficult to obtain. However, there is increasing evidence or correlation between hepatic carcinoma and aflatoxin consumption (Campbell and Salamat, 1971) in human beings. The W.H.O. has recommended the maximum level to be 0.3 ppm in food for young children in regions where protein malnutrition is common (Butler, 1974).

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PRODUCTION OF BALL COPRA BY HEAT TREATMENT

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The conventional way of preparing ball copra is by storing the fully matured coconuts on a raised platform inside a shed or in the attic for a period between nine and 12 months (Thampan, 1981). The partially dehusked nuts were also reported to be used for ball copra preparation (Nair and Joseph, 1987). Heat is sometimes provided to hasten the drying process. However, to overcome the poor quality of the product and the longer periods required for drying a procedure has been standardised to produce ball copra in a short period using an agricultural waste based dryer.

Two hundred and fifty fully matured nuts of West Coast Tall variety were partially dehusked and dried in a drier developed by CPCRI (Patil, 1983) for small coconut growers using agricultural waste as fuel. Drying was done at a temperature of 55° to 60°C for eight hours daily for three days and then stored outside in gunny bags for 10 days. Intermittent heating was continued till all the nuts were converted to ball copra. Four trials were conducted one each initiated in June, 1989 (P_1) October, 1989 (P_2) January, 1990 (P_3) and May, 1990 (P_4). Two hundred and fifty partially dehusked nuts stored in the attic served as control. The weight of kernel and ball copra produced were recorded and drying characteristics were studied.

Partially dehusked puny nuts (300 numbers) were also used for another set of trials. The first trial with puny nuts was initiated in June, 1990 and the second trial in January, 1991.

The coconut oil extracted from the experimental treatments was subjected to qualitative tests, namely, acid value (AV), iodine value (Anonymous, 1963), freely fatty acid (FFA) content (Tribolt and Aurand, 1963) and peroxide value (PV), (AOAC, 1970). Soxhlet extraction method was followed for estimating the oil content using petroleum ether (AOAC, 1984).

All the nuts under heat treatment became ball copra within six months whereas there was only 15 to 25 per cent conversion in control. In control 96 to 98 per cent conversion took place only from the tenth month onwards and about 2 to 4 per cent of the nuts were germinated. Following the method described in this paper it is possible to prepare up to 11 batches of ball copra in a year compared to one batch in the conventional way. The conversion of ball copra and rate of drying were slow during the period June to August. The present study suggests October to May as a suitable period for preparation of ball copra.

Similarly the puny nuts under heat treatment were transformed into ball copra within three to four months as against the control taking five to six months. The conversion of nuts into ball copra was faster during January to May when compared to June to November period.

Ball copra samples prepared by providing intermittent heat in a dryer had significantly low population of bacteria, fungi and lipolytic microorganisms when compared to that produced in the conventional way. There was a three-fold reduction in the counts of bacteria and two-fold reduction in the counts of fungi and lipolytic microorganisms in the heat treated samples. A comparison of the population at different seasons revealed significantly low population in samples dried during October to May.

The oil from the heat treated samples and low levels of free fatty acids (0.131 per cent), acid value (0.620) and peroxide value (1.48 m. eq peroxidase/kg) a higher iodine value (11.12) as compared to control which recorded 0.317 per cent, 1.20, 2.01 m eq peroxidase/kg and 7.63 for FFA, AV, PV and IV respectively. For WCT nuts a similar trend was recorded for puny nuts experiment also. An increase in the level of FFA, AV and PV in any oil is indicative of its deterioration. Since the primary stage of deterioration of coconut oil is hydrolytic in nature the quality is better judged by the levels of FFA. Here the lower values of FFA and AV in the heat treated ball copra samples suggest that ball copra preparation by intermittent heating in the drier developed by CPCRI for small coconut growers gives a better quality oil. However, the levels of FFA which were higher in the samples prepared during the monsoon period in both the treatments may be due to high relative humidity (85 per cent) during this season.

There was no significant variation in the oil percentage between treatments. The present cost of fabrication of CPCRI Small Holders' Copra Dryer is worked out to be Rs. 2,700. The cost of production of one kg of ball copra using CPCRI dryer was calculated as Rs. 3.65. The comparative study of the preparation of ball copra using the drier and by conventional way was also worked out (Table 88.1). A net profit of Rs. 2,845 per annum can be obtained by this method.

Table 88.1: Comparative study of the cost analysis of preparing ball copra by heat treatment and by conventional way

A. By heat treatment		
1.	Cost of ball copra as on III week of October:	Rs. 3600/q
2.	Ball copra production capacity of CPCRI Small Holders' Dryer:	440 kg pa
3.	Cost of production of ball copra:	3.65/kg
4.	Production of ball copra in half year:	220 kg
5.	Cost of 220 kg of ball copra:	7920
6.	Interest gained in a year @ 10%:	396
7.	Earnings by selling ball copra in a year:	Rs. 15840
8.	Total earning (6 + 7):	Rs. 16236
9.	Total cost of production (3 × 2):	Rs. 1606
10.	Net earnings:	Rs. 14630
B. By conventional way		
1.	Production capacity in the same volume of space:	80 kg
2.	Cost of production:	Nil
3.	Earnings by selling ball copra @ Rs 3600:	2880/q
4.	Earnings by selling the remaining 2250 coconuts and by way of interest:	8905
5.	Total earnings (3 + 4):	Rs. 11785
	Net profit (A_{10}–B_5):	Rs. 2845

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ECONOMICS, DEVELOPMENTAL PROGRAMMES AND TRANSFER OF TECHNOLOGY

Chairman E.G. Silas

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FAO SUPPORT FOR COCONUT RESEARCH AND DEVELOPMENT BETWEEN 1981–1991

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ABSTRACT

The FAO supports and strengthens existing organisations involved in coconut R and D and assists in the creation of new organisations. The involvement of FAO in coconut programmes to assist APCC, TCP (Technical Cooperation Programme), UNDP and other Donor Supported Projects, inter-governmental projects on oilseeds, oils and fats, and publications are summarised.

INTRODUCTION

The Food and Agriculture Organisation of the United Nations (FAO) has always provided much assistance to small holder farms. One of the typical aspects of millions of small holder farms in the humid tropics is the presence of a few up to several hundred coconut palms. In fact, about 96 per cent of the world coconut production of about 41 billion nuts is produced by small holders.

This immediately exposes one of the fundamental problems in coconut development: it is not backed up by a prosperous plantation industry as is the case in rubber, oil palm, tea and sugarcane. In contrast, research and development in coconut has normally been funded from poorly filled government coffers.

FAO has played a major role in this respect by executing and financing specific research and development programmes in cooperation with various government departments and research institutes in many countries by providing specialists; organising numerous conferences, workshops and courses; providing university fellowships and study tours; and a wide variety of equipment.

FAO played, for example, a major coordinating role in organising the Technical Working Parties between 1961 and 1979, where research workers

met, germplasm exchange was arranged and the foundation of new research stations was formulated.

The Government of the Philippines was assisted by FAO to identify the nature of the *cadang-cadang* disease, which is a major threat to the coconut crop.

Ohler (1984) in his FAO publication "Coconut, tree of life", provided an excellent summary of FAO's activities in respect of coconuts. FAO's coconut related activities over the last 10 years are listed in this paper.

Regional Cooperation in Asia and Pacific

After the discontinuation of the Technical Working Parties in 1979 there was still a need for regional coordination of coconut research and development. UNDP provided the funds and FAO executed project UNDP/RAS/80/032 involving technical cooperation between eight Asian and 11 Pacific countries. The project started its activities in 1986. Assistance was provided to re-establish the library and data base of the Asian and Pacific Coconut Community (APCC) in Jakarta, which was destroyed by fire. Under the project a course was organised on the biological control of *Oryctes*. Coconut workshops were convened on integrated pest management; replanting; intercropping and intergrazing; farmers' receptivity to new coconut technology. Coconut working group meetings were organised on diseases of unknown origin; nutritional deficiencies; coconut based farming systems; and processing. All these activities were coordinated by a Regional Network Coordinator in Jakarta and his staff was made available by the Government of Indonesia. The network has become dormant due to lack of funds since December 1989 after the UNDP financing was withdrawn.

I went into some detail in this example, as it is a clear demonstration of a major problem facing coconut research and development, that is, a lack of long-term continuity in funding and staffing, and too much reliance on donor agencies.

Review of FAO Executed Projects

General Information: Project UNDP/RAS/80/032 is only one of the 54 coconut projects world-wide under execution by FAO between 1981 and 1991. Projects can be grouped in Technical Cooperation Programmes (TCP) and donor projects executed by FAO.

The TCP projects are funded by FAO and last normally one year with a maximum of two years. They frequently precede a larger scale project, or filling a specific gap in technical know-how and lack in equipment in existing country programmes.

The donor projects executed by FAO are frequently of three to five years duration and may have a much broader orientation. Also, their level of funding is much higher. The two groups of projects are considered separately.

Technical Cooperations Programmes (TCP): The TCP projects are meant to provide a quick response to small scale requests from member countries. The programme concentrates on training, investment preparation, emergencies,

technical advice to governments, programming of technical assistance and supply of limited and urgently needed inputs to support development.

During the period 1981 to 1991 FAO has executed 37 TCP projects related to coconuts ranging in budget from US $ 6,900 to US $ 207,000. The average cost was US $ 75,000 per project.

National seed production programmes frequently require germplasm introduction, establishment of seed gardens and training in seed production and breeding. Such assistance was provided to China, Dominican Republic, Cook Islands, Western Samoa, Costa Rica and Thailand.

Assistance in the control of *Oryctes* was provided to the Maldives and the Philippines. Coconut mite control was attempted in Santa Lucia. Coconut pollinating honey bees were introduced in the Maldives.

Major activities were developed in coconut timber utilisation in many states in the Caribbean area as well as in Sri Lanka, Western Samoa and Thailand. Reviews and advice on the coconut industry were provided in Fiji and Tonga.

Coconut replanting frequently leads to increased *Oryctes* development and an active policy to destroy cut/fallen coconut stems is desirable. Stem utilisation for timber and charcoal production will facilitate this. TCP projects on training in coconut wood utilisation were organised on a regional scale in Asia, in the Pacific and in Latin America, and in Western Samoa, Sri Lanka, Thailand, and Jamaica.

UNDP and other Donor Supported Coconut Projects: The 17 operational, donor funded coconut projects executed by FAO between 1981 and 1991 had budgets ranging from US $ 52,000 to US $ 2,900,000. The total assistance for operating projects amounted to US $ 16,500,000, or about US $ 1,000,000 per project.

In a number of projects the objectives were broad as in Vietnam. Under project UNDP/VIE/80/009 the whole coconut research and development infrastructure was established by a resident FAO chief technical adviser. This infrastructure consisted of overseas training of four scientists; establishing 11 comparative varietal trials; a coconut seed garden; nine agronomical trials; a small germplasm collection; establishment of a coconut extension service; supply of equipment for a soil and leaf analysis laboratory; office equipment; heavy agricultural equipment; meteorological equipment; and, staff training. For your interest one of the agronomical trials had fresh-water shrimps as a component of the farming system.

In another project, such as UNDP/RAS/81/110, "Regional Coconut Wood Training Programme", the objectives were well defined in a limited field. During the project 106 managers, technicians and operators from 13 countries in Asia and the Pacific were trained in the Philippines by the staff of the Philippine Coconut Authority and the Zamboanga Research Centre. The designs of three coconut wood houses were prepared and houses constructed under the project to demonstrate the versatility of coconut timber. Under the project research was conducted on coconut wood strength, properties and

carbonisation methods for charcoal production. Coconut wood components lend themselves well for urban, low cost housing development.

Another project, UNDP/INS/85/014, "Development of Integrated Coconut Pest Control Programme", was executed by FAO in Indonesia.

Coconut is, in general, a low input crop and simple and cheap technologies are required for pest control which frequently excludes the use of pesticides. The development of biological pest control methodologies is considerably more difficult than formulating chemical pest control, but the biological control will be in the end much cheaper. Development of biological control methods requires experienced and specially trained staff. In service, training courses were organised for 59 research staff covering subjects, such as, coconut pests and diseases, weed control and computer programming, and for 72 extension staff covering *Oryctes* control, coconut crop protection, *Metharizium* production and *Artona* control. Five fellowships were awarded for study in the USA, UK and Australia. Eleven study tours were provided to the Philippines, Maldives, UK, Thailand, Kenya and Ivory Coast. Laboratory equipment was supplied.

The project concentrated on developing, or perfecting appropriate biological control methods against *Oryctes rhinoceros, Sexava, Artona catoxantha, Plesispa reichei* and slug caterpillars. Immature nut fall and death of palms due to attack by the fungus *Phytophthora* were not serious problems in Indonesia before the large scale introduction of hybrid palms obtained from seed gardens of Malayan Yellow Dwarf × West African Tall (MAWA) and Nias Yellow Dwarf × West African Tall (NIWA). These seed gardens were established during the seventies under an IRHO/World Bank project. The West African Tall is more susceptible to *Phytophthora* induced bud rot than other varieties. MAWA is susceptible to *Phytophthora* induced nut fall disease in Indonesia, but shows a high susceptibility to *Phytophthora* bud rot in the Philippines. There is enough evidence to suggest that West African Tall, Malayan Yellow Dwarf and Nias Yellow Dwarf are highly susceptible to *Phytophthora*. A large scale field trial was started in 1988 to compare resistance to *Phytophthora* between 18 coconut varieties.

Publications

Besides several hundreds of technical publications as a result of projects and meetings, also a number of books were published during the last decade. "Coconut, tree of life" (1984) by J.G. Ohler was published as FAO Plant Production and Protection Paper n. 57 in both English and Spanish. "Pastures and cattle under coconuts" (1988) by S.G. Reynolds was published as FAO Plant Production and Protection Paper n. 91 in English. A Spanish translation will be published during 1992 in view of the importance of grazing under coconuts in Latin America. "Coconut wood, processing and use" (1985) was published as FAO Forestry Paper n. 57. These books have very complete bibliographies to guide interested readers.

Many articles on coconut pests and diseases appeared during the past decade in the FAO Plant Protection Bulletin from FAO executed projects.

COCONUT DEVELOPMENT PROGRAMMES IN THE SOUTH PACIFIC REGION

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ABSTRACT

Coconut continues to play an important role in the lives and economies of the South Pacific countries. But the recent decline in prices for copra and coconut oil has encouraged them to diversify into other areas both within and outside the coconut industry. In the case of the former, an increased awareness has been created to develop the coconut industry by improved production, downstream processing and market expansion. However, they face many constraints some of which are peculiar to South Pacific countries. In spite of these, there are at least a few that have made considerable progress in increasing their export earnings through various development programmes.

Compared to the South Pacific countries, Asian coconut producing countries have made substantial progress in research and development in the country industry. There is much they can offer from which South Pacific countries should be able to benefit, to develop the coconut industry in their region.

INTRODUCTION

The land area of Pacific is divided among more than 10,000 islands of varying sizes. Of them 22 (with five erstwhile colonial powers) have formed into the South Pacific Commission which is a technical and development oriented organisation. These 22 countries cover a land area of 550,044 sq km. Of these 22, seven, namely, Federated States of Micronesia, Fiji, Papua New Guinea, Solomon Islands, Vanuatu, and Western Samoa with Palau as an associate member are in the Asian and Pacific Coconut Community. These seven countries account for 524,081 sq km more than 95 per cent of the land area of the South Pacific region.

Importance of the Coconut Industry

To the Pacific Islands for centuries coconut has been the most important crop. In fact regarding the original home of coconut Child, has called attention

"to the very strong argument for a Melenesian origin put forward by P. Lepesme in his encyclopedic work *Les Insectes des Palmiers*. The Melanesian area is generally regarded as extending southward to the Tropic of Capricorn between 145° and 180° E, that is roughly from New Guinea to Fiji. The weight of evidence is in favour of an original home for the coconut somewhere in this region" (Child, 1964).

Although the Pacific countries depend heavily on the coconut tree for their economic and social well-being, their total output is only about 6 per cent of the world coconut production (Table 92.1). Yet for some, coconut is still one of the biggest foreign exchange earners (Table 92.2).

Table 92.1: Production of coconuts in nut equivalent during 1985 to 1989 (in 1000 nuts) in South Pacific

Country	*1985*	*1986*	*1987*	*1988*	*1989*
F.S. Micronesia	60000	39000	34000	50000	50000
Fiji	316000	344000	279000	275000	284000
Papua New Guinea	1356000	1248000	1252000	1134000	1117000
Solomon Islands	222000	176000	155000	165000	191000
Vanuatu	402000	429000	423000	380000	538000
Western Samoa	146000	159000	149000	138000	130000
Palau	70000	70000	70000	70000	70000
Amer. Samoa	6250	6250	6250	6250	6250
Cocos Islands	6250	7500	7500	7500	7500
Cook Islands	15000	12500	12500	12500	12500
Fr. Polynesia	187500	187500	150000	118750	162500
Guam	42500	42500	45000	46250	46500
Kiribati	112500	62500	68750	137500	133750
Nauru	2500	2500	2500	2500	2500
New Caledonia	12500	13750	17500	17500	17500
Niue	3750	2500	2500	2500	2500
Tokelau	2500	2500	2500	3750	3750
Tonga	63750	85000	56250	66250	81250
Tuvalu	3750	3750	3750	3750	3750
Wallis etc.	3750	3750	3750	3750	3750
Total South Pacific Countries	3034500	2897500	2740750	2640750	286400
World production	46246000	47981250	47071751	46692500	48754750

Source: APCC Coconut Statistical Yearbook, 1989.

Table 92.2: Contribution from the coconut sector to export earnings (%)

Country	*1985*	*1986*	*1987*	*1988*	*1989*
Western Samoa	47.3	35.1	51.1	52.1	n.a.
Vanuatu	71.0	48.0	45.0	54.0	25.0
Solomon Islands	22.6	5.18	8.00	9.00	12.2
Papua New Guinea	6.34	2.20	2.29	3.60	2.82

Source: APCC Coconut Statistical Yearbook 1989.

Domestically coconut is a heavily consumed food item. In Vanuatu the estimated consumption per household per day is calculated at six for humans and nine for animals. In Solomon Islands out of an annual coconut production of 50,000 tons copra equivalent, domestic consumption averaged 13,000 tons a year (Ilala, 1989).

Recent Trends

What is evident from the above is that the contribution from the coconut sector to export earnings (except in Western Samoa) is on the decline. This can be attributed to several factors. Over the years there has been a decline in the price of copra and coconut oil in the international market (Table 92.3). These countries affected by the low prices realised the need to diversify into other fields and to other crops as is seen from Papua New Guinea.

Table 92.3: Average price of copra — 1984 to 1989 (US $ per ton CIF. Europe)

1984	710
1985	386
1986	197
1987	309
1988	398
1989	348
1990	231

In the Pacific countries in both plantation and small holder sectors coconuts are allowed to fall naturally and are collected from the ground. When the price for copra goes down there is no incentive for the farmers to collect and process them into copra. This factor and increased local consumption naturally reduced the exportable supplies and the contribution from coconut products to export earnings declined. However with the historical importance of the coconut industry and the potential it holds, an awareness was created in the countries of the region to develop the coconut industry which was the backbone of the economy of the countries earlier. The attainment of independence by these countries no doubt further stimulated them in this direction. In addition there was another move. With the low prices for copra, as seen in Vanuatu there has been a continued decline of the plantation sector and the rising relative importance of small holder copra production.

In 1980 copra derived from the plantation sector amounted to 9000 tons and comprised 27 per cent of the total national production. By 1990, this contribution had fallen to just 13 per cent with a plantations production of around 6000 tons. Small holder production on the other hand continues to expand reaching a record level of production of 39203 tons in 1990 when it accounted for 87 per cent of the total national production.

One of the first measures taken, initially by Papua New Guinea and later followed by some of the other Pacific countries was the introduction of a "copra price stabilisation scheme". The general objective of the scheme was to insulate the growers from external price fluctuations. Although the scheme came to effect in the late forties because of the remunerative producer prices

which prevailed, the need for utilisation of the stabilisation fund did not arise at least during the first 20 years of its existence. Nevertheless, the potential benefits of the scheme became obvious in the early seventies with the declining copra prices.

The strategy adopted to attain this objective was the moving long-term average price strategy with levies collected when prevailing prices were above and bounties paid when the prevailing prices fell below the long-term average. Thus, over a period there was an equalisation around long-term trend. The scheme though faced many vicissitudes over the years continues to-date with modifications effected time and again.

Research and Production

In Papua New Guinea the Cocoa and Coconut Research Institute was set up in 1962. About the same time, Oil Crop Research Stations located at Saraoutou and Espirita Santo in Vanuatu came under the management of IRHO on behalf of the government. In Solomon Islands where coconut research has been initiated since 1952 in Yandina a Joint Coconut Research Scheme between Levers and the Solomon Islands Government was established in 1960. Some research in coconut was also initiated in the Alafua Campus of the University of South Pacific in West Samoa. While these institutes were directly involved with research, in most of the countries ministry of agriculture was in charge of overall supervision of research and development activities relating to coconut.

With nearly half of the coconut stand in these countries being senile and with an eye on increased production, the research programmes were directed on selection and breeding, seed gardens, improved seed-nuts for nurseries, pest control etc. The Saraoutou Station in Vanuatu had done considerable amount of work in these areas, and two high yielding varieties were made available to small holders for replanting: (i) Improved local tall, and (ii) Vanuatu Red Dwarf × Vanuatu Tall hybrid (VRD × VTT) which is more precocious and capable of producing double the yield that of tall. In Fiji, the establishment and progress of the hybrid seed garden in the island of Taueun is said to be the basis of all future development programmes in coconut. It is envisaged that commencing in 1991 hybrid seed-nuts would be produced for demonstration and for replanting programmes from 1995 onwards.

Research and extension programmes in these countries also cover pests and disease control. In Papua New Guinea, pest control is of high priority due to *Scapanes* beetle which is a major threat to production. The finding of a *cadang-cadang* like viroid strain in Solomon Islands recently has created a new awareness to direct research on disease control.

Increased attention is now being paid to coconut based farming systems especially with export oriented cash crops, including traditional ones like yaquana. In Solomon Islands, under the Ministry of Agriculture and Lands a Farming Systems Agronomy division has been established to investigate a number of different intercrops. At the same time the countries are keen to

disseminate information and technology on Coconut Based Farming Systems to coconut farmers.

Processing

Except as in the case of Papua New Guinea where several desiccated coconut factories were in operation in different parts of the country in the thirties and the fifties which were closed down following suspicion of salmonelle contamination the main processing activity in the Pacific is processing of copra and in some cases crushing it into coconut oil.

But with the decline in the price of copra the countries realised the need to further process the products and by-products which has generated a spurt of interest in them. For example, in Papua New Guinea in 1990 a government institution called the Small Business Development Corporation had been set up to coordinate the institution of programmes and strategies for small scale processing. Solomon Islands with UNIDO assistance has commissioned an opportunity study (1991) on small scale coconut processing facilities in the country. South Pacific Commission under UNDP assistance was to send a three-member team in September–October 1991 to study the coconut processing in Asian countries.

However, there are several constraints these countries face on their road to downstream processing of coconut products. Limited supply availabilities of raw material, distance from the traditional markets, competition from established suppliers of these products especially from Asian producers, lack of technology, lack of finance, high cost of labour and high quality standards expected by consumers are some of them.

But even with these constraints there are at least a few success stories from the Pacific. In 1979, Federated States of Micronesia had embarked on a programme of processing coconut products by installing machinery for soap making and deodorising coconut oil. With technical assistance received from UNIDO it has continued to grow and currently manufactures a wide number of coconut processed products — laundry soap, toilet soap, body oil, hair oil, shampoo, cooking oil, liquid soap, suntan lotion and shell charcoal. The value of these exports for 1989 and 1990 had been US $ 33,685 and US $ 48,831, respectively.

Western Samoa was one of the first countries to embark on the manufacture of coconut cream. The success of this first venture has prompted two other companies to follow suit resulting in increased volume of export of non-traditional processed products. This is important in that for the first time export earnings from coconut cream had exceeded any other single coconut product from the country (Table 92.4).

But for the majority of South Pacific countries it will have to be small scale processing units. Suggestion has been made that they be combined into integrated processing unit. But as Etherington (1988) mentioned, "Integrated processing poses many questions for the islands." They have to be tackled taking country by country and not *en masse*.

Table 92.4: Export of coconut products — Western Samoa (value in Tala Thousand)

	1985	*1986*	*1987*	*1988*	*1989*	*1990*
Coconut oil	15622	6542	8730	11688	7000	4168
Copra meal	560	658	757	929	653	375
Copra	954	1049	65	1970	3237	1101
Coconut cream	2833	2822	3109	3874	5093	5576

1 US $ = 2.27 Tala in 1989.

Marketing

With limited number of products and volumes, there has been no serious attempt in the past to undertake market promotion programmes.

A study was conducted in 1989 to determine the feasibility of establishing a coconut processing venture in the South Pacific to produce high quality products for the export market. The objective of this market research was to "locate 'niche' markets, that: (1) present suppliers have not tapped because of different quality expectations between producers and buyers, (2) do not compete with major suppliers of coconut oil from other regions or other vegetable oils unless subject to consumer concerns about saturated fat content, and (3) represent new markets that have not yet been tapped, but which exhibit interest by potential buyers." However, the study was mainly concentrated in the North American market.

It is evident that most of the non-traditional products from this region are entering non-traditional markets as opposed to the UK, Japan and the USA proper. The big buyers of West Samoan coconut cream are New Zealand, Australia and Hawaii. Micronesia products are sold in Marshall Island, Palau, Guam and Saipan. Even for the traditional products there can be a market closer home. In spite of the availability of coconut, in some of the Pacific countries, other oils are preferred over coconut oil. Imported vegetable cooking oils principally soybean oil are widely used in Cook Island. Imports are estimated to be in the region of 45,000 l per year. Substantial volume of vegetable oils is imported by American Samoa, Fiji, New Caledonia, Papua New Guinea, French Polynesia and Tonga.

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DISCUSSION

M.R. Sharma: What are the priority areas relating to development of the coconut industry in the South Pacific Region?

P.G. Punchihewa: For the South Pacific Region priority areas are processing and marketing. The growers need higher prices as they depend very much on coconuts.

IMPACT OF TRANSFER OF TECHNOLOGY ON SMALL COCONUT HOLDINGS OF KERALA

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ABSTRACT

With a view to enhancing the socio-economic condition of the farm families in the villages of Kerala, two operational research projects on integrated land use and garden land management at Muttathody village in the northern zone and package of practices for the coconut root (wilt) affected disease area at Krishnapuram village in the southern zone of Kerala were started. Identified technologies were adopted and the developmental activities were extended to farmers in collaboration with different agencies. These activities included popularising agricultural and animal husbandry practices for different strata of farming community, integrated land use plan, timely supply of inputs, arranging agricultural credit, constructing community irrigation tanks and providing electrical energy to the village. The post-operational survey revealed that there was considerable increase in the nutrient consumption as well as yield of coconuts when compared to the pre-operational period. There was 49 per cent decline in the leaf rot disease. The yield of paddy has increased from 1.37 to 2.67 t per ha between 1974 and 1983. The adoption of intercropping and mixed cropping in coconut and arecanut gardens also increased considerably. The improved goat breeds Sannen and Malabari introduced into the operational area enhanced the milk production by three times. The production rate of fresh-water fish in the Krishnapuram village increased from 0–244 kg/ha during 1976 to 395–700 kg/ha during 1982-83. The total area under irrigation increased by 50 per cent. The number of pumpsets installed in the village increased from 95 to 388 during the project period. By arranging power supply to the Muttathody village 295 wells and 502 houses were electrified.

INTRODUCTION

A considerable yield gap exists between the yield level of farmers' plot and that of research farms. This so-called "extension gap" can be effectively narrowed down only through transfer of appropriate technology. An integrated programme in a viable operational unit for the testing, adoption and demonstration of the new technological developments was found to be necessary. Two

out-reach programmes, namely, Operations Research Project for Integrated Land Use Management in Muttathody village of Kasaragod district and Operational Research Project—adoption of Package of Practices for the root (wilt) affected area in Krishnapuram village of Kollam district were initiated by the Central Plantation Crops Research Institute.

Project Inputs

Departments of Agriculture, Animal Husbandry, Fisheries, SFDA, Irrigation, Community Development, Education, Cooperation and Health (Government of Kerala), Kerala State Electricity Board and financing agencies like Syndicate Bank and Land Mortgage Bank cooperated with CPCRI in implementing the programmes.

The village at Muttathody covers an area of 1,210 ha and falls in the northern midland agro-climatic zone of the state. The area has humid tropical climate and lies between 12° and 13° north latitude. Being closer to the sea and having good rainfall, the humidity is around 90 per cent. The mean annual maximum temperature is around 31°C and minimum 23°C. Maximum rainfall is received in July and the rainfall decreases steadily from August and tapers off in October. Rainfall is practically nil from December to March. The high rainfall concentrated within a short period, results in erosion of surface soil from slopes and water stagnation in low lying areas. The soil type is typical laterite.

Krishnapuram village in Kollam district in southern Kerala was selected for the project based on the intensity of root (wilt) disease. This village has an area of about 700 ha with predominantly sandy loam soil.

The first bench-mark survey was conducted in March 1974 in order to assess the overall economic condition of the Muttathody village at beginning of the O.R.P. There were 940 households with an average of 6.15 persons and 0.7 ha of cultivable land per household. The crops grown in Muttathody village were arecanut, coconut, jackfruit, tapioca, banana, cashewnut, etc. Paddy occupied 22 per cent of the cultivated area. Paddy was cultivated in about 40 per cent of the households which had an area of above 0.5 ha. To a large extent the terrain of the village is hilly and the irrigated area was about 37 per cent of the total cultivated area. Forty per cent of the households having about 0.25 ha were identified as the target group on which maximum effort was made although the objective was to cover all the households. The top 12 per cent of the households owned about 47 per cent of the cultivable land and 71 per cent of the irrigated land. About 90 per cent of the households grow coconut on their holdings. Irrigation to coconut was given by only half the households of top stratum owning more than 2 ha of land and also applied fertilisers for coconut.

The bench-mark survey which was conducted during 1975 in Krishnapuram village revealed that the village consisted of 2,023 households having 43 per cent minikit farmers (with less than 0.1 ha of land), 54 per cent marginal farmers (0.1 to 1.0 ha) and only 3 per cent of small farmers (more than 1.0 ha). The average holding size is 0.25 ha and 55 per cent of the families were

connected with agriculture either as cultivators or as agricultural labourers. The remaining 45 per cent families though having non-agricultural occupations had coconut palms in households. Coconut was the main crop grown in the village which was affected by the debilitating root (wilt) disease to the extent of 65 per cent. Leaf rot, bud rot, rhinoceros beetle attack, red palm weevil infestation, coreid bug, etc. were the other serious menaces to coconut in this village.

For Muttathody village farm plans were prepared for the families by the Scientists of the Institute. Initially planting materials were distributed free of cost to the identified target groups and at cost to others. Fertilisers amounting to 25.5 tons of N, 11.3 tons of P_2O_5 and 18.5 tons of K_2O were distributed. The Pyrites, Phosphates and Chemicals Limited, distributed 20 tons of rock phosphate free of cost as an incentive to all those who purchased N and K fertilisers. The SFDA gave grants and subsidies worth Rs. 76,500. A fertiliser godown was also constructed in the operational area. Assistance was provided to the villagers for digging wells and installing pumpsets. Two community irrigation tanks were also dug. During the project period 106 poultry units of 10 birds each were started. Eight milch buffaloes, 13 milch cows, 28 milch goats of improved breeds and three pairs of work bullocks were supplied. Three thousand two hundred and eighty fodder grass slips were also supplied. Eighty farm families were enrolled as members of the Poultry Cooperative Society of Kasaragod. Two Sannen cross-bucks for upgrading the local goat population and 11 Malabari goat kids were supplied. Calf feed subsidy was arranged through Dairy Development Department. Six hundred fingerlings of common carp were released in 21 tanks. As a part of the health programme a dispensary under the auspices of the Lions Club functioned in the area for three days every week till 1978. One nutrition garden was set up in Alampady area and 1200 papaya seedlings were distributed. Two applied nutrition project units were started.

About 80 per cent of the womenfolk in this village were unemployed at the time of initiation of the project. A self-employment programme of training in *beedi* making was conducted. Arrangements were made to provide loans to 442 beneficiaries for various purposes such as digging wells and tanks, purchase of pumpsets, milch cows, improving crop, constructing houses, purchasing of sewing machines and for poultry. A vigorous drive was organised for enrolling members to the cooperative society and the membership was raised from 193 to 746 in the ORP area. The Kerala State Electricity Board was approached for giving electricity connection for installing pumpsets and also for house connections. Through informal education, transfer of technology was extended to the schools. With the help of crop plants, specimens, models, charts and other teaching aids chemistry, botany, zoology etc. were taught in the schools with a bias to agriculture. A set of these teaching aids and books on agriculture and animal husbandry were also supplied to each school. In order to involve the students in agricultural operations, school gardens were also maintained. One of the village extension officers was given training in fish culture. Two training camps were organised in the village and 98 farmers were trained in

four batches. Training in plant protection was also given. Fifteen film shows on crop production techniques and animal husbandry were arranged for the benefit of the villagers. Twelve seminars on agricultural topics and cashew spraying were held. A farmers' meeting was organised under the auspices of AIR. A Mahila Samajam was started and members were given 100 laying hens, Malabari goats, vegetable seeds and plant protection equipment like hand sprayers.

In Krishnapuram village, under the rejuvenation programme 3,451 unproductive and root (wilt) affected palms were removed over a period of three years and replaced with quality seedlings. Coconut seedlings, pepper cuttings, clove seedlings, nutmeg, cocoa seedlings, green manure seeds, high yielding varieties of paddy seeds, etc. were supplied. Irrigation facilities were expanded by providing loans through Small Farmers Development Agency (SFDA) and other agencies. Twenty demonstration plots were laid out to popularise intercropping in coconut gardens with pulses (10), tubers (5) and betelvine (5). Thirty-five cross-bred cows, 82 goats, nine buffaloes, seven bullocks and 275 poultry birds were supplied to the farmers of this village. In the operational area shallow ponds were used for scientific fish culture. Carp fingerlings were distributed free of cost to 359 farmers and fresh water prawns to 26 farmers during 1980-81.

In this village the breeding places of rhinoceros beetle in 282 households were treated with BHC, 253 palms were treated against coreid bug and 342 palms against red palm weevil. Prophylactic spraying against leaf rot was given to 35,000 palms during four years, in addition to 771 palms treated for leaf rot. Three rat control campaigns were conducted using zinc phosphide and warferin.

During 1977 and 1979 Kisan Melas were organised and training on spraying, rat bait preparation and poisoning and coconut management were given to farmers. Vegetable gardens were maintained in five schools of the village. One agricultural seminar was organised during 1980 and two medical camps were also organised during the entire period of the project.

Project Impact

As a result of the adoption of scientific package of practices the fertiliser consumption increased by 263 per cent in the case of N, 212 per cent in the case of P_2O_5 and 205 per cent in the case of K_2O (Table 93.1) in Muttathody village. At the start of the project there were only 95 pumpsets and 250 wells which increased to 288 pumpsets and 785 wells during the project period. The irrigated area also increased by about 40 ha. Improving the availability of fertilisers and irrigation facilities in the operational area resulted in increased yields of many of the annual crops. The yield of coconut under the good management practices increased by 24.4 per cent in Muttathody village. The yield of paddy increased from 1.37 t/ha in 1974 to 2.67 t/ha in 1983. The adoption of intercropping and mixed cropping in coconut and arecanut gardens was also increased. Only 20.2 and 28.3 per cent of the coconut and arecanut farmers respectively were practising intercropping in 1974 which

increased to 26.1 and 34.4 per cent respectively in 1983. The improved goat breeds of Sannen and Malabari introduced into the operational area increased the milk production on an average from 0.5 to 1.5 l. Industrial ventures such as bread making and sandalwood oil industry, intercropping and mixed cropping contributed to the increased employment opportunities and the number of earning members increased by 0.39 per household. The number of farmers practising plant protection increased to 33 per cent from 5 per cent in 1974.

Table 93.1: Nutrient consumption in Muttathody village (in kg)

Nutrient	*1974*	*1983*	*Per cent increase*
N	1972	7168	263
P_2O_5	879	2743	212
K_2O	1588	4842	205

In Muttathody village 295 wells and 502 houses were electrified during the project period. The membership of the cooperative society which was only 579 at the time of initiation of the project increased to 1,868 in 1983.

In Krishnapuram village, a root (wilt) affected area, 14 per cent increase in coconut yield and 49 per cent decrease in the leaf rot disease was achieved. The fertiliser intake increased from 12.5 t to 40 t in 1982. The production rate of fresh-water fish in Krishnapuram village increased from 0–244 kg/ha during 1976 to 395 to 700 kg/ha during 1983.

Constraints

The Operational Research Programme has contributed much to the overall improvement of the Muttathody and Krishnapuram villages. However several constraints were identified in the course of implementing these programmes. Most of the land in Muttathody village was undulating and due to the erosion of top soil it was difficult to grow crops profitably. Most of the families did only part time farming as the income from agriculture alone was not sufficient for their livelihood. Absentee landlordism, lack of irrigation facilities, irregular spacing, high cost of labour, very small holding size, lack of cooperative ventures etc. were other constraints. For getting returns from crops like coconut, arecanut and cashew the farmers had to wait for a long time which in most of the cases discouraged the farmers to depend solely on agriculture.

DISCUSSION

E.G. Silas: Was a bench-mark survey made for the two Operational Research Products? Did the impact survey show economic returns for the families involved despite higher costs in inputs?

M.K. Muliyar: Yes. Root (wilt) management in Krishnapuram (coconut) and spraying endosulfan against tea mosquito (cashew) showed economic returns.

COCONUT DEVELOPMENT IN INDIA

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ABSTRACT

The first phase of its growth in India coincided with the expansion of the European Soap and Edible Oil company in England and substantial quantities of copra and coconut oil were exported during the period. The outbreak of the First and Second World Wars and consequent recession affected the coconut industry also. Immediately after the Second World War, the Indian Central Coconut Committee was established in 1945 for the organised development of coconut industry in India. The committee functioned till 1966. With the abolition of the committee the development aspects of the crop were entrusted to the erstwhile Directorate of Coconut Development under the Ministry of Agriculture, Government of India. During the period between 1966 and 1981, the area under the crop increased to 1.1 million ha and the production to 5,940 million nuts.

Central Government established the Coconut Development Board, a statutory body, in 1981, for the integrated development of coconut industry in India. Production of coconut in India could register a significant growth rate of 6 per cent during 1981 to 1990 and for the first time crossed the 9000 million nuts mark, achieving the target fixed. From the base productivity level of 5,842 nuts per ha before the Seventh Plan period, productivity increased to 6,150 nuts per ha. A substantial addition to area under coconut could be effected during the period, to the extent of 0.3 million ha both in traditional and non-traditional regions.

The target of production is estimated at 13,095 million nuts by the year 2000. Organised attempts are made to tackle the problem areas of development, namely, (1) the root (wilt) and other serious diseases of coconut which cause substantial reduction in production and productivity of the crop, (2) poor management practices and lack of infrastructure for irrigation in the major coconut growing regions, (3) lack of organised marketing network for coconut and its products, (4) violent fluctuations in price levels of coconut products, and (5) slow pace in development of indigenous technology for product diversification and by-product utilisation.

In some of the major coconut growing states as well as in the non-traditional belts in northern and north-eastern parts of India, the potential area to the extent of 0.2 million ha could be made use of for horizontal expansion of the crop. Thrust areas identified to achieve the targeted production of coconut are: (a) stepping up the area under coconut in all potential states, and (b) increasing the productivity of existing gardens through an integrated management system involving replanting with improved cultivars/hybrids, manuring, irrigation, crop protection and coconut-based farming systems.

HISTORY

The growth of coconut industry in India was marked by ups and downs during different periods of the last century. The first stage of development of the crop in India could be traced to the increased pace of industrialisation in Europe which paved the way for the expansion of European Soap and Edible Oil Company during the latter half of the last century. Opportunity in export trade brightened the pace of development of the crop resulting in slow and steady increase in area and production. Separate departments under the different state governments were formed to look after agriculture and more attention was paid to problems relating to coconut cultivation, as well.

The early years of the present century saw India as one of the leading exporters of copra and coconut oil, the annual quantum of exports of these items recording 30,000 tons and 10,000 tons respectively. With the onset of the First World War prices of commodities started nose diving in the international markets resulting in erosion of exports and post-war India became a net importer of coconut products. The period coinciding with the Second World War also had a dampening effect on the growth of the coconut industry in the country. Sensing the need for revamping the crop situation and desirous to put it back on the rails, the Central Government had set up the Indian Central Coconut Committee in the year 1945 enacting the Indian Coconut Committee Act of 1944. The Committee was given statutory powers for the systematic development and research aspects of the crop. During the period from 1945 to 1966, the Committee did yeoman service for the growth of coconut industry in India. In 1966 the Committee was abolished and the development of coconut crop was entrusted to the erstwhile Directorate of Coconut Development, a Central Government Organisation under the Ministry of Agriculture. The research wing was transferred to the Indian Council of Agricultural Research. The functions of the directorate included planning and coordination of programmes pertaining to development, processing and marketing aspects of the crop in India. The directorate functioned in close liaison with the State Agriculture Departments as well as the Central Government. The Directorate of Coconut Development ceased to exist when the Central Government established the Coconut Development Board Act of 1979. The main functions of the Coconut Development Board are:

i) Adopting measures for the development of coconut industry.

ii) Recommending measures for improving marketing of coconut and its products.

iii) Providing financial and technical support for expansion of area under coconut.

iv) Encouraging adoption of modern technologies for processing of coconut and its products.

v) Imparting technical advice to those engaged in coconut cultivation and industry.

vi) Adopting measures to get incentive prices for coconut and its products.

vii) Recommending measures for regulating imports and exports of coconut and its products.

viii) Fixing grades, specifications and standards for coconut and its products.

ix) Financing suitable schemes to increase the production of coconut and to improve the quality and yield of coconut.

x) Assisting, encouraging, promoting or financing agricultural, technological, industrial or economic research on coconut and its products.

xi) Collecting statistics on coconut and its products and publishing them.

xii) Undertaking publicity activities and publishing books and periodicals on coconut and its products.

Since its inception, the Board has been implementing major development programmes such as expansion of area under coconut, production of improved planting materials including hybrids, promoting grower's cooperatives for primary processing and marketing, establishment of a technology development centre, collection of vital information on production, and processing, marketing and publication of regular extension literature.

DEMAND

Domestic demand for vegetable oils in India has been expanding at a much faster rate than the domestic production. Viewed from the perspective of demand for edible oils, the contribution of coconut oil to the edible oil pool assumes considerable significance. Coconut, one of the richest sources of edible oil (72 per cent) in the country contributes to the extent of 7 per cent to the total edible oil production in India.

Taking into account all the above aspects the projected demand for coconut for both edible and non-edible end uses is placed at 11,811 million nuts by the end of the Eighth Plan and 13,095 million nuts by the turn of the century (Table 94.1).

Table 94.1: Demand and supply profile of the coconut industry

Year	*Demand** *(nuts in million)*	*Supply (nuts in million)*
1989–90	9284	9283.4
1990–91	9609	9576.0
1991–92	9945	9878.3
1992–93	10293	10190.5
1993–94	10654	10513.0
1994–95	11026	10846.2
1995–96	11412	11190.4
1996–97	11811	11546.0
1997–98	12224	11913.3
1998–99	12652	12292.9
1999–2000	13095	12685.1

*Demand expected to grow at the rate of 3.5 per cent per annum.

The development programmes for coconut are being formulated keeping in view, the gap between the demand and supply position of coconuts in the ensuing years.

ONGOING DEVELOPMENT PROGRAMMES

i) Production and Distribution of Planting Material

The annual production of coconut seedlings is given in Table 94.2. Under this programme the improvement of genetic potential of coconut in the country through the production and distribution of both T × D and D × T hybrids is envisaged. The T × D production programme has been under implementation since 1969–70 and is still continued as a programme of the Board in the states of Kerala, Karnataka, Andhra Pradesh, Orissa, Tamil Nadu and Goa in collaboration with the concerned state governments.

Production of D × T hybrid is going on in the hybrid seed gardens established in 200 ha each in the states of Kerala, Karnataka and Tamil Nadu and in 40 ha in Orissa.

Table 94.2: Annual coconut seedlings production through the government sector

State	*Hybrid (nos.)*	*Tall (nos.)*
1. Kerala	90,950	12,60,350
2. Tamil Nadu	7,00,000	7,00,000
3. Karnataka	40,000	10,00,000
4. Andhra Pradesh	60,000	5,00,000
5. Orissa	3,00,000	3,00,000
6. Bihar		1,00,000
7. Tripura		1,00,000
8. West Bengal		1,00,000
9. Others		2,00,000
Total	11,90,950	43,00,000

Demonstration-cum-seed production farms were established under the auspices of the Board in 200 ha in the states of Karnataka (20 ha), Madhya Pradesh (40 ha), Bihar (40 ha), Assam (40 ha), Tripura (40 ha) and Kerala (20 ha) (Table 94.3). Among the farms established by the Board, production of hybrids has already commenced in DSP Farm, Mandya in Karnataka. During the Eighth Plan period commencing from 1992–93, six more farms are proposed to be established one each in the states of Kerala, Karnataka, Tamil Nadu, Andhra Pradesh,Maharashtra and Orissa. All these farms on reaching full production stage would enable to wipe out the wide gap existing between the demand and supply of quality planting material.

To assist the various state governments and other agencies in the procurement of quality seed-nuts of desired cultivars from disease free locations, a Seed Procurement Unit has been established by the Board.

Table 94.3: The seed gardens in the country

Location	*Area (ha)*
Coconut Development Board, Demonstration-cum-Seed Production Farm, Mandya, Karnataka	20
CPCRI Seed Garden, Kidu (Karnataka)	43
CSF, Aralam, Kerala	250
Dharmaveera Farm, Karnataka	200
Coconut Development Board, Demonstration-cum-Seed Production Farm, Neriyamangalam, Kerala	20
Elite Seed Farm, Biswanagani, Orissa	50
Elite Seed Farm, Navlok and Ettankulam, Tamil Nadu	200
Andhra Pradesh	20
Coconut Development Board, Demonstration-cum-Seed Production Farm, Tripura	40
Coconut Development Board, Demonstration-cum-Seed Production Farm, Bihar	40
Coconut Development Board, Demonstration-cum-Seed Production Farm, Assam	40
Coconut Development Board, Demonstration-cum-Seed Production Farm, Madhya Pradesh	40
Total	963

ii) Expansion of Area under Coconut

The programme of expansion of the area under coconut is being implemented, since the Board came into existence in 1981. The project aims at bringing more and more areas under coconut in the traditional as well as non-traditional regions where a suitable area exists for raising the crop profitably. The scheme envisages an incentive subsidy of Rs. 3000 per ha to be paid in three annual installments. Farmers who own a minimum of 25 cents (0.1 ha) are eligible for availing the subsidy. Subsidy to the tune of Rs. 5 crores has already been granted to about 60,000 small and marginal farmers during the last decade and an area of 30,000 ha could be additionally brought under coconut under the programme.

iii) Improving Productivity of Coconut

A scheme for integrated farming in coconut small holdings in Kerala for productivity improvement was initiated by the Board in 1986–87 in an area of 10,000 ha. The project envisages an integrated farming system involving the combination of crops, animals and energy sources. For cutting and removing the diseased/unproductive palms, a subsidy of Rs. 100 is provided and quality planting material is supplied at a subsidised rate for replanting/underplanting. Subsidy is also extended for introducing multispecies cropping in the gardens and for installation of irrigation pumpsets or erecting irrigation sources. Necessary institutional support for credit facilities is arranged and technical support extended to needy farmers for undertaking different package of practices.

Considering the importance of irrigation as the most important input in improving the productivity of coconut, a scheme for providing financial assistance for irrigation facilities is also under implementation in the states of Kerala,

Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra and Goa. Subsidy is granted to coconut farmers for the installation of irrigation pumpsets at the rate of Rs. 1000 or 25 per cent of the cost of installation whichever is less.

iv) Technology Development

Product diversification and by-product utilisation are the areas requiring appropriate technological support from developmental agencies. To fulfil this objective a technology development centre for improving the post-harvest processing and marketing of coconut was established by the Board in 1991. The centre conducts techno-economic feasibility studies to promote and sponsor technological research and extends financial assistance to processing industries for adopting new technologies for product diversification and by-product utilisation. This centre has also sponsored various research programmes like, coconut cream manufacture briquetting of coir pith and coconut shell flour manufacture. Financial assistance is also extended to artisans engaged in the production of handicraft items utilising coconut wood, shell and other palm products. For processing industries financial assistance is provided in the form of a grant to the extent of Rs. 1 lakh or 50 per cent of the capital cost whichever is less for developing infrastructure. A pilot plant for integrated coconut processing is also being set up to explore new avenues for product diversification and by-product utilisation. The Board has already developed a technology to process and pack coconut cream in collaboration with the Regional Research Laboratory (CSIR), Thiruvananthapuram — A Coconut Cream Plant is being set up at Kalamasserry, Kochi.

Integrated Control of Major Pests and Diseases

The Board has sponsored a scheme for integrated control of a leaf eating caterpillar in the state of Karnataka and Orissa by establishing parasite breeding laboratories for the multiplication and liberation of parasites.

For adopting timely plant protection measures in farmers' gardens a programme for training unemployed youths in harvesting and plant protection operations for subsequent self-employment is also implemented by the Board.

STATE SECTOR SCHEMES

Apart from the above developmental programmes of the Board, most of the coconut growing states and union territories have been implementing their own programmes mainly aimed at production and distribution of planting materials. Nearly 4.5 million seedlings are produced and distributed through governmental agencies in the states of Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Orissa, West Bengal, Tripura, Bihar, Assam, etc.

Another area where the state governments have been giving more emphasis is on plant protection measures. Subsidised distribution of plant protection chemicals and fertilisers form an integral part of the coconut development programmes like in Kerala, Karnataka and Andhra Pradesh. In Karnataka, nearly 50 parasite breeding stations have also been established for the

multiplication of parasites against leaf eating caterpillars and four major seed production farms have been established for both talls and hybrids.

IMPACT OF DEVELOPMENT PROGRAMMES

The area under coconut and production of coconut during the decade 1971 to 1981 remained almost stagnant (Table 94.4). The growth rates recorded only marginal increases during the period. However, the crop showed signs of improvement in production during the eighties. The development programmes implemented by the Coconut Development Board also influenced the crop prospects with a highly positive growth rate both in area and production.

Table 94.4: Trend in area, production and productivity for the last four decades (all India)

Year	*Area ('000 ha)*	*Production (million nuts)*	*Productivity*
1949–50	604.3	NA	NA
1959–60	707.2	4765.4	6738
1969–70	1033.3	5858.7	5670
1979–80	1075.8	5662.0	5263
1989–90	1509.5	9283.4	6150

The Board came into existence during 1982 and concentrated on three thrust areas for increasing the production of the crop. The first and the foremost among them is expansion of area under coconut. The objective of the programme has been, apart from creating future production potential, to help the small and marginal farmers as well as to create employment opportunities in the rural area. The programme was implemented not only in the littoral coconut growing states, but also in the non-traditional belts such as Bihar and Madhya Pradesh. Along with this six demonstration-cum-seed production farms were established to meet the demand for quality planting material in addition to the existing seed production farms. Irrigation being a single major input in stepping up productivity of the existing gardens, financial assistance was extended for installation of irrigation systems in coconut lands. All the three projects encompassing long-term programmes of creating future production potential, making available quality planting material and improving productivity in the existing gardens especially in the disease affected areas, have started showing their impact on the production front, as evidenced in Table 94.5.

The area under coconut increased by about 0.42 million ha during the period 1980 to 1990 and the production by more than 3,350 million nuts. The increase in area has been around 40 per cent and production 56 per cent. All the traditional coconut growing states/Union Territories have registered spectacular improvement both in area and production of the crop. Kerala, which is the leading coconut growing state in India recorded an impressive growth in production with the addition of 1,350 million nuts during the period. In Tamil Nadu, the increase has been to the extent of 950 million nuts registering 70 per

cent increase. In Andhra Pradesh, the increase has been around 273 per cent. The indices on area and production point to the fact that the crop improvement programmes implemented and extension activities undertaken during this period paid rich dividends in the form of higher production and expansion of area of the crop at the state and all India levels.

Table 94.5: Area and production of coconut in India for the years 1980–81 and 1989–90

State/Union Territory	*Area ('000 ha)*		*Production (million nuts)*	
	1980–81	*1989–90*	*1980–81*	*1989–90*
Andhra Pradesh	42.4	59.0	175.3	654.7
Assam	6.0	9.8	51.8	69.4
Goa	18.7	23.5	105.0	107.5
Karnataka	171.5	225.4	890.0	1158.7
Kerala	666.2	875.9	3036.4	4394.0
Maharashtra	10.2	7.8	61.7	108.3
Orissa	22.5	27.1	98.8	113.7
Tamil Nadu	116.0	225.9	1354.4	2302.4
Tripura	1.4	7.0	1.7	4.2
West Bengal	3.3	19.8	32.3	238.5
A and N Islands	20.7	23.8	97.8	83.1
Lakshadweep	2.8	2.8	21.4	25.2
Pondicherry	1.6	1.7	15.4	23.7
All India	1083.3	1509.5	5942.0	9283.4

Source: Directorate of Economics & Statistics, Ministry of Agriculture, Government of India.

FUTURE STRATEGY

The growth registered by the crop fully emphasises the fact that India is poised for a major breakthrough in coconut cultivation and the utilisation of its products. On the production front a major thrust will be on making significant improvements in irrigation facilities. Maximising income per unit area is sought to be achieved by adopting multispecies cropping, mixed farming and developing coconut based farming systems. In some of the regions where root (wilt) disease has become a threat to the crop, projects aiming at rejuvenation and rehabilitation of diseased and senile gardens will go a long way in sustaining the production on a long-term basis. There is also ample scope for further expansion of area under coconut both in traditional and non-traditional pockets.

Another thrust area requiring more emphasis is product diversification and by-product utilisation. Developing new technologies on processing of coconut kernel into different food products with attractive packing and long shelf life is one area identified for future research and development. The processing of kernel into coconut cream is successfully perfected. Utilisation of fresh nuts in areas where coconut is not converted into copra, will go a long way in boosting the demand for fresh nuts for industrial exploitation.

Processing of tender coconut meat and water into a variety of products and marketing them in asceptic packages is already in vogue in some of the major coconut growing countries. Similarly desiccated coconut (coconut powder) is also a potential consumer product, with varied end uses in various food processing and in the household edible sector, the quality standards of which are to be standardised.

When mature nuts find demand in the processing sector for making altogether new products with consumer acceptance, dependence of farmers on the price of coconut oil can be minimised. A vast untapped potential still exists in the export of items made out of coconut by-products such as timber, shell and coir.

All the above development programmes require regular inflow of resources and development of infrastructure. Training and technology upgradation is required to make the resources fully utilisable. Coconut production, productivity, processing and marketing activities could be stepped up substantially if matching resources are made available to the Board.

CONTRIBUTION OF THE BUREAU FOR THE DEVELOPMENT OF RESEARCH ON TROPICAL PERENNIAL OIL CROPS

O.Du Four

BUROTROP, 17 Rue de La Tour, Paris, France

The Bureau for the Development of Research on the Tropical Perennial Oil Crops was created at the initiative of the EEC and several European countries to strengthen and coordinate research and development activities on oil palm and coconut. BUROTROP started its activities in March 1990 and held the first plenary meeting of its executive committee in May 1990.

The Bureau comprises:

1) An executive committee of 15 members: Seven from producer countries of Africa, Latin America, Asia and the Pacific of whom one is a representative of APCC, seven members from consumer countries and one representative from the EEC.

The chairman is Mr. R.W. Smith from O.D.A. of the U.K. The vice-chairman is Dr. Kullaya from NCDP in Tanzania.

2) A programme committee with six members, of whom three are from producer countries. This committee gives technical advice to the executive committee. It guides and controls BUROTROP activities.

3) A very light structure based in Paris.

The aim of BUROTROP is not to conduct research, but to strengthen existing research and development activities in producer countries and facilitate the coordination of donor countries' and organisations' operations.

BUROTROP is open to all donor and producer countries willing to join forces for the future of coconut and oil palm research.

The objectives of BUROTROP are to:

1) Help to identify production constraints and research requirements.

2) Favour exchange of information and experience among coconut and oil palm research institutions.

3) Initiate and encourage research on tropical perennial oil crops and enable the coordination of research activities of institutions willing to work together.

4) Coordinate operations of donor countries willing to join means.

5) Identify training needs, detect and strengthen existing means.

Owing to its structure and its mandate, Burotrop has the following characteristics:

a) It is a privileged forum for permanent cooperation among producer and donor countries.

b) It is destined to encourage bi- as well as multi-lateral cooperation. Although it is an European initiative, BUROTROP is an international Organisation willing to work with all producer and donor country institutions.

BUROTROP can facilitate the access of producer countries to research institutions of donor countries and to technical and financial means.

Outline of BUROTROP's Activities

Burotrop has started a newsletter: the BUROTROP Bulletin, printed in French and English, whose objective is to encourage exchange of information and experience, among researchers and developers. We are currently setting up a data base and an extensive list of research institutions, their programmes and research teams, in order to answer the question **"who does what?"**

BUROTROP is engaged in the deliberations on the constitution of an international coconut germplasm network which took place in October 1991 in Indonesia under the aegis of IBPGR.

BUROTROP also contributed to the elaboration of the coconut research programme of the Secretariat of the Inter-governmental Group on Oilseeds, Oils and Fats of the FAO which is to be put up for funding by the Common fund for commodities.

One of the priorities of the programme set down by the executive committee for BUROTROP's first year, was the organisation of two seminars in Africa; one on coconut and the other on oil palm. The objective of these seminars was to draw an accurate picture of the R and D priorities as voiced by the producers and to initiate research activities in network.

The coconut seminar was held in February 1991 in Tanzania jointly with the NCDP and the oil palm seminar was held in June 1991 in Abidjan with the participation of the African Association for the Development of Oil Palm.

In 1992 a meeting of European, African and Asian Scientists on *Phytophthora* disease of coconut will be organised in Indonesia with the assistance of BUROTROP.

BUROTROP will favour activities in Latin America, without in any way, of course, neglecting Asia, in 1992.

BUROTROP collaborates actively with the Asian and Pacific Coconut Community; and would like to strengthen this collaboration in particular where the organisation of COCOTECH meetings are concerned. BUROTROP would very much like to spread APCC's know- how to other continents.

ECONOMICS OF COCONUT CULTIVATION IN DIFFERENT COUNTRIES

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ABSTRACT

Coconut ranks very high in a number of countries in the Asian and Pacific region in the context of both economic and social importance. In order to establish economic and social efficiency of coconut cultivation, using criteria such as net present value, internal rate of return, land use factor, crop intensity factor and employment generation potential, the necessary series data relevant to individual countries are not readily available. In the circumstances, the estimated crop budgets applicable to coconut cultivation in a selected number of countries were made use of to derive various efficiency indicators. In intra-country comparisons made using IRR, the returns from monoculture cultivation of hybrids are much higher compared with the indigenous tall coconut variety. Under monocropping in Sri Lanka different options available for systems of replanting as well as intercropping were considered by using secondary data. The results confirm the higher economic efficiency of replanting of old stand with hybrid varieties of coconut. The intercropping models tested under different stages of growth of coconut, namely, mature coconut, replanted as well as underplanted with tall variety and replanting with 50 per cent of the land area show the potential for increasing the economic efficiency. More specifically, the data presented show that intercropping under coconut increases the LUF to 100, CIF to 2.21 and EGP to 148 man-days per year. In contrast, under monoculture, the LUF is 25 per cent, CIF 1.0 and EGP is 80 man-days per year. This demonstrates the possibility of increasing economic gains through intercropping coconut lands.

INTRODUCTION

Of the estimated area of 11 million ha of coconut in the world, around 90 per cent or 10 million ha are grown in the Asian and Pacific region. In a number of coconut producing countries in the region, it is the main or the only source of fat and protein for a majority of population. There are other countries where coconut products export is the primary source of foreign exchange earnings.

Therefore, the coconut industry has a direct or indirect influence in the livelihood of millions of people in the region.

However, in a number of countries, coconut cultivation does not figure prominently in deciding investment priorities due to low returns it generates. This is specially applicable for monocrop coconut cultivation. Under monoculture, the coconut palm uses only about 25 per cent of the land area. The technical options available for use of the unused land area in coconut ranges from cultivation of a single intercrop to establishment of multistoried cropping and livestock systems.

This paper attempts to evaluate the economic efficiency of monoculture coconut cultivation and some of the cropping systems in selected countries in the Asian region.

CRITERIA USED FOR EVALUATION OF ECONOMIC EFFICIENCY

In evaluating the economic efficiency, the criteria of the sum of the net present value (SNPV) and internal rate of return (IRR) are used.

Sum of Net Present Value

The net present value (NPV) of a net return, one year after investment is calculated by using the following formula:

$$NPV = \frac{R_1}{(1+r)}$$

where NPV = net present value,
R_1 = return in one year, and
r = discount rate.

The sum of the net present value (SNPV) of the future net return, stream R_1, R_2, R_3....R_T over the finite time horizon, T is computed by means of the following expression, when the discount rate is assumed to remain constant:

$$SNPV = R_0 + \frac{R^1}{(1+r)^1} \frac{R^2}{(1+r)^2} \frac{R^3}{(1+r)^3} \cdots \frac{R^T}{(1+r)^T}$$

where R_0 is the net return of the present year.

Internal Rate of Return

Another and similar criterion is the internal rate of return (IRR). IRR, p, may be expressed as:

$$O = R_0 + \frac{R^1}{(1+p)} \frac{R^2}{(1+p)^2} + \cdots \frac{R^T}{(1+p)^T}.$$

The net returns stream R_0, R_1 . . . . R_T for the first finite horizon, T is common to both the SNPV and the IRR criteria. However, instead of computing the present value, given r (the opportunity cost of capital or real rate of interest), as in the SNPV criterion, the IRR criterion solves for p. The decision rule usually employed with this criterion is to invest only if $p > r$.

The above SNPV and IRR may not yield the same ranking of alternative investment. For example, a small investment may have a larger IRR than a larger project in which case it would be ranked above the larger investment but, the larger investment could yield a larger SNPV and so rank above the smaller one on the SNPV criterion.

The SNPV criteria could be effectively used in ranking alternative investments within a country, where the project with the highest SNPV would receive the highest ranking. However, due to currency differences SNPV is not a suitable criterion to compare and rank intercountry projects. For ranking intercountry investments an appropriate criteria is the IRR. In this paper criteria of SNPV is used for ranking the projects within a country, while criteria of IRR is used to rank intercountry projects.

Land use efficiency (LUE) and employment generation potential (EGP) of crop activity also could be considered in evaluating the economic efficiency. LUF is determined through land use factor (LUF) and crop intensity factor (CIF).

Land Use Factor

The land use factor (LUF < 1) is defined as the proportion of the surface area of land used by a crop at a particular plant density (Etherington and Karunanayake, 1981). In the case of most intercrops where the coverage of the canopy and root zone are not very different, the LUF is the proportion of land area allocated to a particular crop and not the sum total of the area occupied by individual plants.

However in the case of coconut palm, where the canopy cover extends beyond the root space, the surface area of land used by the root system is much smaller than the area allocated to the palms at the normal planting density of 26 × 26 ft. The roots of a mature coconut palm are concentrated within a radius of 6.5 ft. around the palm under normal management conditions. Vertically, the top one foot of the soil is practically devoid of functional roots and about 85 per cent of roots are found between one and four to five feet depth from the surface (Kushwah *et al.*, 1973). Thus out of the 676 ft.^{2} (26 × 26) allocated to each palm, the surface area occupied by active roots is 132.8 ft.^{2} (where r = 6.5 ft.). Therefore, the per cent of land used by the palm is 132.8/672 × 100 = 19.7 per cent.

In a pure stand of coconuts, under normal management, about 5 to 6 per cent of land is occupied by drains, bunds and paths. Thus, about 75 per cent of the total area is generally unutilised. Therefore, the gross land use factor for coconut on an average is taken as 0.25 per cent.

Crop Intensity Factor

The relation between the population density of intercrops to their respective mono-culture levels is measured by crop intensity factor (CIF ≤ 1). This is defined as the ratio of a particular plant density for an intercrop to the normal or standard plant density when the crop is grown as a sole crop.

$$\text{CIF} = \frac{\text{Plant density of an intercrop}}{\text{Plant density of the same crop under monoculture}}.$$

For example, CIF for growing pepper on coconut is 128/800 = 0.16 where 128 vines are grown, while the standard plant density for a sole pepper crop is taken as 800 vines to the acre. The CIF is analogous to the multiple cropping

index used in annual crop studies and gives a measure of the intensity of intercropping of coconut lands (Etherington and Karunanayake, 1981).

Employment Generation Potential

Employment generation potential of a crop can be measured by estimation of the total number of man-days per year of employment the crop activity generates. This could be further analysed by comparing with labour supply potential available in the farm.

Data

In order to generate such indicators, data in respect of input/output coefficients for a range of crop alternatives over a reasonable length of time for a given unit of land is required. Normally such data are generated from actual farm budgets.

Due to lack of record keeping practices by the coconut farmers actual farm budgets with adequate information for an analysis of proposed dimensions are scarce. Research institutes though maintain meticulous records on their experiments, generally give low priority for collecting economic information and as a result available data are very often inadequate for detailed economic analysis. The actual field data—farm budgets, generally available from pilot programmes, are more often limited to a few years. In the present study actual data from the pilot programmes, one in the Philippines for hybrid coconuts and the other in Sri Lanka for replacement of senile coconut palms in small holdings are used.

Actual data available from these two sources have a number of limitations. Philippine data are aggregated for regions and are available only for 10 years. Further, the available data are deficient in respect of a number of basic components, including labour utilisation and crop density. Data from Sri Lanka are only for four years and do not cover labour utilisation.

Due to the above data limitations, the discussion relies heavily on farm budget estimates originating from two main sources. Farm budgets for monocultivation of coconut for few countries were obtained from Varnakulasingam (1978). Cropping systems farm budgets are for Sri Lanka, obtained from the work of Karunanayake (1982).

RESULTS

Coconut in Monoculture

Section A of Table 96.1 shows the indicators of economic efficiency of monoculture cultivation of tall and hybrid varieties of coconut in India, Indonesia, Malaysia, the Philippines and Sri Lanka. In general, for all the countries, the IRR, for hybrid coconut was higher relative to that of tall coconut variety. The higher internal rate of return for hybrid varieties of coconut is attributed to the high yield potential of such varieties. Among the countries considered, IRR (39.3 per cent) for hybrid coconut variety was the highest for Sri Lanka, followed by India (27.9 per cent). The lowest IRR (17.1 per cent) was for hybrid coconut in the Philippines.

Table 96.1: Coconut monoculture — Indicators of economic efficiency

Country	*Coconut variety*	*SNPV*	*Net LUF*	*IRR*	*BCR*
A. *Estimates*					
India	Tall	Rs. 4308	21.0	11.2	1.9
	Hybrid	21319	21.0	27.9	2.7
Indonesia	Tall	Rp. 40201	15.6	5.6	1.5
	Hybrid	71386	15.6	22.4	2.7
Hybrids under NES projects		570000	15.6	20.7	4.3
Hybrids under SCDP projects		340000	15.6	27.2	5.9
Malaysia	Tall	M$ 918	15.6	6.8	1.4
	Hybrid	3811	15.6	24.7	2.1
Philippines	Improved tall	P 6010	16.8	13.7	2.1
	Hybrid	7508	16.8	17.1	1.9
Sri Lanka	Tall	Rs. 71	16.6	6.6	3.9
	Hybrid	8786	16.6	39.3	3.9
Pilot project for replanting		2871	16.6	1.1	
B. *Actuals*					
Philippines — Pilot Programme for Hybrids					
West Mindano	Hybrid	P. 474		-25.7	0.49
North Mindano	Hybrid	1006		0.8	1.1
South Mindano	Hybrid	1332		3.8	1.3
Sri Lanka — Pilot Programme for Replanting					
Rambukkana	Hybrid	Rs. 3765	16.6	−0.21	

Source: 1. Varnakulasingam (1978).
2. PCA (1988).
3. De Silva (1988).

In the case of tall coconut variety, the IRR varied between 5.6 and 13.7 per cent among the countries. The Philippines reported the highest IRR, for an improved tall variety. Among the ordinary tall varieties, IRR was highest for India (11.2 per cent) and the lowest for Indonesia (5.6 per cent).

In Section B of Table 96.1, the actual data obtained from a pilot programme for hybrid coconut in the Mindano Island of the Philippines and a similar programme for replanting hybrid coconut in small land holdings in Sri Lanka are given.

The IRR for the hybrid coconut in the Mindano Island of the Philippines during the first 10 years varied between −25.7 per cent and 3.8 per cent. The highest IRR was reported for Southern Mindano. The IRR for the first four years for replanting of coconut in small land holdings in Sri Lanka amounted to −0.21 per cent. Since the above data cover only the first few years of the project, the above indicators do not represent the true cost and returns, which is a great limitation.

Under monoculture coconut the net LUF varied between 15.6 and 21.1 per cent. It was the highest for India and the lowest for both Indonesia and Malaysia.

The third situation under monoculture coconut is shown in Table 96.2. These statistics computed from Karunanayake (1982), have the basis of crop budgets estimated for Sri Lanka. In this Table, a number of options available for replacement of old coconut stands are given in comparison with a mature cultivation of coconut tall variety. The options considered for replacement are underplanting of tall variety, replanting of tall or hybrid varieties and replanting of 50 per cent of the land area with tall coconut variety.

Table 96.2: Monocropping of coconut

Model	*Average annual labour requirement*	*SNPV @ 12 % (Rs.)*	*LUF*	*CIF*
1. Mature coconut tall	60	140060	0.25	1.0
2. Underplanting tall	42	−3319	0.50	1.0
3. Replanting tall	26	−4234	0.25	1.0
4. Replanting hybrid	30	13274	0.25	1.0
5. 50 per cent replanted tall	21	20	0.25	1.0

On the SNPV criteria, mature tall coconut ranked highest as the plantation was in full production phase. Replanting of hybrid coconut ranked second while replanting and underplanting of tall variety resulted in a negative SNPV. The 50 per cent replanting with tall variety however had a lower SNPV.

In terms of gross LUF, underplanting led to a doubling of the factor due to the presence of two stands of the same crop. However, the LUF would decline to normal level with the removal of the old stand. The CIF was the same for all the other situations.

The employment generation potential (EGP) in terms of man-days per year was the highest for mature coconut plantation.

Intercropping Models

In Tables 96.3, 96.4, 96.5 and 96.6, coefficients estimated by Karunanayake (1982), for intercropping models of selected annual and perennial crops for mature coconut, replanted selected talls, underplantings and 50 per cent replanted old coconuts are given.

In Average Mature Coconut Lands

As evident from Table 96.3, introduction of intercrops resulted in raising of the gross LUF to 95 per cent from 25 per cent under monocropping of coconut. The CIF for certain models increased to 2.29 while the EGP went up to 148 man-days per year.

In Table 96.3, the intercropping model consisting of pepper on coconut palms, betel in the first eight years and pepper in the interspace had the highest SNPV and was the most preferred model. It also has a 90 per cent gross LUF, 1.74 CIF and EGP of 148 man-days per year.

Table 96.3: Intercropping under average mature coconut (1 acre)

Model	*SNPV 12% (Rs.)*	*Gross LUF*	*CIF*	*EGP (man-days/ year)*
1. C_m, P_p^c, Bt_a, Bt_b, G_a, T_a, G_d, T_b,	53821	95	2.29	143
2. C_m, P_p^c, Bt_a, Bt_b, M, G_b, G_d, T_b	50989	95	2.29	144
3. C_m, P_p^c, Bt_b, PA_a, B_b	44235	95	1.74	142
4. C_m, P_p^c, Bt_a, Bt_b, P_p	54142	90	1.74	148
5. C_m, P_p^c, Bt_a, Bt_b, C_f	48774	90	1.71	142
6. C_m, P_p^c, PA_a, B_b	28244	90	1.76	82
7. C_m, P_p^c, B_a, B_b	27089	90	1.76	84
8. C_m, P_p^c, P_p	41760	90	1.76	89
9. C_m, P_p^c, C_f	34618	90	1.76	80

Source: Karunanayake (1982).

In Replanted Selected Tall Coconut Lands

The intercropping models for lands replanted with selected talls resulted in a LUF of 85 per cent and the CIF varied between 1.63 and 2.13 during the first four years and between 1.0 and 1.30 during four to eight years. The models also generated an EGP of 82 to 90 man-days per year (Table 96.4).

Table 96.4: Intercropping models for replanted selected tall coconut (1 acre)

Model	*SNPV @ 12% (Rs.)*	*Gross LUF*	*CIF*		*EGP (man-days/ year)*
			1–4 years	*5–8 years*	
1. C, Bt_a, G_a, T_a	17821	85	2.13	1.0	82
2. C, Bt_a, M, PA_a	13147	85	1.63	1.3	90
3. C, Bt_a, PA_a	12831	85	1.43	1.0	86
4. C, Bt_a, B_a	10835	85	1.63	1.0	79

Source: Karunanayake (1982).

Of the three intercropping models given in Table 96.4 the model with betel in years one to four, ginger in years one to two and turmeric in years three to four, yielded the highest SNPV. In this model, LUF amounted to 85 per cent, the CIF, 2.13 in years one to four and 1.0 during years four to eight and EGP, 82 man-days per year.

In Underplanted Lands

Table 96.5 includes six intercropping models formulated for underplanted coconut lands. These models enabled achieving a LUF of 100 per cent, CIF of 2.0 in years one to four and an EGP of 90 man-days per year.

However, on the basis of SNPV criteria, the model with betel in years one to four, ginger in years one to two and turmeric in years three to four again

ranked the best. It contains a LUF of 85 per cent, CIF of 1.63 during the first four years and EGP of 86 man-days per year.

Table 96.5: Intercropping models for underplanted selected tall coconuts (1 acre)

Model	*SNPV @ 12% (Rs.)*	*Gross LUF*	*CIF*		*EGP (man-days/ year)*
			1–4 years	*5–8 years*	
1. C, Bt_a, G_a, T_a	15571	85	1.63	1.0	86
2. C, Bt_a, PA_a	12291	85	1.28	1.0	90
3. C, Bt_a, B_a	11962	85	1.38	1.0	86
4. C, G_a, T_a	9612	100	2.0	1.0	59
5. C, PA_g	4702	100	–	1.0	61
6. C, B_a	2696	100	–	1.0	54

Source: Karunanayake (1982).

50 Per Cent Replanted Old Coconut Lands

Six intercropping models developed for old coconut lands with 50 per cent replanting are shown in Table 96.6. These models show the possibility of increasing the LUF to 100 per cent during the first four years and to 90 per cent during years five to eight, CIF to 2.21 in years one to eight and EGP to 137 man-days per year.

Table 96.6: Intercropping models under 50 per cent of the palm population replanted with tall seedling coconuts (1 acre)

Model	*SNPV @ 12% (Rs.)*	*Gross LUF*		*CIF*		*EGP (man-days/ year)*
		1–4 years	*5–8 years*	*1–4 years*	*5–8 years*	
1. C, P_p^c, Bt_a, Bt_b, G_a, T_a, G_d, T_b	42545	90	90	2.21	2.21	136
2. C, P_p^c, Bt_a, Bt_b, M, G_b, G_d, T_b	39710	90	90	2.21	2.21	137
3. C, P_p^c, Bt_b, PA_a, B_b	32041	90	65	1.51	1.46	132
4. C, P_p^c, M, G_b, G_d, T_b, PA_a, B_b	18375	100	75	1.64	1.63	69
5. C, P_p^c, PA_a, B_b	24986	100	75	1.20	1.08	74
6. C, P_p^c, B_a, PA_b	24286	100	100	1.20	1.20	79

Source: Karunanayake (1982).

Index to Crops

C	= Coconut	T_a	= Turmeric-years 3–4
C_m	= Mature Coconut	T_b	= Turmeric-years 7–8
P_p^c	= Pepper on coconut	M	= Manioc
Bt_a	= Betel-years 1–4	PA_a	= Pineapple-years 1–4
G_a	= Ginger-years 1–2	PA_b	= Pineapple-years 5–8
G_b	= Ginger-years 2–3	B_a	= Banana-years 1–4
G_c	= Ginger-years 5–6	B_b	= Banana-years 5–8
G_d	= Ginger-years 7–8	P_p	= Pepper
C_f	= Coffee		

On the basis of SNPV criteria, the model with pepper trailed on coconut palms, betel during years one to eight, ginger one to two and seven to eight years and turmeric in three to four years was the best model. It consisted of a LUF of 90 per cent from years one to eight, CIF of 2.21 for years one to eight and an EGP of 136 man-days per annum.

CONCLUSIONS

Two sets of data on inter-country situation are given in Table 96.1. Of this, the actual situation on pilot programmes in the Philippines and Sri Lanka are of limited value as the data are for the initial few years.

The statistics computed on the basis of crop budgets for evaluation of economic efficiency of monoculture coconut among different countries show a greater return from cultivation of hybrid varieties of coconut compared with tall coconut variety.

Different options available for replacement of monoculture coconut cultivation for Sri Lanka again reveals the greater economic efficiency of replanting of old stand with hybrid varieties of coconut.

The intercropping models under mature coconut, replanted tall, underplanting and replanting with 50 per cent of the land area show the potential for increasing of economic efficiency in coconut lands through the introduction of cropping systems. As evident from the data, intercropping in coconut lands enable the increasing of the LUF to 100 per cent, CIF to 2.21 and the EGP to 148 man-days per year. This compared with 25 per cent of the LUF, 1.0 of CIF and an EGP of 60 man-days per year for monoculture coconut, clearly indicates the potential for increasing economic gains through intercropping in coconut lands.

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ECONOMIC PROSPECTS OF COCONUT SECTOR IN INDIA

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ABSTRACT

This paper covers three major aspects to trace the economic prospects of coconut sector in India. First aspect measures the growth in area, production and productivity in terms of compound growth rates. The relative contribution of area expansion and yield improvement to output growth is studied with the help of the Minhas-Vaidyanathan decomposition technique. In the second aspect, the nature and extent of price instabilities have been observed. Besides this, the seasonal influence on prices has been worked out by eliminating the trends and cyclic components. The third aspect relates to the yield expectations under different management levels and consequent economic returns.

INTRODUCTION

Coconut is cultivated in India since ages and fits very well into the socio-economic background. In many instances, it is the only source of income of the inhabitants of the major coconut growing areas. Though it is true that modern technologies are available in India for increasing the productivity of this crop, it is still managed to a great extent by the same way it was managed earlier. The increase in production of nuts from 3,448 million in 1949–50 to 9,283 million in 1989–90 was by and large through the area expansion rather than by the adoption of new technologies. In this context, it is worthwhile to examine all aspects of coconut economics.

MATERIALS AND METHODS

The data on area, production and productivity were collected from the Directorate of Economics and Statistics of the Ministry of Agriculture, Government of India. The data on wholesale prices of coconut, copra and coconut oil were

collected from the Coconut Development Board. Input-output data relating to the permanent observation plot of the Central Plantation Crops Research Institute, Kasaragod which consisted of the following three treatments, namely, (plot 1) cultivation and manuring; (plot 2) cultivation but no manuring; and (plot 3) no cultivation and no manuring were analysed to find out the economics of different management levels. The average yields relate to palms of 35 to 60 years age group. The 1990–91 prices were taken for studying the economics of coconut production under three different management levels.

The relative contribution of area expansion and yield improvement to output growth was studied with the help of Minhas-Vaidyanathan decomposition technique. To study the trend of wholesale prices of coconut and its products third degree polynomials were fitted by using the least square technique. For computing seasonal indices, standard time series technique was used by eliminating trend and cyclic components.

RESULTS AND DISCUSSION

In terms of coconut area (1.5 million ha), India ranks third in the world which is about 13.8 per cent of the total area under coconut in the world. Cultivation in India is mostly concentrated in the four southern states, namely, Kerala, Karnataka, Tamil Nadu and Andhra Pradesh which together account for about 91.8 per cent of area in the country. In terms of production (9,283 million nuts), India again ranks third among the coconut producing countries in the world. Four southern states account for nearly 8,510 million nuts which is about 91.7 per cent of total production. Kerala accounts for about 58 per cent of the total area, but contributes to 47 per cent of the total production in the country. The other three southern states, namely, Karnataka, Tamil Nadu and Andhra Pradesh together contribute to about 44 per cent of the production, though they account for only 36 per cent area under coconut.

Growth in Coconut Area

From the growth rates worked out for the four important coconut growing states, namely, Kerala, Tamil Nadu, Karnataka and Andhra Pradesh during different decades it is seen that for Andhra Pradesh and Karnataka the growth rate was positive during all the decades starting from the fifties with maximum during the eighties, showing that there has been a steady increase in area in these two states. For Kerala, however, during the seventies, there was a negative growth rate. But it was seen to reverse during the next decade.

In Tamil Nadu, in the initial period, there was a negative growth. But the trend reversed during other decades with the highest growth rate of 7.70 per cent being observed during the eighties. The trend of growth rate at the all India level was exactly similar to that of the Kerala showing the state's importance in the coconut sector (Table 97.1).

Growth in Productivity

In the case of productivity there was no clear trend in the growth rates. In the case of Andhra Pradesh, during the first three decades (1950–51 to 79–80) the growth rate was negative while during the eighties there was a high positive

growth rate of 7.47 per cent. For the other states the growth during the latest period (1980–81 to 89–90) was negative. In the case of Tamil Nadu particularly during the first three decades (1950–51 to 79–80) the growth was positive while during the latest decade (1980–81 to 89–90) it was negative. This may mainly be due to the big area expansion which took place during this period (Table 97.1).

When increase in production from 1950–51 to 1989–90 was considered at all India level, it was seen that the increase was mainly due to the area effect (89.7 per cent), while yield had a negligible contribution (4.3 per cent). The remaining 6 per cent was the interaction effect.

Table 97.1: Compound growth rate of coconut during 1950–51 to 1989–90

State		*Area*	*Production*	*Productivity*
Andhra Pradesh	1950–51 to 1959–60	0.59	−0.01	−0.06
	1960–61 to 1969–70	0.67	−2.68	−3.33
	1970–71 to 1979–80	0.80	0.24	−0.56
	1980–81 to 1989–90	2.96	15.72	7.47
	1950–51 to 1989–90	1.13	−0.55	−1.66
Karnataka	1950–51 to 1959–60	0.34	3.79	3.44
	1960–61 to 1969–70	2.38	2.19	−0.17
	1970–71 to 1979–80	2.92	3.09	0.16
	1980–81 to 1989–90	3.10	2.94	−0.15
	1950–51 to 1989–90	2.68	3.44	0.74
Kerala	1950–51 to 1959–60	1.96	5.42	3.39
	1960–61 to 1969–70	4.01	2.20	−1.73
	1970–71 to 1979–80	−1.72	−3.37	−2.07
	1980–81 to 1989–90	3.44	3.84	−0.24
	1950–51 to 1989–90	1.67	0.62	−1.05
Tamil Nadu	1950–51 to 1959–60	−2.22	−0.87	1.39
	1960–61 to 1969–70	6.01	4.96	0.79
	1970–71 to 1979–80	1.12	2.34	1.21
	1980–81 to 1989–90	7.70	7.79	−1.42
	1950–51 to 1989–90	3.51	4.14	0.59
All India	1950–51 to 1959–60	1.21	2.41	1.19
	1960–61 to 1969–70	4.07	2.56	−1.44
	1970–71 to 1979–80	−0.17	−1.04	−0.88
	1980–81 to 1989–90	3.80	5.27	1.42
	1950–51 to 1989–90	2.16	1.58	−0.57

Wholesale Price of Coconut, Copra and Coconut Oil

The average annual wholesale prices of coconut, copra and coconut oil in the eighties is presented in Table 97.2. Between 1980–81 and 1989–90, the price of coconuts ranged between Rs. 1137 and 2607 for 100 nuts and copra between Rs. 892 and Rs. 2182 for 100 kg and for coconut oil between Rs. 1319 and 3240 for 100 kg. Year to year fluctuation was of a high order (cv from 31 to 33 per cent showing the erratic behaviour of prices. The C.G.R. ranged between 7.6 for coconut and 8.42 per cent for coconut oil.

Table 97.2: Average annual wholesale prices of coconut, copra and coconut oil at Calicut (Kerala) market during the eighties

Year	*Wholesale prices of*					
	Coconut		*Copra*		*Coconut oil*	
	(Rs./1000 nuts)	*% var.*	*(Rs./100 kg)*	*% var.*	*(Rs./100 kg)*	*% var.*
1979–80	928	–	856	–	1219	–
1980–81	1158	24.78	1161	35.63	1577	29.37
1981–82	1137	−1.81	892	−23.17	1319	−16.36
1982–83	1271	11.79	1021	14.46	1542	16.91
1983–84	2493	96.14	1588	55.53	2384	54.60
1984–85	2602	4.37	2182	37.41	3240	35.91
1985–86	1215	−53.31	1152	−47.20	1710	−47.22
1986–87	1920	58.02	1700	47.57	2592	51.58
1987–88	2118	10.31	2057	21.00	3097	19.48
1988–89	2277	7.51	1923	−6.51	2873	−7.23
1989–90	1830	−19.63	1572	−18.25	2322	−19.18
Mean	1722.60		1464.00		2170.50	
SD	574.91		451.55		696.20	
CV (%)	33.37		30.84		32.08	
C.G.R. (%)	7.61		7.80		8.42	

Seasonal Behaviour of Prices

When a larger set of monthly data were subjected to analysis, the seasonal indices worked out showed that wholesale prices exhibited a distinct seasonal pattern. Coconut prices ruled high during October to February and low during April to September, whereas copra prices ruled high during October to February and low during April to September. Seasonality of coconut oil price was more or less on similar lines with copra for obvious reasons (Table 97.3).

Table 97.3: Seasonal indices of wholesale prices of coconut and its products at Calicut market (1970 to 1990)

Month	*Coconut*	*Copra*	*Coconut oil*
Jan	113.45	106.81	102.46
Feb	118.13	103.27	97.83
Mar	112.59	100.18	92.25
Apr	109.42	93.02	94.53
May	100.81	91.02	92.86
Jun	91.25	93.15	95.82
Jul	88.01	95.36	98.69
Aug	87.57	96.23	98.44
Sep	91.01	99.46	102.11
Oct	90.58	103.56	104.56
Nov	90.36	106.29	108.22
Dec	100.71	105.00	105.86

Note: Trend and cyclic components are eliminated.

An effort was made to see if the average wholesale prices of these commodities follow a pattern. It was seen that a third degree polynomial fits very well in the average wholesale prices of coconut, copra as well as coconut oil (Fig 97.1).

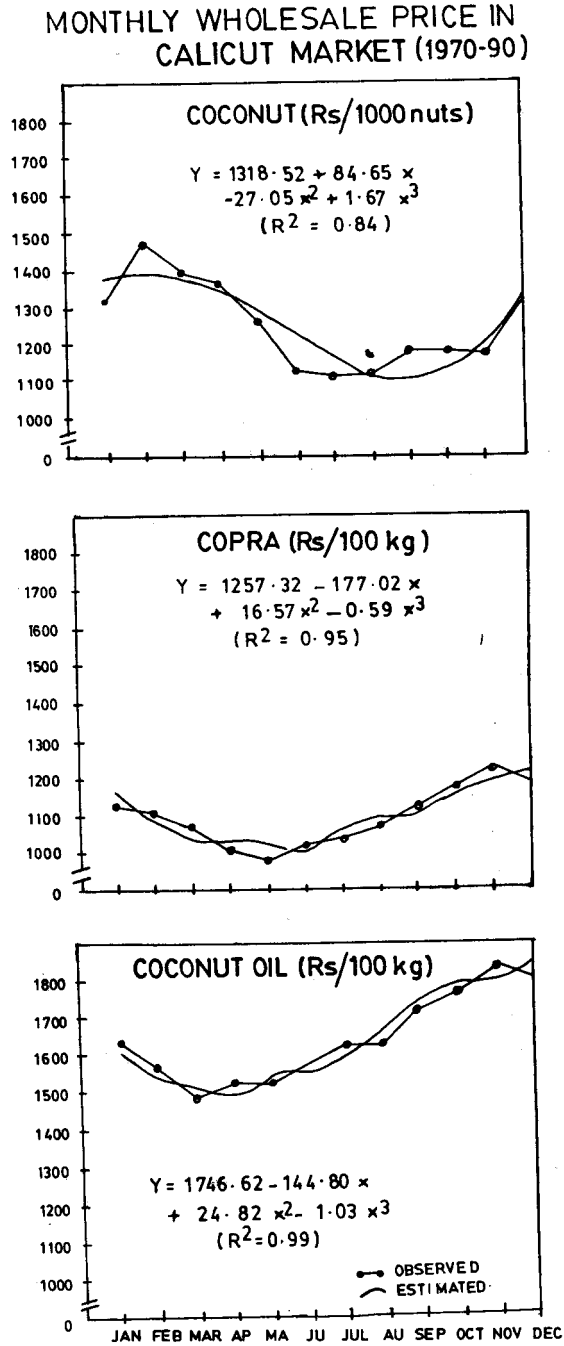

Fig. 97.1: Monthly wholesale price in Calicut market (1970–90).

The equations are as follows:

1) Wholesale price of coconut (Rs./1000 nuts)
$$Y = 1318.52 + 84.65 X - 27.05 X^2 + 1.67 X^3 \ (R^2 = 0.84)$$
2) Wholesale price of copra (Rs./100 kg)
$$Y = 1257.32 - 177.02 X + 16.57 X^2 - 0.59 X^3 \ (R^2 = 0.95)$$
3) Wholesale price of coconut oil (Rs./100 kg)
$$Y = 1746.63 - 144.80 X + 24.82 X^2 - 1.02 X^3 \ (R^2 = 0.97)$$

where Y is the predicted value and X = 1 for January; X = 2 for February; and X = 12 for December.

Since R^2 values for these equations are high the trend of prices of these commodities follows a pattern. It is suggested that in order to minimise the price instability, an appropriate supply management should receive priority in development strategy.

Profitability of Coconut Farming Under Different Managements

The yield data pertaining to the period 1933 to 1958 which corresponds to the age group of around 35 to 60 years of the palms were considered for the economic analysis under three different management levels. In other words, this study covered the yield during a stabilised period for a valid conclusion. It may be noted here that the management trials were carried out under rainfed conditions with monoculture. The average rainfall at Kasaragod for the period 1962 to 1981 was 3579 mm with 116 rainy days in a year. June to September accounts for 85 per cent of total rainfall in a year. The soil of this block is a well drained deep red sandy loam and is within 0.8 km from the sea coast. The water table is about 7 m below the surface level.

The average yield/ha for plot 1 was 10,080 nuts while for plot 2 and plot 3 it was 8,435 and 2,680 nuts, respectively. Thus per palm yields in these three levels of management were 57.6, 48.2 and 15.3 nuts, respectively (Table 97.4).

Table 97.4: Costs and returns of different management levels in permanent observation plots of CPCRI, Kasaragod (Rs./ha/year)

Plot	*Yield/ha (nuts)*	*When price per nut is Rs.*	*Annual cost*	*Gross return*	*Gross margin*
Plot 1 (cultivation and manuring)	10080	2.50	4420	25200	20780
		3.00	4420	30240	25820
		3.50	4420	35280	30860
Plot 2 (cultivation but no manuring)	8435	2.50	2220	21100	18880
		3.00	2220	25300	23080
		3.50	2220	29520	27300
Plot 3 (no cultivation and no manuring)	2680	2.50	1160	6700	5540
		3.00	1160	8040	6880
		3.50	1160	9380	8220

Input-output data relate to 1933 to 1958. Economic analysis is based on 1990–91 prices.

Since input data for the initial period of establishment of the palms were not available, it was not possible to work out the net returns. Hence the final analysis was limited to gross margin. Besides, under small land holdings situation it is the gross margin that matters in the economic decision.

According to the analysis, the estimated cost of maintenance for plot 1 at 1990–91 factor market prices was Rs. 4,420/ha for plot 2 Rs. 2220/ha and Rs. 1160/ha for plot 3. Returns with three levels of prices (Rs. 2.50, Rs. 3 and Rs. 3.50 per nut) were assumed based on the recent trends of coconut prices. It can be seen (Table 97.4) that when price per nut is Rs. 3.50 the gross return amounts to Rs. 35,280 and gross margin Rs. 30,860/ha in plot 1. Corresponding figures for plot 2 were Rs. 29,520 and Rs. 27,300/ha and for plot 3 Rs. 9,380 and Rs. 8,220/ha.

Hence, it is seen that by spending an additional amount of Rs. 3,260/ha in gardens which were regularly managed an additional return of Rs. 22,640/ha can be realised. Since the management packages referred to here are quite affordable by a small farmer, it is surprising to observe that most of our farmers have not put any effort to adopt good crop husbandry mostly due to their lack of understanding about economic prospect of this social crop. This study, therefore suggests that there is a need for small holder's attitudinal change towards coconut farming. It is also stressed that the developmental agencies should not only devote their energy and resources towards the area expansion programme, but also simultaneously make serious efforts to motivate the coconut farmers towards better management.

ECONOMICS AND AGRO-INDUSTRIAL RESEARCH FOR COCONUTS

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ABSTRACT

This paper argues that research on processing technology should be a major thrust of any international coconut research initiative within the CGIAR network. Such an agro-industrial research orientation is at variance with the 'supply-shifting' emphasis of existing centres and institutes. But it is critical for a perennial crop whose international market consists primarily of processed products. The major problems facing the industry have to do with product markets — not enhancement of nut supply. Conventional coconut processing is not integrated. Nuts are partitioned into component parts at or near the farm. This action diminishes the robustness and storage qualities of the nut. The ability of coconuts to provide a constant output in any processing plant is reduced. This factor and the enormous biomass energy surplus of whole nuts call for effective research into integrated processing systems. The paper concludes with examples of recent relevant international research.

INTRODUCTION

Coconut is being investigated as a potential candidate for international research effort under the Consultative Group on International Agricultural Research (CGIAR). International agricultural research has achieved many notable scientific successes, particularly in plant breeding, genetics, plant nutrition, pest control, water management, cultivation techniques, and farming systems (Anderson *et al.*, 1988). There have been many unforeseen secondary effects of this "Green Revolution" in equity, access, pest management and genetic diversity. However, the concentration on production technology has resulted in very much larger increases in output than would have been the case without the major effort in international collaborative agricultural research. This paper raises the issue as to whether the conventional "supply side" orientation of the international agricultural research centres is an appropriate research agenda

for the coconut industry. Are the major problems facing the industry agronomic? With coconuts we are dealing with a perennial crop with a lifespan similar to that of healthy people — "three score years and ten". Does this force a different perspective on the research agenda compared to annual crops? Finally, what are the critical attributes of the coconut that need to be exploited for the industry to prosper?

Dialogue on a Research Agenda

In a 1986 report the Technical Advisory Committee (TAC) of CGIAR, concluded that:

"Coconut is the oil crop most in need of international agricultural support. International research on crop is currently underfunded and it has the potential for high pay-off. Furthermore, coconut is a small holder crop that is ecologically sound and offers a broad range of dietary, income and employment opportunities" (CGIAR, 1988).

TAC was then commissioned to discuss proposals for an international initiative for research within the CGIAR framework with people in the coconut industry. The first TAC report (CGIAR, 1988) noted that the benefits of an international research programme must reach many countries and would therefore differ from national programmes. It adopted a conventional agronomic approach with the following ranking of priorities:

1) Germplasm collection, conservation, evaluation and distribution.
2) Coconut breeding.
3) Tissue culture.
4) Disease control.
5) Socio-economics.
6) Rehabilitation of existing plantings.
7) Pest control.
8) Post-harvest handling and food technology.

Only the first five issues were to be on the international agenda. The remaining topics were to be the responsibility of bilateral agencies. The ranking implies that the most significant problems facing the industry are agronomic problems which can be mitigated by enhancing yields. It implies an optimistic view of the market prospects for traditional coconut products. Or, the intention is to focus solely on new production plantations rather than on the needs of existing farmers (small holders). An additional underlying assumption is that the problems of the industry are not urgent but can be resolved systematically over the next century or so. These conclusions follow the fact that the first three priority areas all relate to 'embodied' technological change. Here, new technologies are embodied in new planting material so the impact of the research on the industry must await replanting with HYVs. This is ideal for annual crops where new varieties are issued with relative rapidity and mistakes remedied with further issues. However, tree planting involves long-term investment decisions with long-run consequences. Replanting involves an even more complex decision calculus (Etherington, 1977; 1990a). The benefits of a breeding-planting-replanting programme for existing farmers will only become

evident over generations rather than in decades or years. Thus from an economist's point of view, this ranking of priorities implies a zero or negative discount rate on future income generation. The fourth priority is certainly very important with local and regional impact. However, the ability and willingness of farmers to carry out disease control measures will be related to relative prices. The socio-economic research envisaged was to be directed at farming systems to exploit the synergistic interactions possible in multistorey cropping.

The proposed initial international initiatives leave out rehabilitation and pest control. While they may be highly location-specific, they do represent 'disembodied' technological change. They are not usually variety specific. Farmers can often apply them to their existing palm groves. Thus benefits can be widespread and rapidly acquired by farmers. Finally, item 8 (post-harvest handling, processing and food technology) has the potential for influencing the market for final products. The impact on the industry could be very rapid and would enhance the returns from existing plantings. This was well recognised by a 1983 Asian Development Bank report for the Solomon Islands which concluded that

> Nothing could benefit the rural economy more and no benefit could be transferred to the small holders faster than an increase in the value which they receive for their coconut sales (Asian Development Bank, 1983).

Immediate Problems of the International Coconut Industry

The initial ranking of research priorities failed to take adequate account of many of the major problems facing the industry. Some of the major factors not taken into account include:

1) World prices for coconut oil fluctuate more widely than any other vegetable oil and have been on a consistent downward trend over the last 40 years (World Bank, 1990).

2) There is strong and increasing competition from other vegetable oils, particularly from palm kernel oil—a nearly perfect substitute. Technical substitution between oils is also made possible by the chemical manipulation of fatty acids.

3) The American Soybean Association has waged a vigorous—indeed vicious—campaign against "Tropical Oils" to reduce their importation into the USA (Asia Week, 1987). This campaign has focussed on the supposedly deleterious effects on human health caused by consumption of saturated fats of tropical origin (Blackburn, 1987; PJCS, 1987b).

4) Legislation in the European Community (EC) regarding lower permissible levels of aflatoxin in oils is now being implemented with the potential implication that copra imports will be severely curtailed.

5) The industry only uses a small portion of the total available coconut biomass.

6) Many countries and millions of coconut producers and consumers cannot draw any benefit from the very wide range of products produced from the coconut.

While, devastating regional outbreaks of disease have occurred, such as lethal yellowing disease in the Caribbean and cadang-cadang in parts of the Philippines, the matters of major international concern are not raw material output. Rather they relate to end products and the demand side of the market equation. These issues are extremely complex. They need urgent study but such research falls outside the normal realm of responsibility of international agricultural research institutes. Nevertheless, TAC addressed the issues in its second report (CGIAR, 1989) by defining the broad objectives of coconut research to be:

i) Increase nut production to satisfy increasing domestic requirements.
ii) Increase the size of the coconut processing industry.
iii) Strengthen its competitive position.
iv) Increase the size of the markets for coconut products.

Within these broad guidelines, priority research areas were listed but not ranked. They included germplasm improvement; disease and pest control; post-harvest aspects and the sustainability of coconut-based farming systems (My emphasis).

In a meeting leading up to the second TAC report, Adair of the Natural Resources Institute (NRI — formerly TDRI and ODNRI) made a strong case for final product research (CGIAR, 1989). The opportunities are enormous: many non-conventional, high value, coconut products can be produced. Processing technologies can be greatly improved (Hagenmaier, 1980; Gonzalez, 1986; Leufstedt, 1990). Because of its high nutritive value, coconut meat of high moisture content deteriorates rapidly with the growth of fungi and bacteria. The bulk of marketed coconut is preserved by processing it into copra. This technique was designed for the era of sailing ships and unskilled labour with little equipment over a century ago. Not surprisingly, the technology has been described as 'stone age' (Romero, 1987). It is roughly equivalent in status to sun-dried meat.

The disadvantages of the current procedures lie in the extreme denaturing of the fruit and the wastage of potential by-products. Kiln or sun-drying copra with unhygienic handling and storage changes a highly edible product into a potentially toxic product. There is grave concern regarding aflatoxin contamination (APCC, 1988). This may cause the ban of copra imports to Europe. The protein and vitamin content in coconut is reasonably good for a plant source. However, essential amino-acids and tocopherol (Vitamin E) are destroyed by the high temperatures to which copra is subjected (Banzon and Velasco, 1982). The nutritional qualities of copra cake are degraded and coconut oil expelled from copra is inedible. Refining the oil is essential. This may be ideal for many industrial uses but it results in an inferior edible oil. For example, alkali refining and steam deodorisation remove remaining tocopherols. Processing *via* copra is convenient but it severely limits the market potential for coconut products.

Ways Forward

Positive responses to the strong negative price trend faced by the industry include: (1) manufacturing the chemical 'building blocks' of oil rather than the

oil itself; (2) trying to obtain a premium for higher quality oil; and/or (3) expanding the markets for non-conventional coconut products. The first option dictates no change to the existing copra trade but it requires a sophisticated chemical engineering capability (PJCS, 1987a). This is the path being taken by the Philippines. It is not a feasible option for many smaller countries. "Higher quality oil" can be obtained directly from fresh coconut by mechanical extraction and filtering or *via* the 'aqueous' process (Hagenmaier, 1980; Leufstedt, 1990; Breag *et al.*, 1991). The resulting natural coconut oil has a very low free fatty acid content, retains the tocopherols and has a very long shelf life.

'Non-conventional' markets vary from young coconuts (promoted domestically as a healthy drink), to the export of desiccated coconut, coconut water and cream (Leufstedt, 1990). Such expansion in the non-oil sector results in selling higher value-added commodities and reduces the supply of coconuts for the vegetable oil market. Whole fresh (green) coconuts and dehusked coconuts are sold in supermarkets several thousand km from their source. Back-loads in otherwise empty chilled shipping containers provide excellent, inexpensive transport to high income markets. Similar mechanisms to supply domestic urban markets in large countries or geographic regions need exploring. The price differential between nuts sold in local urban markets and those used for copra is typically about 10:1. The export value (FOB) differential of nuts made into desiccated coconut (DCN) is between 3 and 4:1 compared to copra. The ratio of coconut cream to copra is between 5 and 8:1 (Etherington, 1990).

However, more urgent than research into any one process, market or infrastructural development, is the need to bring the economic benefits of integration to the coconut industry. These have been vital to palm oil processing. The coconut industry is characterised by disintegration. Typically farmers send components of whole coconuts in different directions. In most of the South Pacific Islands, farmers abandon the husks, shell and water in the field. In other cases, they sell dehusked nuts to the fresh market or to desiccated coconut or coconut cream producers or to larger scale copra kilns. Husks only have a significant market in India and Sri Lanka.

Whatever the extent of disintegration of processes, the effect is to severely handicap the economic efficiency of the industry. Two key natural attributes of the coconut remain little used. Firstly, coconuts are produced all the year round with few purchased inputs. If untampered with, whole nuts are extremely robust and durable. They are easily stored for periods of at least three months. Such regularity of output and ease of storage is rare among agricultural products and allows processing plants to run at high levels of throughput throughout the year. Average fixed costs of processing decline rapidly as throughput increases. This means that the capital cost of a plant will have little effect on its profitability—the rate of throughput is critical.

Secondly, whole coconuts contain a vast energy surplus compared to any likely processing requirements. Theoretically, 1000 whole nuts can produce over 350 kWh of electricity from the coir dust and producer gas from coconut shell charcoal production using mono-tube boiler and modern reciprocating

steam engine technology (Etherington and Hagen, 1989; Kaneff et al., 1987). The significant economic lesson to be drawn from this energy surplus is that an integrated plant can operate with very low variable recurrent costs compared to plants having to purchase their energy requirements. These two factors, constant high throughput and the energy surplus, mean that relatively high capital cost processing plants can be extremely profitable. High capital costs allow for much higher standards of processing than are now used in copra production. Hygienic final products (even if only coconut oil and cake) would be directly edible by humans without further refining. The 'reservation' markets of such plants would be standard unrefined oil and copra cake. However, the oil would be superior to RBD for most edible purposes. The copra cake could be marketed as defatted desiccated coconut. The energy surplus would also allow further processing of nut and husk (fibre) products.

This attractive scenario is faced with two transport problems: delivery of whole nuts to the plant and the shipping of higher quality products. Bulky commodities, such as whole nuts, are expensive to transport. Therefore integrated plants are best located near the source of supply. This factor works in favour of small holders since the cost advantage will lie with smaller local plants rather than large centralised facilities. The durability and ease of storage of whole nuts can allow for fluctuations in deliveries. Aseptic packaging, chilled containers and containerisation itself have greatly improved the ease of shipping higher quality coconut products (Brookfield, 1984).

CONCLUSIONS

There is now empirical evidence to support the central hypothesis of this paper, that international coconut research devoted to post-harvest, or agro-industrial processing of coconuts can be very effective, and provide high economic returns. The Natural Resources Institute of the U.K. has undertaken extensive research in this area. Their work has included marginal improvements in equipment design to improve cleanliness; the development of small scale expellers (Barrett *et al.*, 1987) and a dehusker; and, the development and extension of the waste heat recovery unit (WHRU) for joint production of coconut shell charcoal and producer gas (APCC, 1989). This last development is particularly significant as it encourages the integration of energy production with final products. So far these have included charcoal, desiccated coconut and improved copra and coconut oil (Breag *et al.*, 1991). Allied technologies have been developed by commercial firms (Leufstedt, 1990). Others need developing.

Modest scale hygienic processing plants are possible (Etherington, 1991). They could be highly profitable with high rates of throughput. The bulky nature of whole nuts would increase the demand for nuts from farms in the vicinity of such plants. Resultant increases in nut prices would encourage improved cultural practices on existing palms and the planting of the HYVs that the agronomic research will produce. Without the development of improved

processing and markets, it is unlikely that farmers will be interested in new varieties.

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DISCUSSION

G. Breag (comments): Dr. Foale had also emphasised that technology transfer should be carried out cautiously. In my view, the difficulty of technology transfer is often underestimated and consequently underfunded.

Sumith De Silva: Dr. Dan Etherington developed the concept of integrated processing plant few years ago and he was trying to find financial assistance for assembling a pilot plant. Would you be able to tell us whether he was successful in this effort?

M.A. Foale: Funding has not been found for the development of the entire integrated process. However, there has been progress in advancing the development of a suitable steam generator. In addition, the governments of several South Pacific countries are now beginning to take strong interest in the idea. This may provide the stimulus needed for international funding agencies to come forward and support this project.

COCONUT RESEARCH IN FIJI

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ABSTRACT

This paper reviews the coconut agronomic and breeding research in Fiji and the past and present coconut research and development constraints are highlighted.

The long-term NPK trial at Wainigata showed a significant effect of N on the yield of copra; but P, K and interactions had no effect. Fertiliser application and weed control demonstration trials in Cakaudrove highlighted the overwhelming yield increases that could be achieved by proper fertiliser application and weed control. A nutritional survey conducted in Cakaudrove and Taveuni revealed widespread deficiencies of N, P, K and Cl. Intercropping trials with annual crops showed that rice, maize, *dalo* (*taro*) and cassava are suitable intercrops under mature stands of coconut in the wetter regions of Cakaudrove. However, their performance depended on variety, time of planting and other agronomic practices. Fertiliser application studies on hybrid coconut seedlings showed a significant response to only nitrogen application on growth, while similar studies on Malayan Red Dwarf seedlings showed a significant response to N, K and Cl application on seedling growth. Mother palm selection studies on Fiji Tall, Rotuman Tall and Niu Leka have been completed and progeny testing is in progress.

INTRODUCTION

Coconut industry in Fiji is of considerable national importance not only as a foreign exchange earner through import substitution but also as daily food and livelihood to more than 30,000 farm families. The coconut area is estimated at 66,000 ha grown largely on coastal soils of the 300 islands grouping Fiji. There are two major islands in Vanua Levu and Viti Levu and a large proportion of the coconuts is grown on wet zone of Vanua Levu where the annual rainfall is between 1800 and 3000 mm.

Coconut research in Fiji dates back to the late twenties when Marechal (1928) pioneered the hybridisation work. Unfortunately, after his departure in the early thirties this work was terminated. Coconut research recommenced in 1962, but greater emphasis was given to it starting 1970. Research on the agronomy and breeding of coconut from the inception to 1971 was reviewed by

Leather (1972) and from 1970 to 1975 by Vernon *et al.* (1975; 1976). Haydock and Black (1984) reviewed fertilizer trials on crops and pastures in Fiji. Martin (1984) reviewed mainly the agronomic and breeding research conducted since 1976. This paper highlights some of the research achievements and constraints faced by coconut breeders at Fiji, and how such constraints are being overcome along with suggestions for future research.

OVERVIEW OF THE PAST AND PRESENT COCONUT RESEARCH

Coconut research in the early twenties concentrated on coconut pests. Coconut breeding research commenced in the late twenties when Marechal (1928) pioneered the hybridisation of coconuts by crossing Malaysian Red Dwarf (MRD) with Niu Leka Dwarf (NLD). His MRD × NLD hybrids planted at Navosu, near Nausori, reached the bearing age in just over three years, but suffered from lack of maintenance and regular recording (Leather, 1972). Also he had crossed Malayan Red Dwarf with Rotuman Tall which commenced bearing in 1936. In 1970, Leather recommenced the hybridisation work (Leather *et al.*, 1971) which was continued by Satyabalan (Satyabalan *et al.*, 1972) and Sundaram (Sundaram *et al.*, 1975). These hybrid trials were started on steep slopes where soils were marginal for coconuts, had inadequate plot size and had large variability caused by death of trees due to cyclones and as a result these hybrid trials were terminated in 1977 (Vernon *et al.*, 1978).

The coconut breeding work recommenced in 1983 (Martin *et al.*, 1983; 1984). After rectifying the previous weaknesses a hybrid evaluation trial was started in 1988 (Manciot *et al.*, 1987) at the Taveuni Coconut Centre.

Agronomic research since 1959 concentrated on fertiliser trials of young coconuts, but the trials were discontinued in 1964. The only long-term NPK trial on Fiji Tall coconuts was terminated in 1982 due to drawbacks, such as, poor location on a steep hillside, confounding the effect of sulphur with that of all the nutrients tested (Haydock and Black, 1984) and inadequate rate of different nutrients to determine the optimum response. Till to date no comprehensive fertiliser response trial has been established in Fiji on Fiji Tall or hybrid coconuts.

The non-uniformity of the stand was also caused by the death of palms due to devastating cyclones which are very common in Fiji. Coconut research on suitable farmers' fields was often not successful due to poor cooperation of the farmers. Because of such constraints a large number of agronomic and breeding trials were terminated prematurely.

Other factors that had contributed to lack of cohesive coconut research in Fiji were: discontinuous service of expatriate professionals, non-availability of qualified local professional staff, no proper manpower development and training, and lack of government commitment to provide necessary funds and suitable land for research. The consequences of such factors and underestimation of importance to research by government had led the coconut industry in Fiji to the stage where national coconut production declined from 40,000 t in the sixties to about 15,000 t in 1989.

The major cause for this decline had been the low yield from coconut groves brought about by poor maintenance, lack of fertiliser application and an unsuccessful replanting programme. About 60 per cent of the stands are senile which need replanting.

A replanting programme with Fiji Tall from 1968 to 1970 and from 1974 to 1978 with hybrid coconut has not been successful. The later replanting did not have any sound research data backing and the quality of hybrids produced was poor. The results from these hybrids were not convincing and hence failed to attract the farmers' interest. The hybrid seed garden that was set up in early 1971 had a number of weaknesses. As a result the quality of hybrid and the percentage of hybrid out-turn were very low. The seed garden was established on marginal nigresant soil which was less than 1 m deep with soft stone pans. The MRD mother palms along with interplanted Fiji Talls despite judicious fertiliser application did not perform well. The seed garden did not have any isolation boundary to prevent rogue pollination. Further, the pollen parent (Fiji Talls) had not been tested for their combining ability with MRD. It is suspected that Fiji Talls do not have a good combining ability (Manciot *et al.*, 1987).

From the silent experience Fiji had, it is clear that coconut research should form an integral part of coconut development if the industry has to succeed. However, small coconut producing countries like Fiji do not have sufficient physical and economic resources to back up their coconut development by a proper research establishment to provide all the necessary services such as improved variety, package of practice under various agro-climatic conditions and systems of farming, and general technology dissemination information for farmers to adopt the technology.

With the joint support from IRHO, European Community and Fiji Government a coconut research and development centre had been established on the Island of Taveuni, in Fiji on 380 ha of land. While establishing this centre consideration had been given to previous mistakes. An 80 ha seed garden had been established that would produce four hybrids, MRD × ROT (Rotuman Tall), MRD × RLT (Rennell Tall), MYD × ROT and MYD × RLT. Also a hybrid evaluation trial, Fiji Tall progeny testing studies, germplasm evaluation and a fertiliser trial on MRD has been established. Besides, the centre has a one ha nursery and extension staff training facilities. Emphasis also has been given to local manpower training and development.

All this would not have been possible without external assistance. To strengthen coconut research further, a 200 ha land for agronomic and inter-cropping research is being sought. European Community and IRHO support is expected till 1995.

While the research back-up services are being strengthened their profound effect on the coconut industry will come to be realised many years later. Whether the government will still remain in a position to carry forward all the coconut research activities effectively without external support, is yet to be seen.

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DISCUSSION

M.K. Muliyar: Does the hybrid Niu Leka × Malayan Dwarf produced in 1928 is still growing in your farm?

R.N. Duve: It is still present in our collection. However it has not been fully tested.

H.C. Harries (comments): The hybrid between Malayan Dwarf and the Niu Leka was favourably reported in Fiji and the Director of Agriculture took F_1 seed to Jamaica. Despite segregation, the F_3, F_4 and F_5 generations resist lethal yellowing and have an attractive habit. It would make sense to include the Niu Leka in breeding programmes in Fiji.

M.A. Foale: For the sake of historical precision I want to say that the hybridisation of Niu Leka and Malayan Red Dwarf was done in Fiji in 1925. The report on the work was published in *'Fiji Agricultural Journal'* in 1928.

THE DEVELOPMENT OF COCONUT RESEARCH IN TANZANIA

Lother Diehl

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ABSTRACT

Coconut research in Tanzania is in the mandate of the National Coconut Development Programme. This programme was started in 1979 with assistance from the Federal Republic of Germany and a loan from the International Development Agency (IDA). In the beginning research areas were:

1) Introduction, testing and production mainly of D × T hybrids.
2) Crop management in terms of plant nutrition, weeding, spacing etc.
3) Study of the lethal disease, its causal agent and vector.
4) Control of *Oryctes monoceros*.

The direction of research has now changed to be more location specific and more geared towards small scale intercropping agriculture. Thus the topics now are: (i) improvement of the local East African Tall (EAT); (ii) intercropping experiments and on-farm trials; (iii) disease resistance trials; and (iv) biological control of *Pseudotheraputs wayi*.

INTRODUCTION

Coconuts in Tanzania are mainly used for household consumption in the form of coconut milk which is used for cooking. Processing into copra and oil for industrial use or production of coir and utilisation of shell and timber play hardly any role at all.

We estimate that there are some 22.6 million coconut palms in Tanzania covering an area of approximately 239,000 ha. About 25 per cent of the palms are located on the islands of Zanzibar, Pemba and Mafia. About 95 per cent of the palms are grown by small scale farmers and the rest by some medium and large scale growers. The mean annual yield is 23 nuts per palm amounting to a total annual production of 541 million nuts. Assuming an average copra content of 175 g per nut the equivalent copra production would be around 94,000 t per annum (Balingasa, 1990).

Rainfall in the coconut growing coastal belt varies from 900 to 1200 mm per annum on Tanzania mainland while on the islands of Zanzibar and Pemba rainfall of 1400 to 1800 mm is received. The rainfall is unevenly distributed with a six-month dry period on the mainland. Since the late sixties coconut production in Tanzania showed a downward trend. Major causes for the decline were unattractive prices and inefficient marketing arrangements, overaged palm stands, pests, disease, limited availability of good seeds and planting material. Growers were not inclined to invest much energy and expenses in the crop, as it was not economically attractive. Consequently husbandry practices were poor and often consisted of nothing more than harvesting (NCDP, 1987).

In 1979, the National Coconut Development Programme (NCDP) was launched with technical assistance from the Federal Republic of Germany. The project was to:

i) identify disease and pest control methods;
ii) examine the possibilities for introducing improved varieties;
iii) produce high yielding seed and planting material;
iv) train extension staff; and
v) organise a field advisory service.

Activities were expanded with the assistance of an IDA credit which covered:

a) agronomy and crop rehabilitation trials;
b) seed farms for the production of hybrids;
c) additional support for extension activities; and
d) training.

At present the project involves some 20 graduate-staff working in research, extension and project management, seven stations for agronomy and variety trials (120 ha); six sites for disease resistance screening (103 ha); two seed farms comprising about 120 ha mother palms and 45 ha pollen parents and a head office with laboratory and workshop facilities.

THE RESEARCH PROGRAMME

The research programme is an applied one. It is directed towards solving problems encountered in the field and to produce extension messages. Research is organised in five sections: agronomy, breeding, disease control, pest control and farming systems research.

Agronomy Research

The initial focus of agronomy research was on plant nutrition and crop management. In addition, the Agronomy section was charged with the varietal trials, as the outstations were under this section.

Plant Nutrition

Exploratory and long-term fertiliser trials were and are conducted on all the major soil types of the coconut growing coastal belt. While fertilisers were generally moderately beneficial, outstanding response was observed for phosphate on red brown loamy sands of the mainland; and for potash on the Kinongo soil series of Zanzibar (Romney, 1987).

Crop Management

Varietal trials were and are conducted to address the question of optimal crop management.

Weeding

Trials comparing different sizes of weeded rings with complete cultivation were carried out on four stations. Results indicated that growth of palms was correlated with size of weeded rings and was best under complete cultivation (Romney, 1988).

Varieties of palms were tested under two management levels. Ring-weeding and slashing with fertiliser application, to represent plantation management and intercropping with annual food crops and no fertiliser, to represent farmers' management . It was soon obvious that intercropped palms grew better than ring-weeded and fertilised palms.

Mulching

Mulching was beneficial only when large amounts of organic material were imported into the field and applied on the rings around the palms. This, however, was uneconomical and unpractical for farmers. The main conclusion from these trials was that competition for water was the most limiting factor for coconut production and hence, conservation of soil moisture is the most important consideration in crop management. Intercropping with annual food crops seemed to be most beneficial for palm development since it offered least competition to palms particularly in the critical dry period after the crop had been harvested.

Spacing

Spacing trials together with first experiences in the field gave evidence that the recommended 9 × 9 m triangular planting pattern was too dense for Tanzanian conditions. Consequently these trials were altered in 1990 to wider spacings with corridors for food crop cultivation, similar to alley-cropping arrangements. Fertilisers are now applied to the intercrops rather than to the palms. The response to this is yet to be seen.

Thus integration of palms and annual food crops is now the focus of agronomy research together with studies on the incidence and cause of wilt under varying conditions.

Crop Improvement

During the initial phase of the project emphasis was placed on testing various exotic hybrids. Dwarf × Tall hybrids were found to be more precocious than both the local tall and the Tall × Tall hybrids. Initial yields from the former were encouraging, leading to the release of two hybrids: Mawa (Malayan Yellow Dwarf × West African Tall) and Camwa (Cameroon Red Dwarf × West African Tall).

However, problems developed with these hybrids. So far all tested hybrids proved to be highly susceptible to lethal disease, making them unsuitable for diseased areas. They are also sensitive to drought. Under stress they show

severe wilting symptoms up to total collapse. Since a large part of the Tanzanian coconut belt is drought prone and sub-optimal for coconut cultivation, hybrids cannot be recommended in these areas. Finally hybrids are also heavily attacked by the coreid bug (*Pseudotheraptus wayi*).

With this experience, emphasis has recently been shifted to the improvement of the local East African Tall.

Disease Control Research

Studies on symptomatology and epidemiology of the lethal disease and the search for the causal organism started right from the onset of the programme.

The pathogen was soon identified to be a mycoplasma-like-organism (MLO). The search for the putative insect vector and transmission trials, however, has so far been unsuccessful (Schuiling *et al.*, 1981).

The occurrence and spread of the disease are continuously monitored. Recently, the disease was observed in the island of Mafia which was considered disease-free until 1989.

As there is no cure for the disease the main line of action is the search for disease resistance. The Phase-I observation trials were planted in 1981 with mainly Dwarf varieties and their crosses with West African Tall. In Phase-II, planted in 1982 a number of Dwarf × Tall hybrids were planted. Phases-III and IV (1983 to 1985) consisted of tall and hybrid varieties with EAT as the male parent. Phases-V and VI were planted between 1986 and 1989 mainly with EAT subpopulations of various origins plus a few imported varieties.

The results obtained so far indicate that none of the imported varieties, whether dwarf, tall or hybrid have a high level of resistance to the disease. The only entries that show some promise are sub-populations of the local East African Tall (EAT) which have their origin in the North of Tanzania.

Pest Control Research

In the early stages of the project pest control research concentrated on the study and control of the rhinoceros beetle (*Oryctes monoceros*). Biological control with *Baculovirus oryctes* was successful in the laboratory, but field release did not result in a satisfactory reduction of the population (Seguni and Lohr, 1989). A closer look at the problem revealed that whilst damage is widespread, the economic losses in terms of yield reduction are in fact very low. The beetle is a serious threat only to young palms which can be killed by beetle attack. At that stage, however, the beetle can be effectively controlled by regular visual inspection of the palms and pulling the beetle from its feeding channel with a hook and destroying it.

Recently emphasis in pest control work has shifted to the study and control of the coreid bug (*Pseudotheraptus wayi*). The feeding punctures of this pest causes the young nutlets (buttons) to drop. In pure-stand coconut plantations as few as 50 bugs/ha can cause almost total loss of the crop.

Initially, chemical control of the bug was studied. Different chemicals were screened and techniques to determine spraying thresholds were developed. However, from the beginning it was clear that chemical control was only

practical with young palms that could still be reached. Therefore, methods of biological control using the red weaver ant, *Oecophylla longinoda* were investigated.

Various studies on the biology of *Pseudotheraptus wayi* itself as well as of *Oecophylla longinoda* ants suggested that control can be achieved by enhancing *Oecophylla* populations in coconut plantations. Introduction of *Oecophylla* nests from outside colonies did not result in colonies that could be sustained for more than a year.

Farming Systems Research

Farming systems research within NCDP started in 1979 with the following objectives:

1) Describe the major farming systems in the coconut growing areas of Tanzania and understand their mode of operation.
2) Identify problems and constraints that hamper agricultural production.
3) Test and adapt technologies for farmer needs.
4) Provide background information for planners and policy makers.
5) Provide a basis for the setting of research priorities.
6) Train personnel in FSR methodologies.

Socio-economic surveys revealed that the availability of labour and land tenure rights have great influence on farming practices, particularly with respect to the potential for perennial crops, specifically coconuts (Wirth *et al.*, 1988; Diehl and Mwinjaka, 1988). Otherwise most farming systems share the following characteristics:

a) small size of holding;
b) low technical standard of soil conservation;
c) extremely low utilisation of farm inputs and hired labour;
d) lack of capital for investment in farming;
e) high percentage of subsistence production; and
f) integration of perennial and annual food or cash crops.

By economic analysis it was also found that a very extensive, low input way of coconut production in fact gives very high returns. It is therefore often practiced by farmers with labour constraints at least on that part of their land that is not intercropped with annual food crops.

On-farm experiments have been established:

i) to develop intercropping systems with annual food crops and other perennials in both old or newly planted coconuts, so that farmers can optimise the use of limited resources according to their preferences; and

ii) to compare the performance of newly developed planting material with the local East African Tall (EAT) under farmers' conditions.

CONCLUSION

Coconut research in Tanzania has undergone some distinct changes. In the area of genetic improvement for yield and disease resistance, the transfer of technology by introducing varieties considered successful elsewhere was a

failure. More attention is now given to develop local solutions on the basis of selected and improved local East African Tall material. In the field of agronomy the more fundamental but narrow questions of crop management like plant nutrition, spacing and weeding are now replaced by questions that take a wider look at the farmers' production system. Research is now more geared towards specific problems of small scale agriculture and also includes other crops. With this approach, the results obtained may be more easily applied on farmers' fields. They are however, also more location specific.

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ECONOMICS OF COCONUT CULTIVATION IN BIHAR

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In Bihar, coconut is a small holders crop and mostly the old plantations are in the homestead gardens. The Purnea and Saharsa region of Kosi division under Kosi Command Development Authority account for nearly 65 per cent of the total area under coconut in Bihar. The area under coconut as per the 1990–91 estimate was 9000 ha out of which 5,475 ha is under young non-bearing palms and about 3,525 ha is under adult and bearing palms which produce about 33 million nuts per year. The potential area estimated to be available for coconut culture in the state is about 50,000 ha (Thampan, 1988).

When Coconut Development Board tried to introduce this crop on scientific and commercial lines in the state there were relevant queries at the farmers' level about the economics of this new crop in Bihar. Therefore, this study was conducted to find out the economics of growing coconut in Bihar.

The output-input data were collected and analysed in the two situations, namely, (1) from the farmers' field (survey year 1990–91); and (2) from the Demonstration-cum-Seed Production Farm (DSP), Singheshwar (Madhepura), Coconut Development Board, Government of India.

In the first situation output-input data were collected with the help of a specially prepared schedule of enquiry by survey method from 198 sampled coconut growers of Kosi region. A simple random sampling procedure was used to select the sample unit of coconut growers. While estimating the average yield per palm per year the stabilised bearing palms have only been taken into account. As the area under coconut in the homestead gardens and small sporadic orchards were found to be very small during the survey of the sampled farms, for the purpose of computing data, 175 palms per ha were considered standard equivalent to one ha garden land.

In the second situation input data were gathered from the relevant records of Demonstration-cum-Seed Production Farm for coconut, Singheshwar (Madhepura) from the inception to March 1991 (where a recommended

package of practices is followed and the farm is managed by trained technical persons). Based on the yield data available from the coconut gardens adjacent to DSP farm, the yield and economic life of coconut has been assumed to be 95 nuts and 60 years respectively.

The estimated costs and returns under farmers and DSP farm situations are given in Table 101.1. The analysis revealed that on an average, it takes 15 years in farmers' situation and 12 years in DSP farm situation to recover initial investment cost and to get net returns. It was found that the average yield at the farmers' fields was 65 nuts per palm per year and the sale price at the farm's gate during the survey year was Rs. 300 per 100 nuts. Yield at DSP farm, Madhepura was estimated to be 95 nuts per palm per year. The economic life of coconut palm was estimated to be 50 years in the farmers' field situation.

Table 101.1: Cost of production and net return for coconut cultivars grown in DSP farm Madhepura and farmers' fields in Bihar

Sl. No.	*Items of expenditure*	*Value in Rs./ha*	
		Farmers' fields	*DSP farm*
1.	Wages	1360	3400
2.	Cost of seedlings including 10 per cent gap filling	1925	1925
3.	Cost of plant protection chemicals	50	375
4.	Cost of manures and fertilisers	600	1800
5.	Charges for energy	100	453
6.	Cost of shade materials	–	350
7.	Contingencies	100	450
8.	Total direct cost (1–7)	4135	8753
9.	Annuity value	3362	10853
10.	Gross cost (8 + 9)	7497	19606
11.	Net return from intercrops and by-products	500	2500
12.	Net cost (10–11)	6997	17106
13.	Average yield (nut/palm)	61	95
14.	Average yield (nut/ha)	10675	16625
15.	Cost of production (Rs./nut)	0.65	1.03
16.	Net profit (Rs./ha)	25028	32769

The cost of cultivation per ha and net return based on the analysis of output-input data collected from farmers' fields worked out to be Rs. 6,997 and Rs. 25,028, respectively. The cost of production per nut in farmers situation is calculated as 65 paise. The cost of production and net profit per ha computed for DSP farm for coconut (Madhepura) are Rs. 17,106 and Rs. 32,769, respectively. The cost of production per nut is estimated to be Rs. 1.03.

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RECOMMENDATIONS OF INTERNATIONAL SYMPOSIUM ON COCONUT RESEARCH AND DEVELOPMENT-II

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Genetic Resources

1. An international network of coconut genetic resources may be established with the support of International Board for Plant Genetic Resources.

2. The existing gaps in each country's collection may be identified and action initiated to enrich the collection.

3. The rapid replanting of senile gardens with high yielding varieties and hybrids is resulting in gene erosion. The extent of gene erosion by this process is to be assessed and priorities for new collections of germplasm are to be fixed to conserve the local genotypes.

4. Protocols for use of embryo culture technique in germplasm collection, storage, transport and regeneration should be perfected. Only healthy planting material is to be transferred from the disease affected areas to the disease free areas. The available indexing procedure needs to be fully evaluated and carefully used to meet this requirement. The possibility of collecting disease tolerant/resistant accessions from within the disease prevalent areas may be explored.

5. Specialised training in leading laboratories should include isozyme analysis, DNA-finger-printing and embryo and tissue culture.

6. Systematic documentation of the country's germplasm and compiling and publishing an International Directory on Coconut Genetic Resources may be undertaken.

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Crop Improvement

1. Priorities in breeding programmes identified include breeding for yield stability, identification of biochemical characters influencing yield and their exploitation, identifying genetic markers for high yielding genotypes at the seedling stage, incorporating dwarfing genes in high yielding genotypes, breeding for tolerance to drought, major diseases and pests and tailoring varieties for stabilised yield under low input requirements.

Biotechnology and Physiology

1. There is uncertainty in obtaining reproducible results in coconut tissue culture. Physiological and biochemical characterisation for possible genotypic variation needs to be investigated to overcome this problem.

2. *In vitro* approaches should be actively pursued and furthered to include protoplasts and different aspects of cytoplasmic sterility.

3. The available information on isolation of growth factors from coconut water indicates that such basic studies could be made for better control of *in vitro* embryogenesis.

4. Biochemical and biophysical markers for high yield and stress tolerance need to be identified.

Crop Management and Farming Systems

1. It has been established that potassium plays a significant role in coconut production. Interaction of potassium with magnesium and effect of magnesium and nitrogen in relation to productivity needs detailed investigation.

2. Use of organic manures should receive priorities in scheduling nutrient input in coconut. Role of vermiculture also needs to be studied further.

3. Systematic field trials need to be undertaken to study the effect of drip irrigation and related problem and use of sea water for irrigation of coconut palms.

4. Cropping/farming systems to suit different agroclimatic conditions and to obtain maximum return from unit area need to be developed.

5. Fertiliser schedules for cropping systems may be developed considering the system model as a unit rather than following crop specific fertiliser schedules.

6. Emphasis should be given on nutrient recyclying in the system and system environment in scheduling and rescheduling fertiliser inputs.

7. Nutritional input requirements in relation to drought needs detailed investigation.

8. The model developed in Sri Lanka for differential fertiliser recommendation based on soil and plant nutrient levels needs to be refined incorporating variability of nutrient relations to yield.

9. Sound fertiliser prescription schedule for different age group cum productivity levels of coconut palm need to be developed.

10. A strategy for fertilisation in coconut need to be developed in view of the available information on the residual effect of phosphorus and possibility of withholding phosphorus application for few years in coconut garden.

11. To counter the undesirable effects of long term application of acid forming fertilisers in coconut, a sound liming policy will have to be developed.

Pest Management

1. Integrated pest control measures with emphasis on biocontrol programmes must be developed with a view to reducing the use of harmful chemical pesticides.

2. Collaborative programmes involving exchange of biocontrol agents with other countries may be thought of.

3. Integrated pest management models for field application for various pests of coconut have to be evolved.

4. The possibility of introducing newer pests through exchange of planting materials needs serious consideration and constant vigil will have to be maintained through monitoring and surveillance to prevent such entry.

5. Strict quarantine measures are to be enforced to prevent the entry of key pests like red ring nematode, *Promecotheca* etc.

6. Economic threshold levels for major pests need to be worked out.

7. Computerised data base for programming for scheduling an operation against the pest may be established.

8. Prediction of pest activity with sequential sampling and forecasting system for a pest emergence in relation to meteorological factors may be developed.

9. Pest out-break will have to be predicted utilising the weather parameters and work out population dynamics.

10. Residue toxicity in the end product have to be determined on a priority basis wherever pesticides are used.

11. In view of the prevalence of coreid bug throughout Kerala State (India) detailed studies will have to be undertaken to assess the damage potential.

Disease Management

1. Evolving coconut varieties resistant to *Cadang-Cadang*, Lethal yellowing and Root (wilt) disease seem to be the only permanent solution to these diseases.

2. Suitable resistant/tolerant exotic cultivars need to be introduced to each coconut growing countries with the cooperation of International Board for Plant Genetic Resources.

3. Though MLO etiology has been confirmed in root (wilt) disease, work is needed to evolve suitable remedial measures. The progress made in containing the root (wilt) disease and management of the disease to obtain economic yield level need to be popularised.

4. The available technique on indexing viroids and DNA probe technique for MLO detection should be adopted in coconut growing countries having similar problems.

5. International collaboration may be thought of for both training and popularisation of indexing and DNA probe technique in all the coconut growing countries.

Harvest and Post-harvest Technology

1. Work on high value product development and diversification of coconut product need to be intensified.

2. Efficient and economically viable technique for bottling tender and matured nut water with acceptable quality and taste need to be standardised.

3. Collaborative research project for efficient utilisation of coconut timber, especially of those trees which are removed in the disease affected areas, need to be undertaken.

Economics, Developmental Programmes and Transfer of Technology

1. Appropriate technologies to meet the situation existing in the field are to be formulated.

2. Coconut Development Board in India should have close link with the Research Institutes for better implementation of the developmental programmes.

3. A programme for replanting of root (wilt) disease affected areas in Kerala and Tamil Nadu in India is to be formulated giving adequate subsidy to the coconut growers.

4. Rationalisation of input and management in relation to the price fluctuation in coconut is to be looked into.

5. Efforts are to be made to bring changes in the farmers to adopt improved technologies developed in the country.

6. Labour saving efficient devices are to be developed for harvesting coconut.

Synthesis

1. There is need for arranging subject-wise meeting of coconut research workers for better interaction.

2. To have a better understanding of the coconut germplasm available in different places, the Scientists working on coconut germplasm may be provided opportunities to visit the germplasm holdings in different countries. This will also enable import of all accessions which are required for specific purposes, after the Scientists acquiring first-hand knowledge.

3. To impart necessary training to the coconut workers in a given country in germplasm holding, it was suggested that a team of leaders may be identified and sent to different countries instead of giving the training at one place.

4. It was emphasized that it is absolutely safe to import germplasm material provided specific quarantine regulations adopted for establishing the World Coconut Germplasm Centre are followed *in toto*. Any apprehensions in this regard should be cleared in the field on the basis of expert opinion and not based on views expressed with preconceived presumptions.

5. Priorities in the breeding programme need to be refixed in each country's programme. Introduction of dwarfing genes in the promising genotypes and incorporation of resistant genes should receive top priority.

6. The possibility of increasing harvest index through judicious selection, hybridisation etc. needs to be explored.

7. The possibility of identifying a large number of general combiners for use as parents for shortening the testing period needs to be explored.

8. Reliable technique for screening for drought resistance/tolerance needs to be standardised.

9. There should be constant dialogue between the laboratories engaged in tissue culture for overcoming the present stalemate and inconsistent results. It was also felt that there should be more open discussion and exposure on the methodologies employed to save time.

10. In cropping system models, intensive studies on rooting pattern, canopy architecture and nutrient recycling should be included in future studies.

11. It was generally felt that most profitable crop combinations developed in the research institutions may not be the farmers' choice. Therefore, it was suggested that initial identification of farmers' choice and later refining the practices of the farmers' will be of more use and will gain acceptance in the transfer of technology programmes.

12. In the pest management practices of cropping system models there is a need to rationalise the pesticide use. Instead of crop-specific pest control, it should be model specific pesticide recommendation.

13. The approach hitherto adopted for containing the root (wilt) disease can also be extended to control the spread of other diseases. The possibility of identification of tolerant types through biochemical tests may be developed.

14. Post-harvest technology and marketing often received less attention in the national programme. They should be given due importance in the research programmes. Transfer of post-harvest technology may be organised by international organisations like Buro Trop and APCC.

15. Research on developing a small dehusking machine and small scale processing plants for oil extraction needs to be intensified.

16. Sectorial studies on energy requirement, environment and safety practices followed in the processing industries need to be studied and rationalised.

17. To increase the production of coconuts, judicious fertiliser application is the immediate priority. A change in farmers' approach is needed to overcome the low productivity.

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