1.0 Introduction

Coconut (*Cocos nucifera* L.) is one of the important perennial crops belonging to Palmae. In India this crop is grown in a wide range of agro-climatic conditions. Coconut is grown in around 38 countries from Asia, Australia, Africa and South America. Major producers of coconut include India, Sri Lanka, Indonesia, Malaysia and Philippines. Coconut is an economically important plantation crop, as almost all parts of the palm are commercially exploited and more than ten million Indian farmers are dependent on this crop for earning a sustainable livelihood. Major products of coconut are copra, oil, coir and tender nuts. Manufacturing of coir and coir products is one of the major agro based cottage industry in the country which supports more than half a million people belonging to economically weaker sections of the rural population. About 80 per cent of the workers in the coir industry are women. Apart from these, leaves and stem are also used for various purposes.

2.0 Area and production

Coconut is a resource poor farmers' plantation and is mainly grown in home-stead gardens. Globally, coconut is grown on 11.5 million hectares with a production of 53,600 million nuts of which 89% is from Asia and Pacific countries. The Latin American countries and Caribbean Islands account for 5% and African countries for 3% of global production. Indonesia is the major coconut producing country, accounting for 26% of the global production, followed by Philippines (23%), India (16%) and Sri Lanka (5%). Areawise, coconut is grown on 3.71 million hectares in Indonesia, 3.16 million hectares in Philippines, 1.78 million hectares in India and 0.49 million hectares in Sri Lanka. Other countries where coconut is grown in small areas include Mexico, Vietnam, Papua New Guinea, Fiji, Malaysia, Solomon Islands, Thailand, Vanuatu, Western Samoa, Palau. Apart from these, coconut is also grown in small areas in some other countries in Africa, America, Asia and in Pacific countries. Globally, coconut is the 7th most important source of vegetable oil. Since the coconut oil is rich in lauric acid (45-50%), it is the major source of lauric oil for industrial purposes. Philippines and Indonesia are the major exporters of coconut oil and coconut meal (copra) accounting for around 80% of global exports.

In India, the area under coconut is close to 1.79 million hectares with a production of 12,252 million nuts and productivity of 6892 nuts ha^{-1}. The four southern states viz., Kerala, Tamil Nadu, Karnataka and Andhra Pradesh account for 90% of total area and production. Kerala tops the list with 50% (0.9 million ha) of area and 42

% (5I67 million nuts) of production in India. Area wise Karnataka is second with 0.32 million ha (18%) followed by Tamil Nadu 0.3 million ha (17%) and Andhra Pradesh 0.1 million ha (5.7%). Coconut is also grown in Assam, Goa, Maharashtra, Orissa, Tripura, West Bengal, Andaman and Nicobar Islands, Lakshadweep and Pondicherry. Productionwise, Tamil Nadu is second with 3222 million nuts (26.3% of national production) followed by Karnataka (13.6%), Andhra Pradesh (8.6%), West Bengal (2.7%) and Assam (1.2%). Even though national productivity is only 6892 nuts ha-1, wide variation exists in productivity among the states. Highest productivity is reported from Maharashtra (15,000 nuts ha^{-1}), followed by West Bengal (13,000), Tamil Nadu (10,500), Andhra Pradesh (10,300), Kerala (5747) and Karnataka (5210).

3.0 Composition and uses

Coconut is mainly consumed as raw nuts, copra and oil. In India, only 10% of the national production is used for tender nut water. Raw nuts (50% of production) are mainly used for domestic purposes and only 5% of raw nuts are used for industrial purposes. The industrial products include desiccated coconut, cream, milk powder, vinegar, nata-de-coco etc. Of the national production of copra, 35 to 40% is used for milling or for edible purpose. From milling copra, 40% goes towards the production of coconut oil, 46% for toiletery (soap) and 14% for other industrial purposes. Coconut oil is used in industries like soaps, textile dyes, pharmaceuticals, cosmetics etc.

3.1. Coconut components

Coconut palm gives a variety of nut-based products, which include epicarp (outer husk), endocarp (shell), endosperm (kernel, copra, oil) and liquid endosperm (coconut water). The first two are used for the production of a variety of commercial products. The later three possess rich nutritional and medicinal values and are used in a wide range of industries for commercial production of value added products.

3.1.1 Coconut water

Water from tender coconut (7-8 months old) is a refreshing drink, effective in cases of gastroenteritis, diarrhoea, vomitting and in preventing dehydration. It is also a useful substitute for saline glucose in intravenous infusions. Tender nut water is a rich source of B-group vitamins, minerals, sugars etc. On the contiary, the nut water from mature coconuts is less nutritious (Table 1). However, the water obtained from mature nuts form the main source of products like nata-de-coco (a gelatinous dessert), soft drink, coconut vinegar, food yeast, edible mushroom etc. In addition, coconut water can also be used as a rubber coagulant to obtain good quality rubber.

Table 1: Composition of tender and mature coconut water

Composition	Tender coconut water	Mature coconut water
Total solids (%)	6.5	5.4
Total sugars (%)	5.7	2.0
Reducing sugars (%)	4.4	0.2
Minerals (%)	0.6	0.5
Protein (%)	0.0 1	0.1
Fat(%)	0.01	O.1
Acidity (mg per cent)	120.0	60.0
Potassium (mg%)	290.0	247.0
Sodium (mg%)	42.0	48.0
Calcium (mg%)	44.0	40.0
Magnesium (mg%)	10.0	15.0
Phosphorus (mg %)	9.2	6.3
Iron (µg%)	104.0	79.0
Copper (µg%)	26.0	26.0
PH	4.5	5.2

(Rajagopal and Ramadasan, 1999)

3.1.2. Coconut husk

The husk usually forms 35 to 45% of the weight of the whole ripe (12 months old) nut. When the nuts mature, the quantity of the fibre in the husk does not decrease. The thickness of thin-husked cultivars ranged from 2.5 to 3.0 cm, while that of thick-husked cultivars from 4.0 to 5.0 cm. Talls and hybrids in general recorded higher husk content than the dwarfs (Kasturi Bai *et al.*, 1996 a & b). Coir fibre and coir pith are the products of importance derived from coconut husk.

3.1.3. Coir fibre

The husk of an average coconut weighs about 0.4 kg, of which 30% constitutes coir fibre and the balance 70% is pith and outer skin. There are two types of fibres viz., white and brown fibre. Lignin and cellulose are the major constituents of pure fibre. Extraction of fibre from husk involves a complex process of natural, mechanical or chemical methods of retting.

3.1.4 Coir pith

Coir pith constitutes nearly 70% of the husk. Pith, generally mixed with short fibres, contains lignin, cellulose and hemicellulose as major constituents (Table 2). Coir pith or dust, after proper composting, can be used for conservation of soil moisture. Coir pith is used as a soil conditioner, surface mulch and rooting medium. Pith can also be used for biogas generation and also power gas in industrial engines. Many commercial products like hard-boards, insulators, expansion joint fittings can be prepared from coir pith.

Table 2: Composition of coir pith (percentage)

Composition	Fine coir dust	Coarse coir dust	Husk
Moisture	15.77	20.39	—
Organic matter	86.87	96.43	96.5
Ash	13.13	3.57	3.5
Nitrogen	1.00	0.39	0.26
Potash	0.39	0.33	0.31
Lignin	37.71	43.65	45.45
Pentosan	11.95	13.10	19.15
Pentosan: lignin	0.32	0.30	0.42
Sand	9.29	0.87	0.36
P_2O_5	0.07	0.06	0.08
Lime	0.79	0.87	0.94

(Rajagopal and Ramadasan, 1999)

3.1.5. Coconut shell

Coconut shell, the endocarp of coconut is another important commercial product, with major use as a fuel. Dwarf cultivars have less shell content than the tall cultivars and hybrids. In general, each nut contained shell of around 140g (Kasturi Bai *et al.*, 1996a and 1996b). Shell is used to manufacture various domestic utensils, curios, fancy items etc. The major commercial utilization of shell includes charcoal, activated carbon and shell powder. Cellulose, followed by lignin and pentosan are the major constituents of shell. Charcoal is manufactured by different methods and is used as colouring matter, deodorizer and in laundries and smitheries. The commercial value of shell charcoal lies in its use as the primary raw material for the production of activated carbon.

Activated carbon is extensively used as agents for purifying, refining and bleaching of volatile oils and chemical solutions. They are also in demand as adsorbent of gasses. Coconut shell flour is another important product used in the production of glues in plywood and plastic mould industries, and also as bunker oil in boiler operations. It is also used as a filler in the manufacture of agarbathis and mosquito repellents.

3.1.6 Wet meat

The kernel of seven to eight-month-old nuts is very soft with maximum contents of protein and sugar. Kernel is consumed either as such or along with the sweet nut water. As the nut matures the quality gradually decreases. The ripe kernel derived from 11 to 12 months old nuts contained 5.5% protein, 44% fat, 10% carbohydrates, 3% crude fibre and 2.1% ash (Naresh Kumar, 1998). Fresh kernel is consumed in the grated form and in the form of milk or cream obtained by squeezing the gratings with or without addition of water. Processed forms of kernel and milk find applications in the food industry.

3.1.7 Coconut milk

Coconut milk is an emulsion of oil in water along with the soluble components of the meat. This is mainly used for culinary purposes and is used extensively in a wide range of preparations in the food industry. The milk has a high percentage of protein (2,8 to 4.1%). Preserved forms of milk such as canned cream milk with a fat content of 40% and dehydrated whole milk with a fat content of 12.5% are available. Coconut skim milk is a good source of quality protein suitable for the preparation of many useful allied food products or as supplemental protein source, especially in places where animal protein is deficient. During the processing of coconut cream and other related products, the fibrous residue obtained after expelling the milk is dried and powdered to yield coconut flour, which is nutritionally comparable to most of the common seed flours. The composition of coconut milk includes moisture - 52.0%, oil -38.0%, protein - 3.5%, ash - 0.9%, total solids (non fat) - 9.0%, pH - 6.0.

Coconut jam is prepared from coconut skim milk by adding sugar and glucose. It is an ideal spread for bread.

3.1.8 Desiccated coconut

Desiccated coconut (DC) is the white kernel, comminuted and desiccated to a moisture content of less than 3%, with high nutritional value. The common grades of DC have a particle size of less than 5 mm. It is an important commercial product with a wide demand in confectionery and other industries, like chocolate and liquorice. The composition of desiccated coconut includes moisture (2.0%), fat (67.5%), carbohydrates (5.9%), protein (5.9%), ash (9.3%), fibre (2.4%), pentosans (8.9%) (Ruehrmund, 1959).

3.1.9 Copra

The dried coconut endosperm is called copra. With oil contents of 65% to 70%, copra is the richest source of fat. In general, copra content in each nut varied from 140g to 300g(Kasturi Bai *et al.*, 1996). There are two types of copra, edible copra and milling copra. Edible copra is available in two forms, ball copra (fully mature, whole, unsplit nuts) and cup copra (mature, split nuts). The processing of fully mature coconuts into copra for milling involves dehusking, splitting the nuts into halves and drying the split halves to a final moisture content of 5 to 6%. Different methods of dehusking and drying are-adopted for obtaining milling copra.

3.1.10. Coconut oil

Coconut oil is extracted from milling copra. In general, oil yield varies from 1.5 t ha^{-1} to 3 t ha^{-1}. The oil is referred to as lauric oil in the world market and is rich in saturated fatty acids, mainly lauric and myristic acids. When compared with other vegetable oils, coconut oil was low in unsaturated and polyunsaturated acids, particularly linoleic acid (Naresh Kumar, 1998; Naresh Kumar *et al.*, 2000a). Cultivar varied in their fatty acid composition. The saponification value of coconut oil is the highest, while iodine value is the lowest (Table 3). On account of its low iodine value, it is classified as non-drying oil. Coconut oil contains the largest percentage of glycerol compared with other oils and fats. The quality of the oil depends on the quality of copra, storage conditions of milling copra and storage conditions of oil. Coconut oil obtained from coconut milk is called virgin coconut oil. The oil is considered superior for use as edible oil, hair oil and baby oil because of its pleasing aroma and purity. Because of its low free fatty acid (FFA) content, this oil has a long shelf life.

Table 3: Physical characteristics of coconut oil

Composition	Physical characteristics	Composition	Physical characteristics
Specific gravity(25°C)	0.918	Saponification value	251.0-18.0
Viscosity (25°C)	1.4530-1.4560	Polensk value	15.0-18.0
Iodine number	8.0-9.6	Melting point (°C)	23-26
Titre of fatty acids	20.4-23.5		

(Jamieson, 1943)

3.1.11 Coconut cake

After the extraction of coconut oil from copra, the crushed copra (32 to 40% of the copra) is called cake. The output of cake and its final composition depends upon the extraction methods employed and is valuable as cattle feed rich in fat. The composition of coconut cake (expeller cake) includes moisture (7.0%), fat (6.7%), protein (21.2%), nitrogen-free extract (47.4%), fibre (11.2%), minerals (6.5%).

3.1.12 Miscellaneous product

Coconut toddy: Tapping of toddy is an important rural industry in states like Kerala and Goa and is an excellent beverage. It is a rich source of sugars (15-16%) and contains fair amounts of vitamins B_1, B_2, A and C. Seventeen amino acids are reported to be present in fresh coconut toddy, glutamic acid being the major one followed by threonine and aspertic acid.

Handicrafts: Manufacturing of coconut based handicrafts is a cottage industry. Coconut shell, fibre and wood are mainly used to manufacture handicrafts which range from utility articles to show pieces. Coconut wood is also used to manufacture furniture, wall panels etc.

Coconut leaf : Plaited coconut leaves are used as a thatching material in rural areas. The leaflets of the spindle leaf is used for decoration and to make head dress in many folk arts. The midribs of the leaflets are used to make brooms and handicrafts.

Coconut jaggery: Fresh toddy when boiled to 118-120°C and allowed to cool solidities. The solid mass is known as coconut jaggery. Calcium and phosphorus are the important minerals contained in coconut jaggery.

3.2 Quality aspects during storage

The quality of produce is influenced by the quality of processing and storage, during which chances of microbial attack are high. Therefore, it is essential to follow the standard processing and storage technologies in order to obtain a good quality end product.

3.2.1 Processing and storage of copra

The quality of milling copra depends on the drying process, which ultimately determines the quality of oil and the residual cake. The factors that influence the quality of copra are moisture content, colour and cleanliness, microbial load, rubberiness, case hardening and charring. Based on these, the copra is graded for milling purposes. Quality of copra is assessed based on oil percentage, acid value, FFA, peroxide value and iodine value of the oil extracted. Method of drying will not deteriorate the quality of copra (Table 4). The values are within the accepted standard specified for coconut oil.

Table 4: Effect of drying methods on the quality of coconut oil

Treatment	Acid value	Free fatty acid(%)	Peroxide value	Iodine value	Oil(%)
Sun drying (cement floor)	0.934	0.509	1.50	11.15	67.1
Sun drying (mud floor)	0.812	0.544	1.42	9.26	68.2
Solar dryer	0.893	0.739	1.09	7.36	69.0
Electric dryer	0.691	0.425	1.33	8.78	66.9
CPCR1 small holder's dryer	0.785	0.644	0.88	9.64	68.1

(Rajagopal and Ramadasan, 1999)

Copra quality varies with the type of storage condition viz., air tight tin boxes and polybags (black and white) and fumigated by different fumigants like biogas, neem leaf gas, SO_2, CO_2, and nitrogen. Storage in biogas, neem leaf gas and SO_2 environments, prolonged the keeping quality upto six months.

3.2.2 Storage of coconut oil

Rancidity in coconut oil: Unrefined coconut oil is susceptible to rancidity due to the variation of a proportion of FFA. This is accelerated by the presence of initial moisture and by the action of air, light and fat splitting enzymes. Rancid oil has a bad smell that results from the accumulation of decomposed products of oxidation reactions. Most of the free acids accompanying odour and taste originate in the copra itself. Oil derived from damaged copra favours the growth and multiplication of microorganisms. Spoiled copra yield poor quality oil with low iodine value, higher FFA and higher peroxide value. Fumigation with a mixture of carbon dioxide and ethylene oxide (99:1) proved effective against insect pest of copra (Lever, 1979). Proper packing material is also an important factor in maintaining the quality of oil. Oil treated with citric acid, common salt, tamarind or sodium metabisulphite possessed longer shelf life as indicated by lower acid value and FFA %. Viscosity and specific gravity did not vary with storage condition. Oil kept in either plastic cans, brown bottles or white bottles retained the quality for 180 days. Hence, it is important that for obtaining best quality oil, storage conditions of copra and oil should be maintained at optimum conditions. Preservatives/anti oxidants like sodium metabisulphite (5000 ppm), citric acid (500 ppm). benzoic acid (500 ppm), common salt (1%), tamarind (2%), clove (0.5%), pepper powder (0.1%), butylated hydroxy toluene (BHT 100 ppm) and containers like white plastic can, aluminium tins, brown bottle, white bottle and clay pots prolonged shelf life of oil. In addition treatment with biogas, neem leaf gas, SO_2 and CO_2 gases were also effective (Rajagopal and Ramadasan, 1999).

4.0 History, origin and distribution

Martius (1850) and Cook (1901) considered the West coast of Central America as the centre of origin of coconut. On the other hand, de Candolle (1886) considered coconut to be of Asiatic origin. There are a lot of controversies pertaining to the origin of coconut. Whichever the place of origin of coconut, it is presently disseminated throughout the tropics.

Coconut fossils are discovered in India, New Zealand, etc. Since coconut has a thick husk, which allows it to float on water for long distances, it could have been dessiminated through seawater ensuring wide spread. Apart from this, migration of people from one place to other even as early as 1000 BC could also have caused its dessimination to wider areas. During 16th century, European explorers had taken coconuts to West Africa, the Carribean and America.

5.0 Botany

Coconut is a monocotyledonous palm belonging to the family Palmae. It has only a single species *'nucifera'* in the genus *Cocos*, with the chromosome number of 2n=32. The synonym for *Cocos nucifera L.* is *Cocos nana*. The palms have a robust, cylindrical, erect stem with a single growing point from where the successive leaf production takes place producing a terminal crown. Palms can grow upto 20-30 metres in tall cultivars and 10-15 metres in dwarf cultivars. Leaves are pinnate and, are called 'fronds', which are generally 4 to 6 metres in length and 1.5 to 2 metres in width. Leaves have a strong rachis to which the leaflets are attached on both sides. Around 400 leaflets are present in a frond. Leaflets are linear- lanceolate. Canopy of coconut ('crown') consists of 28 to 36 fronds at the tip of the stem arranged in circular or ovular or semi circular shapes. Generally one frond is added to the canopy every month and one frond is abscessed from the stem. The inflorescence of coconut emerges from the axil of each frond every month. Inflorescence is protandrous. Unopened inflorescence looks like a spadix within a spathe. It takes 44 months from inflorescence primordial initiation to nut maturity. In a crown one can see all stages of inflorescence. In the 'spadix', the pistillate flowers and staminate flowers are attached to spike like rachillae. As many as 200 to 300 male flowers and only one or a few female flowers are attached to these rachillae. Male flowers are found 1 to 3 together, sessile and pale yellow in colour with three small sepals, three larger petals and six stamens in two whorls. They have a rudimentary pistil. Female flower is solitary, larger than male flowers in size, globose in bud, enveloped by two small scaly bracteoles, three sepals and three petals, ovoid at anthesis, sub-oricularm sub-equal, persistant and enlarging in fruit, pistil with large trilocular ovary, three sessile triangular stigmas and three nectaries near the ovary base. Within two to three weeks after the spadix opens, pollination takes place. Coconut is mainly a cross pollinated crop. But the 'dwarf' type coconuts are predominantly self-pollinated. It takes 12 months from pollination for a pistillate flower to develop in to mature nut. Fruit is a globose, ovoid or ellipsoidal fibrous drupe. Tender coconuts are generally 7 to 8 months old. Fruit (nut) has an outer greenish pericarp, fibrous middle mesocarp and hard endocarp (shell). Inside the endocarp, the fruit consists mainly of solid, white endosperm (copra), liquid endosperm (nut water) and a single embryo. Coconut has an adventitious root system, which goes to the depth of only 1.5 to 2 metres but with a horizontal spread of 4 to 5 metres. Decayed roots are replaced regularly due to the formation of new roots.

It takes 44 months from inflorescence initiation to nut maturity. Generally, the nut matures 12 months after fertilization. Mature nuts can germinate soon after harvest. The embryo enlarges and the apical part emerges from the shell. The cotyledon develops into haustorium which supports the growth of seedlings by absorbing nutrients from solid endosperm and nut water. Shoot emerges out of husk in about 2 to 3 months after sowing. After another 1 to 1½ months time, the first leaf starts unfolding. Leaves, which are initially formed, remain unsplit until seedling has 8 to 10 leaves. The subsequent leaves split to give a pinnate shape. Usually seedlings are field planted a year after germination. Coconut is propagated only through nuts (seed nuts).

Palms remain juvenile for the next three to four years and then the first inflorescence emerges from the leaf axil. Generally, Dwarfs produce inflorescence earlier than Talls, which take 5 to 7 years. Hybrids come to flowering in 3 to 5 years after germination. Tall type palms can survive for 60 years and can give economically profitable yields for 45 years. Generally, yield during initial years after flowering is not stable and palms attain stable yield only 15 to 17 years after germination. Some palms also have the tendency to exhibit partial alternate bearing phenomenon, where yields will be very low in one year and very high the following year.

6.0 Classification and cultivars

The coconut palm, belongs to the monotypic genus with no known wild or domesticated relatives. However, the present day population of this palm presents a wide range of variability and a number of workers have attempted a classification of the various forms of coconut. A widely accepted classification puts cultivars into two groups - Talls and Dwarfs, on the basis of a few important characters like stature, growth characteristics of the palm and precocious nature of flowering, and nut and copra characters. In addition, certain variants have also been observed. One is the seedless coconut or male coconut tree, which produces only male flowers and another is spikeless coconut palm or spicata, wherein the inflorescence does not carry spikelets (the male and female flowers are borne directly on the primary spike). In coconut germplasm more than 300 types of cultivars exist. Apart from these, there exists a lot of natural variations, which are present in one or a few palms. Performance of some promising cultivars is given in Table 5.

Table 5: Performance of some promising cultivars

Cultivars	Yield (nuts palm^{-1} year^{-1})	Copra content (g nut^{-1})	Oil content (percent)
'East coast Tall' (ECT)	86	100.0	63.0
'Andaman Ordinary' (AO)	94	160.2	66.0
'Gangabandam' (GB)	60	148.0	68.0
'Kappadam'	90	283.5	67.0
'Fiji Tall'	106	199.1	65.2
'Laccadive Micro' (LM)	210	117.0	75.0
'San Ramon'	64	349.6	68.0
'Straits Settlements Green' (SSG)	108	186.1	67.0
'Chowghat Orange Dwarf' (COD)	56	158.0	66.0
'Chowghat Green Dwarf' (CGD)	75	60.0	66.0
'Malayan Green Dwarf' (MGD)	80	167.0	68.0
'Malayan Yellow Dwarf' (MYD)	91	143.0	66.0
'Malayan Orange Dwarf' (MOD)	88	164.0	67.0

7.0 Genetics and breeding

Coconut is a perennial crop, which takes at least 2 years to produce the F_1 generation seedlings and 7 to 8 for the F_2 generation seedlings. Each female inflorescence has to be pollinated to obtain the hybrid nuts, which can yield none to 20 nuts. Thus to get a large population of seedlings is also difficult. The problem is compounded by the fact that nut-setting percentage is very low particularly in hybridized inflorescences. Added to this, a low germination percentage in coconut warrants to make hybridization in a large number of inflorescence to get the desired F_1 population.

7.1 Cytology

Santos was the first to study the cytology of *C. nucifera* in detail. He reported that the chromosome number of coconut as n = 16. In India, the chromosome number (n = 16) was reported in several publications (Janaki Ammal, 1945; Venkatasubbayya, 1945; Ninan *et al.*, 1960; Abraham *et al.*, 1961). These studies and those of several others (Nambiar and Swaminathan, 1960; Swaminathan and Nambiar, 1961; Raveendranath and Ninan, 1973) have confirmed the somatic chromosome number of 2n = 32.

7.1.1 Karyomorphology

A comparison of the gross features of chromosome complements of Tall (WCT) and Dwarf cultivars reveal certain interesting facts. Raveendranath and Ninan (1973) observed that secondary constrictions were present on the long arm of chromosome VI in Talls and long arm of chromosome III in Dwarfs. However, these differences were not consistent and additional satellites were observed on chromosome II (long arm), chromosome I (short arm), short arm of chromosome XII (Raveendranath and Ninan, 1973), long arm of chromosome XII (Thankamma Pillai *et al.*, 1983) and IX (Nambiar and Swaminathan, 1960) in Talls and in chromosome VI (long arm) in Dwarfs (Raveendranath and Ninan, 1973). Nambiar and Swaminathan (1960) observed that in Talls, majority of the chromosomes had submedian centromeres, with two pairs of chromosomes much longer and three pairs relatively short. On the other hand, Raveendranath and Ninan (1973) observed that Talls as well as Dwarfs had a preponderance of chromosomes with median centromeres, with four submedian chromosomes (II, IV, VII, XIV) in 'WCT', three (chromosome II, VII, XII) in 'Dwarf Orange' (DO) and only one (chromosome II) in 'Dwarf Green' (DG). In higher plants, karyotypic evolution has been from complete symmetry to asymmetry (Stebbins, 1950). From this angle, 'WCT's show a more evolved karyotype than 'DO' and 'DG'. Total chromatin content was found to be greater in 'DG' than 'WCT' (Raveendranath and Ninan, 1973). The total chromatin content was more in wild species than cultivated ones. Therefore, 'DG' appears to be the most primitive among the three cultivars studied. However, evidences from morphology, breeding system and meiotic behaviour support the possible evolution of Dwarfs from Talls.

7.1.2. Meiotic studies

The different cultivars of Talls and Dwarfs, open pollinated and inbred populations showed significant differences in their meiotic behaviour. The Dwarfs show less stable meiosis than Talls, and it has been proposed that ancestral types show more stable meiosis (Lindquist, 1960). In general, microsporogenesis is more regular in open pollinated than inbred progenies. Nambiar *et al.* (1970) studied cytological behaviour of 'Laccadive Ordinary' (LO), 'Philippines Ordinary' (PO), 'Andaman', 'New Guinea' and 'Cochin China' cultivars of coconut and observed that microsporogenesis was relatively regular in both inbred and open pollinated progenies of 'Laccadive ordinary', while comparatively higher frequencies of chromosome aberration and pollen sterility was observed in inbred as well as open pollinated progenies of 'Cochin China' and 'New Guinea' and inbred progenies of 'Philippines' and 'Andaman' cultivars. The lack of inbreeding depression only in 'Laccadive' cultivar may either be due to differences in intensity of inbreeding and selection between these geographically distinct cultivars, or due to the 'Laccadive' genotype being comparatively less sensitive to inbreeding.

Nambiar and Swaminathan (1960) observed many meiotic irregularities in Apricot from Straits Settlements and 'Dwarf Red' forms, which are derived from the Dwarfs, while meiosis was regular in 'Laccadive Ordinary'. Consequently, higher pollen sterility occurred in these two Dwarf derivatives in comparison to 'Laccadive Ordinary'. Thankamma Pillai *et al.* (1983) studied meiosis in nine cultivars and hybrids and indicated that the percentage of abnormalities was highest in 'DG' and 'DO', while chromosome abnormalities and sterility were very low in 'D x T' and 'T x D' hybrids. They concluded that the higher degree of inbreeding in Dwarfs might be the reason for higher chromosome aberrations and sterility in them. Cytological studies on *Spicata* cultivar (Ninan *et al.*, 1960; Ninan and Satyabalan, 1963) showed that meiosis was irregular with inversions, translocations and many other abnormalities. *Spicata* palms, being predominant outbreeders, are believed to have arisen from Talls through mutation. Further, cytological studies have been undertaken on abnormal palms, bulbiferous palms and root wilt affected palms. Nambiar and Prasannakumari (1964) studied the effect of root (wilt) disease on microsporogenesis in coconut and observed low frequency of cytological aberrations, high pollen fertility and seed set. Thankamma Pillai and Vijayakumar (1972) studied the course of microsporogenesis in the progeny of a self-pollinated 'New Guinea' palm, which produced defective nuts and observed aberrant meiosis. The sterility in this palm was attributed to inbreeding. Raveendranath *et al.*, (1975) found no appreciable karyological differences between the Talls and abnormal coconut palms producing bulbils in the place of inflorescences and opined that cryptic structural changes or genetic mutations might be responsible for the appearance of this type of coconut palm.

7.1.3 Cytology of endosperm and embryo

Abraham and Thomas (1962) reported free nuclear divisions in coconut water (liquid endosperm). But, this was disputed by Mondal *et al.* (1970), based on the biochemical analysis of coconut water. Abraham and Mathew (1963) and Abraham *et al.* (1965), observed that size of nuclei varied considerably in the developing endosperm, based on their studies on 6-month old nuts. They found that the tissues adjacent to endothelium were normally triploid (3x = 48), less frequently hexaploid (6x = 96) and still less frequently dodecaploid (12x = 192) and proposed that higher ploidy levels arise by C-mitosis. They also recorded an inverse relationship between ploidy and percentage oil content, with the inner part of the endosperm having the highest ploidy level and lowest oil content (Abraham, 1963; Abraham *et al.*, 1965). In the Tall cultivar, the percentage oil content in the outer, middle and inner layers of endosperm was 75.7, 54.1 and 41.4, respectively. Abraham *et al.* (1965) recorded higher ploidy levels (48x and above) in buttery endosperm ('Philippines Macapuno' coconuts), which they felt arose through amitosis and nuclear fusion. Unlike the endosperm, the young coconut embryos are diploids and divide by normal mitosis. Raveendranath and Ninan (1973) studied karyomorphological features of somatic chromosomes from six-months-old embryos and observed an essential uniformity in relative chromosome length from root tip (Nambiar and Swaminathan, 1960) and embryo cells of 'WCT' palms. Ninan and Raveendranath (1965) reported occurrence of a haploid embryo in a 'WCT' palm.

7.2 Crop improvement

India tops the world in coconut production, with an annual yield of 12,252 million nuts. However, the average annual productivity is 36 nuts palm^{-1}. This contrasts sharply with the yield of 110 nuts palm^{-1} year^{-1} realized by a progressive farmer, 175 nuts palm^{-1} year^{-1} for 'T x D' hybrids at Research Stations (Swaminathan, 1983) and 471 nuts palm^{-1}year^{-1} recorded in certain elite palms (Iyer *et al.*, 1979), indicating the vast scope for coconut improvement. The fact that coconut belongs to a monotypic genus with no known wild/domesticated relatives limits the possibilities of tapping gene pools of related sources. Moreover, the available variability within coconut is being slowly depleted through large scale replanting programmes, thereby necessitating immediate collection and conservation of existing native populations.

The first organized coconut breeding was started in 1916 at the erstwhile Coconut Research Stations at Kasaragod and Nileshwar, now under the Central Plantation Crops Research Institute (CPCRI) and Kerala Agricultural University, respectively. However, genetic improvement of perennial crops, in general, and coconut in particular is very tedious and time consuming.

CPCRI has undertaken extensive explorations and it now maintains the world's largest collection of coconut germplasm. Based on multilocational trials, promising cultivars have been selected and released for different parts of the country. Eleven hybrids have been released for cultivation with a yield potential of 95 to 141 nuts $palm^{-1} year^{-1}$. Drought tolerant and disease resistant cultivars have been identified and are being used to develop high yielding hybrids. Biotechnological research is in progress for clonal propagation, gene transfer and use of molecular markers for fingerprinting germplasm.

7.2.1 Germplasm collection and conservation

In India, germplasm collection began in 1924 with the introduction of cultivars from Fiji, Indonesia, Malaysia, Philippines, Sri Lanka and Vietnam (Cochin China) at the Central Coconut Research Station, Pilicode. Subsequently selfed and open pollinated progenies were planted at CPCRI (then CCRS), Kasaragod, in the 1940s. The germplasm collection was further intensified in 1952, and in 1958 the first indigenous germplasm survey and collection was started. In 1981, survey and collection was made from six Pacific Ocean countries under an FAO/IBPGR funded expedition, which added 24 exotic collections. Recently (April-May, 1997) an Asian Development Bank funded germplasm collection was undertaken at CPCRI, Kasaragod, and 15 accessions (including three dwarfs) were collected (in the form of embryos) from the three Indian Ocean Islands of Mauritius, Madagascar and Seychelles. Presently, CPCRI has the world's largest collection of coconut germplasm with 147 accessions from 25 countries of South and South-east Asia, Caribbean Islands, Indian Ocean Islands, Pacific Ocean Islands and African countries, and indigenous collections from Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Goa, Gujarat, Orissa, West Bengal, Andaman and Nicobar Islands and Lakshadweep Islands. Among these, 62 exotic and 40 indigenous accessions are maintained at Kasaragod and the rest (24 Pacific Ocean collections and 6 Nicobar collections) at the World Coconut Germplasm Centre (WCGC), Andamans. In addition, subsamples of these collections are maintained at Pilicode, and the centres under the All India Coordinated Research Project on Palms (AICRP on Palms), namely, Aliyarnagar, Coimbatore and Veppankulam in Tamil Nadu, Ambajipet in Andhra Pradesh, Arsikere in Karnataka, Konark in Orissa, Jagadalpur in Madhya Pradesh, Jalalgarh in Bihar, Mondouri in West Bengal and Ratnagiri in Maharashtra, for testing their regional adaptability. Germplasm characterization is undertaken using the IBPGR descriptor (Anon., 1978). CPCRI has so far prepared a descriptor for 48 different coconut accessions (Ratnambal *et al.*, 1995).

7.2.2 Cultivars released through selection

Screening of the available coconut cultivars for their performance under different ecological conditions is a promising method of obtaining ecotypes suited for the different regions of our country.

At CPCRI, on the basis of a preliminary evaluation of available coconut cultivars, promising cultivars were selected for further multilocation trials. Laccadive Ordinary was found to be a superior yielder in the states of Andhra Pradesh, Kerala, Tamil Nadu and Maharashtra and was therefore, released by CPCRI in 1985 under the name 'Chandra Kalpa' (Anon., 1985). 'Philippines Ordinary', another promising exotic cultivar, has been recommended for release as a national cultivars (Chandra Tara) by the XII Workshop on AICRPP (December, 1995) for commercial cultivation in the West coast, including Konkan regions, coastal Andhra Pradesh and West Bengal (Anon., 1996). Perera *et al.*(2002) identified a new coconut cultivar 'Nana', the dwarf coconut of Sri Lanka, with brown nuts, petioles and inflorescence using amplified fragment length polymorphism DNA markers and comparison of morphological characters, precocity and breeding behaviour. This cultivars was named 'Sri Lanka Brown Dwarf'. In the sandy soil of Konkan region of Maharashtra state in India one local cultivar 'Banawali Green Round' (Pratap) has been released, while two cultivars ('Laccadive Ordinary' and 'Philippines Ordinary') and one hybrid ('T x D') have been recommended for cultivation in the Konkan region (Nagwekar *et al.*, 2002). 'Pratap' was released based on the evaluation of five coconut cultivars of Banawali types ('Banawali Green Round', 'Banawali Green Long', 'Banawali Yellow Round', 'Banawali Yellow Long' and 'Banawali Red Round') for their morphological, inflorescence, fruit and yield characters in the Konkan region of Maharashtra, India. Among the cultivars, 'Banawali Green Round' produced the highest average yield of 142 nuts $palm^{-1}$ $year^{-1}$ for the last 24 years (1978-2002), followed by 'Banawali Yellow Round' (120 nuts) and 'Banawali Green Long' (116 nuts). On the basis of superior morphological, inflorescence and fruiting characters as well as high yield potential, 'Banawali Green Round' was released in 1987 under the name of Pratap for commercial cultivation in the region (Nagwekar *et al.*, 2003).

The coconut palm population of the Cocos (Keeling) Islands of the Indian Ocean displays fruit characteristics consistent with what is thought to be the wild-type form. The population of North Keeling Atoll remains unaffected by human activity, whereas that of the Main Atoll has been managed for copra and oil production for 160 years. Genetic improvement has been attempted on Main Atoll by selection and germplasm importation. The population of Main Atoll is more productive than that of North Keeling, where the palms produce few fruits due to high population density and competition with other plant species. Although Main Atoll fruits and all their components were heavier, proportions by weight were the same as on North Keeling. Main Atoll fruits were not longer, but wider than North Keeling fruits, and contained larger nuts.On Main Atoll, improved environment and seed selection contributed to more endosperm, from larger nuts. This is the first comprehensive description of a wild-type coconut population, which was judged to have been uninfluenced by human activity. The genetic uniqueness of the North Keeling population holds possible value for improvement of Atoll populations elsewhere (Leach *et al.*, 2003). Jayalekshmy and Rangaswamy (2002) did cluster analysis in 30 genotypes based on 20 morphological traits which included both vegetative, inflorescence and fruit characters. Genotypes were grouped into six clusters. All the dwarf cultivars were grouped into one cluster. Tall cultivars resolved into three clusters. All the 'T x D' hybrids came along with the tall cultivars and the 'D x T' hybrids were clustered with the dwarf cultivars. 'Laccadive Micro' formed a separate cluster and the inter-cluster distance was the highest for this cluster, 'Andaman Giant' and 'San Ramon', which showed distinguishing nut characters, constituted a separate cluster. This analysis indicated the possibility of obtaining promising progeny from the parents of divergent clusters. The study also confirmed the distinctness of the cultivars such as 'Laccadive Micro', 'San Ramon' and 'Andaman Giant'. The nut characters were efficient in assessing genetic divergence. According to Manna *et al.* (2003),the highest number of spadix plant^{-1}, female flowers spadix^{-1} and nuts palm^{-1} were produced by 'D x T'. Kernel and husk production were better in 'Philippines Ordinary', followed by 'D x T', 'Strait Settlement Green' and 'T x D' under West Bengal conditions. The yield performance of the released coconut cultivars is given in Table 6.

Table 6: Yield performance of released coconut cultivars

Cultivar	Commercial name	Mean yield (nuts palm^{-1} year^{-1})	Copra yield nut^{-1} (g)		State for which recommended	Year of release	Agency responsible for release
'Laccadive Ordinary'	'Chandra Kalpa'	97	195	18.9	Kerala, Tamil Nadu, Andhra Pradesh, Maharashtra	1985	CPCRI
'Banawali Green Round'	'Pratap'	151	250	22.7	Goa, coastal Maharashtra	1987	Konkan Krishi Vidyapeeth
'Philippines Ordinary'	'Chandra Tara'	110	189	20.8	west coast, coastal Andhra Pradesh, West Bengal	1995	CPCRI
'WCT'		80	176	14.1	Local check		CPCRI

7.2.3 Hybridization

Hybridization work was first started in Fiji (Marechal, 1928) but was discontinued due to economic crisis. In India, hybridization was initiated in 1932, followed some 15 years later by Sri Lanka. In the early 1960s, IRHO and its partners started their hybridization work, while other coconut growing countries started much later.

In India, Patel initiated the hybridization programme with three intra-cultivar and one inter-cultivar cross at the Coconut Research Station, Nileshwar, in the year 1932, and was the first to report hybrid vigour in coconut (Patel, 1937). Over the years, more than 95 hybrid combinations have been evaluated at CPCRI and the various coordinating centres and so far 11 hybrids have been released for cultivation, the yield potential of which varies from 95 to 141 nuts palm^{-1} year^{-1} and 13.20 - 26.40 kg copra palm^{-1} year^{-1} (Table 7).

Table 7 : Performance of released coconut hybrids

Sl. No.	Hybrid	Parentage	Nut yield palm^{-1} year^{-1}	Copra yield nut^{-1} (g)	Copra yield palm^{-1} (kg)	Oil content	States for which recommended	Year of release	Agency responsible for release
1.	'Chandra Sankara'	'COD' x 'WCT'	116	215	24.9	68	Kerala	1985	CPCRI
2.	'Laksha Ganga'	'LO' x 'GB'	108	195	21.1	70	Kerala	1987	KAU
3.	'Chandra Laksha'	'LO' x 'COD'	109	195	21.3	69	Kerala	1985	CPCRI
4.	'Kera Ganga'	'WCT' x 'GB'	100	201	20.1	69	Kerala	1988	KAU
5.	'Ananda Ganga'	'AO' x 'GB'	95	216	20.5	68	Kerala	1988	KAU
6.	'Kera Sankara'	'WCT' x 'COD'	108	187	20.2	68	Kerala, Coastal Maharashtra, Coastal Andhra Pradesh	1991	CPCRI
7.	'Kera Sree'	'WCT' x 'MYD'	141	187	26.4	66	Kerala	1992	KAU
8.	'Kera Sowbhagya'	'WCT' x 'SS Apricot'	116	196	22.7	65	Kerala	1994	KAU
9.	'VHC 1'	'ECT' x 'MDG'	98	135	13.2	70	Tamil Nadu	1982	TNAU
10	'VHC 2'	'ECT' x 'MYD'	107	152	16.3	69	Tamil Nadu	1988	TNAU
11.	'Godavari Ganga'	'ECT' x 'GB'	140	150	21.0	68	Andhra Pradesh	1992	APAU

7.2.4 Breeding for specific traits

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Coconut breeding programmes, in addition to yield improvement, are also aimed at development of drought tolerant and pest resistant cultivars. Farias Neto *et al.* (2003)estimated the coefficient of repeatability for production of fruits and solid albumen in coconut palm using statistical methods of the variance analysis, main components (covariance and correlation) and structural analysis (covariance). Significant variability was detected between hybrids for fruits and solid albumen productions. Repeatability coefficients obtained by the variance analysis and structural analysis (correlation) showed the smallest values. If the level of 90% is considered sufficient to select hybrids with relative superiority for fruit and solid albumen productions based on the estimation of repeatability by the main components method (covariance), then it would be recommended to perform five and three evaluations for fruit and solid albumen productions, respectively. A high degree of variability is observed for copra yield, dehusked nut weight, nut yield, copra weight and whole nut weight. All these characters showed high heritability and genetic advance. The copra yield in coconut was strongly and positively correlated with nut yield, copra weight, kernel weight, whole nut weight and dehusked nut weight. The direct effects of dehusked nut weight, percentage of husk to whole nut weight, percentage of kernel to whole nut weight, copra weight and nut yield on copra yield were positive and high. These characters are to be given emphasis while selection for improvement of copra yield in coconut is made (Ganesamurthy *et al.*, 2002a). Pramod *et al.* (2003) described a method to utilize commonly found dwarfs for the production of 'D x T' hybrids (where the dwarf palms are the female parents) through controlled natural pollination in Kerala, India. The method consists of the following key steps: (1) selecting dwarf mother palms with high yield and other desirable characters; (2) emasculating the inflorescence of the dwarf mother palm within 2 to 3 days of its opening by cutting and removing all the spikes together with the male flowers borne on it; (3) harvesting mature nuts from the bunches usually 10 to 11 months after pollination; (4) sowing the seed nuts in nursery beds; (5) selecting 'D x T' hybrid seedlings based on the exclusive characteristics of the male parent (such as colour of petiole, length and breadth of leaves and leaflets, hybrid vigour, plant height); (6) and uprooting one-year-old seedlings and planting them in the main field. Further, qualitative parameters of tendernut water were studied for selection of the best tendernut cultivars.

7.2.4.1 Drought tolerance

Coconut palm requires an average monthly rainfall of 150 mm for ideal palm growth and good nut yield and unlike annuals, the adverse effect of drought persists for the subsequent two to three years. Coconut is cultivated mainly as a rainfed crop in peninsular India, which accounts for 90% of the coconut area in the country, and is exposed to the vagaries of monsoon, resulting in poor yields.

Rajagopal *et al.* (1991), Chempakam *et al.* (1993) and Naresh Kumar *et al.* (2000) revealed the possibility of identifying drought tolerant cultivars based on different anatomical, physiological and biochemical parameters. Subsequently, Rajagopal *et al.* (1988, 1990) screened different coconut cultivars for drought tolerance and found 'WCT' x 'WCT', 'Federated Malay States' ('FMS'), 'Java Giant', 'Fiji', 'Andaman Giant', 'LO' x 'GB' and 'LO' x 'COD' to be drought tolerant. The identified drought tolerant cultivars are currently being used in the breeding programmes at CPCRI, Kasaragod, to evolve high yielding, drought tolerant hybrids.

7.2.4.2 Insect resistance

A number of insect pests attack coconut palms, of which, rhinoceros beetle and red palm weevil are the two major ones. These respond to conventional plant protection measures and therefore, no specific breeding programmes for developing resistant genotypes have been initiated. Preliminary screening of cultivars/ hybrids against leaf eating caterpillar, *Nephantis serinopa* (Kapadia, 1981) and rhinoceros beetle, *Oryctes rhinoceros* (Sumangala Nambiar, 1991) indicated variations in susceptibility among cultivars, though no resistant cultivar was observed.

7.2.4.3 Disease resistance

Coconut is affected by a number of diseases, of which the major ones are *Phytophthora* bud rot, stem bleeding, Thanjavur wilt/Ganoderma disease and root (wilt) disease. Among these, root (wilt) disease is the most serious and in the absence of effective control measures against the disease, evolving resistant cultivars are of utmost importance.

Studies on identifying coconut genotypes resistant /tolerant to root (wilt) disease were initiated by Varghese in 1934. Since 1961, the CPCRI Regional Research Station, Kayangulam, has made considerable efforts to screen the available cultivars for tolerance to root (wilt) disease. However, all the cultivars/ hybrids screened were found susceptible to the disease (Menon *et al.*, 1981). Only the cultivar 'CGD', was found to have field tolerance of over 90% to the disease (Anon., 1972). A survey of the disease-affected areas ('hot spots') identified some high yielding, disease-free 'WCT' and 'CGD' palms (Iyer *et al.*, 1979). Presently, phenotypically and serologically disease-free 'WCT' and 'CGD' palms are used in the breeding programmes to produce different cross combinations - 'WCT' x 'WCT', 'WCT' x 'CGD', 'CGD' x 'WCT', 'WCT' self, 'CGD' self. In addition, mixed pollen from all selected healthy palms in the diseased tract is also used for pollination to develop a gene pool of field tolerant palms. So far 2455 seedlings have been planted in the disease-affected areas for screening against root (wilt) disease (Anon., 1997). A few progenies of the cultivar 'Gudanjali' from Gujarat have also been planted for screening (Anon., 1994). Subsequently, healthy 'COD' mother palms in the 'hot spots', have also been used in the resistance breeding programme (Anon., 1996).

A few exotic cultivars screened against root (wilt) disease were found susceptible to the disease, though significant differences in disease intensity between cultivars were observed (Mathai *et al.*, 1985, 1991). However, since no tolerant cultivar has been identified, exotic cultivars are presently not being utilized in the root (wilt) disease resistance-breeding programme. Meanwhile, *inter se* and selfed nuts of the 24 exotic accessions from the South Pacific Ocean Islands being evaluated at the WCGC, Andamans, and have been planted in the 'hot spot' areas for screening for resistance/ tolerance to root (wilt) disease (Jacob and Rawther, 1991).

At the CPCRI Regional Research Station, Kayangulam, the 'CGD' x 'WCT' hybrid progenies planted in 1991 have started bearing and have so far not taken up the root (wilt) disease (Anon., 1995, 1996, 1997; Nair *et al.*, 1996). The relative tolerance/resistance to the disease of these 'D x T' hybrids, coupled with their high yield potential has highlighted the scope of developing this hybrid as a suitable planting material for the disease endemic areas.

7.2.4.4 Nut water quality

The consumption of tendernuts as a natural, nourishing and refreshing drink is becoming increasingly popular in our country. As a result of the high demand, tendernuts are being harvested from the existing Talls, sacrificing the quality of nut water and at the cost of valuable copra and oil. Therefore, at CPCRI, a study was initiated to identify a suitable cultivar for tendernut purpose (Dhamodaran *et al.*, 1993). Among the cultivars evaluated, the cultivar 'COD', had the maximum total sugars (7.0%) and reducing sugars (4.7%) coupled with low sodium and potassium levels (Table 8). On the basis of the superior nut water quality, the Xth Workshop of the All India Coordinated Project on Palms (September, 1991), recommended the release of 'COD' as a tendernut cultivars in Kerala (Anon., 1991). Poduval *et al.* (1998) evaluated 10 coconut cultivar for tendernut purpose for West Bengal. Among the cultivars 'Phillipines Ordianry', 'MYD', 'WCT' and 'WCT' x 'MYD' were found to have appreciable amount of nut water and sugar during seventh month after fruitset and the cultivars were suggested for cultivation in West Bengal to serve as tendernut. Ganesamurthy *et al.*(2002b) evaluated 40 tall and dwarf coconut genotypes for their physico-chemical properties during the tendernut age. The volume of coconut water was highest in 6-month-old tendernuts of tall genotypes and 7-

month-old tendernuts of dwarf genotypes. The tall genotype 'San Ramon' recorded the highest volume of coconut water (635.4 ml). The heaviest endosperm was observed in the tall genotype 'Andaman Giant' (207.7 g) and the dwarf genotype 'AOD' (140.4 g). The total sugar and mean reducing sugar content of coconut water increased with the ageing of nuts, with the dwarf genotypes recording higher total sugar and mean reducing sugar content than the tall genotypes. The mean potassium content decreased, whereas the mean sodium content and pH of the tendernut water of both tall and dwarf genotypes increased with the ageing of the nuts. The tall genotypes 'Zanzibar' and 'West coast', and the dwarf genotypes 'Chowghat Orange' and 'Malayan Orange' were superior in terms of tendernut water.

Table 8 : Biochemical constituents of tendernut water and nut yield in 12 coconut cultivars

Cultivars	Volume of water (ml)	Sugars (g 100^{-1} ml)		Free amino acids mg 100^{-1}ml	K (mg l^{-1})	Na (mg l^{-1})	Yield (nuts palm^{-1} year^{-1})
		Total	Reducing				
'New Guinea'	358	5.8	3.0	1.4	2258	21	73
'Philippines Ordinary'	457	5.8	3.7	1.3	2273	24	113
'Fiji Long' 'Tongwan'	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 Ordinary'	274	5.3	3.3	2.1	2272	27	94
'SanBlas'	263	6.0	3.4	1.7	2703	28	65
'MYD'	238	6.2	3.8	1.7	1998	36	53
'MOD'	303	4.1	6.7	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

Considering the importance of the crop and the pioneering role played by India to preserve the coconut germplasm available in all the coconut growing countries of the world, a World Coconut Gene Bank for South-east Asia is proposed to be set up under Central Plantation Crops Research Institute (CPCRI). This would prevent coconut cultivars from becoming extinct. Some of the other areas in which research has to be carried out more intensely are as follows:

1. Conserving and cataloguing of coconut germplasm.
2. Breeding for resistance to root (wilt) disease.
3. Breeding cultivars for tolerance to drought.
4. Intensive biotechnological research for clonal propagation, gene transfer and use of molecular markers for fingerprinting germplasm.

8.0 Biotechnology

Research on coconut tissue culture was started in the eighties after success was reported in oil palm tissue culture. It was initially thought that application of these techniques in coconut would result in success. This was proved wrong. The culture media developed for oil palm was indubitable for coconut and it was later proved that the coconut palm is highly recalcitrant to *in vitro* manipulations and every stage of the procedure brought its share of problems (Verdeil *et al.*, 1998). Besides, this technique would also help in the rapid propagation of elite hybrids. The success obtained in embryo culture and its use in germplasm collection has been one of the major achievements in this direction. The research on coconut tissue culture was thus aimed at solving the problems of phenol production using anti-oxidants other than activated charcoal, production of embryogenic calli and regeneration of plants. Biotechnological research on coconut is being intensively carried out at present only at CPCRI in India and a few laboratories abroad, although there have been sporadic attempts made in several other laboratories (Iyer, 1993; Iyer, 1995). Tissue culture of coconut has been carried out in several countries besides India including UK (Wye College), France (IRHO/CIRAD), USA (Florida University), the Philippines, Australia, Indonesia and Sri Lanka. As a result of these programmes, a few clonal plantlets have been produced over several years, but a repeatable and commercial protocol is yet to be achieved (Iyer and Parthasarathy, 2000; Parthasarathy and Bose, 2001).

A viable protocol for micropropagation of desired coconut hybrids/selections is thus fundamental for disseminating the benefits of various breeding programmes among the farming community. The technique thus perfected could also be used for the mass multiplication of the disease resistant/tolerant types especially, in the context of the epidemic and devastating nature of root (wilt) disease in Kerala, which is estimated to cause a loss of more than 960 million nuts annually. Other international ramifications are the deadly diseases like lethal yellowing which is reported to be spreading at the rate of 100km year^{-1} in Mexico and would eventually wipe out all the country's estates (Verdeil *et al.*, 1998). Recently a lot of interest has focussed on molecular aspects of coconut and markers including microsatellite and AFLP are being used to characterize the palms.

8.1 Molecular markers

The use of biochemical and molecular markers in coconut has been a recent one. The biochemical markers like isozymes and molecular markers like Restricted Fragment Length Polymorphism (RFLP), Random Amplified Polymorphic DNA (RAPD), Amplified Fragment Length Polymorphism (AFLP) and Sequence Tagged Microsatellites (STM) are presently being tried. A comprehensive review on the application of molecular markers was first presented by Rohde (1993) and later by Ashburner (1999). Fernando and Gajanayake (1997) have reported protocols for detection of isozyme polymorphism in coconut leaf tissues. They found esterases to be useful for studying the genotypic variations in coconut. Cardena *et al.* (1998) used electrophoretic patterns of leaf peroxidases, endopeptidases and coomassie blue stained proteins in four cultivars and two hybrids. The polymorphism detected fit the expression of two alleles of a dimeric peroxidase, two monomeric endopeptidase and a pair of active and null alleles of a Coomasie blue stained protein. They concluded that the protein markers would broaden the alternatives available to breeders of coconut. Geethalakshmi *et al.* (2000) observed limited polymorphism for esterase and polyphenol oxidase while polymorphism for peroxidase was absent. However, earlier attempts by Meunier *et al.* (1992) and Carpio (1980) failed to achieve any success. The diversity and phylogenetic analysis in 22 populations of Mexican coconut and six imported populations, were estimated using 15 enzymatic systems and the allele frequencies in: peroxidase (PER), endopeptidase (ENP), and glucose 6-phosphate dehydrogenase (G6PD). There was very low polymorphism, not more than two alleles per locus. The Wright fixation indexes F(it)=0.62, F(is)=0.40, and F(st)=0.36 indicated low total heterogygosity and low heterogygosity within populations suggesting endogamy and genetic drift, and a high diversity among populations due to differentiation between Pacific and Gulf of Mexico coastal populations (Zizumbo Villarreal *et al.*, 2002). The phylogenetic tree with values for genetic distance, indicated three groups on the Pacific coast related to 'Rennell Tall' and 'Polynesian Tall', and two groups on the coast of the Gulf of Mexico, one related to 'West African Tall' and another related to Mexican Pacific coast populations. This corroborates historical antecedents and morphological and physiological patterns. The Dwarf coconuts related to the 'Pacific Tall' populations, 'Rennell Tall' and 'Polynesian Tall'. There was no difference between local and imported Dwarf populations (Zizumbo Villarreal *et al.*, 2002). Parthasarathy *et al.* (2004) analysed the diversity using isozyme banding data with 11 isozyme systems in 40 different cultivars and six hybrids and their parents. The cultivars grouped into six clusters. In case of hybrids and their parents, the hybrids clustered intermediate between parents.

Rohde's (1993) preliminary studies have revealed molecular characterization of the nuclear genome, which has provided evidence for the existence of truncated, *copia*-like repetitive sequences indicating that retro-elements may have played their role in the generation of genetic diversity in coconut. Rohde *et al.* (1995) described a novel approach for the analysis of coconut germplasm by the use of coconut specific primers complementary to the *copia*-like *Eco*RI elements. PCR amplification of spacer regions for a subset of tandemly arranged repeats detected polymorphisms, which allowed an analysis of biodiversity within coconut populations. Rohde (1996) has subsequently described Inverse Sequence Tagged Repeat (ISTR) analysis. Duran *et al.* (1997) analyzed 48 coconut genotypes using different DNA marker techniques, namely, RAPD, microsatellite primed PCR and ISTR. All three approaches detected a large number of DNA polymorphism among the genotypes and allowed the identification of single genotypes by individual-specific fingerprints. The use of polymorphic microsatellites for assessing genetic diversity in coconut has been gaining popularity of late (Karp, 1999). CIRAD in collaboration with COGENT developed a set of 14 microsatellite markers with sufficient discriminating power for practical identification of coconut cultivars. These projects culminated in developing standard protocols without the use of radioactive probes as well as development of dedicated statistical software - Gene class 2, adapted to use in the producing countries (Baudouin and Labrun, 2002). Hautea *et al.* (2000), Perera *et al.* (1999) and Perera (2001) used microsatellites (simple sequence repeat - SSR) to assess the genetic diversity of selected germplasm. The SSR data indicated a high degree of allelic diversity for microsatellite markers within the tall populations. Diagnostic SSR markers were identified for use in hybrid testing and two diagnostic markers were identified for use in hybrid test. Perera *et al.* (2000a) used eight pairs of SSR primers to analyze the genetic diversity in 130 individuals of coconut comprising of 75 tall individuals and 55 dwarf individuals, representing 94 different coconut ecotypes throughout the world. Fifty-one alleles were detected, with an average of 6.4 alleles per locus. Fifty alleles were detected in tall coconuts (talls: mean alleles $locus^{-1}$ 6.3) compared with only 26 (mean $locus^{-1}$ 3.3) in dwarfs, and the average diversity value in talls (0.589) was also significantly higher than that in dwarfs (0.348). Using the eight SSRs, they were able to uniquely discriminate 116 of the 130 individuals. A phenetic tree based on DAD (absolute distance) values clustered individuals into five groups, each mainly composed of either talls or dwarfs. Perera *et al.* (2000b and 2000c) also used SSR to study SSR polymorphism. They used 39 coconut specific microsatellite primers developed from an enriched small insert genomic library. Eighteen of those were used to assay Sri Lankan coconuts. The out breeding tall variety *typica* accounted for most of the diversity in contrast to inbreeding varieties *nana* (dwarfs) and intermediate (*aurantiaca*) types. Partitioning of the genetic variability revealed that for dwarf and intermediate forms most variation was observed between rather than within forms. In contrast, tall forms exhibited as much variation within as between forms. A reduction in allelic variability was observed in dwarfs compared with talls and the pattern of allelic distributions suggested that Sri Lankan dwarfs were introductions. They used twelve pairs of microsatellite primers to screen a collection of global coconut germplasm. Eighty four alleles were detected in talls as compared to 42 in dwarfs with an average diversity value of 0.703 which was significantly higher than that detected in the dwarf sample (0.374). They concluded that dwarfs are a subset of the tall coconuts and have directly evolved from talls and from 'Niu vai' types of tall (South-east Asia and Pacific origin). Microsatellite markers have been successfully used to study the genetic diversity in coconut in many laboratories. Meerow *et al.*(2003) analyzed genetic variation within *Cocos nucifera* germplasm collections at two locations in South Florida, representing eight cultivars using 15 simple sequence repeat (SSR) microsatellite DNA loci. The loci were also used in a parentage analysis of progeny of the 'Fiji Dwarf' cultivar at both locations. A total of 67 alleles were detected, with eight the highest number at any one locus. These loci identified 83 of the 110 individual palms. Gene diversity of the 15 loci ranged from 0.778 to 0.223, with a mean of 0.574. 'Fiji Dwarf', 'Malayan Dwarf', 'Green Nino' and 'Red Spicata' cultivars resolve as distinct clusters in a neighbour joining tree using modified Rogers distance, while the tall cultivars form two aggregates. The highest gene diversity was found in the tall cultivars (H=0.583 cumulatively), and the lowest in the 'Malayan Dwarf' (H=0.202). After the tall coconuts, the 'Fiji Dwarf' was most genetically diverse (H=0.436), and had the largest number of unique alleles. Genetic identity is highest among the 'Malayan Dwarf' phenotypes, and between the tall cultivars. The 'Red Malayan Dwarf' is genetically distinct from the 'Green' and 'Yellow Malayan Dwarf' phenotypes, which cannot be distinguished with the SSR loci used. Off-type 'Malayan Dwarf' phenotypes (putative hybrids with talls) can be identified genotypically. Parentage analyses of 30 'Fiji Dwarf' progeny propagated from five adults surrounded by other cultivars estimate that only 20% of the progeny were out-crossed to the other cultivars, while 40-46% were possible selfs. This suggests that a seed-production orchard of the cultivar maintained at reasonable distance from other cultivars, will likely yield only 'Fiji Dwarf' genotypes. The extent of genetic diversity and the genetic relationships among 94 coconut cultivars/ populations (51 talls and 43 dwarfs) representing the entire geographic range of cultivation/distribution of the coconut was assessed by Perera *et al.*(2003) using 12 pairs of coconut microsatellite primers. A high level of genetic diversity was observed in the collection with the mean gene diversity of 0.647±0.139, with that of the mean gene diversity of talls 0.703±0.125 and 0.374±0.204 of dwarfs. A phenetic tree based on DAD genetic distances clustered all the 94 cultivars/

populations into two main groups, with one group composed of all the talls from South-east Asia, the Pacific, West coast of Panama, and all dwarfs and the other of all talls from South Asia, Africa, and the Indian Ocean coast of Thailand. The allele distribution of dwarfs highlighted a unique position of dwarf palms from the Philippines exhibiting as much variation as that in the tall group. The grouping of all dwarfs representing the entire geographic distribution of the crop with talls from South-east Asia and the Pacific and the allele distribution between the tall and dwarf suggest that the dwarfs originated from the tall forms and that too from the talls of South-east Asia and the Pacific. Talls from Pacific Islands recorded the highest level of genetic diversity (0.6±0.26) with the highest number of alleles (51) among all the regions.

Genetic diversity in coconut populations across the entire geographic range was assessed using SSRs and AFLP by Teulat *et al.* (2000). Nagaraju *et al.* (2002) were the first to standardize DNA amplification fingerprinting (DAF) in coconut. They used DAF and amplified fragment length polymorphism (AFLP) markers for studying the phylogenetic relationships among coconut accessions grown in India. The AFLP approach was more efficient as the number of primer combinations detected polymorphic DNA markers were more in contrast to DAF. However, the number of polymorphic bands identified using primers selected in both techniques were comparable. The genetic similarities among the accessions were determined. In DAF, out of 300 primers screened, 28 (9.33%) detected polymorphism producing an average of 5 polymorphic bands while in AFLP 55 (86%) primer combinations generated polymorphic bands (6.42). Dendrogram of the coconut accessions by UPGMA cluster analysis indicated grouping of all the dwarf accessions into one group in both DAF and AFLP analysis.

The use of RFLP and RAPD has been also reported. RFLP markers were used by Lebrun *et al.* (1998a, 1998b and 1999) to study the spread and domestication of coconut using the genetic diversity. They used 289 palms, representative of 26 Tall and 16 Dwarf ecotypes originated from major coconut areas. Twenty cDNA probes from oil palm, rice, maize and coconut and one cytoplasmic probe from wheat were hybridized on digested DNA using four restriction enzymes. Based on the molecular polymorphism they defined two main groups of tall coconut palms, originating from South-east Asia and Pacific Ocean and another from the Indian subcontinent and West Africa. The cultivars from East Africa and from the Andamans shared markers from both groups, whereas the Panama Tall appeared to be derived from the first one. All the dwarfs (except Niu Leka) formed a highly homogenous group related to the first group of talls. Lebrun *et al.* (1999) reported that RFLP analysis is an efficient and powerful technique to obtain a precise picture of coconut diversity and the ways in which it has spread and evolved. Everard *et al.*

(1996) and Ashburner *et al.* (1997) and later by Wadt *et al.* (1999) described the use of RAPD in coconut. Ashburner *et al.* (1997) studied the diversity in coconut in the South Pacific region. They reported moderate level of genetic diversity although very few RAPD markers were unique to specific populations. Recently Upadhyay *et al.* (2002) screened 100 random primers and found only 53% of the primers amplified coconut DNA and 34% primers detected polymorphism between 'West Coast Tall' and 'Chowghat Orange Dwarf'. Analysis of the genetic distances revealed that all dwarf accessions were grouped together whereas tall accessions showed much heterogeneity. Dewi Hayati *et al.* (2000) used RAPD to analyze genetic diversity of four dwarf populations from east Java. They found that variability of coconut population grown outside east Java was higher than that in east Java since those coconut populations were collected from seeds of open pollinated plants. Randomly amplified polymorphic DNA (RAPD) markers were used to analyze genetic diversity and genetic relationship among coconut accessions using DNA from 81 palms representing 20 accessions, 15 Indian and 5 exotic, with 8 highly polymorphic primers (Upadhyay *et al.,* 2004). The 8 primers yielded 77 markers, with an average of 9.6 markers primer^{-1}. The within-accession genetic diversity ranged from 0.057 to 0.196. In general, tall accessions were more heterozygous as they had higher proportions of polymorphic bands and genetic diversity. The proportion of variation explained by within accession and between accession diversity was 0.58 and 0.42, respectively. Similarly exotic accessions exhibited more variation. Dwarfs from geographically distant regions did not cluster separately. In an earlier study Upadhyay *et al.* (2002) analysed 14 coconut accessions (9 tall, 4 dwarf, and 1 intermediate type) using RAPD markers to establish genetic similarity among some indigenous and exotic coconut accessions maintained in the coconut germplasm centre in Kerala, India. Of the 100 primers tested, only 54 primers amplified coconut DNA. Thirty-four primers detected at least one polymorphic band between one tall ('WCT') and one dwarf ('COD') accession. The number of polymorphic bands primer^{-1} ranged from 1 to 16. A total of 245 bands were generated by 34 polymorphic primers, of which 116 (47%) were polymorphic. The average number of polymorphic bands primer^{-1} was 2.2 (3.4 when only polymorphic primers were considered). Six primers generated 51 bands in 14 accessions, of which 35 (69%) bands were polymorphic. Among tall accessions 50 bands were present, of which 33 (66%) were polymorphic. In contrast, dwarf accessions had 30 bands and only 14 (47%) were polymorphic. The total heterogeneity among 14 accessions was 0.49 whereas that for tall and dwarf accessions was 0.46 and 0.40, respectively. The pair-wise genetic distance varied from 0.189 to 0.62. The average genetic distance among dwarf (0.31) was significantly less than that among tall (0.45) accessions. Daher *et al.*(2002) also estimated the genetic divergence among 19 coconut tree populations by random amplified polymorphic DNA. The DNA samples obtained from the leaves of each cultivar were amplified with 24 primers. A total of 127 polymorphic and 61 monomorphic loci were obtained. Six different clusters, possibly heterotic groups, were formed. Group 1 included the dwarf group cultivars. Giant accessions, abbreviated to GBR ('Brazilian Giant'), formed group 2, except GBRPF, which together with 'West African Giant' (GOA) formed group 4. The most distant accession was the 'Tonga Giant' cultivar (GTG) that did not group with the others and presents potential for hybridization with the six cultivars in the dwarf group cultivars and with the five in the GBR group. Group 3 consisted of GRL, GPY and GRT and Group 5 of GML and GVT. The dendrogram obtained by the nearest neighbour method was in line with the clustering obtained by the Tocher optimization method. The markers used permitted the identification of each of the populations showing that they were genetically different (absence of duplicity). The use of compound samples was effective to investigate the interpopulational genetic diversity.

The application of AFLP in coconut has been recently reported by Perera *et al.* (1998). They generated 322 amplification products from the 42 genotypes with eight pairs of primers (*Eco* RI and *Mse* I). Overall wide variation was detected in the tall (*Typica*) rather than the intermediate (*Aurantiaca*) and dwarf (*Nana*) forms. A hierarchical analysis of molecular variance (AMOVA) was used to quantify and partition levels of variability into, between and within form components. They found that for the inbreeding dwarf and intermediate forms showed most variation between, rather than within forms. In contrast, the outbreeding tall forms exhibited as much variation within as between forms. These observations have important implications for the maintenance and collection of coconut germplasm. Morphologically *Aurantiaca* group is considered to be intermediate between the tall and dwarf accessions. Estimation of genetic relatedness based on AFLP analysis identified the *Aurantiaca* group as being more similar to the dwarf rather than the tall group. In addition, putative duplicate accessions were identified in the *Aurantiaca* group.

The first linkage map on coconut was reported by Rohde *et al.* (1999) using a first population of 52 F_1 plants from the 'MYD 20' x 'LAG 07' ('Laguna Tall') using ISTR. An initial analysis of this mapping population identified 51 polymorphic ISTR markers, 43 of which could be arranged into 12 linkage groups comprising a total of 542 recombination units. Subsequently Herran *et al.* (2000) and Lebrun *et al.* (2001) constructed linkage map. Herran *et al.*'s (2000) work was identical to that of Rohde *et al.*'s (1999) using identical mapping population while Lebrun *et al.* (2001) used 'Rennell Island Tall' (RIT) population. They reported the total genome length to be 1971 cM for the RIT map, with 5-23 markers per linkage group.

QTL analysis for yield characters in two consecutive sampling periods identified nine loci while three and two QTLs were detected for number of bunches and one and three QTLs for number of nuts. Their study indicated that the co-segregation of markers with these QTLs provides an opportunity for marker-assisted selection. Cardena *et al.* (1999) described the prospects for marker assisted breeding of lethal yellowing resistant coconuts. The only effective means for controlling LY is replanting with resistant germplasm. Breeding coconuts for any desirable traits is hindered by the long generation time, low multiplication rate, and ineffective clonal propagation of this crop. Additionally, the lack of adequate genotypes for identifying markers linked with LY resistance demands alternative approaches. Cardena *et al.*(2003) identified three coconut populations which could be used for this purpose, and comprised the susceptible 'West African Tall' ('WAT'), the resistant 'Malayan Yellow Dwarf' ('MYD'), and a resistant population of 'Atlantic Tall' ('AT') plants. This latter material was closely related to 'WAT', and both of them were distantly related to 'MYD'. The objective of this work was to use those populations for identifying RAPDs associated with LY resistance. RAPDs were considered as associated with that trait if their frequencies were high in 'MYD' and 'AT', and low in 'WAT'. A total of 82 RAPDs could differentiate the DNA pools from 'MYD' and 'WAT', and 12 of them appeared at frequencies _0.85 in 'MYD', and _0.15 in 'WAT'. Five of such markers were in AT at frequencies of 0.80 (-B4570) or 1 (-A11990, -B111140, -AL31160 and -AL7350).

Molecular markers have been successfully used in coconut to study and characterize the pathogens associated with various diseases. Lethal yellowing (LY) disease of coconut palm in Cuba has been reported since the end of the 19th century. To ascertain the presence of phytoplasmas associated with this disease, Llauger *et al.*(2002) took leaf samples from plants showing typical disease symptoms and assayed for the LY agent by the polymerase chain reaction (PCR) using LY-specific primers. Selected PCR amplification products were cloned, sequenced and compared to that of a Mexican LY isolate from the Yucatan region. The results obtained confirm the presence of LY phytoplasma in Cuba. Cuban and Mexican isolates show an overall high degree of sequence similarity with occasional point mutations and small deletions or insertions. Based on these identified genetic differences, LY isolates from the Havana and the Yucatan region cluster together and apart from isolates originating at Maisi in Eastern Cuba. Harrison *et al.*(2002) detected DNA of phytoplasmas in lethal yellowing (LY)-diseased palms by a nested polymerase chain reaction (PCR) assay employing rRNA primer pair P1/P7 followed by primer pair LY16Sf/LY16-23Sr. Polymorphisms revealed by HinfI endonuclease digestion of rDNA products differentiated coconut-infecting phytoplasmas in Jamaica from those detected in palms in Honduras, Mexico, and Florida, USA. A three fragment profile was generated for rDNA from phytoplasmas infecting all 21 Jamaican palms whereas a five fragment profile was evident for phytoplasmas infecting the majority of Florida (20 of 21), Honduran (13 of 14) and Mexican (5 of 5) palms. The RFLP profile indicative of Florida LY phytoplasma was resolved by cloning into two patterns, one of three bands and the other of four bands, that together constituted the five fragment profile. The two patterns were attributed to presence of two sequence heterogeneous rRNA operons, rrnA and rrnB, in most phytoplasmas composing Florida, Honduras and Mexican LY strain populations. Unique three and four fragment RFLP profiles indicative of LY phytoplasmas infecting *Howea forsteriana* and coconut palm in Florida and Honduras, respectively, were also observed. By comparison, the Jamaican LY phytoplasma population uniformly contained one or possibly two identical rRNA operons. No correlation between rRNA interoperon heterogeneity and strain variation in virulence of the LY agent was evident from this study. Cordova *et al.*(2003) detected in the DNA of the lethal yellowing (LY) phytoplasma in 13 of 72 embryos from fruits of four diseased Atlantic Tall coconut palms by polymerase chain reaction (PCR) assays employing phytoplasma universal rRNA primer pair P1/P7, nested LY group-specific rRNA primer pair 503f/LY16Sr or LY phytoplasma-specific nonribosomal primer pair LYF1/R1. Phytoplasma distribution in sectioned tissues from six PCR positive embryos was determined by *in situ* PCR and digoxigenin-11-deoxy-UTP (Dig) labelling of amplification products. Dig-labeled DNA products detected by colorimetric assay were clearly evident on sections from the same three embryos investigated in detail by *in situ* PCRs employing primer pairs P1/P7 or LYF1/R1. Deposition of blue-green stain on sections as a result of each assay was restricted to areas of the embryos corresponding to the plumule and cells ensheathing it. By comparison, similarly treated embryo sections derived from fruits of a symptomless 'Atlantic Tall' coconut palm were consistently devoid of any stain. Presence of phytoplasma DNA in embryo tissues suggests the possible potential for seed transmission which remains to be demonstrated. Ganoderma wilt is a serious disease in both coconut and oil palm. Latiffah *et al.* (2002) conducted restriction analysis and sequencing of the ITS regions and 5.8S genes of ribosomal DNA on 53 Ganoderma (causing basal stem rot on oil palms) isolates from infected oil palm and 15 isolates from coconut stumps to determine their relatedness. Restriction patterns of the ITS regions and 5.8S gene using seven restriction enzymes, namely, HindIII, EcoRI, BamHI, HaeIII, MspI, TaqI, and AluI did not produce any patterns that could distinguish between Ganoderma isolates from infected oil palm and coconut stumps. Variations of restriction patterns were observed within and between the two groups of Ganoderma which showed that the isolates were genetically heterogeneous. Based on the dendrogram from cluster analysis of the restriction patterns, the Ganoderma isolates from infected oil palm and coconut stumps were clustered together, indicating a close relationship. Phylogenetic analysis of the nucleotide sequence of the ITS regions and 5.8S gene of 12 Ganoderma isolates using parsimony and distance methods also showed that the two groups of Ganoderma did not cluster separately. Based on the present study, the Ganoderma isolates from infected oil palm and coconut stumps were indistinguishable and closely related which suggests that the coconut stumps in oil palm plantings may have an important role in disease development.

8.2 Tissue culture

Coconut is a difficult crop to manipulate *in vitro*. However, after Eeuwens' (1976) initial standardization of media and successful report of callus induction from various explant sources like stem, leaf, and inflorescence, a few laboratories around the world initiated intensive research. Unlike many crops, coconut was posing many problems besides this, the number of laboratories working on this crop was also less. Appreciating this, an international collaborative project was formed in 1995 consisting of researchers from France, Cote d'Ivoire, U.K., Germany, Philippines and Mexico. The results of this collaboration led to solving a large number of problems encountered in coconut tissue culture (Hocher *et al.*, 1998). Most commonly used basal medium at present is Y3 formulation (Eeuwens, 1976). However, Rosario (1984) found no difference between Murashige and Skoog's (1962) and Y_3 media. Her work indicated that glucose was better for callus growth than sucrose. The major problem in coconut tissue culture has been the browning of tissue and its consequent death. To offset this problem, the antioxidant used is activated charcoal (AC), which adsorbs even auxins and kinetins such as 2,4-D and benzyl aminopurine (BAP) to the tune of 99.4% and and 97.8% respectively after 5 days of culture media preparation (Ebert *et al.*, 1993). This kind of inactivation of supplementation results in excess use of auxins and cytokinins. Oropeza and Taylor (1994) used radiolabelled 2,4-D to study the uptake by coconut inflorescence explants. The tissue took up most of the radioactivity within 24 hours. At this time the volume of the explant was only about one tenth of that of the external medium and the uptake of 2,4-D occurred against a concentration gradient. Thus, uptake of radio labeled 2,4-D by coconut inflorescence cannot be explained by simple diffusion. Alternatively, 2,4-D may be taken up by facilitated diffusion. They emphasized the importance of pH for 2,4-D uptake by coconut explants. Among other auxins used, one was 2,4,5-T, which led to the formation of nodular calli on inflorescence explants (Buffard- Morel *et al.*, 1988), and others like NAA and IAA resulted in direct embryogenesis in leaf explants (Raju *et al.*, 1984).

Plantlet development was first achieved at CPCRI, Kasaragod from tender leaf tissue explants taken from 1-2 years old 'WCT' seedlings (Raju *et al.*, 1984). However, it was not reproducible in subsequent trials. Profuse callus induction was achieved from immature zygotic embryos. Regeneration of somatic embryos from the embryogenic callus has been achieved but plantlet differentiation is not regular. Several experiments in this direction are in progress. Somatic embryogenesis is usually indirect in coconut and has to pass through the callogenesis stage. Raju *et al.* (1984) reported direct embryogenesis and embryoid were reported to arise from vascular tissue but others reported this to be unusual as this area gives rise to root primordia normally. Karunaratne and Periyaperuma (1989) found that the embryogenic capacity of leaf explants was related to their physiological maturity in young palms of coconut. Leaf tissues from 12 to 24 months old palms were embryogenic but the potential was quickly lost with the onset of juvenility. Even in young palms, explants of tender leaves responded differently according to their maturity. Only a particular leaf in a particular state produces embryogenic cells and only a portion of this leaf yielded embryogenic explants (Karunaratne *et al.*, 1991). This may be one of the reasons why the experiments of Raju *et al.* (1984) were difficult to reproduce. Sporadic reports of success were reported using leaf explants by other workers also (Blake and Eeuwens, 1982; Shirke *et al.*, 1993; Siqueira de and Inoue, 1992; and Verdeil *et al.*, 1994). Buffard-Morel *et al.* (1992) reported successful production of somatic embryos from leaf explants which was supported by detailed histological studies. According to them the primary formations resulted from mitotic divisions of perivascular cells and differentiation of a cambium like layer insured the growth of nodular calli.

Tissue culture work with other explants such as zygotic embryos, leaf base, apical meristem and endosperm were also tried (Verdeil and Buffard Morel, 1995). Calli initiated from embryos, leaves, leaf bases, and apical meristem could not be regenerated (Neera Bhalla Sarin *et al.*, 1986). Calli induction from anthers and rachilla did not give repeatable response (Neera Bhalla Sarin *et al.*, 1986). But root explants (Jones, 1983), and sub apical and leaf explants due to their limited embryogenic potential (Karunaratne *et al.*, 1991) have limited potential. Immature inflorescence and immature embryos have been found to be of promise. Blake and Eeuwens (1982) reported initial success using inflorescence tissue for callus production. They used immature rachillae on Y3 medium (Eeuwens, 1976) supplemented with 0.5μM NAA. Branton and Blake (1986) produced plantlets in 9 months from immature rachilla explants through somatic embryogenesis of nodular callus by reducing 2,4-D on Y3 medium to 100μM 2,4-D, with 5μM each of 2ip and BAP, and 0.25% AC. Areza *et al.* (1993) soaked the inflorescence tissue in antioxidants viz., Citric acid (50mg l^{-1}) and Ascorbic acid (100mg l^{-1}), prior to slicing and culturing in Y3 medium supplemented with activated charcoal, which resulted in less browning. Verdeil et *al.* (1994) reported successful embryo maturation through somatic embryogenesis from inflorescence explants, which further regenerated into plantlets. They cultured immature inflorescences of coconut belonging to three different genotypes (PB-121, PB-111 & MYD), on an agar medium supplemented with activated charcoal (0.2%) and a range of 2,4-D (0.15 to 0.35 mM). Globular white callus emerged from immature floral meristems, depending on inflorescence age and 2,4-D levels. The use of immature inflorescences has been most successful among the different explants tried, and plantlet regeneration has been successful even though the transfer to nursery is yet to be achieved. The use of plumular tissues from germinating embryos has been another source from where success has been forthcoming, because of the juvenile nature of the tissue (Hornung, 1995). Buffard-Morel *et al.* (1995) used young non-chlorophyllous leaves and immature inflorescence in Eeuwens inorganic nutrients supplemented with Morel and Wetmore vitamins, 30 gl^{-1} sucrose, 2 gl^{-1} activated charcoal and 40 to 60 gl^{-1} 2,4-D. They observed calli, 6-8 months after culture initiation. They observed a multicellular pathway, which led to the formation of meristematic and epidermised structures with low 2,4-D (40 to 60 gl^{-1}). The first stage of development of these structures was characterised by the fragmentation of the cambium like zone and the formation of complex meristematic structures followed by their epidermisation. They observed a unicellular pathway, which led to the appearance and individualization of embryogenic cells isolated by a thick wall, with dense cytoplasm, a high nucleo-cytoplasmic ratio, and single large nucleolus and starch and protein reserves. This pathway was the result of the presence of high 2,4-D concentration (80 - 120 g l^{-1}). Chan *et al.* (1998) developed a protocol using plumules of zygotic embryos. They used Y3 medium supplemented with 0.1mM of 2,4-D, 2.5 g l^{-1} activated charcoal, and solidified with 3g l^{-1} gelrite. The cultures were incubated for 3 months in darkness at 27°C. The calli bearing embryogenic structures were cultured in same medium with 1μM 2,4-D and 50μM BAP at a photoperiod of 12-hour light at 27°C, and subcultured every three months. Plantlets were produced after 6 to 9 months.

Griffis and Litz (1997) used anthers and filaments, unfertilized ovaries and immature leaf pieces. Both callus initiation and direct initiation of somatic proembryos were stimulated by addition of 2,4-D to the culture media. In a few cases, somatic embryos arose directly on filaments attached to immature anthers after several months in culture. Unfertilized ovaries cultured in media supplemented with 2,4-D and diethylstilbestrol (DES) monitored for 24 months indicated substantial fresh weight gains and numerous unusual morphogenic changes in ovaries in Y3 medium supplemented with 5 or 15 mg l^{-1} DES, 25 or 50mg l^{-1} 2, 4-D and 3 mg l^{-1} 2iP. Several unfertilized ovaries formed callus and adventitious roots but not somatic embryos. On similar media, some seedling immature leaf tissues formed callus on their cut edges while other formed roots or numerous somatic proembryos directly. Some proembryos also developed haustoria like tissues or roots and obvious bipolarity, but further shoot apical development did not appear except in one case.

Abscisic acid is also reported to induce somatic embryogenesis in coconut. Studies carried out by Adkins *et al.* (2002) have shown that whole immature, or mature sliced, zygotic embryos are a very good starting explant for coconut somatic embryogenesis. The highest rate of somatic embryogenesis was obtained when certain polyamines were added into the culture medium as well as activated charcoal (AC) to absorb unwanted phenolics. These past studies also showed that the development and maturation of the somatic embryos produced could be improved by the addition of abscisic acid (ABA), alone or with one of several osmotically active agents, into the culture medium. In the present study this well characterized somatic embryogenic system for zygotic tissues is being modified and applied to somatic tissues. This recent approach should be a better method for the rapid production of clonal, true-to-type coconut palms. The present research approach is focused on young leaf section explants which have been very responsive to callus production. Young leaf sections produced optimum callus when cultured on media containing 2,4-D (150 μM) and the amount produced could be increased by soaking the sections in sterile water (15 to 60 minutes) or ascorbic acid (15 to 30 minutes) prior to culturing. Further improvement in callus production, as well as a reduction in the time taken for callogenesis was obtained when casein hydrolysate and/or certain polyamines were added to the callus induction medium. The development of the somatic embryos was improved by using ABA and polyethylene glycol (PEG) in the maturation medium.

Fernando and Gamage (2000) induced nodular callus from 7-9 months old immature zygotic embryos in BM72 medium supplemented with 24 μM 2,4-D. This callus was subcultured into the medium supplemented with 2.5-7.5 μM ABA for 3-7 weeks and subsequent subculture at 5 weekly intervals on media containing gradually reduced concentrations of 2,4 -D. They found incorporation of ABA enhanced the production of somatic embryos. These emrbyos formed normal plants. Studies by Samosir *et al.* (1999) have indicated that the development and maturation of coconut somatic embryos can be improved by using ABA alone or with any of the osmotically active agents, preferably PEG.

Immature zygotic embryo explants were more likely to undergo somatic embryogenesis than mature ones. Samosir *et al.* (1998) used longitudinally sliced mature zygotic explants and cultured them in medium supplemented with 125-μM 2,4-D and 2.5 gl^{-1} activated charcoal. Plantlets were successfully produced by the application of NAA (10μM), allowed for normal seedling growth to occur. Control of ethylene and polyamines has been found to improve somatic embryogenesis in coconut. Adkins *et al.* (1998) used cotyledonary slices from coconut embryos and cultured in medium with additives like aminoethoxyvinylglycine (AVG) and silver thiosulphate (STS), which could reduce ethylene production or polyamines such as spermine, putrescine and spermidine. Somatic embryogenesis was promoted by supplementation with AVG (2μM) or STS (3μM) or by the addition of putrescine (7.5μM) and spermine (1μM). STS also aided somatic embryo proliferation, maturation, and germination.

Use of zygotic embryo culture for germplasm collection, storage and retrieval has been standardized and put into practice in India (Karun and Sajini, 1994; Karun *et al.*, 1996). Koshy and Kumaran (1997) collected 15 accessions from the Indian Ocean Islands of Mauritius, Madagascar and Seychelles (Anon., 1998) and later Parthasarathy (2001) used this technique to collect four accessions from Sri Lanka.

Santamaria *et al.* (1999) suggested that sucrose might be important in early stages of coconut embryo cultures, to maintain high chlorophyll concentrations and a high number of chloroplasts. The continuous growth of the resulting plantlets in sucrose containing medium, however, will affect the development of photoautotrophy and in turn affect the performance when transferred to soil. Physiological and biochemical variations in plantlets due to variations in media compositions have been studied (Naresh Kumar *et al.*, 2002a). The establishment of photosynthetic mechanism in *in vitro* development of zygotic embryo-cultured coconut plantlets and during acclimatization had been delineated (Triques *et al.*, 1997a and 1997b; Naresh Kumar *et al.*, 2001). Plantlets also undergo chlorophyll and leaf morphological acclimatization (Ranasinghe *et al.*, 1999). The RUBISCo activity was low in *in vitro* coconut plants just before acclimatization. The ratio of PEPCo to RUBISCo decreased during the *in vitro* development and is an indicator of transition from heterotrophic to autotrophic phase in coconut (Triques *et al.*, 1997a and 1997b). Later, Naresh Kumar *et al.* (2001) observed that the embryocultured coconut plantlets undergo photosynthetic acclimatization with increased PSII efficiency and water use efficiency during plantlet acclimatization process. They also noted that even though the zygotic embryocultured plantlets initially have less photosynthetic rates, they attain rates similar to those in seedling raised ones in due course of time. Sandoval *et al.*(2003) studied the cell cycle of coconut palm tissues cultured *in vitro* in order to regulate regeneration. Coconut palm is a plant for which it is difficult to monitor the ability of the meristematic cells to actively divide. Cell nuclei were isolated from various types of coconut palm tissues with and without *in vitro* culture. After the nuclei were stained with propidium iodide, relative fluorescence intensity was estimated by flow cytometry. Characterization of the cell cycle reinforced the hypothesis of a block in the G0/G1 and G1/S phases of the coconut cells. A time-course study carried out on immature leaves revealed that this block takes place gradually, following the introduction of the material *in vitro*. Synchronization of *in vitro*-cultured leaves cells using 60 μM aphidicholin revealed an increase in the number of nuclei in the S phase after 108 h of treatment.

8.3. *In vitro* conservation

Coconut is a recalcitrant species and the nuts donot undergo maturation drying and are shed at a relatively high moisture content (Parthasarathy, 1999). One of the earliest reports of cryopreservation coconut embryos was reported by Chin *et al.* (1989). They found that embryos cryoprotected with 10% DMSO showed the highest percentage survival after cryopreservation followed by 10% glycerol. Earlier Bajaj (1984) reported only elongation of whole embryos or proliferation of the cut ends of transverse halves of the embryos after cryopreservation and he did not observe normal development. He used 7% DMSO and 4% sucrose as cryoprotectants and the percentage of survival was low (17-25%). Karunaratne *et al.* (1985) reported one of the earliest attempts to preserve the coconut embryos in culture in a dormant state. They devised a special survival medium, which suppressed the growth of embryos for a period of 5 months. Assay-Bah and Engelmann (1992a) found that immature embryos of coconut (7 to 8 months after pollination) can withstand rapid freezing in liquid nitrogen after 4 hours of pregrowth on a semi solid medium containing 600g l^{-1} glucose and 10 to 15% glycerol or sorbitol. In these conditions, survival ranged from 10 to 43% and one embryo developed into a rooted plantlet, 2.5 months after freezing. While in a later study Assay-Bah and Engelmann (1992b), observed mature embryos (10-12 months after pollination) of four cultivars of coconut could withstand cryopreservation in liquid nitrogen and develop into plants. Pretreatment consisted of a 4-hour desiccation in the air current of a laminar flow cabinet followed by a 11 to 20 hours culture on a medium containing 600g l^{-1} glucose and 15% glycerol. They carried out freezing and thawing with recovery rates between 33 and 93% of frozen embryos, depending on the cultivar. Assay-Bah and Engelmann, (1993) subsequently developed optimal conditions for the medium term conservation of zygotic embryos. After 6 months of storage on a medium devoid of sucrose and containing 2g activated charcoal l^{-1}. Hundred per cent of the embryos developed into whole plantlets within 5 months after transfer to the recovery medium. After a 12-month storage period on medium containing 15g l^{-1} sucrose and devoid of activated charcoal, 51% of the embryos germinated within 2 months after transfer to the recovery medium. The presence of sucrose in the storage media has been reported to initiate the embryonic response to cellular expansion and elongation as well as cell division of the epidermal layer to keep pace with the expanding tissues (Mkumbo and Hornung, 1997). Engelmann *et al.* (1995) studied the factors affecting the cryopreservation of coconut embryos. They found that embryos should be used only when they are in an optimal physiological state as regards their maturity and metabolic status. Modifications of recovery conditions can greatly increase the survival rate of zygotic embryos.

Recently, a large number of basic studies on the physiological and biochemical aspects of somatic embryogenesis and regeneration have been published. Based on the response of coconut callus to somatic embryogenesis induction medium (SEI), Magnaval *et al.* (1997) observed 3 types of response, namely, the traits that were modified by SEI condition and varying over time; the second type of response corresponded to traits modified by the SEI condition but constant over time and the third type of response corresponded to traits unchanged by the SI condition and over time. They studied the specific nutritional requirement of coconut calli during these phases. In another study by the same group (Magnaval *et al.*, 1995), they classified the calli into five groups based on their amino acid composition by a clustering method. Dussert *et al.* (1995) presented a detailed study on nutrient uptake and growth of *in vitro* coconut callus. Another aspect of research worth mentioning is the photosynthetic ability of *in vitro* grown coconut plantlets. Triques *et al.* (1997) studied various photosynthetic parameters using complementary approaches. Transmission electron microscopic studies revealed a complete ultrastructural organization of chloroplasts in plantlets at the end of the *in vitro* culture process (6 weeks under light). Studies by Rival *et al.* (1999) proved that coconut belongs to the class of plants in which the *in vitro* grown leaves can contribute to autotrophy and then play an active part in acclimatization as indicated by the dramatic decrease in the PEPCO / RUBISCO (ribulose, 1, 5 bisphosphate carboxylase/oxygenase) activity ratio and the increase in the photochemical activity of PSII.

9.0 Climate and soil

The coconut palm is highly adaptable to a variety of environments. But, for healthy growth and satisfactory production, soil and climate parameters have to be given due consideration particularly when establishing plantations in new regions where it was not grown before. The coconut palm derives its characteristics from the fact that it is essentially a tropical plant. In this connection factors such as latitude, altitude, rainfall, temperature, humidity, sunshine etc. require detailed consideration.

9.1 Climate

9.1.1 Latitude

The coconut palm occurs widespread in the coastal area of the tropics, 90% of the world's total acreage and production of the crop lie in between 20° N and 20° S latitude (mostly in Philippines, India, Indonesia, Sri Lanka, South Sea Islands and Malaya) (Menon and Pandalai, 1960). The palm is grown even beyond this region, as far as 27°N and 27°S, but not on an extensive or commercial scale. The extreme South to which the coconut is reported in South Dolphin in Madagascar-latitude about 25° south and as far North as Lucknow in India-latitude about 27° north, but they are found to be unproductive (Patel, 1938). Coconut is grown in parts of China also. In extreme latitudes the palm is reported to put on good vegetative growth but not to bear fruits satisfactory. There are coconut gardens near Kandy, Sri Lanka, 7° N latitude and at an elevation of 520 m, with an average annual mean temperature of 25° C, which is roughly the limit of commercial successful cultivation in Sri Lanka (Child, 1974).

In India the palm is found grown at different altitudes within 26°N latitude. At different latitudes, it is the temperature that determines the limit to altitude upto which the palm can be grown successfully. Thus, nearer to equator where the temperature would be favourable, the palm can be grown at higher elevation of even upto 1000m above the sea level. Thus, in places like Bangalore, India at latitude 13°N, the palm grows and yields exceedingly well at 900 m above sea level (Menon and Pandalai, 1960). Moving further from the equator the temperature tends to drop and becomes less favourable and, consequently the cultivation is to be confined to low lands (Menon and Pandalai, 1960; Patel, 1938; Thampan, 1984). In Jamaica at latitude 18°N, the coconut palm is usually not grown 120 m above sea level (Thampan, 1989). In Philippines which lies between latitude 4° 23′ and 20°N, the palm is adapted to altitudes ranging from sea level to 800 m, where the rainfall is fairly abundant and of even distribution with no period of prolonged drought, and a rather humid atmosphere (Thampan, 1989).

9.1.2. Altitude

The latitude sets the limits to altitude upto which the palm can be grown successfully. In areas further from equator, the palm is confined to low lands. In India, Sri Lanka, Philippines and Malaysia, the major parts of coconut areas extend to an altitude of upto 600 m (Menon and Pandalai, 1960). It may be possible to grow the palm at elevations upto 900 m near the equator, where temperature is favourable for its growth. According to Cooke (1936), an altitude of 600m appears to be the limit for commercial cultivation of palm in the Philippines. At higher elevations the palm has poor and stunted growth, takes considerably longer period to bear, and yields only a few nuts of small size (Child, 1974). In Indonesia, it has been observed that palms growing at elevations above 500m are invariably poor yielders, producing nuts of comparatively lesser oil content (Thampan, 1989). Critical studies of the performance of palms in different countries are inclined to conclude that 800 to 900m is possibly the upper limit for economic production.

9.1.3. Temperature

Temperature is the one weather factor that seems to decide the territorial boundaries of the coconut area in latitude and altitude. The palm needs a temperature that is not only high, but also as constant as possible. A mean annual temperature of 27°C with diurnal variation not exceeding 7°C is considered optimum for the coconut palms (Menon and Pandalai, 1960). A temporary steep fall or rise in temperature, which probably happens occasionally in all places does no harm, provided that such extremes do not last for long periods at a stretch (Nair, 1979). However, places where the climate is characterized by long spells of hot day weather during summer and severe cold associated with cold wave and frost during winter and cyclone prone areas and also places at high altitude lying further from the equator where temperature would act as a limiting factor are not suitable for coconut cultivation (Thampan, 1989). The ideal mean annual temperature for coconut growing is usually considered to be in the region of 29°C (27-32°C), with abundant sunshine and a well-distributed annual rainfall between 1250 and 2250 mm (Cornelius, 1973; Purseglove, 1972). Persly (1992) suggests that for optimum production, coconut requires an average temperature of 29°C with a diurnal variation not exceeding 7°C, and an annual rainfall of at least 1800mm evenly distributed throughout the year. Although the distribution of coconut palm extends outside the tropics in places as far north as 26°N and south to 27°S, the major areas of production lie between latitudes 20°N and 20° S, and below the 300m contour. High temperature might cause the young developing inflorescences to dry up, and limit production to those months in the year when the temperature remains at a satisfactory level (Menon and Pandalai, 1960). Higher temperature than the optimum are tolerated and are only harmful when they coincide with low humidity, possibly aggravated by hot dry winds, causing a rate of transpiration from the leaves insufficiently compensated by water supply through the roots (Child, 1974). Occasional short spells of low temperature, provided they do not reach freezing point, may do no considerable damage, but may check development. Frequent, even short periods of temperature below 15°C result in abnormalities of fruit such as bicarpelate nuts (Child, 1974). Various authors quote a degree or two either side of 27°C for the optimum production of palm.

9.1.4. Rainfall

Rainfall is one of the important factors that affect successful growth of coconut palm under natural conditions. The coconut palm can grow and bear fruits with a well-distributed rainfall of 100cm, but for the profitable cultivation, 100 to 225 cm annum^{-1}, evenly distributed throughout the year appear necessary (Menon and Pandalai, 1960). It can stand even much higher precipitations, if the soil is well drained. As the tree stores little moisture and has no tap roots, it is not suited for regions with long and pronounced dry spells during which the water table goes down considerably (Menon and Pandalai, 1960). In shallow and well-drained soils the adverse effects will be more pronounced. Under such conditions and also where annual rainfall is less than 100cm, economic production is possible only under irrigation. In parts of Gujarat state in India, receiving only 25 cm to 50 cm of rainfall annum^{-1}, good coconut gardens have been raised with abundant irrigation water (Menon and Pandalai, 1960). On the other hand palms do not tolerate high water table and stagnant water over long periods (Menon and Pandalai, 1960; Nair, 1979). Spikelets of the inflorescence is formed about 15 months before the opening of the spathe, and of the female flowers before 12 months. Even after the spathe is opened, female flowers remain for about 11 to 12 months to develop into full mature nuts. Therefore, severe drought during early formative period of the inflorescence may kill the growing points due to desiccation resulting in the abortion of spadix (Thampan, 1989). However, rainfall is not a limiting factor under certain favourable conditions if irrigation facilities are provided. Coconut can be grown even with lower rainfall which is evident from the fact that in Zamboanga (Philippines) where the best coconut cultivars are reported, the average rainfall is below 100 cm (Patel, 1938). The distribution of rainfall is more important than the total quantity. In Sri Lanka and Malaya there are no months during which rainfall is not received, but on the West coast of India, there are at least two to three rainless months.

On the West coast of India wherein lies the major coconut belt, rainfall increases in quantity from the south to north; but its distribution becomes less and less favourable. This difference in the distribution is reflected in the general productivity of the crop. The annual rainfall in Sri Lanka, which is well known for its coconut industry, varies from 125 to 225 cm. Annual rainfall in other important coconut growing countries like Java, Seychelles, Zanzibar is 229 cm; Dutch Guyana and Marshall Islands –398 cm; Trinidad –155 cm; and Malaya from 178-391 cm.

The gross effect of severe drought is very pronounced in coconut plantations of the dry zones. Unless ground water conditions are favourable, a period of three months with less than 50 mm precipitations month^{-1} will be deleterious. The number of nuts harvested was lowest, 13 months after the end of the drought and recovered to normal only two years after the end of the drought (Park,1934). In an experiment in Trinidad (Smith, 1966), it was found that the yield in a particular year was correlated with the integrated soil water deficit over the 29 months preceding the beginning of the season.

Of all the factors, which influence coconut yield, rainfall is the most important but the relationship is not a simple one, as Salter and Goode (1967) in their review of crop response to water pointed out; with so great a time lapse between the initiation of leaf and inflorescence primordia and flowering, and with many other influences present at the time, it has been found difficult to relate accurate growth, flowering or yield responses to any particular climatic conditions. However, recent research efforts could indicate the impact of drought (Rajagopal *et al.*, 1996; Rajagopal *et al.*, 2000) and various weather (Naresh Kumar *et al.*, 2002b) variables on coconut yield.

The effective rainfall received during the different periods of the year is more important than the total rainfall received during any particular period of the year and effectiveness or otherwise of the rainfall received during any particular period is determined by the texture and depth of the soil type, length of the day, atmospheric temperature and humidity (Thampan, 1989; Rajagopal *et al.*, 2000; Naresh Kumar *et al.*, 2002b).

9.1.5 Humidity

The coconut palm, in general, likes a climate characterized by warm and humid conditions (Menon and Pandalai, 1960). The highest relative humidity is generally recorded on the West coast of India; the average monthly humidity at 7.30 am rarely falls below 70% (Patel, 1938). According to Copeland (1906 and 1931), persistence of highly humid condition right through is not considered good for the palm from two aspects. One is that it reduces transpiration and thereby reduces the uptake of nutrients. The other is that it provides congenial conditions for the rapid spread of fatal disease of the palm, viz. bud rot, etc. The leaf disease of coconut palm in Kerala (India) is found to spread rapidly during rainy months where atmospheric humidity is high. In Sumatra, high humidity was reported to cause premature decay of fruit (Menon and Pandalai, 1960).

9.1.6 Sunshine

The coconut palm requires plenty of sunlight and does not grow well under shade or too cloudy regions. It becomes stunted under heavy shade, and cannot survive competitions from unchecked forest growth (Menon and Pandalai, 1960; Child, 1974). Young palms may be grown for a time under the shade of old palms, as during replanting, but the demand for root room and light by the under plants make it desirable to remove the old plants by the seedlings attaining eight years age (Child, 1974). Wickremasurya (1968) related accelerated development of spadix primordia to length of day in West Sri Lanka. Ziller (1960) reported that the copra outturn and the potash–copra outturn response were correlated with sunshine in last months of ripening of the nut. The Madampe district of Sri Lanka, one of the premier producing areas of the islands has an average bright sunshine of 7.1h day^{-1}, and this may be taken as typical of optimum sunshine condition (Child, 1974).

9.1.7 Wind

Dry and windy atmosphere is conducive to the best growth of the palm provided soil moisture conditions remain at optimum level, but that where the soil is dry, only little wind is desirable (Copeland, 1931). Windiness increases the transpiration rate and helps in the uptake of more nutrients in the soil solution. But regions, which are vulnerable of violent winds are not suitable for the palm (Menon and Pandalai, 1960). They not only uproot or break the trees but also twist the crown or break the leaves and destroy a considerable part of the crop. The cyclones that struck the Southern districts of Madras (India) in 1952 and again in 1955 and Andhra Pradesh, Gujarat and Orissa states (India) in 1996 and 1998 destroyed so many palms which will take years before the level of production can be brought back to that of the pre-cyclone period (Menon and Pandalai, 1960; Child, 1974; Dash *et al.*, 2002). In Sri Lanka in October 1967, it was estimated that of a total of 6.5 million palms in Chilaw district, about 400,000 (6%) had fallen, about 300,000 were slanting perilously and a further 350,000 had crown damage or other injuries, a total of over 10 per cent, in addition there was a high proportion of remaining palms liable to rhinoceros beetle and for palm weevil attack (Abeywardena, 1967). A cyclone, which struck Jamaica in 1944, is reported to have destroyed 40 per cent of the palms (Menon and Pandalai, 1960). The remote possibility of a cyclone occurring, however, is no reason why coconut cultivation should not be undertaken if the area is otherwise congenial for the crop.

9.2 Soils

Climate and soil are very closely related. The type of soil in any given area depends more upon the climate and consequent weathering conditions than on the parent material of the past (Child, 1974). Coconuts are grown under diverse soil conditions ranging from littoral sands to clayey soil, ill drained and low lying areas to well drained with slopes, strongly acidic peaty soils to alkaline calcareous soil. The palm is found to be growing on all these soil types irrespective of the parent material from which they have originated. Thus it has been found to be grown well on white or gravely sand, alluvial soils, laterite or lateritic, peaty or *Kari* soil, volcanic and pumic soils and marine and coral soils (Menon and Pandalai, 1960).

Tempany (1954) believes that the palm grows only in tropical climate and does best in light easily permeable soils with slowly moving sub soil water at a shallow depth. There are vast areas of coastal land throughout the tropics, which have been and could be used for coconut cultivation (Martyn, 1955). It can however, grow well on heavier soils provided they are well drained. Menon and Pandalai (1960) have described the soil of the major coconut growing area of the world. Fremond *et al.* (1966) grouped the major coconut soils of the world under five categories: sandy, lateritic, alluvial, volcanic, and clayey. Even though the relative ease of adaptation of the palm has enabled it to spread widely over the very varied soils of the tropical zone, the best coconut soils are characterized by a light texture such as deep alluvium and sandy loam, good drainage, adequate supply of soil moisture and nutrients, and at least 1m depth without hard layers (John, 1949, 1952; Nair, 1979).

9.2.1 Characteristics of coconut soil

The major soils of the coconut areas of India lies in certain well defined zones on the West and East coasts and the tableland of Karnataka, more than two-third of it being in the strip of land between the Western Ghats, and the Arabian sea (John and Menon, 1947). The coconut areas in India can be grouped into the following well-defined zones:

1. Coastal sandy soils of the West and East coasts of the peninsular lying in Kerala, Karnataka, Maharashtra, Goa, Tamil Nadu and Andhra Pradesh states.
2. The lateritic soil of the midland and upland regions lying between the coast and hill slopes of Kerala, Karnataka, Maharashtra and Goa
3. Sandy loam soil of Kerala and Tamil Nadu
4. Clayey reclaimed areas of the backwaters of Kerala
5. Red soils of Karnataka and Tamil Nadu
6. Alluvial soils of Kerala, South Kanara districts of Karnataka and Godavari delta of Andhra Pradesh
7. Forest soils of Andaman Islands and
8. Coral soils of Lakshadweep Islands

Sankarasubramony *et al.* (1954) carried out detailed studies of coconut soils in Travancore-Cochin and found that coconut grows and yields well in the coastal soil, alluvial and loamy inland soils as well as on laterite and reclaimed soils. With suitable management practices, all normal soils could be used for coconut cultivation (Sankarasubramony *et al.,* 1954; Pandalai *et al.,* 1953). Sankaranarayanan and Velayuthum (1976) described the characteristics of some of the major coconut soil types of South India. Laterite soil which occupy a major portion of the coconut area in India are characterized by red to reddish brown colour, abundant ferruginous gravel, shallow to moderately good depth, good drainage, a friable to hard substratum of laterite, and very low water table (6 to 9 m) in summer. They are low in available phosphorus and potassium, poor in base status, medium in nitrogen, high in free oxides of aluminum and acidic in reaction (Menon and Pandalai, 1960). Coastal sandy soils are of marine origin, very coarse in texture, with less than 3%

clay, highly drained, excessively permeable and leached, very poor in organic matter and plant nutrients and acidic in reaction (Menon and Pandalai, 1960).

The red sandy loam soils are deep, well drained, and devoid of gravel impenetrable layer, with low water table (below 6m) in summer and high water table during rains, have medium status of available nutrients and organic matters, and are acidic in reaction (Menon and Pandalai, 1960).

The reclaimed marshy soils of Kerala are formed by reclamation of low-lying swampy and marshy lands adjoining the backwaters. The reclamation process consists of forming mounds by heaping up layers of sand, silt, and organic wastes to a height of one metre above ground level or water table, on which coconut seedlings are planted. In course of time, the gaps between mounds are filled using the above materials and providing drainage channels between rows of palms (Nelliat, 1956). These soils are black in colour, coarse to medium in texture at the surface, tending to be finer at stratum approaching the original soil beneath, very acidic with fair amounts of soluble salts (acidic sulphate soils), high in nitrogen and organic matter, but low in P and K, and have high water table (1m). Alluvial soils are formed from alluvial parent materials transported and deposited by rivers and streams and vary in characteristic from place to place. The texture ranges from sandy to silty, clay loam to clay, deep and well drained in the uplands, but poor drained in low-lying areas with high water table and clayey subsoil. Coral soils of Lakshadweep islands are underlined by limestone gravels of different shapes and sizes, the calcium carbonate content is very high (about 85%) and the pH above 8. The forest soils of Andaman islands are rich in organic matter and plant nutrients, but leached, and acidic in reaction. The nutritional status of major coconut growing soils of Kerala was investigated in details (Sankarasubramony *et al.*, 1954, Pillai *et al.*, 1975; Anon.1972). According to Patel (1938) the largest area under coconut in India is located on the red laterite soils. Good yields are obtained in black clayey soils also. Coconut can be grown in almost pure white sand, to all appearance quite barren, provided there is an underground supply of fresh water within the reach of the roots. The best soils for the coconut are rich alluvial soils with sufficient quantity of sand to provide good drainage. Coconut is also grown on hill slopes, but terracing has to be resorted to, so as to prevent erosion and to facilitate cultural operations. Hard rocky pan near the surface of the soil is undesirable because during the rainy season the trees suffer from water logging. Palms standing on the bunds of rice fields yield very well, mainly due to sufficient aeration of the roots, adequate supply of water to the plant and good amount of light to the leaves.

Sandy soils, especially of littoral type without any source of ground water, stiff clayey soils with impeded drainage, laterite soils with hard rock beneath the surface and highly eroded and impoverished soils are not congenial for coconut plantations (Thampan, 1972). From the point of view of intensive cropping, special areas such as mangroves, coral soils, reclaimed marshy lands, littoral sands and raised bunds, which are suitable or made suitable by appropriate ameliorative measures, for the establishment of coconut palms, are not suited for economic intercropping. But for such areas most of the soils in which coconuts grow in India can support other crops and are thus suitable for intensive cropping (Nair, 1979).

In the Philippine islands, the soil varies from sandy to clay. Cooke (1936) compared the clay soil of this region with typical soil conditions obtained in Malaya, the sandy soil with certain regions in Sri Lanka and certain volcanic soils with similar ones in South Sea Islands. Clay soils are regarded as the least suitable for coconut cultivation, the best being the light alluvial limestone soil of river valleys and along the shores. Volcanic soils are also said to be highly suitable for coconuts. Typical soil pH values are 6.2 for poor yielding clay, 7.0 for a high yielding volcanic alluvium and 8.3 for high yielding coral sands (Menon and Pandalai, 1960).

According to Grange (cited by Eden, 1953), all the soils of Western Samoa may be termed laterites and they are uncommon in that they contain from 7.8 to 12.6 per cent of titanium oxide. The Samoan soil is very fertile even though old disintegrated lava lies either a few centimetres below the topsoil or in jumbled masses on the surface. Coconuts grow there sending their roots through the surface lava and find rich deposits of soil in the lower and older lava flows. In Seychelles, according to Durocher Yvon (1953), coconut cultivation is carried out on the two main soil type, the granitic and coral. In the granitic islands, the coconut plantations form a peripheral belt around the mountain massif, cultivation encroaching up the lower slopes. Some of the smaller islands are entirely planted with coconut. The plantations comprise flat narrow coastal stripes of coral sand of marine origin. This type of soil is very light, extremely friable and allows free percolation, with water table of 1½ metre to 2½ metre below. Fluctuation of the water table with the rise and fall of the tide coupled with the slow movement of the hillside drainage water through the plateau are responsible for the optimum conditions. The alluvial plantations are on the richest soil but are only restricted in area, while the largest areas are on the sedentary laterite soil. These are not very good for coconut, having lost their original structure through sheet erosion and offer minimum porosity, permeability and water holding capacity, physical conditions so detrimental to the coconut.

Several thousands of acres now under coconuts on the coastal soils which are shallow, recently weathered clays and clay loam, mixed with some loose coral and appreciable amounts of organic matter (Burcham,1947). In the Kedoe plain of central Java, in Southern Luzon and on the Coromandal coast of India, paddy lands and coconut groves are found interspersed. Some of the best coconut thrive on such lands, which are found to be most productive. This is due to suitable soil conditions besides plenty of sunshine. In Malaya, on the West coast and the inland areas, the crop is usually cultivated on heavy clay soils but on the East coast, however, cultivation is on sandy soils. The heavy soils are classed as clays (less than 20% loss on ignition), organic soils (between 20 and 80 % loss on ignition) and peat soils (over 80% loss on ignition). On the peat and organic soils growth and yield depends to some extent on the distance of mineral clay from the surface. Drainage is extensively practiced on all soil types. The heavy clays respond well to drainage as they posses considerable permeability and being well supplied with nutrients, they do not require much fertilizing (Belgrave, 1931). Smith (1932) discussed cropping capacities of heavy alluvial soil in Malaya.

Wernigg (1932) described the coconut industry in Andaman islands and found that the soil was a rich clayey loam, fertile but somewhat deficient in available phosphoric acid. However, after exploring the possibilities of coconut cultivation in Andamans, John (1951), reported that the soil and environmental conditions especially in lower slopes of the hills and land bordering the sea appeared to be suitable for the coconuts. These soils were virgin and therefore of high fertility status. According to Albuquerqe (1955), coconuts in Car Nicobar islands are grown on soils which were formed largely of decaying vegetable matter mixed with soft coral rock beneath. The soils are rich in many parts of the island with high lime content. The water table is high being 2½ metre to 3 metre below ground level on summer. The rich soil and favourable distribution of rainfall made the island pre-eminently suitable for the coconut and large plantations are in existence along the coastal coral and sandy belt in all parts of the island. In Viti Levu in the Fiji Archipelago in the South-west Pacific, coconuts are grown on different soil type such as alluvial, terrace soil, rolling land soil, hill land soil and marine marshes (Menon and Pandalai, 1960). Coconut soil in Trinidad varies from sandy fringes of beach to the heavy island clays. Coconut in Thailand is grown commercially along seashore and on islands in the gulf of Thailand, while inland, it is grown on scattered areas for home consumption. Henderson (1956) stated in a private communication that the main soil types on which the coconuts are grown in the territory of Papua New Guinea are marine sand along the coastlines of the New Guinea main land, volcanic pumic soils on the Gazelle peninsula of New Britain and mature soils developed over coral in New Ireland

In Solomon islands, the plantation areas predominate on coralline and igneous rocks (Pagden, 1936). The most consistently good estates are on Russel Islands where the main soil type is rich chocolate loam averaging about 1.8 per cent organic matters and pH ranging from 5.5 to 6.0 in the surface horizon. Less satisfactory growth is found on Malaita islands where the soil is heavy, often water logged clay, containing for example 3.64 per cent organic matter having pH value 6.9. Generally better basaltic or alluvial sands and loams occur in the neighboring Guadalcanal islands. Pagden mentions an estate on very hard shelly limestone covered by only a few centimetres of soil, which yielded an astonishing crop of over a ton of copra $acre^{-1}$ (Jacks, 1936).

Child (1955) recorded that in East Africa the soils are mostly sandy or sandy loam, low in organic matter. The pH values are mostly around 6.0. The soils are deficient in phosphoric acid as well as potash. In the quilimane coastal regions there are many swampy areas in the depression, which are not really suitable for coconut cultivation. Coconut cultivation in the Gold coast is largely confined to a narrow coastal belt extending all along the seaboard with the largest areas of cultivation at the eastern and western ends. In the Keta area, the coconut soils are largely coarse marine sands, light coloured and generally deficient in organic matter and derived from tertiary or recent formations. Coconuts are cultivated on the tidal clays in this area and these consist of light sandy clay topsoil of high salinity overlying a black peaty sub-soil. In the western province the coconut soils overlie Appollanian (Certaceous) formations, coastal coarse sand dunes, merging into fertile coarse sandy loam, free draining and being ideal for coconut cultivation. Baldassari (1932) described the soil under coconut in the Italian Somaliland. Pulgar Vidal (1953) stated that in Columbian territories, particularly in the San Andes Archipelago, the most suitable soils for coconut are volcanic or alluvial sandy soil of depth greater than 60 cm.

Bunting (1930) described the soil types in various districts of north-west province of Ceylon as well as methods of soil cultivation and conservation practiced there. Cooke (1932) listed seven common coconut soils,viz, red clay, loam, sandy loam, clayey sand, gravelly laterite coarse and fine sand, all of which according to him are characterized by lightness and deficiency in humus and mineral nutrients. Coconuts are cultivated in the higher parts of undulating grounds, the wide intervening valleys being used for paddy. The soil is shallow and is underlain by rock. Upland soils tend to be more productive than the soil situated near sea level owing to greater movement of soil water in the former. Salgado (1950) described river alluviam estuarine deposits and limestone-derived soil to be good for coconuts, whereas laterite cabook, laterite gravels, cinnamon sands and estuarine clays are poor. The laterite soils are deficient in phosphoric acid and potash and moisture conservation is necessary on the laterite gravels. Cinnamon sands require conservation of organic matter and drainage facilities. The estuarine clays require manuring and deep ploughing and husk burying in order to make coconut cultivation economic on these soils.

9.2.2 Physical and chemical properties of coconut soils

Coconut soils show the widest variations in classification by mechanical analysis. They range from coarse sand of the East coast of Sri Lanka, which contains upto 97% of sand (0.2 to 2.0 mm.) to the East coast, Philippines, heavy soils with about 70% of clay and peat soils of Malaya with over 80% of organic matter (Child, 1974). On the West coast of India, coconut is grown on laterites (clay 52 to 75.6 per cent) coastal sand and red sandy loam, on the East coast on deltaic alluvium (clay 30 to 33 per cent), coastal sandy areas, and on localized patches of red and black soils in the interior areas.

Useful analytical data on soil are pH, base exchange data and C/N ratios (Twyford and Wright, 1965). Coconut soil may vary considerably in these particulars, which thus have limitations in fertility assessment. Coconut palms adapt to a wide range of soil acidity. Cooke's series of Philippines soils showed a pH range between 6.2 for a poor yielding clay and 8.3 for high yielding coral sand, high yielding volcanic alluvium had pH 7.0 (Cooke 1936). The pH of representative Indian soils ranged from 5.2 to 8.0 (Menon and Nair, 1952). In another study, it was found that sandy clay loam with a clay loam subsoil produced very good crops even under unfertilized conditions, whereas a coarse sandy loam with a subsoil of sandy clay loam produced only poor crops (Escritor, 1954).

The red laterite soils, which support the majority of the palms in India, âre deficient in available phosphate, potash and lime (Patel, 1938). Nitrogen in soils is closely associated with the organic matter, and is mostly derived from the breakdown of plant and animal remains to form humus. The C/N ratio is an important analytical figure for soils; it is related not only to the availability of nitrogen, but also to the maintenance of organic matter. The slow decomposition of humus release nitrogen, in forms assimilable by plants, but what is not taken up quickly by growing plants is lost by leaching and in other ways. This is one reason for the need to conserve organic matter in soils. Since the nitrogen in humus is conserved against rapid loss and is made available to plants very gradually. It is not possible permanently to improve the fertility of the soil by the addition of simple nitrogenous fertilizers such as sulphate of ammonia (Child, 1974).

The availability of phosphate is markedly dependent upon soil pH, and is best at levels between 6 to 7. In more acid soils, phosphate becomes 'fixed' by iron and aluminium ions in insoluble compounds, while in basic soils calcium phosphate and other insoluble compounds are formed (Child, 1974). The amount of soil phosphate dissolved by dilute acid (a small fraction of the total phosphate) has been regarded as the indication of the amount available to the plant. In many cases, however, no much correlation is found. Thus, in the fertilizer trials of Coconut

Research Institute, Sri Lanka, there was no phosphorus response over twenty-six years on the 3x3x3 NPK trials at Bandirippuwa, but regular response on the sub-station, Ratnamalagara. Yet amounts of available phosphorus found by acid extraction method (citric acid; Troug) were similar for the two soils. More promising was Olsen's method (extraction by sodium bicarbonate solution) the amounts of phosphorus extracted from these acid soils were very small (<10ppm) but there were differences reflecting the relative P response.

Potash is the dominant requirement of coconut palm. But, the coconut growing soils show poor fixation of potassium. The dominance of kaolinate type of minerals and preponderance of iron oxides are responsible for low potassium retention. In such soils frequent replenishment of nutrients through fertilizers is necessary. Salgado (1951) in Sri Lanka obtained evidence of a relationship between levels of exchangeable soil potassium and yield responses of coconut palms to potash fertilizers. On experimental plots of Bandirippuwa estate on which significant response to potassium had regularly been obtained, the exchangeable potassium was of the order of 0.02 mg equivalents 100^{-1} gm soil, whereas on a sub-station the soil of which had exchangeable potassium some ten times higher, there were no potassium responses.

10.0 Growth and development

Coconut production depends on various physiological and biochemical processes at different developmental stages. Growth and development commences from nut germination through early seedling growth, flowering and fruit development. Dry matter production and nut yield are influenced by both biotic and abiotic factors. The optimum weather conditions for good growth and nut yield in coconut are, well distributed annual rainfall between 130 and 230 cm, mean annual temperature of 27 °C, abundant sunlight ranging from 250 to 350 Wm^{-2} with at least 120 hours $month^{-1}$ of sunshine period (Child, 1974; Murray, 1977).

10.1 Germination, seedling growth and development

The coconut palm is a monocotyledonous, seed propagated tree crop with the fruit (drupe) having a thick epicarp, fibrous mesocrap and a hard endocarp (shell) lined by the solid endosperm. The seed has the endosperm, ranging in dry weight from 50 to 500 gm, which envelops liquid endosperm (nut water). The nut is self sufficient for the embryo germination and growth as it contains all nutrients, hormones and carbon sources required for the process. Out of three carpels in a flower, only one embryo is viable. It is embedded in endosperm, near germ pore or soft eye in the shell. The germination process starts as soon as mature nut comes into contact with moisture for sufficient duration. Mature nuts (11 to 14 months old) are suitable for sowing (Nelliat *et al.*, 1976) and storage of seed nuts in the shade for one month (seasoning) is essential for breaking the dormancy (Fremond and Lamothe, 1966). For germination, the dwarfs required 10 days, hybrids 15 days, while the talls required an average of 20 days (Wuidart, 1981, Manjula, 1990). Germination process was hastened by soaking the nuts in water or in a solution of 0.01 M potassium nitrate and 0.02 M sodium carbonate for 48 h (Thomas, 1974), chopping the husk from both ends of the nuts, injection of different hormones (Liyanage, 1952; Deshpande and Kulkarni, 1962) and also major and minor nutrients (Menon and Pandalai, 1960; Sumathykutty Amma, 1964). Nuts planted more or less horizontally gave rise to better seedlings than those planted vertically (Ambrose, 1951a and 1951b, Viswanathan *et al.*, 1966; Lumige, 1969) due to constant contact of nut water with the embryo.

The first morphological sign of germination is the enlargement of the embryo and protrusion of the apical mass around the shell (Kartha, 1981). The embryo commences to grow in two directions. The plumule moves towards the soft eye to develop as shoot and the other end of embryo develops into an absorbant spongy growth known as the haustorium or the apple, which consists of loosely connected thin walled cells with interspaces in between (Selvaratnam, 1952; Child 1964). The haustorium absorbs food materials from the nut water and kernel and supplies to the growing plant. The volume of haustorium differs among the cultivars and hybrids. Physiological and biochemical changes occurring during early phase of germination viz., solubilization of stored food material and its utilization, are influenced by absorption of water by the nut, activity of enzymes and hormones present in the endosperm. Generally, the root growth was found to be on one side of the nut.

10.1.1 Changes in seed reserves during germination

Coconut endosperm comprises mainly lipids (68-70%), sugars (6-7%) and protein (6-9%) (Nathanael, 1967). The breakdown products of lipids, carbohydrates and proteins from the kernel are dissolved in the liquid endosperm, which then act as a via media for transferring the components to the growing embryo (Manjula *et al.*, 1995). The lipids get solubilized faster during the early stage of germination i.e; 28 days in dwarfs and 42 days in talls after sowing with a concomitant increase in the activity of lipase, which is higher in dwarfs. The kernel is composed mainly of mannans (Balasubramaniam, 1983). During the development of haustorium total soluble sugars and reducing sugars decline in the kernel, along with decreased activity of the respective hydrolytic enzymes viz; amylase and invertase. These products, are absorbed by haustorium upto 13 weeks. Thus, there exists a pool of soluble sugars in the haustorium, formed by the concerted action of b-mannosidases and b-amylase which are utilized by the growing embryo. Seedlings utilize the soluble carbohydrates and the excess are stored as starch to be utilized for growth (Balasubramaniam *et al.*, 1973). The protein content increased upto the formation of the haustorium and then declined rapidly thereafter, with a parallel trend of protease activity (Manjula *et al.*, 1993).

10.1.2 Seedling growth

The growth of coconut seedling is dependent on nut reserves for almost one year. By fourth month, plant is entirely dependent upon the endosperm for its growth and by 15th month, it becomes fully autotrophic (Foale, 1968). The first leaf unfolds at two months after germination. Leaves produced upto fourth month are quite small with a total leaf area (LA) of 80 cm^2 (Kasturi Bai and Ramadasan, 1990).

10.1.2.1 Measurement of seedling growth and seedling vigour

Seedling selection for high vigour is of paramount importance in establishing a stand of superior yielders. Conventionally, selection of vigorous seedlings is done based on girth at collar, total number of leaves, plant height, length and breadth of leaves or leaflets, and early splitting of leaves. Since growth is a function of leaf area development and dry matter (DM) production, the physiological approaches employed to identify superior seedlings are by correlating the phenotypic characters to the seedling vigour (Liyanage, 1953; Menon and Pandalai, 1958). The important contributing factors for the vigour of the seedling are leaf area (LA), girth at collar and SDM (Ramadasan *et al.*, 1980). More over the LA of six months old seedlings was correlated with SDM of 12 months old seedlings (Kasturi Bai and Ramadasan, 1990). Hence, vigour of the seedlings can be determined before the attainment of complete autotrophy. Several regressional equations are developed for non destructive estimation of leaf area and dry matter production (Marar and Pappachan, 1964; Foale, 1968; Satheesan *et al.*, 1983; Shivashankar *et al.*, 1986). Since these equations differ based on the morphology of seedling, and cultivar variations, it is necessary to define growth conditions of seedling to ensure accuracy of estimations.

Studies indicated high correlation between number of leaf produced during the first 40 months and yield of copra at the age of 13-14 years (Liyanage and Abeywardena, 1957). Significant differences among the hybrids in crop growth rate (CGR) and relative growth rate (RGR) and rates of nitrate reductase activity, nitrogen assimilation and nitrogen uptake efficiency were noted (Shivashankar and Kasturi Bai, 1988).

Superiority expressed at seedling stage in terms of rate of leaf production, leaf area, dry weight, seedling height and girth at collar and biochemical constituents such as total chlorophyll concentrations and soluble sugars, was maintained throughout vegetative phase (Voleti *et al.,* 1988). These seedlings also expressed precosity in flowering and superiority in yield components like frequency of spathe production, number of female flowers bunch^{-1} and number of bunches year^{-1} (Table 9). These studies established conclusively the close correlation between seedling vigour and nut yield (Shivashankar and George,1993).

Table 9: Relationship between seedling vigour and nut yield.

Hybrid	Age at 1st flowering (months from planting)	Frequency of spathe production year^{-1}	No. of female flowers bunch^{-1}	No. of bunches produced	No. of nuts bunch^{-1}	Cumulative yield of nuts (first two years of bearing)
'COD' x 'WCT'	54.3	42	12.8	8.7	7.1	113.3
'MOD' x 'WCT'	53.9	38	14.5	9.6	8.8	136.2
'MYD' x 'WCT'	44.7	31	20.8	11.8	10.6	291.8

(Shivashankar and George, 1993)

In the polybag raised seedlings, composition of potting medium influenced the photosystem II efficiency and net photosynthetic rates, seedling growth and vigour (Reddy *et al.,* 2001).

10.1.2.2 Physiological aspects of acclimatization and growth of zygotic embryo-cultured plants

The importance of zygotic embryo culture in coconut is highlighted because of its immense potential as a means of collection and exchange of germplasm overseas. It takes 12 to 18 months for transfer of zygotic embryos from test tube to grow into the plantlet ready for field planting. All the *in vitro* grown plantlets have to undergo physiological acclimatization to be ready to survive in nature. It is important to understand the physiological acclimatization process in order to provide the optimal growing conditions, to increase the survival rate as well as to obtain vigorous seedlings for field planting for better establishment. The establishment of photosynthetic mechanism in *in vitro* development of zygotic embryo-cultured coconut plantlets and during acclimatization had been delineated (Triques *et al.,* 1997a and 1997b; Naresh Kumar *et al.,* 2001). Plantlets also undergo chlorophyll and leaf morphological acclimatization (Ranasinghe *et al.,* 1999). The RUBISCO activity was low in *in vitro* coconut plants just before acclimatization.

The ratio of PEPCO to RUBISCO decreased during the *in vitro* development and is an indicator of transition from heterotrophic to autotrophic phase in coconut (Triques *et al.*, 1997 a and 1997b). Later, Naresh Kumar *et al.* (2001) observed that the embryo-cultured coconut plantlets undergo photosynthetic acclimatization with increased PSII efficiency and water use efficiency during acclimatization. The embryo cultured plantlets had higher photosynthetic rates compared to the nursery raised plants under field conditions. During acclimatization, photosystem efficiency and carbon assimilation efficiency increased to attain efficiency similar to that of the nursery grown seedlings (Naresh Kumar *et al.*, 2001).

Composition of culture medium also influenced the growth and development of embryo and plantlets (Magat and Margate, 1990; Santamaria *et al.*, 1999; Naresh Kumar *et al.*, 2002). While the concentration of sucrose in medium promoted the development of chlorophyll, it inhibited the development of RUBISCO and promoted PEPCO (Santamaria *et al.*, 1999).

10.1.3 Flowering

In coconut, commencement of flowering is the appearance of first inflorescence (spadix) in the leaf axil which takes place around the age of five years or at the 45th leaf stage of growth or beyond, although initiation of inflorescence primordium occurs in the 10th to 14th leaf axil (Patel 1938; Pillai *et al.*, 1973). The inflorescence from the primordial stage takes about 26 months to emerge out of the leaf axil (Patel, 1938). Under average management, 'West Coast Tall' ('WCT') cultivar commences flowering by 6th year after transplantation. Cultivar differences also occur in the flowering duration in palms.

10.1.3.1 Factors influencing the onset of flowering

In fruit trees, a high carbohydrate reserve in the stem is an essential pre-requisite for early initiation of flowering. In 8 year old 'WCT' palms a higher ratio of carbohydrates to nitrogen (C/N ratio) as well as higher leaf number were observed in palms that commenced flowering over those that were not flowered. This indicated that only a rapid rate of leaf production coupled with a large number of leaves on the crown ensure adequate carbohydrate reserve in the trunk, required for the early commencement of flowering (Ramadasan and Mathew, 1977). In juvenile coconut palms (2 to 3 year old), where the stem was not clearly developed, leaves acted as storage organs for carbohydrates. Differences existed in the carbohydrate fractions between the cultivars and also during different seasons in a year. The hybrids were superior to tall ('WCT') in their efficiency in the mobilisation of carbohydrate fractions to inflorescence primordium (Kasturi Bai and Ramadasan, 1983). In juvenile palms, the emergence of first inflorescence was noticed from

August to October. Increased availability of soluble carbohydrate fraction was a pre-requisite for the development and continued growth of the inflorescence. This situation is attained only beyond June because adequate rainfall occured only during this period. (Kasturi Bai and Ramadasan, 1978). Under unirrigated condition, availability of adequate soluble carbohydrate fraction is restricted to monsoon season. Increased productivity in irrigated condition can be due to the assured availability of soluble carbohydrate fractions throughout the year for the initiation and the development of inflorescence. This implies that there is an operation of a pool of carbohydrate from the source (stem) to the sink (inflorescence) for attaining higher productivity levels, which in turn is controlled by environmental variables (Kasturi Bai and Ramadasan, 1982). An imbalance in the nutritional status and lower concentrations of glucose, free amino acid, total nitrogen, protein nitrogen and non-protein nitrogen in the laminae of non-bearing coconut palms than in bearing palms of similar age was noticed by de Silva *et al.* (1973) and Balasubramaniam *et al.* (1974).

10.1.4 Fruit development

The ovary development in coconut palm from the time of inflorescence primordial initiation to maturity of nut can be divided into two major phases, i.e., pre-fertilization phase taking about 32 months and the post-fertilization phase continuing for another 12 months. Growth of the fruit begins immediately following fertilization, with a rapid development of the pericarp at basal region which remains soft and white until fruit is nearly mature. Endocarp is already differentiated as a soft, creamy white structure long before the time of fertilization. During the development of fruit to maturity, embryo sac increases in size leaving a large cavity in the centre (Juliano, 1926). Coconut water (liquid endosperm) starts forming in small quantities from the third month of nut development and reaches maximum by eighth month and declines thereafter with nut maturity. The endosperm of coconut develops as a coenocytic liquid containing many free nuclei and some cells (Cutter *et al.,* 1955; Bhatnagar and Johri, 1972) which coalesce towards the periphery of the embryo sac. Additional cells are formed when free nuclei adhere resulting in the formation of cellular endosperm. In the mature coconut, the liquid which is of cytoplasmic origin (Kumar *et al.,* 1985) do not contain free nuclei or free cells (Cutter *et al.,* 1955). The shell begins to form from fourth month of nut development and continues to grow upto nut maturity. Kernel is the last component to form in seventh month and its growth continues upto eleventh month. The reddish testa which assumes a brownish tint when matures, is laid down before the formation of the kernel. Its growth is proportionately greater than that of kernel during the early stages (Kartha and Narayanan, 1956).

10.1.4.1 Biochemistry of the developing fruit

The liquid endosperm plays a vital role in fruit development by acting as a reservoir of precursors for the synthesis of fruit constituents. Major constituents of the liquid endosperm are sugars (glucose, fructose and sucrose) and minerals while fat and nitrogenous substances form a minor fraction (Caray, 1924; Kamala Devi and Velayudham, 1978).

Reducing sugars form the major part of immature nuts (Child and Nathanael, 1950; Nathanael, 1952). With the commencement of formation of solid endosperm (kernel) at the seventh month, non-reducing sugars and total carbohydrates start accumulating and thereafter increase in concentration both in the kernel and nut water (Sierra and Balleza, 1972; Balasubramaniam, 1983), with a decrease in reducing and total sugars. The fat content of the kernel increases during the same period (Pillai *et al.,* 1959; Jayalekshmy *et al.,* 1988).

The developing fruit contains a variety of nitrogenous substances, of which free amino acids constitute a major part (Baptist, 1956; Tulecke *et al.,* 1961). During nut maturity, the total nitrogen and non-protein nitrogen (NPN) gradually increase, although their levels decrease marginally on whole nut basis (Jayalekshmy *et al.,* 1988). In maturing nut the free amino acid (FAA) content in coconut water increases, whereas concentration of bound amino acids does not show any marked change (Baptist, 1956; Pillai, 1964).

Pipecolic acid, proline are present in tender endosperm (Pillai, 1964). In the liquid endosperm, about 70% of the free amino acids is made up of glutamine, arginine, asparagine, alanine and aspartic acid, while alanine, amino butyric acid and glutamic acid constitute about 75% of the free amino acids of mature nut water. Aspartic acid, glutamic acid, serine, alanine, valine, leucine and isoleucine are found at all stages of fruit development. With increasing age of the fruit, aspartic acid and glutamic acid increase slightly,while alanine increases markedly. Other amino acids do not show much change (Baptist, 1956). The protein content of nut water increases while it decreases in the kernel during maturity (Sierra and Balleza, 1972), and 90% of the proteins could be classified as albumins and globulins (Samson *et al.,* 1971). The coconut protein resembles the FAO reference protein pattern, the major deficiencies being methionine and threonine (Srinivasan *et al.,* 1964).

The endosperm, being a site of active metabolism, contains a large number of enzymes like acid phosphatase (Sadasivan, 1951;Wilson and Cutter, 1952 and 1955; Katherine and Cutler, 1952); decarboxylases (Baptist and Perera, 1965); aspartate amino transferase (Baptist, 1967); RNA polymerase (Mondal *et al.,*1972); pyrophosphatase 3'-nucleotidase, ribonuclease and deoxyribonuclease (Balasubramaniam *et al.,* 1973); glycerol dehydrogenase, amylase lipase, phospholipase (Krishnamurthy and Chandrasekhara 1979) carbonic anhydrase (Padmaja *et al.*, 1980); esterase (Manjula,1990); mannan synthetase GDPmannose pyrophosphorylase (Balasubramaniam, 1983); peroxidase, D-galactosidase (Mujer and Ramirez, 1980; Mujer *et al.*, 1984b; Mujer *et al.*, 1984a); tryptophan aminotransferase (Mujer *et al.*, 1984b); CAMP dependent protein kinase (Janistyn, 1989) and invertase (Balasubramaniam and Alles, 1989). The onset of cellular differentiation in the developing coconut coincides with a rapid rise in acid phosphatase activity (Wilson and Cutter, 1952). The activities of pyrophosphatase 3' nucleotidase, ribonuclease and deoxyribonuclease also remain similar in the kernel of mature and germinating coconuts indicating that mature kernel acts only as a storage tissue.

10.1.4.1.1 Biosynthesis of fats and fatty acid composition

Fat synthesis starts at seventh month, when the kernel begins to form and increases upto the 12th month (Kartha and Narayanan, 1956) while fat content of the nut water shows a gradual increase upto the 10th month and rises gradually thereafter reaching a maximum in the 12th month (Pillai *et al.*, 1959). Fat deposits of the developing nut possess the capacity to selectively synthesize the chain length-regulating enzyme systems for any chain length at any time without reference to the nature and proportions of the other systems present (Sethi and Kartha, 1956, Kartha *et al.*, 1959; Kartha,1964.; Singh and Kartha, 1978). Seventy nine (79) types of triglycerides could be identified in coconut oil which represent 99.8% of the total glycerides (Bomer and Bauman, 1920, Collin and Hildtech 1928, Date and Meara, 1955, Bezard *et al.*, 1971).

In the developing fruit, the pattern of variation of fatty acids in both kernel and nut water appears to be similar although significant deviations in the relative abundance of component fatty acids have been found (Padua Resurreccion and Banzon, 1979, Jayalekshmy *et al.*, 1988). In general, the relative proportions of fatty acids upto C14:0 increase during maturation while a corresponding decrease in the concentration of long chain unsaturated fatty acids occurs. The most characteristic feature is that the content of lauric acid (C12:0) in both the nut water and kernel rapidly increases with maturity, while the contents of most other fatty acids remain low. The typical fatty acid composition of coconut oil includes C12 and C14 acids as major constituents (Table 10) (Naresh Kumar *et al.*, 2000). Four of the fatty acids in nut water,C14:1, C15:0, C16:1 and C17:0 which are present in the early stages disappear as the nut matures, whereas the content of the short chain fatty acids, C6:0, C8:0 and C10:0 which are present in negligible levels initially, rises with maturity in both the water and kernel. The long chain fatty acids C18:3 and C22:0 had been found at all stages of fruit growth in nut water (Jayalekshmy *et al.*, 1988) but not in the kernel (Padua Resurreccion and Banzon, 1979). In the mature nut, saturated fatty acids, mostly of short and medium chain length, like caprylic (C8:0), capric (C10:0), lauric (C12:0) and myristic (14:0) comprise nearly 83%. Variations exist in the proportions and properties of fats at different locations of the developing coconut kernel (Kartha, 1963; Lim and Banzon, 1983). Gradations are present even for the size, shape and number of cells from the inner to outer regions of the endosperm. Besides neutral lipids, coconut oil contains polar lipids, which contain higher amounts of unsaturated fatty acids than the neutral lipids solvent (Krishnamurthy and Chandrasekhara, 1983). Neutral lipids formed major fraction (about 94%) in coconut oil followed by the glycolipids (3.5%) and phospho lipids (2.5%), and lipid fraction content varied with cultivar (Naresh Kumar and Chempakam, 2000). Lysophosphatidylethanolamine comprises about 23% of all phospholipids in coconut kernel. The rest of the phospholipids are composed of phosphatidyl inositol, phosphatidyl serine, phosphatidyl choline, phosphatidyl ethanolamine and other unidentified phospholipids in equal abundance (Monera and del Rosario, 1982).

Table 10: Fatty acid composition of oil from different coconut cultivars

Fatty acid	Cultivar		
	'WCT'	'COD' x 'WCT'	'WCT' x 'COD'
6-C Caproic	0.47	0.60	0.50
8-C Caprylic	6.07	8.44	6.55
10-C Capric	5.10	6.55	8.04
12-C Lauric	44.07	47.10	46.05
14-C Myristic	20.61	16.70	17.50
16-C:0 Palmitic	10.50	6.20	6.93
16-C:2 Palmitoleic	0.11	1.21	1.33
18-C:0 Stearic	2.47	2.90	3.40
18-C:1 Oleic	7.75	9.21	8.59
18-C:2 Linoleic	2.71	0.98	1.04

(Naresh Kumar and Chempakam, 2000).

Oo and Stumpf (1979) did the classic work on fatty acid biosynthesis in the developing endosperm of coconut. The oil content in coconut copra and oil yield hectare^{-1} varied among the cultivars with WCT having ~68% oil and the oil yield ha^{-1} ranged from 2t ha^{-1} in WCT to ~3t ha^{-1} in COD x WCT (Naresh Kumar and Chempakam, 2000).

Variablity among the coconut cultivars for fatty acid composition, though not very high, and most suitable cultivars for different uses have been reported (Rodriguez *et al.*, 1998; Naresh Kumar *et al.*, 2000a; Naresh Kumar and Rajagopal, 2000). In general, the hybrids have low saturated/unsaturated fatty acid ratios indicating better value over the oil from talls for edible purpose. Hybrids with high lauric acid (a conditionally essential fatty acid) concentration and low ratio of saturated to unsaturated fatty acids can be used for both edible and industrial purposes (soap industry). For medicinal and pharmaceutical industries for manufacturing Trilaurin, and ointment bases oil with high lauric acid and high concentrations of medium chain fatty acids (MCFAs) is desirable. High concentration of myristic acid in oil is useful for manufacturing the binder and used in emollient (Naresh Kumar and Chempakam, 2000; Naresh Kumar *et al.*, 2000a; Naresh Kumar and Rajagopal, 2000).

The developing coconut contains many other compounds such as shikimic acid and quinic acid, leucocyanidin and leucopelargonidin, flavonoid pigments, ascorbic acid, silica, RNA and vitamins having specific biochemical roles. (Nair and Sankara Subramanian 1963; Vanderbelt, 1945; Jayatilake, 1974; Grimwood, 1975; Pillai, 1967; Mondal *et al.*, 1970a). Several growth promoters have been isolated in pure form from various parts of the coconut (Van Overbeek *et al.*, 1941). Inhibitory factors develop in the water and kernel as the fruit matures and functions in regulation of germination and related metabolic events by a balance act of promoters and inhibitors.(Ultaman, 1949; Ramakrishnan and Ramakrishnan, 1949; Wilson and Cutter, 1952).

10.1.5 Growth and dry matter production

The palm is in general, an unbranched stem of uniform thickness in adult stage. With a single apical growth point, it puts forth leaves in succession which form regular whorls. The periodicity of leaf production is fast in young seedlings but becomes steady in adult stage. Annually 12 to 14 leaves are produced. In adult palms, along with the production of leaves, spadices are also produced in each leaf axil.

10.1.5.1 Leaf

Variation exists in the morphology of leaves between the cultivars and hybrids (Kasturi Bai, 1993). The length of the leaf (including the rachis) ranges from 4 to 6 metres. Regressional equations for nondestructive estimation of leaf area (LA) and dry weights were developed (Ramadasan and Jacob Mathew, 1987, Jayasekara and

Mathew, 1992, Friend and Corley, 1994). Total area and dry weight of the leaf can be determined with ease by estimating the dry weight of middle six leaflets and leaflet count of the same leaf (Ramadasan and Jacob Mathew, 1987). Once the leaf is completely unfolded there is no perceptible increase in LA and dry weight. The dry weight of individual leaf ranges from 0.97 to 1.36 kg. Differences in area and dry weight between the leaves in a palm are low. Thus, the total canopy area as well as total dry weight produced unit^{-1} time can be estimated by multiplying the estimated leaf area or dry weight of single leaf by the number of leaves produced in an year. Variations existed in the leaf area and dry weights among the cultivars (Kasturi Bai *et al.,* 1996). Rate of production of new leaves is determined by tagging the youngest fully opened frond and counting the new leaves produced unit^{-1} time.

Besides leaf area and dry weight, leaf anatomy has also been recognized as an important component of productivity. Differences were observed in leaf thickness and tissue density (Ramadasan and Satheesan 1980) with hybrids having higher tissue density. However, the coconut leaf tissue in general, has less tissue density with more intercellular volume which is characteristic of all C_3 species as against high tissue density with low intercellular volume in C_4.

Leaflets mean thickness is 341 mm with bottom portion of the leaflet being thicker and tapered towards tip portion. Epidermal cells are closely attached to form a compact layer devoid of intercellular spaces. The upper epidermis is thicker with large size cells than lower epidermis. Cuticle on upper epidermis is two-fold thicker than the cuticle on lower epidermis (Table 11). Cuticle is even thicker at midrib and edges of leaflet. Coconut leaflets are hypostomatus (Naresh Kumar *et al.*, 2000c). Variations were observed in stomatal frequency (SF) and stomatal index (SI) among the talls, dwarfs and hybrids (Rajagopal *et al.,* 1990). The leaflets of WCT had SF of 211/ mm^2 and SI 22.

The guard cells have hook-like protuberances at both ends, a character typical to Palmae. Elongated epidermal cells surrounded the guard cells along their entire length. On the lower epidermis multicellular, shortly stalked scales occur at regular intervals in short depressions. These scales contain tannins (Menon and Pandalai, 1960; Naresh Kumar *et al.,* 2000c). Beneath the upper epidermis, two layers of large hypodermal cells are present which serve as water storage tissue. Whereas, above the lower epidermis, a broken layer of hypoderm is present. Outer margins of the sides of leaflets are folded like a hook. Water tissue or epithelium occur at the upper and lower angles of the straightened margin of the leaflet. These are thin walled tissue. Beneath the upper hypoderma is the multilayered palisade parenchyma spreading nearly to the lower hypoderma. These are closely packed, thin walled and broad elongated cells. The palisade cells become shorter towards the centre of the leaf. The spongy parenchyma is scanty, just above the lower hypodermis. The spongy parenchyma tissue is present only towards the abaxial surface of leaflet and cells are characterized by the presence of lobes by which the neighbouring cells are connected. This distribution of palisade and spongy parenchyma makes the leaflet dorso-ventral (Naresh Kumar *et al.*, 2000c).

Table 11: Anatomical features of coconut leaflet (range)

Parameter	Portion of the leaflet		
	Tip	Middle	Base
Leaflet thickness (μm)	175 - 317	268 - 459	350 - 525
Cuticle thickness (μm)			
Adaxial	2.07 - 5.52	2.76 - 6.21	2.76 - 7.59
Abaxial	1.38 - 4.14	1.38 - 4.14	1.38 - 4.83
Epidermal cell size (μm^2)			
Upper	76 - 286	66 - 317	62 - 261
Lower	24 - 154	33 - 174	50 - 248
Parenchyma cell size (μm^2)			
Spongy	58 - 179	58 - 207	77 - 393
Palisade	165 - 634	193 - 593	165 - 774
Guard cell size (μm^2)	37 - 121	44 - 132	55 - 166
Hypodermal cell size (μm^2)	149 - 1093	242 - 1325	304 - 1366
Water cell size (μm^2)	77 - 552	97 - 759	121 - 690
Sub-stomatal cavity size (μm^2)	135 - 1325	207 - 1691	199 - 1656
Xylem lignification (μm)	1.38 - 4.14	1.38 - 5.52	1.38 - 6.90

(Naresh Kumar *et al.*, 2000c)

There are about 22 to 27 vascular bundles running length-wise on each side of the midrib. Each of them occupy the space between upper hypoderma to lower hypoderma. Each vascular bundle, encircled in a fibre ring, had a few tracheids, one big vessel and a band of phloem elements on lower side. The smaller or diminutive vascular bundles consisting a few tracheids with scalariform thickening, phloem fibres are present in between the two big vascular bundles. The midrib of leaflet is strong with a group of seven to eight large vascular bundles which are encircled with fibrous sheet. Xylem tracheids have thick lignification (Menon and Pandalai, 1960; Naresh Kumar *et al.*, 2000c).

Leaflet thickness, cuticle thickness, sizes of lower epidermal cells, spongy parenchyma cells, guard cells, hypodermal cells and water cells decreased significantly from basal to tip portion of leaflet. However, sizes of upper epidermal cells did not vary significantly with the length of the leaflet. Palisade parenchyma cells were significantly larger at the bottom portion of leaflet compared to middle and tip portion, whereas, sub-stomatal cavities and xylem scalariform thickenings were significantly larger in bottom and middle portions of the leaf than in tip portions of the leaflet. Upper epidermal cell size, guard cell size, xylem tracheid lignification and sub-stomatal cavity size, hypodermal cell size also varied among the cultivars. The indigenous cultivars had extreme values for all the traits related to leaflet anatomy. However, the exotic cultivars had medium values thus indicating the possibility of using some of these parameters to identify ecotypes in coconut (Naresh Kumar *et al.*, 2000c).

Specific leaf weight (SLW) gives an indication of the dry matter produced unit^{-1} area of leaf tissue and is the simplest means for determining the production potential of crop plants. SLW estimated on a diurnal scale indicated that the synthesis, accumulation and partitioning of photosynthates was influenced by the duration of solar radiation. Short term changes in solar radiation greatly influenced the accumulation of photosynthates in coconut leaf (Kasturi Bai *et al.*, 1981).

10.1.5.2 The stem

The trunk of coconut grows erect to a height of 10 to 24 metres. Annual growth of stem is by addition of 'scars' with mark of leaf base as a result of the annual production of 12 to 14 leaves on the crown. As new leaves are added, the old ones are shed leaving 'scars' of leaf base which correspond to a year of growth of palm. Ramadasan and Jacob Mathew (1987) estimated DM production of apical portion of trunk just below the crown, as this portion contribute to growth of stem. The palm produces 12 to 14 leaves annually and data on these segments is sufficient to obtain the quantity of dry matter produced by way of annual stem growth. Besides, any difference in the rate of growth of stem as influenced by variation in soil fertility or environmental variables will be reflected in this portion of stem. The increment in stem height can be easily determined by marking the stem portion just below the crown and taking measurement after a period of time. Increment in stem height year^{-1} ranged between 23 cm and 37 cm and significantly differed between the cultivars and hybrids (Kasturi Bai *et al.*, 1996), even though, no differences in the number of leaf scars in this portion between cultivars and hybrids. The capacity for DM production significantly varied between talls, dwarfs and hybrids (Kasturi Bai *et al.*, 1996).

10.1.5.3 Vegetative dry matter production (VDM)

The dry weights of stem and leaf together constitute the VDM of palm and is a useful criteria for selection. Low VDM is associated with high HI. Significant variation existed in the VDM between the tall, dwarf and hybrid (Kasturi Bai, 1993;

Kasturi Bai *et al.*, 1996a and 1996b), dwarfs exhibited lower production of VDM (18.3 kg) due to characteristic short stature of the trunk because of lower increment in stem height (25 cm) and small size of the leaves (3.4 m), whereas in talls due to higher increment in stem height (36 cm) and long leaves (4.0 m) VDM production was higher (Table 12 and Table 13).

Table 12: Growth characteristics of coconut

Parameter / cultivar	Tall	Dwarf	Hybrid
Total leaves (No.)	35	31	32
Leaf production $year^{-1}$	12	10	10
Leaf length (m)	4.02	3.39	3.83
Rachis length (m)	1.39	1.09	1.28
Leaf width (m)	2.21	1.85	1.87
No of leaflets $leaf^{-1}$	226	201	234
Leaf area (m^2)	5.83	4.53	5.66
Leaf dry weight (kg $year^{-1}$)	30.42	16.44	25.62
Leaf scar (No.)	12	12	12
Stem growth $year^{-1}$ (cm)	36	25	23
Stem dry weight (kg $year^{-1}$)	2.87	1.87	2.25

(Kasturi Bai, 1993).

10.1.5.4 Reproductive dry matter (RDM) production - yield and yield components

Total nut production $palm^{-1}$ $year^{-1}$ showed great variation among the cutivars/ hybrids, but bunch production or spikelet $bunch^{-1}$ did not vary significantly among them. However, female flower production varied significantly among the cultivars/ hybrids (range 100 to 400). Higher female flower production was observed in hybrids than cultivars (Kasturi Bai *et al.*, 1996a).

Dry weights of spathes, bunches and nuts constitute the reproductive dry matter (RDM). Dry weights of spadices and spathes constitute about five per cent of the total RDM production. This shows that RDM production depends mainly on the nut production and partitioning of nut dry matter towards its components, viz.; husk, shell and copra. Nut composition showed significant variation between the cultivars and hybrids which reflect in the partitioning of nut dry matter towards its components viz.; husk (43-58%) shell (20- 27%) and copra (27-34%) (Kasturi Bai *et al.*, 1996a). For obtaining maximum number of hybrid seedlings (dwarf x tall), it is preferable to use pistillate parents which yield nuts having low shell content and a high copra content (Satyabalan and Rajagopal, 1987). The importance of increased partitioning of the total dry matter towards the copra at the expense of other nut components for yield improvement was emphasized (Green and Foale, 1961; Corley, 1983) and selection of parents should be based on nut composition rather than on the total dry weight of the nut.

Table 13: Dry matter production characteristics (kg palm^{-1} year^{-1}) in rainfed coconut palms of stabilized yield.

Genotypes	VDM		RDM	Economic yield		HI	
	Stem DM	Leaf DM		Copra	Nut DM	copra	Nuts
Talls							
'WCT'	3.0	32.2	52.6	16.6	48.1	0.19	0.54
'PHOT'	2.8	33.0	29.3	8.4	25.4	0.13	0.39
'ADOT'	2.8	27.8	36.4	10.9	31.2	0.16	0.44
Dwarf							
'MYD'	1.8	17.9	24.5	7.6	21.4	0.16	0.46
Hybrids							
'WCT' x 'WCT'	2.2	32.1	48.3	13.3	43.9	0.16	0.53
'WCT' x 'COD'	2.4	24.8	73.3	23.0	67.7	0.23	0.67
'COD' x 'WCT'	2.1	19.8	33.7	11.0	29.8	0.21	0.55
'LCT' x 'GBGD'	2.5	25.8	65.5	19.9	62.2	0.21	0.66
'LCT' x 'COD'	2.1	25.3	60.9	20.0	56.7	0.23	0.64

(Kasturi Bai *et al.*, 1996a).

10.1.5.5 Total DM production (TDM)

Based on the dry matter accumulation in the vegetative and reproductive parts, TDM production also greatly varies between the cultivars and hybrids. Kasturi Bai *et al*, (1996a) reported highest TDM production of 17 t ha^{-1} year^{-1} in WCT x COD hybrids. However, the highest value reported was 30 t ha^{-1} year^{-1} in Dwarf x West African Tall hybrid in the Cote d'Ivoire (Corley, 1983). This indicates that there is a huge gap in the realization of yield and the production potential of the palms.

10.1.5.6 Harvest index

The harvest index (HI) has been considered as an important criterion in biological and economic yield. Because of the limitation in estimating the total biomass including the roots, Ramadasan and Jacob Mathew (1987) coined the term 'Annual Productivity Index' (API). They worked out HI in coconut by taking into account annual increment in DM production and expressed as the ratio of the dry weight of the economic product to total dry matter production. Being a crop of continuous productivity API is an appropriate criterion comparable to the harvest index of annual crops. In coconut, since all the parts are economically important several values of HI could be calculated. The values of API estimated ranged from 0.4-0.5 in a group of palms in which the annual yield of nuts ranged from 45 to 91 nuts. Harvest indices can also be calculated based on the total DM production and its partitioning towards the annual copra outturn (Kasturi Bai *et al.,* 1996a). The hybrids gave higher harvest indices indicating better nut composition than talls and dwarfs. The HI based on the copra out turn ranged from 0.13-0.23.

10.1.6 Coconut as energy source

In coconut the harvestable energy is in the form of husk, shell and oil from nut and the leaf petioles (Banzon, 1980 and 1984; Bengali Baboo and Ramadasan, 1986). The energy contained in the harvest of over 12 billion nuts is calculated to be 31×10^{12} K cal. Considering only the energy in the husk and shell, this is equivalent to 3.8 billion litres of gasolene. In a coconut plantation of 150 trees ha^{-1} and bearing 10,000 nuts $year^{-1}$ the calculated energy from the husk, shell and petiole amounts to 54.5 million K calories. Highest coconut sap yield, in terms of ethanol amounts to 109 M.J. $month^{-1} palm^{-1}$ which equals the coconut oil from 20 nuts. This indicates the possibility of greater energy harvest from coconut sap than from coconut oil. At present in Philippines, one of the most important potential source of fuel from plants is coconut oil (Rosario, 1980). Coconut oil is also used as locomotive fuel. This indicates the tremendous potentialities of this palm in meeting the energy requirements of rural areas. The main benefit of this energy source is that it can be used directly as fuel and it is economical. Efforts are being made to produce a cultivar of renewable energy resources such as gas, ethanol and electricity from this tree crop.

10.2 Stress physiology of coconut

Like any other crop, productivity of coconut palm is constrained by the abiotic and biotic stresses. Research efforts led to understand response of palms to abiotic stress like drought and biotic stresses like root (wilt) disease, lethal yellow disease and basal stem rot of coconut. This helped in identification of tolerant cultivars.

10.2.1 Abiotic stress physiology

Growth and productivity of coconut palms are influenced by the external factors such as rainfall, temperature, sunshine duration and relative humidity. Currently most of the information available is on drought stress tolerance in coconut.

10.2.1.1 Climatic requirement

Coconut palm is influenced both by atmospheric and soil droughts as the palms were cultivated on the coastal sandy, red sandy loam and laterite soils. Coconut palm growth and production were hampered when exposed to irradiation above 265 Wm^{-2}, temperature of 33 °C and vapour pressure deficit of 26 m bar (Kasturi Bai *et al.*, 1988) and was aggravated by soil water deficit during the period (Rajagopal *et al.*, 1989). Annual rainfall and its distribution has greater influence on the nut production in coconut (Lakshmanachar, 1963; Abeywardena, 1968). An aridity index of 100% for a prolonged period of 5 to 10 weeks drastically affected productivity of coconut palm (Rao, 1985). Duration of dry spell during initiation of inflorescence primordium, ovary development and button size nut stages, in that order have greater influence on nut yield than other stages (Rajagopal *et al.*, 1996).

10.2.1.2 Response of coconut to soil moisture

The photosynthetic rate, dry matter production and it's partitioning were influenced by the soil water status (Kasturi Bai *et al.*, 1998).). High soil water deficit coupled with atmospheric evaporative demand during dry period showed differential impact on coconut palms grown in red sandy loam and laterite soils (Voleti *et al.*, 1993a). In general, palms suffered more in red sandy loam than in laterite soil as indicated by the stomatal resistance and leaf water potential components. In sandy loam soil, water deficit of 110 mm is a critical level at which coconut suffered most due to moisture stress (Rajagopal *et al.*, 1989a and 1989b). The typical symptoms of coconut palm under drought stress were bending and breaking of dry leaves, poor spathe development and bunches with only one or two nuts. Drought Index, calculated based on the morphological symptoms was related to nut yield and varied among the cultivars and hybrids (Ramadasan *et al.*, 1991; Pomier and de Taffin,1982)

10.2.1.3 Physiological responses to drought stress

Water transport in coconut was carried out mainly by a negative pressure gradient with only a minor role by the root pressure (Milburn and Davis, 1973). Coconut palm adapted to drought stress by maintaining leaf water potential through effective regulation of stomata, deposition of wax on the leaf surface (Rajagopal *et al.*, 1990) and osmotic adjustment by accumulating organic solutes (Kasturi Bai and Rajagopal, 2000). The leaf to air vapour pressure deficit (LAVPD) and leaf to air temperature difference (DT) influenced the photosynthetic efficiency of coconut in irrigated and rainfed conditions via., the stomatal conductance (gs) and water relations during day time (Rajagopal *et al.*, 2000). Seasonal variations in the leaf water potentials (ψleaf) occur depending on the weather, type of soil and soil water availability (Voleti *et al.*, 1993a; Shivashankar *et al.*, 1991). A rapid screening method was developed based on ψleaf in excised leaflets (Rajagopal *et al.*, 1988) for easy handling of a large number of genotypes. The physiological age of palms and of leaves influenced the formation of wax and its composition on leaf surface. Leaves of coconut seedlings had almost 50% less epi cuticular wax (ECW) than those from adult palms even at same degree of stress. Major components of ECW identified were hydrocarbons and esters (Kurup *et al.*, 1993). Role of K^+ and Cl^- nutrition in relation to drought tolerance in coconut has been explained on the basis of stomatal regulation Probably Cl^- replaced malate as an osmoticum for maintaining the turgidity and thereby resisting the effects of water stress. (Braconnier and D'Auzac, 1985). Cl^- had been shown to increase water absorption and reduce transpiration by stepping up osmotic pressure within the cells in coconut (Ollagnier *et al.*, 1983). Increase in drought tolerance and higher stomatal regulatory capacity of palms under dry conditions with the addition of KCl was reported (Ollagnier *et al.*, 1983; Lubina, 1990). Inadequate supply of K^+ and Cl^- resulted in symptoms like yellowing and drying of leaves caused by an imbalance in the water relations of palms.

10.2.1.4 Biochemical responses to drought stress

The biochemical responses of coconut palm to drought stress include upregulation or synthesis of scavenging enzymes to maintain cell membrane integrity thus enabling cells to tolerate stress. Drought stress caused an increase in the activities of some of the stress sensitive enzymes, viz., peroxidase (POD), polyphenol oxidase (PPO), superoxide dismutase (SOD), acid phosphatase (APH) and L-aspartate: 2-oxoglutarate amino transferase (AAT) in adult WCT palms, while activities of malic dehydrogenase (MDH) and nitrate reductase (NR) were decreased (Shivashankar,1990; Shivashankar *et al.*, 1991, Kasturi Bai *et al.*, 1996b; Rajagopal *et al.*, 1988; Shivashankar,1992). Changes in isozymes patterns of the POD, PPO (Shivashankar,1988) and APH (Shivashankar and Nagaraja,1996) was also recorded in stressed coconut leaves.

10.2.1.4.1 Membrane stability in relation to drought stress

At the cellular level, the impact of stress was generally seen on the integrity of membranes and extent of solute leakage was regulated by the cell membrane stability, which differed among the cultivars and with the maturity of leaf (Kurup,1989). Normal cell functions are affected due to changes in peroxidation of cell wall lipids (LP) during stress resulting in increased cell permeability and solute leakage. In coconut lipid peroxidation was high in drought susceptible cultivars as compared to tolerant ones (Chempakam *et al.*, 1993). Since the POD, in combination with SOD and catalase is involved in the defence of aerobic cells against the superoxide radical and hydrogen peroxide in tissues, they are expected to protect the cell against oxidative damage. Drought tolerance is thus characterized by higher activities of the protective enzymes like SOD, catalase and POD and consequently coupled with lower levels of lipid peroxidation and higher membrane integrity. (Chempakam *et al.*, 1993; Kasturi Bai *et al.*, 1996a; Kasturi Bai *et al.*, 2001).

10.2.1.5 Screening for drought tolerance

Cell size and number, sub-stomatal cavity size, stomatal frequency, epicuticular wax content and thickness, leaf thickness, stomatal resistance water potential components, cell membrane stability are the essential anatomical and physiological traits for assessing moisture stress in plants (Rajagopal *et al.*, 1991; Kasturi Bai, 1993; Naresh Kumar *et al.*, 2001). Based on these, coconut germplasm collections comprising of talls, dwarfs and hybrids were screened under field conditions for drought tolerance (Rajagopal *et al.*, 1990).

Under stress conditions, where high evaporative demand in the atmosphere prevail, genotypes exhibited differential adaptability through stomatal regulation. Stomatal resistance (rs) was high in the hybrids followed by talls, whereas in dwarfs rs was almost 50% less than that in hybrids. This reflects on higher loss of water in dwarfs through transpiration than in talls and hybrids. The sensitivity of stomata affected ψleaf to a great extent. The low rs resulting in high E led to lowering of ψleaf in dwarfs, conversely high rs was associated with high ψleaf among hybrids like 'WCT' x 'WCT'. Instantaneous and intrinsic water use efficiency (WUE) increased under mild water deficit conditions (Rajagopal *et al.*, 2000). The transpiration rate (E) was inversely proportional to the content of ECW on the leaf surface.

10.2.1.6 Leaflet anatomy in relation to drought tolerance

Anatomical basis of physiological efficiency for drought tolerance in coconut has been delineated (Naresh Kumar *et al.*, 2000c). The leaflet thickness increased mainly due to increase in parenchyma cell size. It is also associated with lowered stomatal frequency, an indication of adaptation to drought. Increased leaf thickness and thick cuticle are some of the xeromorphic characters, which causes decrease in the ratio of the external surface to its volume. Correlations between anatomical features and physiological parameters also indicated thick cuticle lowers the cuticular transpiration. Water in leaves is conducted not only by the veins and bundle sheath extensions but also by the mesophyll cells, epidermis and through intercellular spaces. Water transport towards the epidermis is much higher through the palisade tissue than the spongy parenchyma. Increased parenchyma cell size (less intercellular space unit^{-1} area) is observed in tolerant types. This may help in reducing the water conductance towards epidermis thus reducing the transpirational rates and maintaining high water potentials. The volume of intercellular spaces in xeromorphic leaves is low thus reducing the water transport to epidermal cells. The surface area of palisade parenchyma unit^{-1} area, thus decreased, lowered photosynthetic rates. The ratio of internal to external surface is positively correlated with the rate of transpiration. Thus, the structure favourable to high photosynthetic rates (large palisade parenchyma tissue surface, i.e., small parenchyma cells) induces at the same time high E due to higher intercellular space (Naresh Kumar *et al.*, 2000c).

The cultivars tolerant to water stress, had thick leaflets, thick cuticle on both sides, larger parenchyma, hypodermal and water cells compared to less tolerant cultivars (Naresh Kumar *et al.*, 2000c). The water storage tissue supply water to other tissue when water is limiting. Cultivars having thick cuticle are able to maintain higher leaf water potentials. Drought tolerant types also had more scalariform thickening on xylem tracheids in vascular bundles and large sub-stomatal cavities. Large sub-stomatal cavities will help in maintaining enough internal CO_2 concentrations required for sustaining the photosynthetic rates during the stress period when the stomata are partially closed. High internal CO_2 concentrations may help in reducing the water loss through stomata. Certain parameters like epidermal cell size (upper and lower) and guard cell size are related to the drought tolerance character of a cultivar. It is possible that cumulative effect of all these traits contribute to the adaptation to drought stress (Naresh Kumar *et al.*, 2000c).

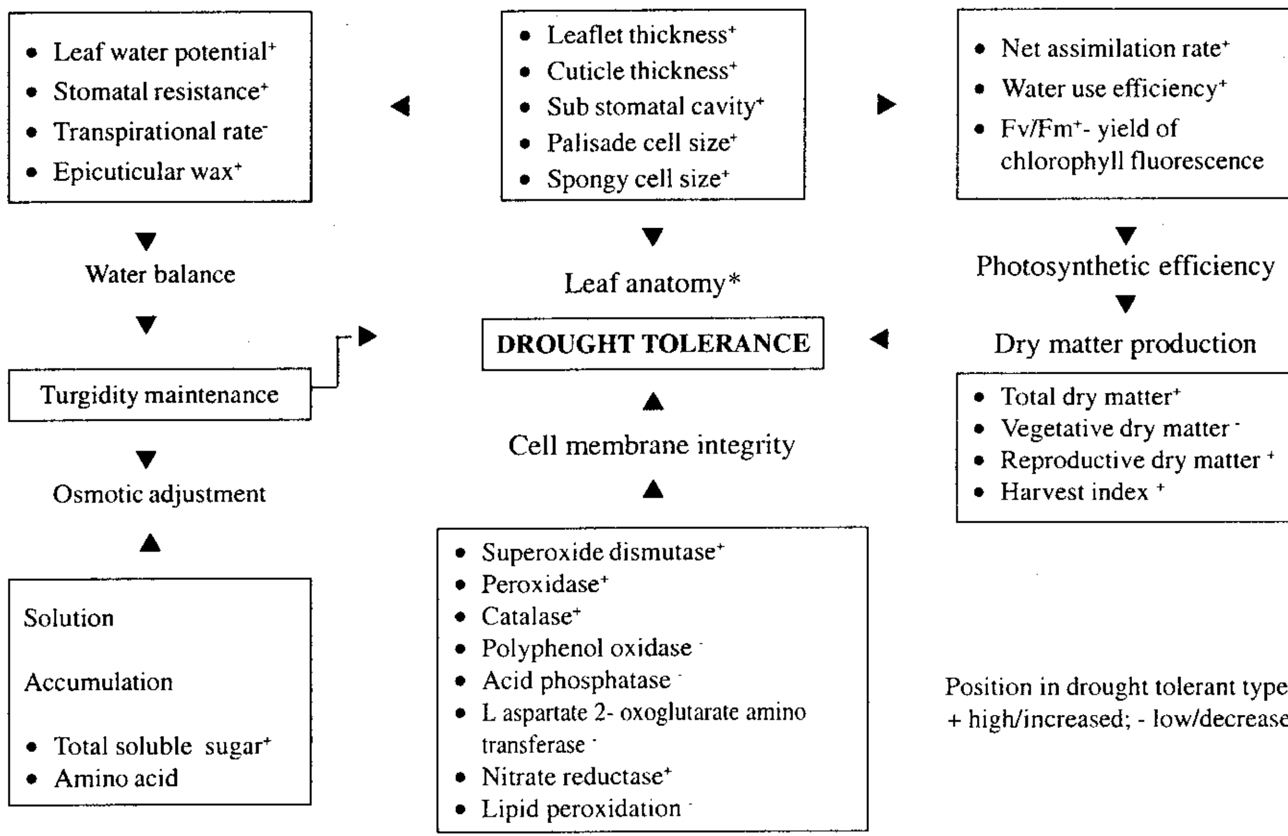
10.2.1.7 Ranking of cultivars for drought stress tolerance

Based on the aforesaid parameters, cultivars like 'WCT', 'LCT' and hybrids 'WCT' x 'COD', 'LCT' x 'GBGD', 'LCT' x 'COD' were identified as drought tolerant types. Ranking for drought tolerance was done based on all stress sensitive parameters using parametric relationships. Thus, coconut cultivars could be identified for their degree of tolerance to drought stress based on the desirable traits, which reflected on the overall water relations of palms (Rajagopal *et al.*, 1990).

10.2.1.8 Drought tolerance mechanism in coconut

All the above mentioned research results helped in deciphering the mechanism of drought tolerance and stability in yield of coconut under water stress conditions. Drought tolerance in coconut is the cumulative effect of several inductive morphological, anatomical, physiological and biochemical mechanism (Rajagopal and Kasturi Bai, 2002; Naresh Kumar *et al.*, 2000c). The genotypes with the above traits for tolerance to drought can be used in the selection for breeding strategies.

FIG 1 MECHANISM OF DROUGHT TOLERANCE IN COCONUT



Position in drought tolerant types:
+ high/increased; - low/decreased

(Rajagopal and Kasturi Bai, 2002; *Naresh Kumar *et al.*, 2000c).

Further the genetics of these important traits are being looked into for developing future crop improvement strategies.

10.2.1.9 Influence of drought stress on photosynthetic efficiency and water use efficiency of coconut

The photosynthetic rates (Pn) were reduced by water stress mainly due to increase in stomatal or mesophyll resistance. Due to stress, more reduction in Pn was noticed in susceptible types than in tolerant types. The ratio of Pn to gs, an estimate of the efficiency of the leaf to fix CO_2 for a given gs, increased during stress period and drought tolerant hybrids exhibited higher increase in Pn/gs ratio and water use efficiency (WUE) than the susceptible types. The Pn rate was independent of ψ_{leaf} until a threshold ψ_{leaf} was reached (Kasturi Bai, 1993).

The potential of palms for higher DM production was reflected on WUE. WUE can be determined based on dry matter accumulation (gDM mm^{-1} water used) as well as by gas exchange measurements (μmol CO_2. $mmol^{-1}$ H_2O). WUE based on dry matter accumulation ranged between 28.8 to 69.3 gDM mm^{-1} water among the cultivars/hybrids used. WUE was high in un-irrigated palms than in irrigated palms (Rajagopal *et al.*, 1989). A close relationship between the measurement of single leaf WUE and the whole canopy WUE had been indicated. WUE correlated with the dry matter production and HI (Kasturi Bai *et al.*,1996b).

10.2.1.9.1 Day time fluctuations

In coconut, the day time leaf surface to air VPD (LAVPD), drought tolerance (DT) influenced the photosynthetic characteristics and water relations. Under mild stress conditions, WUE increased, whereas overall carbon assimilation efficiency was low in rainfed palms (Rajagopal *et al.*, 2000a). The day time trends in gas exchange characteristics, WUE and ψ_{leaf} showed two peaks, one at 9:00 and another at 15:00 hrs under rainfed condition. High partial pressure of CO_2 in the intercellular spaces of the leaf (Ci) and Ci/Ca (partial pressure of CO_2 in the ambient air) in rainfed palms indicate the predominance of non-stomatal inhibition of Pn rates. Increased photo-respiration, impaired chloroplast functioning, Hill activity, high DT under stress conditions also contributed towards inhibition of Pn (Rajagopal *et al.*, 2000a).

During the moderate water deficit periods, the WUE is maintained high as the decrease in E was more than the decrease in Pn. However, when LAVPD increased further, the stomata started closing, decreasing Pn rates and increasing Ci and E thus the WUE reduced drastically under such situations. (Rajagopal *et al.*, 2000a).

Lower ψleaf due to high LAVPD driven high E and also due to low water supply from the roots led to stomatal closure consequently reducing the thermo-regulatory efficiency leading to increase in DT. These conditions adversely affected the photosynthetic efficiency of rainfed palms. This ultimately led to the lower assimilation and production of dry matter and resulting in lower nut yield under rainfed conditions. However, irrigation keeps the palm leaflets cooler due to continuous and adequate supply of water from the root system, ensure the maintenance of high ψleaf. Thus the LAVPD did not increase much and stomata are kept open resulting in high gs. These conditions resulted in efficient thermo-regulation of leaflet as the E was maintained to check the increase in DT. These situations are favourable for high Pn rates under irrigated conditions. This led to higher dry matter production and higher nut yields under irrigated conditions. The stomatal response to microclimatic variations are suggested to change to maximize the WUE, particularly under mild water deficit conditions. Increase in Ci during mid-day closure of stomata may help plants to avoid photo-inhibition by dissipating a part of light energy for CO_2 fixation to maintain Pn rates, even though at lower rates. (Rajagopal *et al.,* 2000a).

10.2.1.10 Nut yield in relation to intensity and length of drought stress

The coconut palm is influenced considerably by the environmental variables in its productive features especially under rainfed condition. Of all the climatic factors rainfall had the maximum influence on the seasonal fluctuation in yield (Abeywardena, 1968). The summer irrigation improved the productivity of the palms (Nelliat and Padmaja, 1978).

Being perennial in nature, coconut palm had a long duration between inflorescence primordial initiation to nut maturity (~ 44 months) with longer pre-fertilization period (~32 months) than post-fertilization (12 months) period. Hence, the impact of drought which occurred during any of the critical stages of the development of inflorescence affected nut yield (Marar and Pandalai, 1957; Rao, 1986; Rajagopal *et al.,* 1996; Rajagopal *et al.,* 2000c). The impact of drought on the ontogeny of coconut inflorescence integrating the overall occurrence of dry spell and growth stages of the developing nut had been delineated (Rajagopal *et al.,* 1996). The intricate relationship between dry spell and stages of nut development right from inflorescence initiation to the nut maturity indicated that coconut production under rainfed condition was influenced by the length of dry spells at critical stages such as primordial initiation, ovary development and button size nut (Rajagopal *et al.,* 1996) and annual nut yield in different agroclimatic zones (Rajagopal *et al.*, 2000c). This implies that by giving life saving irrigation during summer months the adverse effects of dry spells, especially on the development of the inflorescence primordium can be reduced. The summer rains received during March to May influenced favourably the nut yield of the subsequent year by lowering the atmospheric and soil temperature as well as by building adequate soil moisture content. The influence of drought on nut yield was observed in the subsequent year (Jacob Mathew *et al.*, 1988, Rao,1991, Bhaskara Rao *et al.*, 1991). Some of the cultivars identified as drought tolerant based on physiological traits were also good yielders under drought condition (Rajagopal *et al.*, 1992).

The length and intensity of dry spell and influence of rainfall and dry spell on the nut yield in major coconut growing areas in different agroclimatic zones, indicated that the impact of such variations in dry spell on nut yield was discernible (Rajagopal *et al.*, 2000a and 2000b). The longer dry spell affected the nut yield in the fourth year to follow. Fluctuations in coconut yield during different years could thus be explained on the basis of rainfall distribution. However, the length and number of dry spells are more important than the total rainfall *per se* which influence the nut yield (Rajagopal *et al.*, 2000b). The total rainfall and number of rainy days are not as crucial as the length and number of dry spells coinciding with the critical stages such as primordium initiation, ovary development and button size nuts which ultimately determine the yield potential of coconut palms under rainfed conditions. This perhaps helped for developing a computer model for prediction of coconut yield based on an integrated approach on weather variables particularly length of dry spell and critical stages

10.2.1.11 Soil moisture conservation and irrigation management to mitigate drought effect

Ideally coconut palms should receive water every week for good yields. The frequency and amount of irrigation influenced the water relations and DM production of coconut palm (Rajagopal *et al.*, 1989., Kasturi Bai *et al.*, 1997). Soil moisture conservation practices like husk burial in basins, leaf mulching, glyricidia culture, application of compost and farm waste in basins increased nut yield in coconut (Rajagopal and Naresh Kumar, 2001; Rajagopal *et al.*, 2002; Naresh Kumar *et al.*, 2003). Potassium nutrition also played an important role in drought tolernace in coconut (Quencez and de Taffin, 1981; Rajagopal and Naresh Kumar, 2001; Rajagopal *et al.*, 2002).

The increase in yield due to irrigation predominantly is a result of increases in source (the Pn rates) and sink (female flower production) efficiency. In such a situation the final nut yield is directly proportional to the number of female flowers produced with translocation of photosynthates is not a limiting factor as indicated by the increased nut retention. Under rainfed conditions, the palms grown on sandy soil produced less number of female flowers compared to those grown on laterite soils. The three physiological conditions of source and sink in palms grown under different systems of irrigation are defined (Table 14). The drip irrigation provided conditions for better physiological efficiency of source and sink for high WUE and yield. They also indicated that the drip irrigation increased WUE in field and in plant and leaflet level. The drip irrigation is a system where not only the available water is used to the optimum with negligible losses, but also because of presence of dry zones in root system possibly though root-shoot signals act as the stomatal regulation system to provide optimal physiological efficiency for higher WUE and better yields. Drip irrigation increased the WUE not only at field level but at plant and leaf level also. The study indicated that even in basin irrigation, by applying water in such a way that the dry pockets are created in root system, it may be possible to increase WUE with high yields (Naresh Kumar *et al.*, 2000b).

Table 14: Physiological conditions of source and sink as influenced by the type of irrigation.

Source	Sink	Condition	Yield / WUE (instantaneous)	Remarks
Low ψleaf E, gs and Pn	Less female flower production, nut retention	Rainfed	Low/Low	less available water in root zone
Low ψleaf high E, gs and Pn	More female flower production, nut retention	Basin irrigation	High/Low	Adequate availability of water; no dry pockets in root zone
High ψleaf, medium E and gs and high Pn	More female flower production, nut retention	Drip irrigation	High/High	Availability of water in optimum; dry pockets in root zone

(Naresh Kumarr *et al.*, 2000b)

10.2.1.12 Button shedding in coconut

Shedding of buttons is one of the major constraints in coconut production. The production of large number of female flowers, good fruit set and retention of nuts have an important role in improving the production potential of the palms. This can be achieved by checking the button drop. Extensive reports are available on the impact of various factors on the shedding of buttons (Ramadasan e*t al.*, 1991). During summer months under unirrigated condition, soil water deficit is the major cause for the shedding of buttons, which gets aggravated with the changes in the micrometeorological variables. Although high rainfall is not harmful to the palm growth and productivity, shedding was observed due to the impairment of pollination and fertilization (Menon and Pandalai,1958).

Significant differences have been observed in female flower production, shedding of buttons and nut production between the cultivars and the increase or decrease in the button shedding depends on the number of female flowers in the spadix. Seasonal variation in female flower production and button shedding under irrigated and unirrigated conditions were observed. Although female flower production and percentage button shedding did not differ significantly under irrigated and rainfed conditions, irrigation increased female flower production. In general, female flower production was low in post monsoon season as compared to summer (February to May) and monsoon (June-September) months. Irrespective of irrigation or rainfed condition, button shedding occurred in two peaks, one during summer months and the other during monsoon. During post monsoon season, the number of female flower production was less, consequently the drop percentage was also less (Kasturi Bai *et al.*, 2002).

Leaf area correlated with female flower production and nut production (Kasturi Bai *et al.*, 2002 b) and C/N in the subtending leaf showed negative correlation with the shedding of buttons (Kasturi Bai and Khan, 2002)

Every leaf axil is capable of producing an inflorescence, more so the formation of the primordium of the rudimentary inflorescence starts at about the same time as the subtending leaf. The role of the leaf subtending the inflorescence on female flower production and shedding revealed significant reduction in the carbohydrate fractions in the leaf as well as female flower number in the bunch two months after opening of the inflorescence as compared to the initial stage. The observations clearly indicated that coconut palms regulate the female flower production and shedding of buttons through the operation of a steady carbon-nitrogen metabolism which in turn is regulated by the environmental variables.

Chemical contol for button shedding with 2 4-D,Triacontanol (Anon.,1988) did not give encouraging results. However, 2 mM salicylic acid gave promising results with 16% increase in button retention. The treatment effect was found to be more during early summer than late summer.

10.2.2 Biotic stress physiology

The physiological responses of palms to pathological diseases like root (wilt), lethal yellowing and basal stem rot were used to develop the diagnostic techniques for early detection of diseases. In root (wilt) affected palms an impairment in the physiology and biochemistry viz., derangement in the root functioning (Michael, 1964), mineral nutrition (Davis and Pillai, 1966), changes in phloem sap contents (Ramadasan, 1964) water relations, respiration, photosynthesis, phenol metabolism, and loss of membrane integrity of leaf and root tissues (Michael, 1977) was noted. Abnormal stomatal opening in the diseased palms with impaired regulation lead to excessive transpiration and lower Ψ leaf irrespective of the time of the day, season or growing condition (Rajagopal *et al.*, 1986, Rajagopal *et al.*, 1987a). Apparently healthy palms yielded more sap for longer duration than the diseased palms (Rajagopal *et al.*, 1989a). Concentrations of arginine, aspartic acid and tyrosine as well as glucose and galactose were higher in sap from the diseased palms than from apparently healthy palms (Chempakam *et al.*, 1991).

The root (wilt) diseased palms had higher respiratory rates in leaf and roots (Michael, 1978), low chlorophyll concentration , photosynthetic rates, carbonic anhydrase activity (Dwivedi *et al.*, 1978) and higher cellulase and pectinlyase activity in roots (Padmaja and Sumathykutty Amma, 1979; Sumathykutty Amma and Patil, 1985). An impairment of sugar metabolism, translocation and distribution (Chacko Mathew, 1977) and a reduction in the C/N ratio was noticed in the roots and leaves of diseased palms ((Padmaja *et al.*, 1981). Free amino acids in the leaves, particularly arginine, increased with the incidence and intensity of the disease. Isotopic studies revealed delayed uptake of phosphorus in diseased palms compared to healthy palms (Ray *et al.*, 1979). Although total P was more in diseased palms the organic P especially the nucleic acid phosphorus was significantly less in diseased palms than that of healthy palms (Dwivedi *et al.*, 1979).

Based on the abnormal stomatal opening phenomena in diseased palms, an early diagnostic tool for root wilt was developed (Rajagopal *et al.*, 1988) which could detect disease affected palms six to 20 months earlier than the actual manifestation of flaccidity symptom. The leaf water potential measurements could also serve for the early diagnosis of palms affected by mycoplasma like organisms (MLOs) was shown both in lethal yellow disease (LYD) (Eskafi *et al.*, 1986) and root wilt disease (RWD).

The disease can be managed well with summer irrigation in basins with 250 litres $palm^{-1}$ $week^{-1}$ with recommended dose of fertilizers including cowdung and prophylactic measures with Bordeaux mixture which resulted reduction in flaccidity, yellowing, leaf-rot, senescence and necrosis (Rajagopal *et al.*, 1987b).

In contrast to RWD, the LYD resulted in abnormal stomatal closure (Eskafi *et al.*, 1986). Permanent closure of stomata (Mc Donough and Zimmermann, 1979), decrease in turgor, osmotic and water potentials with disease intensity were also observed thus affecting water transport through xylem (Eskafi *et al.*, 1986). During the early stages of LY disease, a decrease in the exudation of phloem sap from the inflorescence was observed (Eden-Green and Waters, 1982). The photosynthetic rate and protein content decreased with the severity of the disease. Free amino acid, arginine content in the leaf is used as a diagnostic tool for the early detection of LY disease (McCoy *et al.*, 1983).

In basal stem rot diseased palms also low stomatal resistance and high transpiration rate were observed as compared to healthy palms (Vijayaraghavan *et al.*, 1989). In diseased palms, mineral nutrients viz., N,P,K,Ca and Mg decreased in the leaf, stem, bole and root tissue (Anbalagan *et al.*, 1987). An increase in total phenols, reduction in soluble sugar levels and an impairment in membrane stability were also observed in the diseased palms.

11.0 Propagation

11.1 Seed

Coconut palm is perennial in nature living for 80 to 100 years with an economic life of 60 years or more depending upon the growth conditions. The palms take about 6 to 10 years to commence to flowering and another 5 years or more to come to the stage of full bearing. Thus, only after 15 to 20 years, the grower is in position to gaze the production potentials of palms. The need to plant quality planting materials is therefore, emphasized that will ultimately give good yields.

The coconut palm is a monocot and is capable of being propagated only through seed. As the palm is heterogeneous and cross-pollinated in nature, the progeny is likely to be variable.

The major coconut producing states in India are Kerala, Tamil Nadu, Andhra Pradesh and Karnataka, which together accounts for more than 80 % of area and production in the country. The crop is also grown in Orissa, West Bengal, Maharashtra, Gujarat, Andaman and Nicobar islands, Lakshadweep islands, Goa, Daman and Diu and also in limited extent in Assam, Tripura, Madhya Pradesh, Bihar and Manipur. The most popular and common cultivar's available is the local tall of the respective states. A few dwarf types are also seen mainly in the house compounds grown for tender nuts and for ornamental purposes.

Systematic evaluation over the past several years resulted in the selection of three high yielding cultivars namely 'Lakshadweep Ordinary' (Chandrakalpa), 'Benawali Green Round' ('Pratap') and 'Philippines Ordinary' ('Kerachandra') for coconut growing tracts of India (Nair *et al.*, 1995). The yields in these cultivars were >97 nuts palm^{-1} year^{-1} as compared to local tall i.e. 'WCT' (80 nuts palm^{-1} year^{-1}). Nearly 80 hybrid combinations have been evaluated over the years in India and so far eleven hybrids were released for commercial cultivation (Table 15). The yield of hybrids was much higher (>100 nuts palm^{-1} year^{-1}) compared to 80 nuts produced by tall 'WCT' cultivar under rainfed conditions (Nair and Nampoothiri, 1993; Iyer and Damodaran, 1994).

Table 15: Performance of released coconut cultivars and hybrids

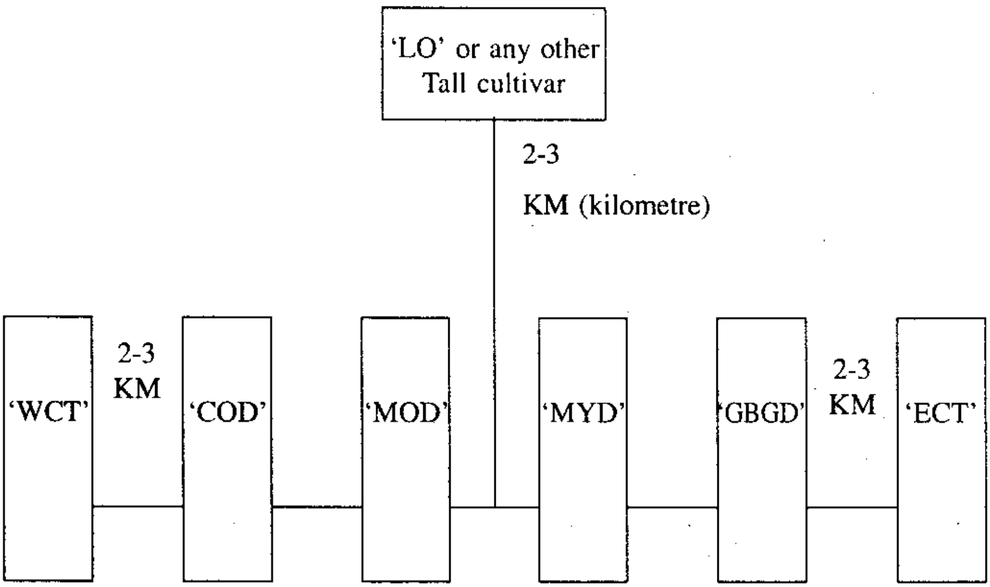
Cultivars / hybrids	No of nuts palm^{-1} year^{-1}	Copra yield		Oil content (%)	States for which recommended	Institution responsible for release
		Mean nut^{-1} (g)	Mean palm^{-1} (kg)			
'Lakshadweep Ordinary'	97	195	18.9	72	Kerala, Karnataka	CPCRI
'Benawali Green Round'	151	152	22.7	65	Goa, Karnataka	CPCRI
'Philippines Ordinary'	110	198	21.8	65	Kerala	CPCRI
'Chandrasankara' ('COD' x 'WCT')	116	215	24.9	68	Kerala	CPCRI
'Kerasankara' ('WCT' x 'COD')	108	187	20.2	68	Kerala, Maharashtra, Andhra Pradesh	CPCRI
'Chandralaksha' ('LCOT' x 'COD')	109	195	21.2	69	Kerala	CPCRI
'Lashaganga' ('LCOT'x'GBGD')	108	195	21.1	70	Kerala	KAU
'Anandaganga' ('ADOT'x'GBGD')	95	216	21.5	68	Kerala	KAU
'Keraganga' ('WCT' x 'GBGD')	100	201	20.1	69	Kerala	KAU
'Kerasree' ('WCT' x 'MYD')	130	216	28	66	Kerala	KAU
'Kerasoubhaghya' ('WCT' x 'SSA')	130	195	25	65	Kerala	KAU
'VHC-1' ('ECT' x 'CGD')	98	135	13.2	70	Tamil Nadu	TNAU
'VHC-2' ('ECT' x 'MYD')	107	152	16.3	69	Tamil Nadu	TNAU
'Godhavariganga' ('ECT' x 'GBGD')	140	150	21.0	68	Andhra Pradesh	APAU
'WCT'	80	176	14.1	68		

CPCRI : Central Plantation Crops Research Institute, India.
KAU : Kerala Agricultural University, India.
TNAU : Tamil Nadu Agricultural University, India.
APAU : Andhra Pradesh Agricultural University, India.

11.1.1 Method of establishing seed garden

The earlier method adopted for establishing seed gardens for hybrid seed production was to plant tall and dwarfs in alternate rows and do crossing by simple emasculation of the female parent. Both 'D x T' and 'T x T' hybrids could be produced either through natural crossing by pollinating agents or through assisted pollination. However, in view of the easiness of operation, the present approach is to plant dwarf and tall in separate compact blocks. A simplified crossing technique developed by the Central Plantation Crops Research Institute for the production of hybrid coconut seeds is now being used at various seed gardens in the country. Since the availability of pollen garden in the vicinity is always preferred, it is suggested to plant the tall pollen parent in compact areas two to three km away from the dwarf seed garden. This will help in avoiding the storage and long distance transport of pollen. The layout of seed garden blocks as indicated in the fig 2, would help in the production of 'D x T', 'T x D' and 'T x T' combinations depending upon the requirements and operational easiness. Periodic inspection of the tall and dwarf cultivars planted in seed blocks should be undertaken and the off types and low yielders are removed to ensure the purity of cultivars and better progeny performance. If the tall pollen parent is established in a larger block, the same will meet the needs of both pollen as well as that of the seed nuts of the tall. All around the blocks it is required to put a border row of same cultivar for maintaining the purity of parents. The seed garden should be free from the incidence of diseases and pests. Phytosanitation besides, timely prophylactic and curative measures as suggested elsewhere can prevent the crop losses and thereby increase the production and productivity.

Fig. 2: Layout of seed garden blocks



11.1.2 Selection of area

Irrespective of the area, seed nuts can be collected from the specifically established seed gardens with selected parents. However, in case of collection of seed nuts from the non-designated seed gardens, it is very important to select proper coconut growing area. In every country where coconut has been under cultivation for a long period, certain areas are found to have earned a reputation for the yield and quality of nuts produced there. There is always a great demand for seedlings from such centres for planting in the other parts of country. In India a number of such centre of repute are known and the result of a critical and comparative evaluation of some of these centres in respect of germination of seedlings and outturn of quality seedlings from them have been reported by Aiyadurai (1954). Such studies will enable really good centres to be located for the large-scale collection of seed nuts.

11.1.3 Selection of gardens

In the selected area themselves all the gardens are not suitable for the collection of seed nuts. Only those with a record of consistently high yields and containing high proportion of heavy bearers and situated under average conditions without heavy manuring or irrigation and free from the incidence of pests and diseases are to be chosen. Coconut is being mostly a cross pollinated crop, the precaution is necessary to ensure that there is a greater chance of female flowers of such palms being pollinated by pollen from heavy yielder. The nut developing as a result of such pollination has a somewhat greater chance of producing superior progeny than others.

11.1.4 Selection of mother palms

Several workers reported the importance of selecting seed nuts from high yielding mother palms having other desirable characters (Sampson, 1923; Mendiola, 1926: Copeland, 1931; Hunter and Leake, 1933; Smith, 1933; Pieris, 1934; Patel 1938; Child, 1950; John, 1952). However, of late, workers from Sri Lanka have questioned the necessity of mother palm selection and have stated that the system of selecting seed nuts on block nuts basis is equally satisfactory (Cheyne, 1952a and 1952b; Liyanage, 1953a and 1953b). In this system the very best nuts are picked up from the heaps of nuts produced by the best blocks or fields of very good estates with consistent records of high annual yield and good copra production. The basis of selection is an annual yield of not less than 10000 nuts ha^{-1} or an annual average of 55 nuts or more $palm^{-1}$ (Cheyne, 1952a). This practice has really emanated from the necessity to produce large number of seedlings in short period which would not have been possible if the mother palm method of selection had been adhered to. Smith (1933) considered the method of selecting nuts from a heap as unsound in the view of the fact that even in a plantation giving high yield, proportion of really high grade palms are always very small. It was admitted that first quality nuts come from mother palms which gave consistently high yield (Cheyne, 1952a, 1952b; Liyanage, 1953a, 1953b).

Several workers have proved the benefit of 'mother palm' selection. Liyanage (1953b) stated that by 'mother palm' selection alone 50 percent efficiency can be obtained though it can be raised up to 90 percent or over by growing selected palms in isolation, permitting natural interpollination between them. Rockwood (1953) obtained remarkable results in his estate due to the use of planting material derived from high yielding selected mother palms instead of using block nuts of doubtful origin. In a trial laid out at Coconut Research Station, Nileshwar (India) with progenies from different sources, there was an indication to show that progenies from high yielding mother palms were better than those from poor yielding ones (Sayeed and Narayana, 1953). Johns (1938) envisaged up to 80 % purity, although cent percent was not possible because of the habit of pollination of palms. Dwayer (1938) also referred to an instance in British Guinea where palms have retained to a marked degree the original characteristics for which they are introduced. The mother palms are to be selected based on the individual performance of palms for nut size, shape, yield, copra content, leaf characters etc. The following standards are to be strictly adhered for quality seed material.

i) Palms should be regular bearer with annual yield of more than 80 nuts and copra content not less than 150 g nut^{-1} under rainfed condition (Irrigation-120 nuts $year^{-1}$). In Sri Lanka, the basis for the selection of mother palm is an annual yield of not less than 75 nuts with an average husked nut weight of 680 g (Anon., 1954a). In Malaya, the requisite standard for the selection is an annual yield of 100 nuts with wet meat content of 500 g (Smith, 1933).

ii) Palms should have reached full bearing stages and been giving consistently high yields for at least four years.

iii) Avoid very young (below 20 years) and old palms (above 60 years age). If the palms are young or old, the assumption regarding their performance can very largely go wrong. This risk one cannot afford to take for reasons already referred. Under normal conditions, palms between 25 and 60 years of age would have reached the full bearing stage and can be selected as mother palms.

iv) Seed nuts can be collected from the newly established seed gardens irrespective of the age of the palms, as the performance of its parents is known and only high yielders are maintained.

v) Palms growing close to houses, cattle sheds, compost heaps, etc., may be avoided. According to Sampson (1923) the trees that respond readily to a great extent to the changes in environment and manurial practice are also not desirable as these indicate a type, which is identically inferior.

vi) A high yielding mother palm in its middle age will have at any time 30 to 40 fully opened leaves in its crown. Total number of leaves in crown is correlated with yield over a long period.

vii) According to the disposition of leaves in the crown it can roughly be grouped into four classes, viz., spherical, semispherical, drooping and erect. Among these the first two are the best, as disposition of leaves is such that the bunches will have sufficient room for normal development and will be fully supported by the leaf petioles. When the crown is of the drooping type the bunches are likely to slip down, break the inflorescence stalk and shed the nuts in the immature stage. Palms with drooping or erect crown should be avoided even if they show other desirable characters.

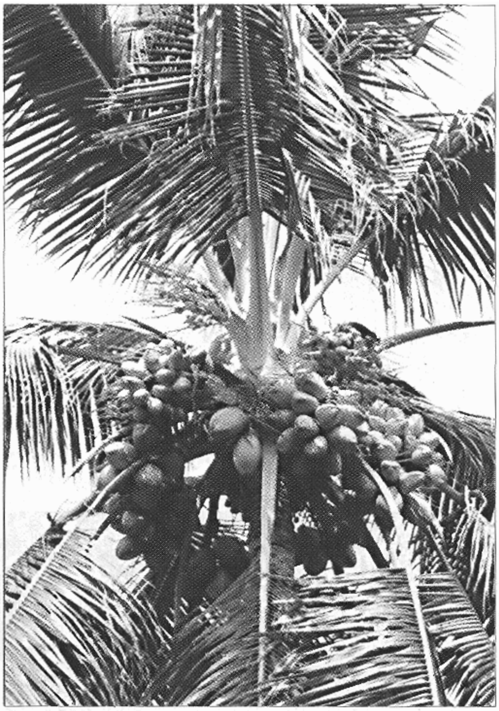
viii) The petiole should be short and stout with wide leaf base firmly attached to the stem to give effective support to the coconut bunches. The bunch stalk should be short and strong and not have any tendency to drop down. Pieris (1934) noted a highly significant positive correlation between length of petiole and length of bunch stalk and this should make the selection of mother palm with these desirable characters easier.

ix) Each leaf axil should have one inflorescence with large number of spikes and one or two female flowers spike^{-1}. There is some advantage in selecting trees, which bear large number of heavy nuts in a bunch. Studies on germination indicated that greater number nut from heavy bunches (12 nuts or more) germinate much quicker than light bunches (6 nuts or below) and that light seed nuts (weighing 680 g and below) give much reduced germination than heavy ones (weighing 680 g and above) (Patel, 1938).

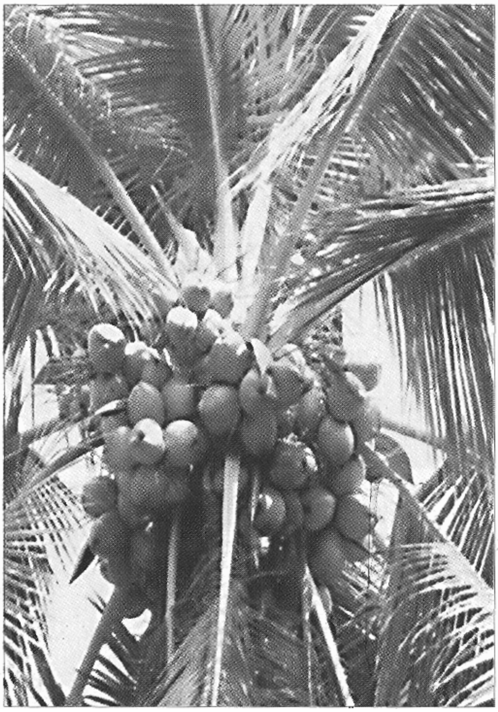
x) Bunch stalk should be short, stout and strong and should not show any tendency to droop down or buckle.

xi) Palms having medium sized nuts (about 1200g when the husk is fully dried) with round or spherical shape and oblong shape are to be selected. Husked nuts should be large (about 570 g) with thick kernel. Such trees not only give high yields but the nuts also contain, in general more copra than the others (Maceda, 1933 and Patel, 1938). The spherical nuts germinate earlier than others, it has been recorded by Maceda (1933) and Patel (1938). Smith (1933) got better germination from medium sized nuts than from larger nuts.

xii) Palms producing habitually barren nuts, i.e., nuts which are empty or do not contain well developed kernel inside or those that shed their nuts before they

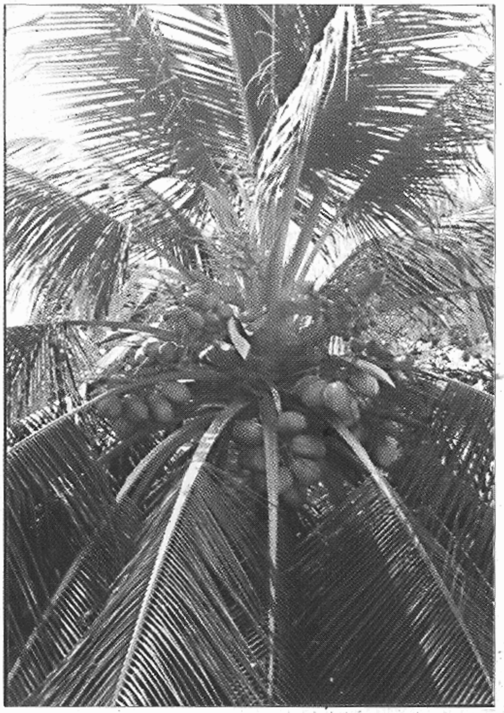


Lakshaganga-a drought tolerant coconut hybrid



Philippines ordinary- a drought tolerant tall coconut

Coconut hybrid-Chandrakalpa



Coconut polybag nursery

High density multispecies cropping in coconut

Multiple cropping in coconut

attain full maturity are to be discarded at the time of selection of mother palms even though such trees may give high yield.

11.1.5 Collection of seed nuts

The season of seed nut collection may vary from country to country and region to region within the country. Always it is better to collect which had undergone development during rainy season for seed nut purpose. On the West coast of India, seed nuts are harvested in the months of February to May as these nuts are bigger in size, have the maximum copra content, give a high percentage of germination (95 %) and larger outturn of good seedlings. The period also just precedes the south-west monsoon so that, with the commencement of rain the nuts can be planted in the nursery. Aiyadurai (1954), discussing the results of experiments carried out on the West and East coast of India, concluded that the optimum period for harvest of seed nuts may vary from tract to tract and it is to be determined for different localities considering the condition prevailing there.

The nuts to be utilized for seed nut purpose are generally harvested only when they are fully mature, that is 12 months old. Recent studies carried out in India and Sri Lanka has shown that the second bunch of nuts, that is, nuts about 11 months old can also be used for seed nut purpose. There was no difference in the performance of seedlings derived from the two groups of nuts either in the early stages or at bearing (Liyanage, 1950). The seed nut bunches should be cut and lowered by means of ropes to avoid damage that may result due to the fall of nuts from the crown. Studies have shown that except in places where the ground is hard or the palms are very tall, this practice has no special advantage.

Discard nuts having irregular shape and size and improper development. Some seed nuts may show superficial cracks or other marks on them. In some others, perianth may be found to get loosened and fall easily at harvest time itself or during storage. These have no effect on germination of the seed nuts or on the subsequent growth of seedlings but such nuts are to be avoided because of some other unfavourable effects they might have (Ummer Kutty, 1955).

11.1.6 Storage of seed nuts

The seed nuts after harvest are not immediately planted in the nursery, but are generally, stored in shade for about a month till the husk becomes dry. On the West coast of India, the nuts may have to be stored for a maximum period of about 4 months because though the seed nut season starts in February, the nuts are planted in the nursery only with the start of south west monsoon in June. During storage period, which is the hottest part of the year, large number of nuts get dried up in spite of storing them in shade. Such nuts do not germinate at all or germinate very late and therefore are not fit for planting in the nursery. To prevent seed nuts from drying up, John and Narayana (1942) recommended their preservation in fine dry sand. The seed nuts are arranged with the stalk end up on the floor of a shed over a layer of about three inches of sand and covered up with it till the time of planting. Storage had no bad effect on the viability of seed nut or the quality.

11.2 Nursery raising techniques

Coconuts are not recommended to plant out directly in the field, since seedling selection, which has been established, facilitates an important factor in crop improvement. The following are some of odd practices followed by growers in the different coconut growing countries of the world for making seed nuts germinate.

(1) Seed nuts are placed on the roof of thatched house during the monsoon and when they sprout they are directly transplanted in the field.

(2) The nuts are heaped in shade and allowed to sprout.

(3) The nuts are tied in pairs with a bit of husk split from each and then suspended from branches of the tree or bamboo posts. Water is sprinkled over nuts regularly till they sprout.

(4) In the Philippines, seed nuts are tied around an upright pole in the open for germination.

(5) Sometimes the seed nuts are allowed to germinate where they fall.

The above methods are all defective. The nursery practices described hereunder are aimed at giving optimum conditions for the germination of seed nuts and subsequent growth of seedlings with a view to obtaining a high percentage of selected seedlings from the nuts planted.

11.2.1 Site selection and raising nursery

Select well-drained, coarse-textured soil near dependable water source for irrigation. In places where sandy soils are not available, it is recommended to remove soil to a depth of about 0.3 m to 0.5 m and fill it with sand. The sandy medium is also recommended because the growth of seedlings will not be influenced by the fertility of soil giving a better opportunity for a proper selection of seedlings to be made on intrinsic merit alone. In Sri Lanka, the nurseries are located on loamy and other soil types also. Nursery is best raised in the open, though it can be raised in the coconut garden itself provided there is not much of shade.

The seedbeds should be preferably long and narrow with provision for walking space or drains in between. The width so adjusted will accommodate four or five rows of nuts only. This will facilitate watering of nursery and examination of seedlings from the sides without getting into the beds. Prepare raised beds if water stagnation is a problem during rainy season. Soil may be treated with chlordane 5% dust @ 120 kg ha^{-1} in place where nursery is raised for the first time as a precaution against white grubs and termites.

The seed nuts should be planted in long and narrow beds at a spacing of 40 x 30cm during May-June, either vertically or horizontally in 20-25cm deep trenches. Spacing of seed nuts in the nursery is determined in relation to the time the seedlings have to be retained in the nursery. In Godavari area and Orissa (India), where much older seedlings are preferred for planting, it is usual to transplant the seedlings when they are one year old to a second nursery with a spacing of 0.9 to 1.5 m between the seedlings. In Sri Lanka planting of nuts giving 22 cm spacing between nuts in the row and between two rows is recommended. Different methods of planting seed nuts are in vogue. Some plant the seed nuts horizontally while the others plant them vertically with stalk end up or in an oblique position. Some are reported to plant the seed nuts even upside down. These methods had been subjected to critical examination and horizontal planting was found to be the best (Espiono, 1922; Ambrose, 1951; Anon., 1951). In horizontal planting, nuts should be placed with the widest of the three segments uppermost. The soft or germinating eye lies below this segment. If planted in this position the sprout can easily come up. The depth of sowing may be so adjusted that the husk appears just above the surface of the soil. Normally 15cm depth will be sufficient.

The time of planting of nuts in the nursery will vary from tract to tract depending mostly upon the outbreak of monsoon. By planting seed nuts at the commencement of rain, it will be possible to ensure optimum condition for germination at very little cost, as otherwise frequent watering has to be done in the initial stages. On the West coast of India, nuts are sown in the nursery in May to June. At the time of sowing, it is necessary to re-examine the nuts individually and discard those, which have dried up completely or have become rotten in the course of storage. Under Orissa condition, in India it was found that the elite tall coconuts recorded the highest values for all the seedling characters. Among the sowing dates, coconuts sown in September grew better (Swain *et al.*, 2002).

Soaking of seed nuts in water for a period upto 15 days has been found to result in quicker and better germination, but if the period is prolonged, germination and quality of seedlings are affected. The effect is likely to be influenced by seasonal condition also. If after sowing of seed nuts, heavy and continuous rains are received the difference due to soaking may not be apparent, but if dry condition prevails, the beneficial effects of soaking will be apparent. Liyanage (1952) did not get any beneficial effect on germination by injecting six different kinds of hormones into the husk. Injection of major nutrients like N, P, and K into the husk tried at the Central Coconut Research Station, Kasaragod had adverse effects on germination.

11.2.2 Care and management of nursery

The nursery is to be watered twice a week or more often according to necessity during rainless periods. It is also to be kept free of weeds by periodical weeding. Heavy infestation of *Cynodon dactylon* is reported to have had a bad effect on growth of seedlings in Sri Lanka. During dry and hot weather the nursery beds should be mulched and shaded with dry coconut leaves or any other suitable material. Coconut leaves mulch had been reported to promote early and better germination, good growth of seedlings and high percentage of good seedlings (Liyanage, 1952; Verghese *et al.*, 1953; Aiyadurai, 1954). For providing shade without incurring much cost, the possibility of using some quick growing plants like *Sesbania speciosa* had been identified by Aiyadurai and Mohammed Ibrahim (1954).

Under favourable condition of the environment, the nuts of tall cultivar of the coconut will commence to germinate 11 to 12 weeks after planting. The percentage of germination reaches the maximum between the 17th and 18th week and then commence to decline. In India, nuts which do not germinate within 5 months from the date of planting are removed from the nursery. A careful watch must be kept for the incidence of pests and diseases so that proper control measures can be taken in time. The important pests and diseases and their control measures detailed under polybag nursery may be followed for field nursery also.

11.2.3 Manuring coconut nursery

Chemical fertilizers are usually not applied to the seedlings in the nursery as it is felt that the intrinsic quality of the seedling is likely to be masked to some extent making a proper selection of seedlings difficult (Sampson, 1923; John, 1952). The seed nut contains adequate nutrients to meet the needs of growing plant, at least upto the field planting stage. However, as their nutrient reserve from the endosperm decreased from the fourth month after germination (Foale, 1968) and as also indicated by analysis of growing parts, the need for fertilizer application to the nursery had been stressed in several reports to produce healthy and vigorous seedlings (Anon., 1941; Anon., 1958; Fremond *et al.*, 1966). In India, studies on fertilizer application to nursery are limited. Preliminary investigations suggested that nursery manuring is not necessary if seed nuts are removed nine months after sowing. After that the plant may respond to fertilization, if soil type is inert sand or with low fertility. There is however, a need to change this concept and apply N, P, K to the nursery in order to produce healthy seedlings, facilitate better establishment, faster growth and early bearing in the main field (Nelliat, 1972). Several studies had shown the superior growth and vigour of seedlings with addition of fertilizer to the nursery (Mathew and Ramadasan, 1964; Srinivasa Reddy *et al.*, 1998). In Philippines, experiments on N and K fertilization in coconut nursery resulted in production of taller seedlings with bigger girth and greater vigour index. Application of nutrients (N, P, K, Ca and Mg) to the seedlings in the nursery had been found to be beneficial to produce seedlings with proper vigour and quality (Nelliat *et al.*, 1976). The collar girth, leaf area, dry matter production and number of roots were superior with application of 25 t ha^{-1} FYM and 160 kg each N and K fertilizers as soil application in three splits at 5th, 7th and 9th months after sowing (Srinivasa Reddy *et al.*, 1998).

11.3 Polybag nursery

Coconut seedling raised in polybag was introduced in 1969 in the Cote d'Ivoire (Wuidart, 1981), superseding the technique of conventional field nursery for production of vigorous seedlings. Their advantages and disadvantages in planting programmes have been well documented (Harries, 1983; Srinivasa Reddy *et al.*, 1996). This technique has certain drawbacks, unless seedlings are raised in close proximity to the planting site, the cost of transportation would be more. Besides, the extra labour for filling bags and material costs are the major constraints in the polybag nursery system.

11.3.1 Selection of site

The nursery must be located near a dependable water source to facilitate satisfactory irrigation throughout the year. Moreover, to reduce the transportation cost, it should be near the site of field planting. The land should be generally flat. It is to be weeded, leveled and top soil compacted. About 25,000 seedlings can be accommodated in one-hectare nursery area at a spacing of 60 x 60 cm.

11.3.2 Filling the bags and sowing nuts

The bags are made of black polyethylene of 500 gauge thickness and 60 x 40 cm size for bigger nuts and 40 x 40 cm for smaller nuts. The bottom portion of bag should be provided with 8 to 10 holes for draining excess water. Polybags of the recommended size, filling two-third portion of the bag with top soil usually weighs about 13-16 kg. The commonly recommended media are top soil mixed with sand in the ratio of 3:1, loose friable soil, river sand in combination with cattle manure and coir dust and soil and compost mixture in 1:1 ratio. Decomposed sawdust, corncobs, rice hull or similar organic materials can also be used. The study at CPCRI, Kasaragod indicated that sowing in potting mixture medium, 1:1:1 mixture of red earth, cowdung and sand either in polybag or cement tank was beneficial in producing vigorous seedlings (Srinivasa Reddy, 1998). Sowing in potting mixture not only holds more moisture but also provides better nutrition to growing seedlings and helps to get higher recovery. In Sri Lanka, it was reported that river sand could be a successful alternative to the more expensive potting media currently used in polybags (Peries and Everard, 1991). However, further study indicated that a mixture containing 3 parts of river sand, 2 parts of cowdung and 1 part of coir dust was shown to be the best (Perera and Jayatileke, 1996). Since, the potting mixture is not only costly but, now-a-days the availability is also very much limited, the study on alternative media indicated that sand+vermicompost mixture in 1:1 proportion, sand+P and K fertilizers+bio-fertilizer treatments were similar in response to potting mixture media in terms of seedling growth, physiological parameters and the final seedling vigour (Srinivasa Reddy *et al.*, 2001). Therefore, sand+ Vermicompost mixture or sand+P and K fertilizers+bio-fertilizer treatment could be considered to replace potting mixture in raising polybag coconut seedlings. The effect of biofertilizer treatment not only helps seedling growth in polybag, possibly it may also result in better establishment of microbial population in the main field which helps in better growth and development and establishment of seedlings.

In the conventional nursery system there should be more than 80 % germination in 20 weeks with optimum management and seed nuts that do not germinate by then are discarded as failures (Harries, 1983). In polybag system, seed nuts are allowed to germinate in a pre-nursery bed, sown very closely and transplanted in polybags when the sprouts are 8-10 cm long. The germinated nuts are picked out from the nursery once a week until 80 % of nuts are germinated or upto 5 months from sowing whichever is earlier. The germinated nut is placed in the half-filled bags with the sprout planted vertically in the centre of the bag and enough potting mixture is added to fill the bag upto two-third portion and the sides slightly pressed to keep the nut firm so that it is not bared during watering. Care must be taken not to cover the collar of the young seedling. The seednuts may be dipped in carbaryl 0.2 % solution prior to planting as precaution against termite attack.

11.3.3 Laying out of polybag nursery

The size and layout on the land depend on the irrigation system adopted and spacing of bags. Spacing of the bags mainly depends on the time the seedlings are to remain in the nursery. The size of the polybag nursery bed can be 3 x 6 m with about 1.5 m spacing between beds. Each bed can accommodate 115 seedlings and these bags are arranged in a triangular manner with 60 cm space between bags.

11.3.4 Maintenance

Good maintenance of nursery ensures better seedling growth and seedling vigour.

11.3.4.1 Irrigation

Regular watering of the polybag nursery is very important to ensure proper growth of seedlings. The frequency of watering should be adjusted depending upon rainfall and other weather conditions, age of the seedlings and type of potting mixture used. Irrigation may be required every alternate day during the summer months on the West coast. Several irrigation systems are available, and the choice must take various factors like ease of use, size of nursery, movement between the seedlings and capital investment into consideration. Sprinkler irrigation is preferable for larger nurseries. In small nurseries, hose irrigation is commonly practised. However, care must be taken not to wash the medium out of the bag while irrigating bags.

11.3.4.2 Weeding

Weeds adversely affect the growth of seedlings and therefore, it is essential to have weed-free nursery and also keep the surroundings clean by controlling the weeds as and when required.

11.3.4.3 Fertilization

The coconut has considerable reserves of essential plant nutrients in its nut. However, the roots are capable of absorbing the nutrients one month after their initiation. Thus, an optimum fertilizer schedule to derive the best benefit from substrate in polybags is worthy of further investigation. Application of 20g ammonium sulphate and 25g potassium chloride after 2 months of germination and 45g ammonium sulphate and 45g potassium chloride after 4 months of germination bag^{-1} as recommended in Indonesia may be adopted (Ratnambal, 1995). The fertilizer is spread around the seedlings and forked into the medium. The polybag must be watered on the same day.

11.3.4.4 Plant protection

Careful inspection is a must in both polybags and field nurseries for detecting the incidence of pests and diseases and suitable plant protection measures are to be taken up as soon as insect/disease symptoms are noticed.

Ants and termites: The medium around the nut is to be treated with chlordane 5 % dust in the bags.

Scales and mealy bugs: Spray dimethoate 0.05 % on the under surface of the leaves.

Mites: Spray dicofol or dimethoate 0.05 % on the under surface of the leaves.

Leaf-defoliators: The whole foliage is to be sprayed with carbaryl @ 20 g in 15 litres of water.

Fungal diseases: The most widespread fungal diseases are leaf spots caused by *Helminthosporium, Pestalotia* and *Colletotrichum* and bud-rot caused by *Phytopthera*. In areas where there is a risk of attack, preventive treatments should be given twice a month, spraying both sides of the leaves with a solution of Bordeux mixture (1%) or Indofil- M45 (0.3%). To back up the treatment, severely infected leaves can be removed and burnt to avoid dissemination of spores.

11.4 Preparation of plants for field planting

The selected seedlings (10-12 months old) should be prepared for field planting. They are abundantly watered to ensure a moisture reserve, handled with care to avoid baring them or tearing the bag. There is also a scope for introduction of bio-fertilizers like VAM (vesicular arbuscular mycorrhizae) and phosphate solublizers in the polybag before field planting for better establishment of organisms. Mycorrhizal colonization in roots and spore density in the root region soils of coconut in a plantation in Kerala, India, were found to be affected under treatments of tillage, herbicide, fertilizers and a combination of tillage+organic and inorganic manures when compared to that in plots which were not receiving these treatments (Harikumar and Thomas 2003). Identification of the AM fungi associated with coconut under different treatments revealed the presence of nine species of AM fungi belonging to the genera viz., *Glomus, Acaulospora* and *Gigaspora*. The distribution of various AM species under different management treatments was also determined. *Glomus macrocarpum* was found to be the most abundant species under different treatments (Harikumar and Thomas 2003).

11.4.1 Age of seedlings

The systematic selection of seedlings in the nursery is indispensable if one is to expect good performance from the future plantations. Such selection is possible only when the seedlings are at least 9 to 12 months old. In Sri Lanka, selection is done when the seedlings have developed about three green leaves (Anon., 1954b). As a general rule, under ordinary condition, seedlings 9 to 18 months old can be considered the best for planting in most places. At this stage they will have about 60 per cent of the kernel till left in the nuts as an unavailable food reserve for the growing seedling and this will facilitate their quicker establishment when transplanted out in the field. These seedlings do not wither quickly and being light in weight, are also easy and cheap to transport over long distance.

11.4.2 Seedling selection in the nursery

In view of the lack of genetic purity in seed nuts, vigorous rouging out of inferior seedlings in the nursery is as important as the selection of mother palms and seed nuts. Research workers in Sri Lanka consider this step as the most important in the production of quality planting material. Liyanage (1953b), analyzing the results of a field trial laid out in Ratmalagara estate (Sri Lanka) to study the comparative effects of selection of seedlings concluded that selection of seedlings alone will increase the crop by 10 %. Selection of seedlings in the nursery is based on the characteristics which are believed and in some instance actually proved to be associated with good yield in the adult palms such as early germination, rapidity of growth, earlier splitting of leaves into leaflets, vigour, sturdiness, and freedom from pests and diseases. The following are the standards prescribed for the selection.

i) Select seedlings that have germinated early. Early germinated seedlings grow faster (Patel, 1938).

ii) Selection of seedlings should be restricted to healthy, vigorous, robust looking ones possessing large number of leaves with short and thick petioles, good girth at base and large number of roots. From the one-year-old nursery, select vigorous seedlings having minimum of six leaves and girth of 10 cm at the collar. Correlation studies also showed that the palms with larger number of leaves begin to flower earlier than those with smaller number of leaves (Jack and Sands, 1924; Liyanage, 1955a, 1955b).

iii) Early splitting of leaves is a good indicator of the rapid developers and early bearing.

iv) Every coconut nursery contains some plants, which are deformed, or whose development is stunted and those that are thin and lanky should be rejected.

v) By adopting vigorous standard of selection, about 40 to 50 % may have to be discarded. Thus, the number of nuts to be planted in the nursery should be nearly twice the number of seedlings actually required.

11.4.3 Maintenance of nursery registers

The particulars of parent trees, seed nuts collected, nuts sown and nuts germinated should be recorded in a register in every nursery. There should be also a record kept for observations made in the nursery.

11.4.4 Removal of seedlings from the field nursery

After selection, seedlings should be removed from the nursery only just before they are required for transplanting in the field, these seedlings should not be pulled out by force, their root should neatly be cut and the seedlings with the nuts gently removed. Pruning of roots is not harmful in younger seedlings (7 to 12 months old) but may cause some delay in establishment and retarded the growth of older ones (Patel, 1938). The seedlings pulled out of the nursery should be planted as early as possible, preferably before 10 days (Aiyadurai, 1954).

12.0 Cultivation

Coconut is grown mainly as a rainfed or irrigated crop in the homestead garden. Cultivation practices include seed nut selection, nursery management and adult palm management.

12.1 Field planting

Before starting a coconut plantation in new areas where coconut has not been cultivated on large scale, the greatest care should be taken to see that the climatic and soil condition in the area are suitable for raising the crop. When once that has been decided, the sequence of steps is to be followed as detailed below.

12.1.1 Preparation of land for planting

The preparation of the land will depend upon its location and condition. If the land is virgin jungle or under scrub growth, the trees and shrubs have to be removed along with the stumps. If the land is sloping, it is necessary to terrace and take erosion control measure to prevent loss of surface soil during rain. Methods conserving soil and water on lands not yet planted have described in detailed by Gorrie (1950). In low-lying areas where water is likely to stagnate, drains should be opened for proper drainage.

In low-lying and backwater areas, in the South of Kerala (India) where the water table remains high throughout the year, coconuts are planted on raised bunds. These bunds may be from 5 m to 8 m in width and are built up by dumping clay and sand in alternate layers inside enclosure made by stone revetments. Bunds are also formed with soil from adjacent strips of land.

The land to be planted with coconut should be fenced properly even at the very outset to protect the planted seedlings from stray cattle, till they grow big enough to be beyond their reach.

12.1.2 Spacing

In the different coconut growing countries where the majority of holdings are small and under peasant ownership, the growers often plant coconuts haphazardly without adopting any proper spacing or system of planting. Closer planting and growing other kinds of trees mixed with coconut are common in homestead farms of Kerala, Andaman and Nicobar islands, and Lakshadweep islands (India).

The spacing actually adopted is found to vary from country to country and within the country from region to region. In India the spacing varies from 6 m to 9 m or more though 7.5 m to 9 m is now recommended for average conditions. It is reported that in Sri Lanka (Pieris, 1945), coconuts were planted as close as 2.75 m or as far as 14 m the more common spacing being 8 m to 8.7 m. A spacing of 8 m is now recommended for most conditions in Sri Lanka. The spacing adopted in some of the other countries viz. Malaya,9 m; Indonesia, 10 m to 11 m; Seychells, 9 m to 10 m; Trinidad, 7.7 m; British Guyana, 9 m.

In deciding upon the optimum spacing, some important factors have to be taken into consideration. It is only reasonable to have a definite number of plants ha^{-1} depending upon the soil and climatic conditions of an area, which will give maximum yield from a given piece of land. Under conditions of close planting, there is a tendency for the palms to grow tall and lanky in their struggle to get sunlight and considerable energy might be lost in producing a tall trunk at the expense of yield.

Soil conditions such as depth and fertility also have some influence on spacing. Briton Jones (1940) recommends that where the depth of the soil is restricted, wider spacing should be given between palms so that the volume of the soil available for exploitation by the root is not unduly diminished. In respect of spacing to be adopted in soil of different fertility, there appears to some difference in opinion. In Sri Lanka and Philippines, in fertile soil, only fewer numbers of palms are recommended, while Patel (1938) and John (1952) suggested that such areas can carry larger number of plants than otherwise. The recommendation of the Department of Agriculture, Jamaica is in line with the latter point of view.

In Sri Lanka, for areas subject to drought condition, close planting of coconut is advocated (Ganarajah, 1954), the argument in favour of it being that under such condition, the soil will be adequately shaded by the overlapping of adjacent palms, thus preventing soil desiccation and loss of moisture. This point of view is however, questioned by Briton Jones (1940) with the remark that the deep shade under closely planted palms does reduce evaporation is readily admitted, but it is obviously futile if the additional palms producing the shade take up more water for their upkeep and growth than would be lost if the mulched soil were exposed to the sun.

12.1.3 Systems of planting

Four systems of planting, viz., square, triangular, oblong or rectangular and quincunx are mentioned in the literature (Ganarajah, 1954) of which the first two are the more common ones. In the square system, the palms are set at fixed equal distance between adjacent rows being the same. In this system about 15 per cent more palms can be accommodated in a unit area. In the quincunx system, the seedlings are planted in the centre of each square of old palms, this method is useful only for under planting in old plantations where old trees will be removed as soon as the new seedlings are established. Abeywardena (1954) has given the formulae for calculating the number of palms that can be accommodated in an area for any planting distance both in the square and triangular systems of planting.

12.1.4 Size of pit

The size of the seedling pit to be dug will depend upon several factors, such as the nature of the land, the type of the soil, the depth of the water table, etc. Generally speaking, the harder or heavier the soil, the larger should be the pit. For light soils 1m x 1m x 1m pits are recommended (John, 1952; Anon., 1965). On hard laterite soils, 1.3 m x 1.3 m x 1.3 m pits size is necessary so that the hardened portion of the soil would have been broken and removed. Cheyne (1951) suggested a modified cruciform planting hole for the ground, the special features of this planting hole is that from the sides of the ordinary one further excavations of smaller dimensions of $^1/_2$ m x $^1/_2$ m x $^1/_2$ m extending outwards are made and this is claimed to facilitate easy spread of the roots of the young seedlings in the early stages of their development. In sandy soils, shallow pits of one-third to one-half metre in depth is adopted.

The seedling pits are usually dug two to three months in advance of transplanting time and allowed to weather. The subsoil removed from the pit is utilised in making a small bund all round to prevent rainwater flowing into the pit.

12.1.5 Depth of planting

The actual depth at which the seedlings are planted is found to vary from place to place. In India, the seedling is planted 0.6 m to 0.75 m below ground level, while in Sri Lanka, it is planted about 20 cm to 30 cm below ground level. In Malaya, the seedlings are planted so that the top of the nut is just above the ground level of the surface.

Surface planting is not advisable particularly where drought conditions are likely to prevail. Surface planting results in restricted bole area and favours the formation of a shallow root system. Under water logging conditions, the seedlings are planted actually on mounds of soil. As the seedlings grow up, the intervening space is gradually filled up to form a continuous bund.

12.1.6 Transplanting in main field

At the time of transplanting the seedlings in the pits already dug for the purpose, the bottom of the pit is well dug up and a mixture of surface soil, sand and ash put into it to about 30 cm in depth. In Sri Lanka, the recommendation is to spread two layers of husks with their concave side up, at the bottom, and then to fill the pit leaving 15 cm to 20 cm from the surface with good topsoil mixed with about 18 kg of wood ash. After the seedling pits are prepared as indicated, the seedlings are placed in a hole, dug in the centre of the pit with the nut buried so that the top of the husk just visible outside. The earth is well pressed down in order to keep the seedlings in position. If the season is windy, the seedlings may be given support by providing suitable props for a year or more till they strike roots and get established. The best method for propping seedlings is to provide three posts in a triangular fashion and tie cross stripes at two or three different heights, according to the height of the seedlings (Patel, 1938). In Brazil, Nascente and Sa (2002) conducted a study to evaluate the vegetative development of three cultivars of dwarf coconut palm ('Verde de Jiqui'; 'AVJ'; 'Amarelo de Gramame', 'AAG' and 'Vermelho Gramame', 'AVG') and two hybrids of coconut palm ('Gigante do Brasil Praia Forte' x 'Anao Vermelho de Gramame', 'GBRPF' x 'AVG'; and 'Gigante Oeste Africano' x 'Anao Amarelo de Gramame', 'GOA' x 'AAG') in Goias, Brazil at 6 and 12 months after transplanting. The hybrids 'GBRPF' x 'AVG' and 'GOA' x 'AAG' and the dwarf coconut 'AAG' presented faster initial development than 'AVG'. The climatic conditions of Porangatu, Goias, were not ideal for coconut cultivation; development of plant was inferior to those in other parts of Brazil, such as Pocone, Mato Grosso and Goiana, Pernambuco.

12.1.7 Season of transplanting

The season of transplanting seedlings will vary from place to place depending upon the condition of the land and climatic conditions. Generally, in most of the areas the best time for transplanting is at the commencement of monsoon. On the West coast of India and Sri Lanka, May to June and October to November are the usual planting seasons. In low-lying areas subjected to inundation during rainy season, planting is done before the commencement of the monsoon or after it is over. By planting in appropriate season, it will be possible to ensure better establishment and save watering charges.

12.2 Care of young plantation

The most critical period of establishing coconut plantation is during the early stages of its life, i.e., from the time of planting to the third or fourth year. It is only by giving careful attention during the period that the palms can be made to bear early and well.

12.2.1 Watering

The newly transplanted seedlings should be watered regularly in the absence of rains till they strike roots and get established. It is also necessary to continue watering the seedlings in the dry months for the first two or three years after transplanting, depending upon local conditions. In West coast of India, it is recommended to provide irrigation @ 40-50 litres of water once in four days during summer months for satisfactory establishment and growth.

12.2.2 Shading

In summer months, when the sun is very hot, the seedlings should be adequately shaded for the first one or two years. Provision of shade has been found to reduce causalities amóng the transplanted seedlings and also the frequency of watering.

12.2.3 Mulching

Mulching the area round the base of the palm before the onset of dry weather will keep the soil moist and prevent the ground from becoming hard. It will thus lessen the bad effects of drought condition and promote better growth of the palms. During rainy season, it will also control the weed growth. Satisfactory mulching can be done with materials available in coconut plantation such as coconut husk, leaves, coir dust, etc.

12.2.4 Interculture

The seedling pits have to be cleaned periodically and kept free of weeds. During heavy monsoon rain, care should be taken to see that the water does not stagnate in the pits continuously for long periods. The ring buds raised around the seedlings pit should be periodically repaired and kept in good condition. After the rains, any excess soil washed down into the pits and covering the growing portion of the seedlings should be removed. The seedling pits can be gradually filled up as the seedlings grow and form the stem.

The immediate surroundings of the newly planted seedlings should be cleaned of weeds and the surface soil kept in a friable condition by digging or forking the land to promote the development of roots. As the seedlings begin to develop, growth can be further improved by getting the entire garden ploughed or dug up with spade or hoe. An alternate way of keeping weeds free is to establish a leguminous cover crop, which will smoother the weeds and also increase the fertility of the soil. Crops such as cowpea (*Vigna catjang*), *Calopogonium mucunoides*, and *Centrosema pubescens*, which are quite suitable for being grown in large estates. When cover crops are raised, it is essential that weeding around the young palms in basin area be done. This will also prevent the creeping types of cover crops from climbing up the young palms and checking their growth.

Unrestricted growth of cover crops or weeds will retard the growth of young palms and delay the period of flowering. Cooke (1936) recorded a case in the Philippines where in a cogon (*Imperata cylindrica*) infested land, the palm took two years more to commence bearing than ordinary condition. The injurious effects of some weeds on coconut palms were also observed in Malaya by Jagoe (1938), in British Solomon Islands by Pagden (1936) and in Sri Lanka by Rajapakse (1950). In Malaya, Belgrave and Lambourne (1934) found the cover crop to retard the growth of young palms growing in cover drained soil.

12.2.5 Filling up of gaps

In spite of all precautionary measures taken, there may be some casualty among the transplanted seedlings. They should be promptly replaced with good seedlings preferably of the same age. Seedlings showing continued unhealthy and stunted growth might also be replaced.

12.3 Care of adult plantation

The young palms begin to flower in about five to six years after transplanting. With the onset of the productive phase, the demands of the palm for the plant nutrients from the soil will increase and the soil management practices should be brought into force to provide optimum conditions for the palms to give of their best for the full growing period. Regular and systematic manuring and control of the pest and disease should receive sustained attention. Any neglect in this regard will have an adverse effect on the growth and yield of the crop.

12.3.1 Nutrient management

Substantial research efforts and informations on nutrition and fertilizer requirement of coconut are available from different coconut growing countries (Menon and Pandalai, 1960; Fremond *et al.*, 1966 ; Child, 1974; Thampan, 1976).

12.3.1.1 Nutrient requirement of coconut

Coconut produces fronds and nuts throughout the year and hence, demands continuous supply of nutrients from the soil (Khan, 1993). The annual nutrient export by various parts of the palm viz. nuts, fronds, trunk, bunch and spathe reported by different workers vary from 20 to 174 kg N, 2.5 to 20 kg P and 35 to 249 kg K ha^{-1} (Pillai, 1919; Pillai and Davis, 1963; Ramadasan and Lal, 1966; Ouverier and Ochs, 1978), but there appears to be a general agreement on the ratio of N and K removed by the palms (1: 1.44 to 1.75). Nelliat (1973) consolidated the information on N, P and K nutrition on coconut and summarized the nutrient uptake by palms as compared by various workers. Some of the more recent estimates of nutrient uptake by palms are given (Table 16). The figures very much depending upon a number of factors such as location, yield level of palms, environmental conditions, method of computation, etc.

Table 16: Nutrient uptake and nut yield in coconut.

No	Authors	Country	Yield $year^{-1}$	Nutrients(kg ha^{-1} yr^{-1})		
				N	P_2O_5	K_2O
1.	Cooke (1950)	Sri Lanka	150 palms ha^{-1} 25 nuts $palm^{-1}$	29	9	27
2.	Pillai and Davis (1963)	India	175 palms ha^{-1}	97	48	146
3.	Ramadasan and Lal (1966)	India	40 nuts $palm^{-1}$ 60 nuts $palm^{-1}$			
4.	Nathaniel (1969)	Sri Lanka	6 tons copra ha^{-1}	94	30	210
5.	IRHO (Ochs and Ollagnier, 1977)	Cote d'Ivoire	100 nuts $palm^{-1}$ 175 palms ha^{-1}	120	18	86
6.	Khanna and Nair (1977)	India	Whole palm	157	28	288

12.3.1.2 Functions of fertilizer nutrients

Field experiments conducted in different coconut growing countries have indicated that the palm responds to N and K fertilizers. Nitrogen increases trunk height and the rate of production of leaves, inflorescence and female flowers but adversely affect the nut characters such as weight of nut, volume of nut and weight of copra (Coconut Industry Board, 1967; 1969; Muliyar and Nelliat, 1971; Kanapathy, 1976). Potassium improves leaf area, leaf colour, setting of female flowers, size of nut and weight of nut (Uexxkul, 1972; Muliyar and Nelliat, 1971). Also the effect of P *per se* is negligible, it is reported to have beneficial effect in the presence of N and K (Spencer, 1963; Nelliat, 1973). Information on the effect of other elements in coconut production is still meagre. In highly leached sandy soils, receiving higher dose of potassium, appearance of magnesium deficiency has been reported (Ochs and Ollangnier, 1977). Severe sulphur deficiency on coconut was found in Papua New Guinea (Southern, 1967; 1969) and in Madagascar (Ollagnier and Ochs, 1972). The importance of chlorine in the nutrition of palms has been highlighted (Ollagnier and Ochs, 1971; Uexxkul, 1972; Magat *et al.*, 1975; Ollagnier *et al.*, 1976). In India, zinc deficiency is suspected to be one of the factors aggravating the root wilt disease, which poses a severe threat to the growth of coconuts in Kerala state (Anon., 1976a; 1977). Young Palms, which receive fertilizer, flower early and improve in growth characters such as number of leaves, length of leaves, and girth of stem (Mathew and Ramadasan, 1964; Nelliat and Muliyar, 1971; Anon., 1976a). One of the important effects of mineral fertilization of the palm is that the time taken to first flowering is considerably reduced in the case of palms receiving adequate nutrients (Anon., 1976a; Nelliat, 1973). Moreover, the damage caused by severe and prolonged mineral deficiency in the early stages cannot be completely rectified by later fertilizer dressings (Fremond and Ouverier, 1971). For example, the palms, which suffered from K deficiency during the pre-bearing stage, remained on an average 15% less productive than those, which had not suffered. These and many other experimental results indicate that in order to get sustained production, coconut has to be fertilized right from the early year of their growth.

Mineral nutrition of coconuts has important effects on the quality of nuts (size and weight of nuts and thickness of kernal), yield of copra and content and quality of oil. Reddy *et al.*(2002)conducted a long-term experiment to study the differential fertilizer response of cultivars. 'West Coast Tall', 'Chowghat Orange Dwarf' x 'West coast Tall' and 'WCT' x 'COD' hybrids of coconut for growth, nutrition, yield and economic returns under rainfed and irrigated conditions at Central Plantation Crops Research Institute, Kasaragod. The average yield for 8 years showed that the fertilizer treatment 1000 g N: 437 g P: 1667 g K palm^{-1} yr^{-1} (M2) recorded significantly higher nut yield (136 nuts palm^{-1} yr^{-1}) than M1 treatment (500 g N: 218 g P: 833 g K palm^{-1} yr^{-1}) and no fertilizer application (M0). Amongst the cultivars/hybrids, the hybrid 'COD' x 'WCT' (128 nuts palm^{-1} yr^{-1}) out yielded its reciprocal cross (114 nuts palm^{-1} yr^{-1}) and 'WCT' cultivar (115 nuts palm^{-1} yr^{-1}). The growth parameters recorded did not show any significant difference in tree height and girth at base among the cultivars/hybrids. However, fertilizer application significantly increased the trunk height and girth at base. Annual application of fertilizers for a period of 32 years to coconut resulted in a marked increase in available phosphorus and potassium status in soil, but a marginal change in soil available nitrogen status was observed. Foliar contents of N remained below the critical levels of 1.8-2.0%. Phosphorus buildup in the soil due to fertilizers, did not reflect in the P contents of diagnostic leaf under both rainfed and irrigated conditions. Application of K fertilizer at M1 level maintained K content of leaves at 1.07% i.e. just above the critical level (0.8-1.0%), whereas application of K fertilizers at M2 level raised the leaf K content to 1.20%. The leaf nutrient contents did not vary much among cultivars/hybrids due to fertilizer application. The cost-benefit ratio was most favourable under fertilizer treatment M1. For every rupee (Rs) invested on manuring, the total net return was Rs 2.80 under M1 level and Rs 2.85 under M2 level of fertilizers.

The adverse effects caused by excess of N on the nut characters, viz, weight and volume of whole as well as husked nuts and copra yield nut^{-1}, have already been mentioned earlier. These characters are reported to be highly improved by K application. Uexxkul (1972) found that in the Philippines K had considerable beneficial effects in producing larger and better filled nuts. Effect of different levels of K on nut components of the new coconut hybrid – 'Port Bouet CC 16' (hybrid of 'West African Tall' and 'Malaysian Yellow Dwarf') was found that both K and Mg had spectacular effects on increasing the number of nuts of the new hybrid, but did not influence the oil content (which remained at 72% at all levels of yield of nuts), or oil composition as in the case of cruciferous oil crops (Appleqvist, 1968). N and K (0.4 N-0.4 K, 0.8 N-0.8 K, and 0.4 N-1.6 K) increased both the number of nuts palm^{-1} and copra yield hectare^{-1} year^{-1} in the sandy soils of Mexico (Perez Zamora 2003). The effect of fertilizer was observed at 4, 8, and 12 months after adding N and K. After 4 months, with K alone (0 N-0.8 K) the number of coconut fruits tree^{-1}, copra yield palm^{-1} and copra nut^{-1} was 18.9% higher than the control, while the additions of N x K (0.8 N-0.8 K and 0.4 N-1.6 K) significantly increased ($P < 0.001$), by 34%, the number of nuts palm^{-1} and the copra yield tree^{-1} with respect to the control at 8 and 12 months after adding fertilizers. In December, the harvest yielded 1.55 more nuts tree^{-1} than the harvest done at 4 and 8 months after applying fertilizers. The estimated responses for copra yield hectare^{-1} and for the nuts palm^{-1} were also expressed by two multiple regression equations with R2=0.97 and 0.96, respectively. The predicted yield, with the multiple regression equation for copra yield was 2.59 t ha^{-1} with 0.491 and 0.974 kg N and K palm^{-1}, respectively. The estimated number of nuts was 100 palm^{-1} when 0.831 and 1.236 kg N and K were applied tree^{-1}, respectively.

Southern (1967) studied the effects of sulphur deficiency on coconut in Papua New Guinea. He found that under condition of S deficiency, the nuts were very small, the meat appeared normal when fresh, but on drying become rubbery and unsuitable for industrial treatment. In severe cases, oil content was reduced to 38%. Oil extracted from the rubbery copra was richer in unsaturated fatty acids (iodine value increased from 7 to 20). The defects could be rectified by the application of sulphur, which restored the oil content to over 60%, six months after the treatment.

In addition to the effect of individual nutrient elements, nutrient interactions are also important for both yield and quality. The importance of proper balances between N and K has been reported from several experiments (Marar and Pandali, 1961; Muliyar and Nelliat, 1971; Anon., 1974 to 1977). In general, K is reported to reduce the adverse effects on nuts characters caused by excess of N. The relationship between N and K in the growth medium and plants has been reported to be important for many crops, particularly for oil yielding crops (Forster, 1977). From the physiological point of view, this could be explained by the well-known effects of K in improvement of carbohydrate synthesis and translocation, since carbohydrates are required as essential components in fat synthesis. Different nutrient management strategies are required for young palms of pre-bearing age and for adult bearing palms.

12.3.1.3 Nutrient management of young (pre-bearing) palms

Young transplanted seedlings require adequate nutrients for better growth on all soils. They respond well to manuring, grow better and start bearing early. The vegetative phase should be completed early. Cooke (1954) also stated that proper manuring of seedlings promoted early bearing and high yield. However, Wilshaw (1941) did not get any benefits out of manuring young palms growing in the fertile and coastal clay soil of Malaya. Application of N,P,K fertilizers to young hybrid palms of 'Chowghat Orange Dwarf' ('COD') x 'West Coast Tall' ('WCT') and its reciprocal cross and high yielding talls resulted in significant increase in growth characters such as tree height, girth and annual leaf production and resulted in early flowering (Nelliat and Muliyar, 1971), and also significantly increased the leaf N and K contents from 1.40 and 0.46 per cent of dry matter in the no fertilizer plot to 1.55 and 0.92 per cent respectively in plots receiving highest amount of fertilizers (1000g N, 437g P and 1667g K palm^{-1} year^{-1}). However, leaf P content did not increase significantly (Kamladevi *et al.*, 1974). The influence of macronutrient deficiencies on the chemical composition of dwarf green coconut seedling was studied in Nigeria (Ejedegba and Onyeneke, 2003). A reduction in magnesium improved protein content while a reduction of nitrogen, magnesium, and potassium reduced shoot height and girth. Elimination of magnesium also reduced chlorophyll concentration. Starch and sugar concentrations improved with nitrogen and potassium but decreased with magnesium reduction. The differences were more pronounced in roots than in shoots (Ejedegba and Onyeneke, 2003).

In Sri Lanka the schedule of manuring of young palms is as the following (Anon., 1955).

Mixture A: Sulphate of calcium or ammonia (cynamide-2 parts; saphos-phosphate-2 parts; muriate of potash 3 parts; Total- 7parts)

Mixture B: Sulphate of ammonia or calcium (cynamide-1 part; groundnut cake-3 parts; saphos-phosphate-2 parts; muriate of potash-3 parts; Total-9 parts)

	Mixture A	Mixture B
2nd year	0.875kg	1.125kg
3rd year	1.25kg	1.50kg
4th year	1.50kg	2.00kg
5th and subsequent years until bearing	2.00kg	2.50kg

Although a high nitrogen mixture is desirable for young palms, it is undesirable to apply N alone. The damage caused by K deficiency in the early stages cannot be fully repaired by later K dressings (Fremond and Ouverier, 1971). Although later application of K enabled re-establishment of good physiological functioning, the palms, which suffered from K deficiency during pre-bearing age, remained on an average 15% less productive than those that never suffered from K deficiency. Significant influence of fertilizer on higher frond production, palm height, precocity in flowering etc. were reported in multilocation experiments with cv. 'West Coast Tall' and hybrid palms. These experiments highlighted the main effect of N,P,K and their interactions. Reports from Balarampuram in Kerala and Ratnagiri in Maharashtra indicated convincing results of the importance of K and N respectively on growth and yield of young palms. Systematic fertilizer application to young palms also reduced the pre-bearing age. At Veppankulam, Tamil Nadu application of 0.34 kg N, 0.23 kg P_2O_5 and 0.45 kg K_2O palm^{-1} induced flowering one year ahead of the unfertilized control plots. When fertilizer dosage was doubled, pre-bearing period was further reduced by four months. Establishment of coconut seedlings in coastal sandy soils was best achieved by recycling of coconut parts like coirpith, coconut shredding and forest leaves and farmyard manure at the rate of 20 kg palm^{-1} year^{-1} along with N,P,K. Such palms flowered early compared to palms treated with inorganic fertilizers alone due to better physical and chemical environment (Nambiar *et al.*, 1983).

The hybrids 'D x T' ('COD' x 'WCT'), 'T x D' and high yielding 'WCT' responded to fertilizer application early at Kasaragod. Fifty per cent of 'D x T' palms receiving 500g N, 500g P_2O_5 and 1000g K_2O palm^{-1} flowered in the eighth year while 'T x D' and 'WCT' palms flowered in the ninth year. In unfertilized plots, 50% flowering stage was not recorded even at the end of 10th year in any of these cultivars (Anon., 1976a). The experimental evidence suggests the necessity to provide a balanced nutrition to young palms from the time of planting in the main field. Since palms of the tall cultivar usually flowered in about five years and as response to fertilizers in terms of yield of nuts is obtained only after two years of fertilizer application, the N,P,K dosage meant for adult palms need to be given from third year of planting. It is therefore, appropriate that one-third of the adult dosage be applied in the first year and two-thirds from second year onwards. For the young seedlings, one-tenth of the adult palm dosage may be applied three months after transplanting (Nelliat, 1972).

In the early stages of development till the stem is formed, manures may be applied close to the palm on the surface. As palm grows, manures may be applied over a large area. The application of green leaves or compost is to be avoided in the early stages, in areas where termite attack is present, as the damage due to it may increase.

12.3.1.4 Nutrient management of adult palms

The perennial nature of the palm as well as its extensive root system poses considerable difficulties in nutrient management. Coconut palms respond well to fertilizer nutrients, especially N and K. Close to 35-40% increase in yield was reported due to fertilizer application (Khan *et al.*, 1990). Coconut cultivars exhibited differential yield response to fertilizer application (John and Jacob, 1959) and that hybrid vigour observed in other crops is often associated with higher fertilizer requirements for realising increased yields. Hybrid palms ('PB-121') require more N and P compared to 'West Coast Tall' ('WCT') and utilised higher proportion of absorbed N (62 %) and P (75 %) for the production of more nuts (Khan, 1993). In 'WCT' palms, N and P nutrients were utilized more or less equally in the production of nuts and growth. For both cultivars, the K removal through bunches was 78 % of K uptake (Pillai and Davis, 1963; Ouverier and Ochs, 1978). An adult palm ('West Coast Tall') producing 40 nuts and 12-13 fronds year^{-1} absorbed 321g N, 69g P and 406g K (Pillai and Davis, 1963). The general recommendation from Central Plantation Crops Research Institute for fertilizing the matured bearing palms is 500g N, 140g P and 1000g K palm^{-1} year^{-1}, to be applied in two split doses viz. one-third in May-June and two-third in September-October (Nelliat, 1973). Murray and Smith (1952) reported from Trinidad that the response to nitrogen was inversely proportional to the pre-treatment bearing level of the palm i.e the poor bearers show greater response to the application of nitrogen. Coconut cultivars responded differential yield to fertilizer application (John and Jaçob, 1959) and that hybrid vigour observed in other crops is often associated with higher fertilizer requirements for realising increased yields. Hybrid palms ('PB-121') required more N and P compared to 'West Coast Tall' ('WCT') and utilised higher proportion of absorbed N (62 %) and P (75 %) for the production of more nuts (Khan, 1993). In 'WCT' palms, N and P nutrients were utilized more or less equally in the production of nuts and growth. For both cultivars, the K removal through bunches was 78 % of K uptake (Pillai and Davis, 1963; Ouverier and Ochs, 1978). An adult palm ('West Coast Tall') producing 40 nuts and 12-13 fronds year^{-1} absorbed 321g N, 69g P and 406 g K (Pillai and Davis, 1963). The general recommendation from Central Plantation Crops Research Institute for fertilizing the matured bearing palms is 500g N, 140g P and 1000g K palm^{-1} year^{-1}, to be applied in two split doses viz. one-third in May-June and two-third in September-October (Nelliat, 1973). The response to nitrogen was inversely proportional to the pre-treatment bearing level of the palm i.e the poor bearers show greater response to the application of nitrogen (Murray and Smith,1952; Muliyar and Nelliat, 1971).

Fertilizer demonstration trials conducted at different locations on the West coast of India revealed that the application of 0.34 kg N, 0.34 kg P_2O_5, and 0.68 kg K_2O palm^{-1} in a year resulted in an increase of 35 % in nut production over the cultivator's practice. Increasing the dosage to 0.90 kg N, 1.135 kg P_2O_5, and 1.135 kg K_2O caused a further increase in yield (John and Jacob, 1959). Another fertilizer trial having two levels each of N, P, and K, *viz.*, 0 and 0.45 kg N, 0 and 0.227 kg P_2O_5, and 0 and 0.454 kg K_2O palm^{-1} year^{-1}, Marar and Pandalai (1961) concluded that the effects of N and K were equal and additive. The effect of N was estimated as 10.7 nuts, that of K as 11.8 nuts, and of NK as 20.8 nuts for the quantities applied. From the results of fertilizer experiments consisting of all combinations of three levels each of N (500, 1000, 1500g), P_2O_5 (250, 500, 750g) and K_2O (750,1250, 1750g) has been laid out in different soil types at different centres under All India Coordinated Research Project on coconut. Based on the results from these trials and experience, the general dose of fertilizers for palms yielding 50 nuts annum^{-1} has been fixed as 500g N, 320g P_2O_5 and 1200g K_2O palm^{-1} year^{-1}, under rainfed conditions. For palms with higher yield potential and under irrigated condition, double this dose is being recommended.

Cooke (1932) has given an example from Sri Lanka to show what improvement in the yield can be brought by systematic manuring and cultivation in an estate while a regularly cultivated and manured block yielded on an average ninety nuts tree^{-1} year^{-1}, the unmanured block produced only an average yield of thirty nuts tree^{-1}. The yield from regularly cultivated and manured plot at Coconut Research Institute, Kasaragod, averaged over a long period of 20 years was sixty-four nuts year^{-1} against a very poor yield of ten nuts obtained from a completely neglected plot. Any number of similar examples can be cited but the above will be sufficient to show that only under good care and management one can sustain high yields.

Palms growing under neglected conditions, that is in extremely depleted soils, could be revived by application of double the recommended dose of fertilizer in the first two years, followed by recommended dose subsequently (Nelliat *et al.*, 1984).

12.3.1.5 Micronutrients

Micronutrients have received less attention in the nutrition of coconut probably due to absence of any serious deficiency symptoms. In a survey based on soil and leaf analysis, coconut-growing soils of Kasaragod district were found to be deficient in Cu, Zn and Mn (Manikandan *et al.*, 1986). Coastal sandy soils have higher incidence of these deficiencies as compared to laterite soils. With the emergence of micronutrient deficiencies, a proper assessment of micronutrient status of coconut plantations is necessary for planning production-oriented policies.

Boron is an often-reported deficient nutrient in most of the coconut growing soils. The disorder has been noticed in about 11% palms in Assam leading to an annual economic loss of 6.38 million nuts. Detailed symptomatology of the deficiency in young palms, which is also referred to as crown choking disease/frond choke, is available (Baranwal *et al.*, 1989). The disorder is cured by application of borax. Some available guidelines in this regard for young palms are provided below (Table 17). The effects of boron (0, 10, 30 or 45 g) on the boron content of the leaf axils (2, 3 and 4) of green dwarf coconut were determined in a field experiment conducted in Rio de Janeiro, Brazil from May 2000 to June 2001 (Santos *et al.*, 2003). Boron leaf concentration increased with increasing rates of boron upto 3-4 months after application. After 6 months of application, the treatments had no effects on the boron content of the leaves of the crop.

Table 17: Treatments for boron deficiency

Area	Treatment	Reference
West Bengal, India	Borax-decahydrate (11.3% B) 20g palm^{-1}	Chakrabarthy *et al.*, (1970)
Kerala, India	Borax- decahydrate 200-500 g palm^{-1}	Cecil and Pillai,(1978)
Assam, India	Borax-50g palm^{-1}. Repeat twice in severe cases at an interval of 3-4 months	Baranwal *et al.*,(1989)
Cote d'Ivorie, West Africa	Borax-pentahydrate (14.8% B) 15 g palm^{-1} once in six months	Brunin and Coomans, (1973)

Pencil point disease or tapering stem disease is generally considered to be due to deficiency of nutrients (especially N), water and unfavourable soil conditions. In the East coast (Thanjavur, Tamil Nadu) the malady was found to occur in upto 40% cases in palms growing on sandy and laterite soils (Bhaskaran *et al.*, 1978). The malady could be cured only through the application of micronutrients cocktail consist of 227 g each of Borax, $CuSo_4$, $FeSo_4$, $MnSo_4$ and 10 g of ammonium molybdate dissolved in 40 litres of water and applied as soil drench. In addition, younger palms also receive a foliar spray of 15 litres in which 30 g each of the above micronutrients salts were dissolved in water along with 2 g of ammonium molybdate.

12.3.1.6 Integrated nutrient management

Both the bulky and concentrated organic manures are usefull for the coconut palm. They not only supply the plant with nutrient elements but also improve the physical properties of the soil. About 25 to 50 kg of organic manure, supplemented with the required quantity of inorganic fertilizers, is the best manurial combination for an adult bearing coconut palm. As a result of extensive investigations carried out on the manuring of coconut palms particularly in India and Sri Lanka, schedules of manuring have been drawn up for the guidance of the growers. The following are some of the manurial combinations recommended for different soil types on the basis that adult palms require about 0.25 kg to 0.50 kg of nitrogen, 0.1 kg to 0.25 kg of phosphoric acid and 0.375 kg to 0.75 kg of potash palm^{-1} year^{-1} (John,1952).

Mixtures for sandy soils

Mixture 1.	Cattle manure or compost	50 kg
	Wood ash	10 to 20 kg
Mixture 2.	Fish guano	7.5 kg
	Muriate of potash.	1 kg
Mixture 3.	Prawn dust	7.5 kg
	Muriate of potash/potassium sulphate	1 kg
Mixture 4.	Groundnut oil cake	7.5 kg
	Wood ash	10 to 20 kg
	Bone-meal	1 kg

Mixtures for soils not deficient in organic matter

Mixture 1.	Ammonium sulphate	1.5 to 2 kg
	Muriate of potash or potassium sulphate	1 kg
	Bone-meal	1 kg
Mixture 2.	Groundnut or other oil cake	7.5 to 10 kg
	Ash	10 to 20 kg
	Bone-meal	1 kg

The above mixtures are recommended for application over a basal dressing of green leaves at 25 to 50 kg or cattle manure or compost at 25 kg year^{-1}. Instead of green leaves, green manure crops can be grown *in situ* and incorporated.

12.3.1.7 Green manure

The growing of a green manure crop *in situ* and its incorporation into the soil has been found to be the easiest and the most economic method of augmenting the organic matter in the soil. Further, green manuring improves soil structure, releases plant nutrients present in the soil in an available form, reduces leaching losses, regulates soil temperature and minimizes soil erosion.

Sun hemp (*Crotalaria juncea*), wild sun hemp *(Crotalaria striata),* cowpea *(Vigna unguiculata), Calopogonium mucunoides, Mimosa sp.* and *Pueraria phaseoloides* are the most suitable green manure crops for growing *in situ* in coconut gardens. Under normal conditions these green manure crops give total green foliage of 5 to 10 t ha^{-1}. It has been observed that application of 40 kg P_2O_5 ha^{-1} to green manure crop, the green matter yield can be substantially increased. To derive the maximum benefit from green manuring, the green manure crops should be incorporated at the correct stage of growth and when soil moisture is sufficient enough to permit complete decomposition of the green matter. Unless cover crops are systematically incorporated into the soil, they are likely to affect coconut crop adversely (Salgado, 1948).Nine species of green manure legumes were tested for their ability to grow and establish in coconut basins in Kerala, *Pueraria phaseoloides, Mimosa invisa* and *Calpogonium mucunoides* were most suitable (Thomas and Shantaram. 1984). These crops contribute 15-30 kg of green matter $basin^{-1}$, which is equivalent to one-third of nitrogen requirement of the palm. Microflora and dehydrogenase activity increased during the vegetative stage and at 30 days after its incorporation (Thomas and Shantaram, 1986). Sahoo *et al.* (2002) assessed the growth potential of leguminous green manure crops such as black gram, cowpea, green gram, horsegram [*Macrotyloma uniflorum*] and dhaincha [*Sesbania sp*], in coconut basins with littoral sandy soil. Results revealed that the plant height of different green manuring crops differed significantly in both years. Maximum plant height (63.45 cm) was observed in dhaincha followed by cowpea at 45 days after sowing. Leaf number $plant^{-1}$ at the time of incorporation was highest (22.05) in horsegram and lowest (12.05) in dhaincha. Root nodulation also varied significantly in both years with dhaincha as the highest (139.43). Biomass production was highest in cowpea (7.23 kg) followed by greengram (6.0 kg) and horsegram (5.72 kg). Highest dry matter content in both years was found in dhaincha followed by greengram and horsegram. The results indicated that cowpea, greengram, and horsegram can be successfully grown *in situ* as green manure crops in coconut basin with littoral sandy soils.

12.3.1.8 Method of fertilizer application

Application of fertilizers in the entire area around the base of the palm upto a distance of 150 cm from the bole has been found to be better than broadcasting in entire interspaces or applying in the centre of four palms or in 90 cm wide circular strips at 90cm distance from bole (De Silva, 1968) or application in alternate half circles or deep placement. Moreover for better efficiency in utilization of applied fertilizers, it is preferable to give them in frequent instalments rather than giving total quantities as a single annual dose (Markose and Nelliat, 1975). The current fertilizer practice recommended by CPCRI consists of applying the fertilizers in the entire area of 180cm radius around the base of the palm and raking it. Under rainfed condition, the fertilizers are given in two instalments, one-third in April - May after the pre-monsoon showers, and two-third in September-October, after the heavy rains have subsided. Under irrigated conditions, the fertilizers are given in four equal instalments in February, May, August, and November. Usually, before the application of fertilizers in August-September, basins of 2m radius, with gradual slope towards the periphery are opened up, fertilizers are applied in the basins, preferably over a layer of organic wastes and then the basins are covered up.

The proper time for the application of manures is when there is sufficient moisture in the soil. Manuring should not be done when there is heavy rain as nutrients are likely to be lost by the surface wash or through leaching. Application of manure during dry periods or when there is not sufficient moisture in the soil is not helpful but positively harmful.

The process of application of manure to coconut gardens, namely spreading and covering is costly operation. Therefore, it is easier and more economical to mix the different manure instead of applying them separately. While mixing, care should be taken to see that manures are compatible. Ammonium sulphate or other fertilizers containing ammonium should not be mixed with wood ash or lime since chemical action will set in and nitrogen will be lost in the form of ammonia. Croucher and Martines (1934) found that a mixture containing two parts of coconut ash and one part of sulphate of ammonia lost 50 per cent of ammonia in five days when spread over dry soil and 80 per cent when the soil is wet. The loss was reduced when the manures incorporated into the soil immediately after spreading or the ash used was completely dry and the mixture stored in a dry place. As a safe precaution, ammonium sulphate may be applied at least a fortnight before or after the application of ash. Salgado (1938) has shown that the losses of nitrogen from ammonium sulphate can also occur if it is mixed with ground mineral phosphate. Potash fertilizers, which absorb moisture and cake up, should not be stored mixed with ammonium sulphate or super-phosphate. There is no harm in mixing them just at the time of application.

12.3.2 Intercultivation

Proper intercultivation of the coconut garden is very essential to keep the plantation free of weeds, pests and diseases. Intercultivation by itself has been proved to increase the yields substantially, under the conditions of West coast of India. Inter cultivation may be done by ploughing the garden or by digging once or twice in the year. The object of intercultivation is primarily to remove weeds and create the soil mulch. Sometimes basins are also opened around the base of the tree. In the sandy soil of the areas of Travancore–Cochin (India), piling the soil of the entire garden into small heaps towards the end of the South-west monsoon and levelling them up again after two months is widely adopted with beneficial results.

12.3.3 Removal of unproductive palms

A few palms showing stunted growth or unproductive nature are often met with even in well-managed garden raised with quality planting materials. These should be removed and replaced as early as possible. The proportion of unhealthy palms is usually large in the gardens of small holders because of close planting and insufficient care. In such cases thinning is to be done until the desired spacing is reached. Unproductive and senile palms should be removed followed by further thinning wherever necessary. Pieris (1945) has given the data regarding the approximate number of palms and the fraction of stand that has to be removed in order to bring about desired spacing. He has also furnished the diagrams to illustrate satisfactory methods of removing the one third and one fourth of the stand.

12.3.4 Irrigation

Soil moisture very often limits coconut production in those areas where long spells of dry weather prevail or where the rainfall is scanty and not well distributed. Production suffers under such conditions unless irrigation is resorted to. It is a widely recognized fact that the coconut palm requires large quantities of moisture for its normal growth and production. In the Philippines, the water requirement of palm was estimated to be 16 litres day^{-1} (Espino and Juliano, 1924). In another study, the daily loss of water from a mature palm was estimated 28.1 kg to 74.0 kg (Copeland, 1931). These figures indicated that soil moisture is the most important factor determining the extent of response of palm to different agronomic practices.

Response of the coconut palm to irrigation has been observed in many countries, especially in India, Sri Lanka and Malaysia. In an irrigation experiment carried out in Kasaragod (India), summer irrigation in the coastal sandy soil recorded striking improvement in the productive capacity of the palms. The effect of irrigation became visible in the second year of experiment and the recorded yield increase was nearly 13 times that of pre-treatment period. The response observed during the transit period was due to a significant increase in the production of female flowers and in the setting of buttons, which were 22.8 and 39.8 % respectively over that of control. In the same station, similar response was observed in the littoral sand where the increase in nut production was more pronounced when flood irrigation was resorted. While basin irrigated palm recorded a mean annual yield increase of 22.6 nuts, the corresponding increase for flood irrigation was 85.4 over control. However, in red sand loam soil, basin irrigation was better than flood irrigation. Based on the experimental results, the irrigation requirement for basin irrigation was fixed at 1000 litres $irrigation^{-1}$ given at 10cm depth in basin of 1.75 m radius, once in five to seven days.

In North Kerala (India), the dry spell extends for a period of about six months from

November to May and coconut palms experience considerable moisture stress during the period. In experiments conducted at Regional Agricultural Research Station, Pilicode, basin irrigation with 800 litres water once in a week increased the yield of coconut palms by 74.2% in sandy loam soil whereas flood irrigation with 50 mm of water once in 5 days increased the yield from 11.2 nuts palm^{-1} year^{-1} to 96.6 nuts in littoral sand (Bhaskaran and Leela, 1977). At CPCRI, Kasaragod the highest yield of 128 nuts palm^{-1} year^{-1} was obtained when 'WCT' palms were given perfo-irrigation at IW/CPE ratio of 1.0 and 750: 670: 1500: 170 g N, P, K, Mg palm^{-1} year^{-1}. While CPCRI recommends 200 litres palm^{-1} once in 4 days for basin irrigation, the KAU recommends quantities ranging from 600L once in 3-4 days in sandy soils to 1600 litres once in 9 days in silty clay soil. Preliminary results of experiments conducted at CPCRI, Kasaragod and CWRDM, Calicut indicated that for drip irrigation @ 30 litres palm^{-1} day^{-1} may be optimum.

Trials carried out at Kasaragod (India) and Sri Lanka showed that irrigation with sea water in sandy soil was as effective as fresh water irrigation. Sea water irrigation gave a slight higher yield (12 %) than fresh water irrigation. When sea water and fresh water used in a ratio 1: 2, the response was still high, recording a yield improvement of 50 %. No toxic effect to salt accumulation was observed. But the effect of sea water in other soil types is yet to be studied under field condition. In a different experiment to determine the effect of irrigation on pre-bearing young palms (four year old) growing on sandy loam soil, it was observed that the largest number of leaves were produced when irrigated with 20 litres of water on every fourth day during the summer months. In a more recent study conducted at Kasaragod (India), it was found that maximum response to higher levels of fertilizers is achieved when it is combined with irrigation. Split application under irrigated condition was more beneficial than under rainfed condition. In this study the cumulative yield of palms which received the higher levels of fertilizers with irrigation was 114.50 nuts compared to 28.4 nuts recorded on the palms which received the same dose of fertilizers but without irrigation.

Irrigation is also conducive to enlarging the size of nuts. In Malaysia, in a field of dwarfs planted in 1920, it was proved that irrigation facilitated a tangible effect in the copra content of the nuts. There is a wide spread belief among growers of gardens, which are regularly irrigated, deteriorate rapidly if irrigation is discontinued, even for a short period.

12.4 Coconut based farming systems

Intercropping in coconut plantations is in practice from the time immemorial in the traditional coconut growing regions/countries. Ninety per cent of the World's total area and production of coconuts comes from the five major coconut producing countries namely, India, Philippines, Indonesia, Sri Lanka and Malaysia. Millions of farmers in these countries are small holders and directly depend on coconut for their livelihood. Cultivating other crops with coconut emanated from the small coconut farmers of these countries. Coconut as a monocrop provides employment only for about 150 mandays $year^{-1} ha^{-1}$ under rainfed condition (Nelliat and Krishnaji, 1976) and consequently the family labour remains unemployed for larger parts of the year. As a perennial crop with a long gestation period, planting of companion crops in the vacant space between palms have been undertaken by the farmers to generate more employment in his own farm in addition to meet the requirements for food and livelihood. Research programmes in sixties and seventies enabled to develop the concept of coconut based intercropping system to increase the productivity and income from unit area of plantations without decreasing the coconut yield and realising the yield potential of inter or mixed crops in the plantations. Coconut based cropping/farming systems have been recognized as a strategy for optimizing the productivity and augmenting the economic viability of coconut lands, particularly in the wet and intermediate agro-climatic zones (Liyanage and Gunathilake, 1998).

12.4.1 Amenability of the coconut to cropping systems

It has been observed that practically all the cultivated crops in the hot and humid tropical conditions establish under the canopy of matured coconut palms. However, the performance of crops depends on the prevailing local conditions. Theoretical calculations have indicated that the potential (maximum) biological productivity of a crop community under optimal conditions could be as high as 280.5 t of dry matter $ha^{-1} year^{-1}$ (Loomis and Williams, 1973). Perennial crops like coconut, which occupy the land continuously for several decades, utilize the natural resources only to a very limited extent producing less than 10 % of the potential for dry matter production in the tropics (Nelliat *et al.*, 1974). A wide gap exists between potential and actual productivities.

A spacing of 7.5 m x 7.5 m in the square system is recommended for coconut (175 palms ha^{-1}) for optimum production. Coconut palm like all monocots has a typical adventitious root system and under favourable conditions, as many as 4000 to 7000 roots are found in the middle aged palms (Menon and Pandalai, 1960). Kushwah *et al.* (1973) reported that about 74% of the roots produced by a palm under good management did not go beyond 2 m lateral distance and 82% of the roots were confined to the 31 to 120 cm depth of soil. Studies further confirmed that more than 80% of the root activity was confined to a lateral distance of 2 m from the trunk (Anil Kumar and Wahid, 1988). On surface area basis, the area occupied by the palm is 56.25 m^2 (7.5 x 7.5 m); the area of active root zone is 12.57 m^2 (pr^2 where r=2 m). Therefore, the fraction of total area effectively utilized by the palm is 12.57/56.25 x 100= 22.24%. Thus, in a pure stand of coconuts at normal planting density and management conditions, about 75% of the total area is not being effectively utilized to the fullest extent by coconut roots.

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. Nair and Balakrishna (1976) estimated that as much as 56% of the sunlight was transmitted through the canopy during the peak hours (10-16 hours) in palms aged around 25 years. The diffused sunlight facilitates growing a number of shade tolerant crops in the interspaces. The leaves in a coconut palm crown are not randomly distributed, but clumped around few widely spaced growing points. This non-random distribution will also lead to low extension coefficient of around 0.65 for PAR. Light penetration through the canopy is influenced by age, spacing, soil fertility, cultivar characteristics, leaf area and time of the day. The amount of light transmitted ranges from 5% in a five to ten year old D x T hybrid at a density of 650 palms ha^{-1} to about 90% in a 60-70 year old plantation at a density of 120 palms ha^{-1} (Reynolds, 1995).

The nature and amount of sunlight transmitted through coconut canopy and falling on the ground shows temporal as well as spatial variations. The angle of the sunrays (and thus the time of the day) influences the amount of light passing through the coconut canopy. With the movement of the sun and the movement of coconut fronds in the wind, the light and shade patterns under the palms are constantly changing. The distribution of light at different positions in the canopy zone of coconut varies very much because of the non-random distribution of leaves. This causes differences in the growth and yield of intercrops at different positions of the plantation floor. In a coconut based farming system, transmitted radiation especially the photosynthetically active radiation (PAR) regime is very important as it had bearing on the behaviour and productivity of intercrops. The response of corn and mung bean under coconut to transmitted light was studied and found that yield nearly a linear function of the PAR received (Eroy and Dauzat, 1997). The apparent coverage of ground by canopies of palms of various age groups varied (Nelliat *et al.*, 1974). When the palms are about 8-10 years old, the percentage of sunlight transmitted is only 20%, and this remains almost constant till about 25 years of age. Subsequently, the per cent light transmission increases progressively and the canopy coverage of ground decreases inversely. By the time the palms are 40 years old, the light transmission increases to about 50%. Based on the growth habit of the palm and the amount of light transmitted through its canopy, the life span of coconut palm could be divided into three distinct phases from the point of view of intercropping.

1. Planting till full development of canopy (about 8 years): Good transmission

initially; but decreasing with age; suitable for growing annuals/biennials.

2. Young palms (8-25 years): Maximum ground coverage and low canopy; poor light availability; not suitable for multiple cropping.

3. Mature trees (more than 25 years): Increasing trunk height; reducing in crown size-light transmission increasing with age; ideal for raising annual and / or perennial crops.

12.4.2 Criteria for selection of subsidiary crops

Selection of subsidiary or component crop for growing under or between a tree crops should consider the following aspects (Allen, 1955; Hartley, 1977).

1. Crops should be selected according to their shade tolerance and amount of solar radiation available.
2. Should not grow as tall as coconut.
3. Should not be more susceptible than the main crop to diseases they have in common.
4. Should not require harvesting or other operations that would damage the main crop or induce soil erosion or damage soil structure.
5. Should not have an economic life longer than the main crop.
6. Its root system should exploit different soil horizons/zones.
7. Crops should be selected according to the soil type, rainfall pattern/irrigation facilities and climatic conditions.
8. Availability of marketing/processing facility and labour availability.

However, it is always not possible to fulfil all these requirements to have successful crop combinations. Based on the experience and experimental results of the crop combination studies at CPCRI and elsewhere in the country, the general features of intermixed, and multistoreyed croppings are described below.

Intercropping: Growing annuals / biennials in the interspaces of coconut.

Mixed cropping: Growing perennial in the interspaces of coconut

Multistoreyed cropping: Growing three or more crops having different morphological characteristics in the interspaces of coconut so as to intercept solar radiation at different level (eg. coconut + black pepper + cocoa + pineapple)

High density multispecies cropping system: Growing a large number of crop species in unit area of coconut plantation at high plant densities to achieve maximum resource use efficiency and to meet the diverse needs of the farmer.

Mixed farming: Subsidiary enterprises such as livestock, poultry, rabbitary etc. are raised with the help of fodder or pasture grown in the coconut garden.

12.4.3 Intercropping

Several reports and experimental research results are available on intercropping in coconut gardens from different parts of the world and covering a number of crops. Several workers reviewed the experiments in India on inetercropping in coconut (Nair, 1976, 1977, Nair and Bavappa, 1975; Nair and Varghese, 1976; Nair *et. al.*, 1974; Nelliat *et al.*, 1974; Nelliat and Krishnaji, 1976; Gopalasundaram and Nelliat, 1979a and 1979b; Chattopadhyay and Mitra ,1995; Srinivasa Reddy and Biddappa, 2000). These reviews indicate that the practice extends to many of the cultivated crops. Notable among them are cereals, tuber crops, pulses, oilseeds, banana, pine-apple, rhizome spices, ornamental and medicinal plants and fodder grass. Nutmeg is a suitable mixed crop for coconut garden (Maheswarappa and Anithakumari, 2002).

12.4.3.1 Cereals

One of the earliest reports on raising rice as an intercrop in coconut gardens from Nileshwar and Kasaragod was not encouraging (Anon., 1934) and the yield was very low, 160 kg ha^{-1} while upland cultivar was profitable at Pilicode (Anon., 1942). But, when summer showers were not adequate the yield of upland cultivars *viz.*, 'PTB 29' and 'PTB 30' were low (Anon., 1960). The profitability of growing finger millet as an intercrop was brought out as early as 1931-32 (Anon., 1932). Intercropping trial with various millets *viz.*, thenai, finger millet, samai, jowar, kudiravalli, panivaragu, bajra and varagu showed that these millets gave equal or better yields under coconut compared to the yield in open (Anon., 1942). However, in Thanjavur district, Tamil Nadu that lies on the East coast, the performance of two finger millet cultivars 'EC 4847' and 'EC 4849' was very poor (Anon., 1978b). Nambiar (1978) reviewed the work done on coconut based cropping systems and indicated *Panicum scrobiculatum* L. (varagu) performed better than upland rice and other millets. In semi arid maidan tract of Karnataka growing finger millet as an intercrop had increased the coconut yield by 19.3% compared to maize and wheat (Shanthamalliah *et al.*, 1982a).

12.4.3.2 Pulses and oil seed crops

Suitability of growing pulse crops *viz.*, horsegram, redgram, soya bean and black gram as green manure at Kasaragod and black-gram, dew gram, red gram, pillipesara, horse gram and cowpea at Pilicode were studied and found that redgram at Kasaragod was better green manure (Anon., 1934). The yield of redgram was good in the first year and poor in the next year at Pilicode (Anon., 1942). The experiments conducted during the seventies at Kasaragod showed that the yield of horsegram was higher (355 kg ha^{-1}) as an intercrop than blackgram (72 kg ha^{-1}), which was very poor (Anon., 1975). At Veppankulam in Thanjavur district of Tamil Nadu the performance of cowpea cv. '152' was good compared to other pulses like cowpea cv. 'PLS 370', redgram, blackgram, greengram and soya bean (Anon., 1978a). Shanthamallaiah *et al.*, (1982a) reported that in the semi arid maidan regions of Karnataka all the four pulses tried *viz.*, cowpea, bengalgram, soya bean and groundnut performed better and increased the yield of coconut as well as income. However, the sowing time of pulses seems to have greater role for the failure or success of pulses as intercrops. Soya bean cultivars 'PK 472', 'MACS 13' and 'MACS 48' also reported highly promising as intercrops in coconut gardens (Hegde *et al.*, 1993b).

Suitability of growing pulse crops viz., redgram, soya bean, cowpea (Anon., 1975; Anon., 1978; Shanthamallaiah *et al.,* 1982a; Hegde and Yusuf, 1993b) and oil seed crop, groundnut (Sahasranaman, 1964; Kannan and Nambiar, 1976; Leela and Bhaskaran, 1978) in the interspaces of coconut is well established in different locations. The suitability of growing groundnut as intercrop at Kasaragod was established even during 1931-32 (Anon., 1932). Sahasranaman (1964) brought out the profitability of growing groundnut and its effect on suppressing the weed growth and maintaining soil tilth. Similarly Kannan and Nambiar (1976) and Leela and Bhaskaran (1978) showed that groundnut as an intercrop increased the coconut yield, income as well as created additional employment opportunities. The unsuitability of sunflower as an intercrop at Kasragod was also proved.

12.4.3.3 Fruit crops

Banana is one of the common intercrop in coconut gardens. In Andhra Pradesh where irrigation facilities are available banana as an intercrop gave a yield of 1200 to 1300 bunches ha^{-1} with an average net profit of Rs. 500-700 (Anon., 1964). Kuttappan (1971) made a survey in the small-holdings and found that 1000 banana plants could be raised in one hectare of coconut garden if coconut population is 125 ha^{-1}. Krishnaji *et al.* (1976) showed that banana as an intercrop gave net profit of Rs. 2905 ha^{-1} and provided an additional employment of 132 mandays and 6 womandays ha^{-1} $year^{-1}$. The unsuitability of banana as a rainfed intercrop in coconut in laterite gravelly soil was brought out at Pilicode (Anon., 1979). Banana was proved to be a suitable companion in coconut holdings. At the research stations of KAU, cultivars of banana such as 'Robusta', 'Nendran', 'Nhalipoovan' and 'Palayankodan' were tested to select suitable cultivars for intercropping. The best yielders were recorded as 'Robusta' and 'Palayankodan' at two stations fetching the maximum income.

In another trial in Kerala, 'Palayankodan', 'Robusta', 'Karpooravally', 'B.B.

Batheesa' and 'Poovan' were identified as suitable cultivars. Other fruits like papaya, pineapple, sapota, guava, Assam lemon and mango (Nair, 1993; Das, 1990) were also found to be profitable intercrops in coconut plantations. Intercropping is a common practice among coconut farmers of Laguna, Batanga and Cavite, Philippines. A study on different cropping systems indicated that an intensive cropping pattern (the intercropping of banana, papaya, gabi and pineapple) resulted in a higher yield and maximum returns (Alviar and Cuevas, 1976). Biomass productivity of coconut-pineapple plantation in Riau Province, Sumatra was 4.3 times higher that of pure coconut stands and this combination was considered to be one of the optimum cultivation patterns in tropical areas (Pen Fangren *et al.*, 1996).

12.4.3.4 Tuber and root crops

The economic feasibility of raising short duration annual crops in middle-aged coconut garden with 'WCT' cultivar was investigated as early as in 1978-79. The intercrops were elephant foot yam, turmeric, ginger, cassava, sweet potato and colocasia. The yield performance of sweet potato and colocasia was poor when others registered satisfactory yield. The maximum profit was obtained from turmeric followed by cassava. The tuber crops are ideal components of homestead gardens as they help to meet the food requirement of a farm family to a certain extent. Tubers like *Dioscorea alata*, (greater yam), *Dioscorea esculenta* (lesser yam), *Coleus parviflorus* (Chinese potato) and *Xanthosoma sagitifolium* (colocasia) compatible as intercrops in coconut was brought out by Varghese *et al.* (1978a and 1978b). In another experiment in a laterite soil type at Pilicode (Kerala), maximum profit was reported from elephant foot yam (Anon., 1979). In different locations, higher yield of ginger and turmeric were reported under intercropping systems. A study on the performance of 6 ginger [*Zingiber officinale*] cultivars under varying shade levels and their compatibility in a coconut-based cropping system indicated the effects of shade on plant height, tiller number, net assimilation rate and rhizome yield. Sen (1956) had indicated that arrow root often grew wild in coconut gardens of West Bengal could be cultivated profitably with a little more care. In a 50-year-old coconut garden intercropping with tapioca, colocassia, and other cereal and pulse crops conducted during 1967-75 showed that the yield of coconut was increased by 30.3% with colocassia. However, the tapioca gave highest net return (Kannan and Nambiar, 1976).

Menon and Nayar (1978) revealed that tuber crops like tapioca, elephant foot yam and yam can be profitably grown as intercrops in the root (wilt) disease affected areas. They also revealed that coconut and tapioca 'H-165' gave the highest net return of Rs.7415 followed by coconut and elephant foot yam (Rs.5890) and coconut and yam (Rs. 5650) while coconut alone gave only Rs. 2520 ha^{-1}. Hore *et al.* (2003)studied the effect of farmyard manure (FYM) and N,P,K fertilizers on the growth and yield of elephant foot yam *(Amorphophallus campanulatus)* as an intercrop in coconut plantations and to evaluate the effect of intercrops on coconut yield. Treatments comprised: two FYM levels (15 and 20 t ha^{-1}) and/or five N,P,K levels (75:25:75, 100:50:100, 125:75:125, 150:100:150 and 175:125:175 kg ha^{-1}). Increasing the N,P,K level from 75:25:75 to 175:125:175 kg ha^{-1} increased the yield of yam from 24.21 to 35.29 t ha^{-1}. Yield was highest with 20 t FYM ha^{-1} + 150:100:150 kg N, P, K ha^{-1} treatment (33.69 t ha^{-1}). The average coconut yield was 59.62 and 65.66 in monocrop and intercropped plots, respectively. The total variable capital requirement ha^{-1} for coconut + elephant foot yam *(Amorphophallus companulatus)* and coconut monocrop was Rs. 76750 and Rs. 19000, respectively. The gross return for intercropping was Rs. 121170, while that for coconut monocrop was Rs. 37170. The net return ha^{-1} from intercrop and monocrop were Rs. 44420 and Rs. 18170, respectively, with a net return of Rs. 20250 from elephant foot yam. The intercropping system cost:benefit ratio was 1:1.4.

12.4.3.5 Medicinal and aromatic crops

Medicinal and aromatic crops have also been reported to be profitable intercrops in coconut gardens. Of the different medicinal and aromatic crops, kacholam (*Kaempferia galanga*), arrowroot (*Maranta arundinacea*), greater galangal (*Alpinia galanga*), penikurkka (*Coleus aromaticus*), iruveli (*Coleus vetiveroides*), periwinkle (*Catharanthus roseus*), ocimum (*Ocimum sanctum*), channakkuva (*Costus speciosus*), koduveli (*Plumbago rosea*), sarpaganda (*Rauvolfia serpentina*), mango ginger (*Curcuma amada*), *Andrographis peniculata*, *Sida retusa*, and patcholi (*Pogostemon cablin*) are best suited to grow under shaded conditions (Sen, 1956; Pandarakalam, 1956; Rajagopalan, 1992; Nair *et al.*, 1991; Viswanathan *et al.*, 1992; Viswanathan *et al.*, 1993; Lalitha *et al.*, 1996). The intercropping trials revealed the better performance of kacholam and arrowroot with respect to number of tillers, chlorophyll a and b, carotenoid content and fresh rhizome yield when grown as intercrops in coconut gardens compared to the monocropping (Maheswarappa, 1997). Srinivasa Reddy and Arunachalam (2002) reported that patchouli can be profitably intercropped in an adult coconut garden and can yield 5 to 7.5 t ha^{-1} air dried foliage year^{-1} ha^{-1}. The farmer can earn a net profit of Rs 50000 to 100000 ha^{-1} year^{-1}.

12.4.3.6 Vegetable crops

Only limited work has been done on intercropping vegetables in coconut. Vegetable cultivation is possible with high amount of labour input and family involvement. Sahasranaman (1961) showed the profitability of growing chilli as an intercrop. French bean recorded the highest increase (26.78%) of coconut yield followed by chilli (18.75%) and potato (14.51%) (Shanthamallaiah *et al.*, 1982a). Rasing of chilli, potato, French bean (Rethinam, 1989), dolicos bean, tomato, knolkhol, capsicum and brinjal (Patil *et al.*, 1992) was found to be profitable as intercrops in coconut gardens. Experiments at Kasaragod indicated vegetables like snake-gourd, bottle-gourd, amaranthus, coccinia, brinjal and bitter-gourd as compatible crops with coconut. Intercropping with vegetables helped to generate additional employment to the tune of 215 to 365 mandays ha^{-1} $year^{-1}$. Among the different sequences tried snake-gourd - ridge-gourd - amaranthus was found to be the most remunerative ones (Rs 22217 ha^{-1} $year^{-1}$) followed by amaranthus-bottlegourd-brinjal (Rs 20920 ha^{-1} $year^{-1}$) (Hegde *et al.*, 1993a). In the Konkan region of Maharashtra, India, it was found that ridge gourd is the best vegetable followed by cucumber to grow as intercrop in coconut plantation under rainfed conditions (Nagwekar *et al.*, 1997).

Trials carried out in Goa indicated the suitability of ginger and turmeric as annual intercrops that gave highest net returns. Among the vegetables, high monetary returns were obtained with okra and cluster beans in *kharif* (rainy) season, brinjal in *rabi* (winter) season and okras in summer season (Manjunath *et al.*, 1998).

12.4.4 Rotation of intercrops in coconut

The advantage of growing crops in sequence is a well-known fact and being adopted all over India. Similarly in coconut based cropping systems also crop rotations have yielded beneficial effects by way of increasing the income as well as enhancing soil fertility status. Varghese *et al.* (1978a) reported that elephant foot yam or tapioca grown continuously every year lowered the coconut yields while a rotation of elephant foot yam alternated with tapioca yielded more. Tapioca - elephant foot yam, tapioca - ginger, elephant foot yam - ginger appear to be good rotations under Kerala conditions. Yield of elephant foot yam increased from 6.4 t ha^{-1} (continuous crop) to 11.8 t ha^{-1} in rotation with tapioca. Shanthamalliah *et al.* (1982a) tried six double cropping practices with coconut and found that potato - wheat gave the maximum net income of Rs. 12801 ha^{-1} followed by French bean - wheat (Rs. 12760 ha^{-1}), ragi - wheat (Rs. 9208 ha^{-1}), chilli - wheat (Rs. 9100 ha^{-1}), maize-wheat (Rs. 8864 ha^{-1}) and cowpea - wheat (Rs. 8646 ha^{-1}) while coconut alone gave only Rs. 3373 ha^{-1}.

12.4.5 Coconut based mixed cropping

Mixed cropping with perennials such as cocoa, pepper, nutmeg, cinnamon, coffee, betelvine, vanilla and mulberry were tried in coconut gardens at different locations. The profitability of growing cocoa as mixed crop in coconut has been established in field experiments conducted both at Kasaragod and Pilicode (Nair *et al.*, 1975; Anon., 1979). The productivity of coconut and net return from the system were significantly higher under mixed cropping with cocoa both in double hedge and single hedge systems (Anon., 1982). In Kasaragod, where the coconut palms were planted at a spacing of 7.5 m, the single hedge system was superior (Nair *et al.*, 1975). The double hedge system was found superior at Pilicode as the experiment was conducted in plantations where the coconut palms were cultivated at a wider spacing of 9 m x 9 m. Mixed cropping of cocoa under older stands of coconuts resulted in greatly improved financial returns in Malaysia (Ramadasan *et al.*, 1978). The beneficial effects of growing cocoa, pepper, clove, nutmeg and cinnamon as mixed crops in coconut plantations were reported by Nelliat *et al.* (1979) and Srinivasa Reddy and Thomas (2001). The yield of cinnamon was 30 - 35 g quills and 15-20 g chips in 1974 and increased to 82 g quills and 30 g chips in 1978 (Anon., 1975 and 1979). Pepper ('Panniyur 1') planted in 1971-72 as mixed crop yielded 2 kg dried berries vine^{-1} and the maximum yield was 5 kg vine^{-1} (Anon., 1977). Experiments conducted in Goa conditions revealed that black pepper grows satisfactorily as mixed crop in coconut gardens and the plants started yielding from the third year onwards. The average yield obtained from one-hectare coconut garden was 0.76 t ha^{-1} and 0.44 t ha^{-1} of dry pepper, respectively from 'Panniyur-I' and 'Karimunda' (Mathew *et al.*, 1993). Large coconut areas on fertile alluvial clays along the West coast of peninsular Malaysia have been underplanted with cocoa. The favourable cocoa bean prices, the unstable copra prices and the availability of the ready-made coconut shade have accounted for the success of the cropping system. Shanthamallaiah *et al.* (1982b) reported that mulberry as a mixed crop increased the yield of coconut by 920 nuts ha^{-1} and net income by Rs. 7379 and doubled the employment potential.

The profitability of growing perennial spice crops such as clove, nutmeg and cinnamon have been reported (Nelliat *et al.*, 1979; Srinivasa Reddy *et al.*, 1998a). Stable cropping systems were developed combining coconut and nitrogen-fixing trees such as *Acacia mangium, A. auriculiformis* or *Casuarina equisetifolia* (Taffin *et al.*, 1991). The N-fixing trees provided wood for domestic purposes; when cut back after 46 months, the small branches and leaves were left on the ground so that 47-52% of the plant biomass (amounting to 80% of the potential total N) was recycled. *A. mangium* produced the most biomass for return to the soil (457 kg ha^{-1}). *A. auriculiformis* provided the highest volume of harvested wood (49 m^3 ha^{-1}).

Evaluation of the six cultivars of black pepper in a coconut garden indicated the better performance of 'Karimunda' and 'Panniyur-I' under mixed cropping system (Potty *et al.*, 1979). Mixed cropping with spice crops such as cinnamon, clove, nutmeg, black pepper, garcinia and allspice was beneficial at Ratnagiri, Maharashtra to increase the coconut yield (Patil *et al.*, 1991). An experiment conducted at Sirsi, Karnataka cultivating cardamom as a mixed crop with coconut revealed that coconut canopy provided adequate shade for shade-loving cardamom in the multistoreyed cropping system. The net return from mixed cropping was 2.5 times greater than from the monocropping (Korikantimath *et al.*, 2000). Cardamom required 97 men and 174 women labour days accounting for 55.65% of the total labour requirement of this system. A study on micro-climatic and physiological characteristics in coconut and cardamom mixed cropping system revealed that the coconut canopy intercepted more light (75.43%) and photosynthetically active radiation (1207 μmol m^{-2} sec^{-1}) than cardamom (32.06% and 388 μmol m^{-2} sec^{-1}) respectively. Coconut had a higher photosynthetic rate, transpiration rate and higher carboxylation efficiency than cardamom. Coconut in combination with cardamom gave better economic returns than coconut alone (Korikantimath *et al.*, 1997).

A survey on coffee cultivation under coconut in non-conventional districts of Karnataka revealed that *Coffea arabica* cv. 'Cauvery' was the type most often grown under coconuts although *robusta* coffee selections S.795, S.10 and S.274 were grown on a few farms (Reddy *et al.*, 1998).

12.4.6 Multistoreyed cropping system

Crops having canopies of varying heights are selected in this intensive cropping system with the objective of greater utilization of solar energy and soil resources. The most profitable multi-storeyed system with coconut as main crop was established at CPCRI, Kasaragod with black pepper trained on coconut, 350-600 cocoa seedlings planted (in one hectare) between rows of coconut and 3500 pineapple suckers planted between rows of coconut and cocoa. The output from the system included 17,000 coconuts, 300 kg dried beans of cocoa, 60 kg dry pepper and 4,000 kg of pineapple ha^{-1} $year^{-1}$ in the single hedge system (Nelliat *et al.*, 1974 and 1979). The multistoreyed cropping models carried out at the Candimas Coconut Seed Garden of the Estate Crops Extension Service, Lampung consisted of 7-year-old coconut palms planted at 10 x 10 m spacing and intercropped with the crop combinations such as 1. kapok + cocoa, 2. clove+kaempferia, 3. kapok+pepper+ginger, 4. cocoa + cinnamon + pepper + pineapple, 5. banana+maize, and 6. coconut monoculture. The highest income ha^{-1} was obtained from model 4, followed by systems5,1,3,2 and 6 (Dwiwarni *et al.*, 1987).

12.4.7 High density multispecies cropping system (HDMSCS)

An HDMSCS model was established at Central Plantation Crops Research Institute (CPCRI), Kasaragod in 1983 with 17 species of annuals/perennials planted at a high density of 14,976 planting points ha^{-1} of coconut plantation (Bavappa *et al.*,1986). As the perennials grew and utilized more and more space, the annual crops except banana were withdrawn from the system. The system now consists of clove, nutmeg, banana and pineapple in coconut stand. The coconut yield increased by 176 % as compared to the pre-experimental yield as a response to the adoption of high density cropping and irrigation.

The experiment was maintained at three fertilizer levels, one-third, two-third and full recommended dose by dividing into three plots. The mean productivity of crops revealed that the yields have declined with reduction of fertilizers below the one-third of recommended dose in the system. The coconut yield did not vary much among one-third, two-third and full dose of recommended fertilizers (147 to 157 nuts palm^{-1} year^{-1}). The component crops viz. clove, pineapple and banana performed better under two-third and full dose of fertilizers in the system. Hence, two-third level of fertilizers was necessary to sustain the yield of coconut and component crops at economically higher level (Srinivasa Reddy *et al.*, 2000). The cash flow analysis of the system was done for the period 1983 to 1997 involving banana, clove and pineapple. The variable capital requirement for adoption of system ranged between Rs. 8200 ha^{-1} during 1984-85 to Rs. 40,570 ha^{-1} during 1996-97. A gross margin of Rs. 92,230 ha^{-1} could be realised in 1996-97 compared to Rs. 1750 ha^{-1} during 1983-84 (Sairam *et al.*, 1999). Studies on canopy architecture in a multi-species cropping system involving 13 fruit crops by Jamaluddeen and Jacob (1983) indicated that the percentage increase in canopy diameter between 24 and 33 months after planting was greatest with coffee (59%), followed by mango (51%), coconut and jackfruit (both 40%). In Assam, adoption of HDMSCS involving coconut + banana + Assam lemon + pineapple + ginger + turmeric + colocasia had resulted in a nut yield increase of 110 and 83 per cent respectively over pre-experimental nut yield (Chowdhary and Deka, 1997).

Besides this, many HDMSCS models as listed below are being evaluated in different Co-ordinating centres in India (Anon., 1998).

1.	Arsikere:	Model-I: Coconut + pepper + sapota + banana + clove + lime + pineapple
	(Karnataka)	Model-II: Coconut + pepper+nutmeg + curry leaf + potato
2.	Kahikuchi: (Assam)	Model-I: Coconut + black pepper + banana + Assam lemon + pineapple + ginger
		Model-II: Coconut + betelvine + banana + Assam lemon + colocasia + lemon
4.	Veppankulam: (Tamil Nadu)	Model-I: Coconut + nutmeg + banana + seedless lime + elephant foot yam + bitter-gourd
		Model-II: Coconut + clove + betelvine + banana + curry leaf + colocasia
		Model-III: Coconut + mango + pepper + banana + seedless lime + bhendi + sirukizhangu

Of the above models, Model-I at Arsikere (Karnataka) and Kahikuchi (Assam) and Model-II and III at Veppankulam (Tamil Nadu) were found promising in terms of total harvest and net returns (Anon., 1998).

Studies on the High Intensity Mixed Cropping Model (HIMCM) at Mid Country Research Station, Sri Lanka indicated the agronomic and economic potential with cash crops such as pepper, coffee and clove and food crops such as banana and lime (Preemaratne *et al.*, 1991). HIMCM is found to be a financially viable, high-density multi-crop system that can vastly improve the income level of upland farmers. The undesirable feature with respect to the resource endowment of small farmers is that it requires high capital cost for establishment.

12.4.8 Mixed farming system

Mixed farming is a common practice on small farms in Kerala, India. Mixed farming studies were started in 1972 at Kasaragod and in 1970 at Kayangulam in healthy and root wilt affected coconut-growing areas, respectively. Sahasranaman and Pillai (1976) screened the fodder crops suitable for mixed farming and found that Guatemala (*Tripsacum laxum*), hybrid napier (Pusa Giant and NB 21), and guinea grass *(Panicum maximum)* gave an yield of 50-60 t of green fodder ha^{-1} $year^{-1}$ under coconut shade and legumes, Brazilian lucerne (*Stylosanthes gracillis*) and cowpea (*Vigna unguiculata*) yielded 30 t ha^{-1}. With a cutting interval of 30-40 days and a feeding rate of 30-40 kg of green fodder in the ratio of 3:1 grasses and legumes $animal^{-1}$ day^{-1}, an area of one hectare could support four milch cows. Mathew and Shafee (1979) had indicated the incremental benefit of coconut + dairy over coconut alone as Rs. 22763 $annum^{-1}$ $hectare^{-1}$. The yield data from 1.04 ha mixed farming model in 1994-95 was 19125 coconuts, 9275 litres milk, 526 kg poultry (live weight), 50 number quail birds, 3500 hen eggs, 1100 quail eggs and 400 kg fish (Anon., 1996).

Sahasranaman *et al.* (1983) showed 28% increase in nut yield in the root wilt affected area by adopting mixed farming practice over a period of five years. They have also indicated that the foliar yellowing of root wilt disease affected palms is ameliorated due to mixed cropping. Regeneration of roots in the diseased palms of the mixed farming area with grass and irrigation was also brought out (Anon., 1976b) besides increased income (Anon., 1976a) and additional employment generation from 150 days ha^{-1} to 1000 mandays by mixed farming (Sahasranaman *et al.*, 1983). In healthy coconut plantations at Kasaragod, Mathew and Shafee (1979) showed increased coconut yield, satisfactory milk yield and employment potential for about 800-850 days as against 150 days for pure coconut as indicated by Nelliat and Krishnaji (1976).

A second-generation mixed farming unit was established in 1988 in an young coconut garden at CPCRI, Kasaragod by integrating poultry, rabbitry and pisciculture in addition to the dairy component. The adoption of mixed farming practices improved the yield of coconut palms and generated additional income and employment opportunities. Mixed farming unit in 1.04 ha coconut garden provided a total return of Rs. 2,25,327 of which dairy contributed Rs. 1,02,850, poultry Rs. 30,537 and coconut and other enterprises contributed the rest (Anon., 1997). A coconut-based mixed farming system involving 14 activities and integrating the crop and livestock systems was found to be the best in the linear programming model. The structural and functional diversity of the components of the model ensure a high level of resource-use efficiency, meeting the multiple demands (food, fodder, fuel and timber) of the home. The model also provides a net return of Rs. 12,628 with a benefit-cost ratio of 1.64 (Salam *et al.*, 1991). The crop-livestock components selected in the model interact synergistically to increase the productivity and to generate higher net returns. The model developed is capable of maintaining soil health and ensuring environmental safety. Hence, it is economically efficient, ecologically sound and biologically sustainable.

The integration of legume-based pasture and dairy cattle to increase sustainability and productivity of coconut holdings in Sri Lanka involving *Brachiaria miliiformis/ Pueraria phaseoloides* mixed pasture, and *Gliricidia sepium* and *Leucaena leucocephala* fodder trees established in mature coconut plantations in 1985, and Jersey X local cross-breed cattle introduced one year later was studied. Results indicated that coconut palms in the integrated system yielded 17% more nut and 11% more copra, while maintaining the nutrient status of the palm above the critical level despite reduced application of fertilizer. Nutrients returned from 73 kg fresh cattle manure and 30 litres urine palm^{-1} year^{-1} could reduce the cost of fertilizing coconut by 69%. The system produced sufficient forage to maintain satisfactory growth of animals as indicated by daily live weight gains of 306-590 g head^{-1}. In addition, each animal produced on an average 3.78 litres of milk daily during the first lactation. Recycling of animal excreta improved soil fertility by providing organic carbon, total nitrogen and available phosphorus. The integrated system was economically viable in comparison with monoculture. Despite several factors (such as the small size of farm holding, lack of capital and appropriate knowledge, inadequate extension support, and non-availability of desirable pasture and animals) which limit its widespread use by farmers, it is indicated that the coconut + cattle integrated system could contribute to the development of a sustainable and productive farming system in Sri Lanka (Liyanage *et al.*, 1993).

12.4.9 Fertilizer management in cropping systems

The importance of intensive cropping systems lies in the nutrient economy as the extensive cover in the plantation floor increases the plant cycling fraction of nutrients (Khanna and Nair, 1977). The crop combination as in coconut based farming system, therefore serves as a buffer against drastic changes in eco-climate which will have considerable effect on the various biological processes occurring in rhizosphere of crops (Nair and Balakrishnan, 1977; Varghese *et al.*, 1978b).

Multistoreyed cropping involves pineapple in lower most tier, cocoa / cinnamon / coffee / clove / nutmeg in the second tier and black pepper trailed on coconut bole as the third tier. Such systems can be practised only under assured irrigation preferably with perfo-system. The crops are manured individually. The fertilizer input is enormous. Results of investigations on intercrops in coconut plantations and their potentialities has been reviewed by Nair (1979). Such a system offers enormous scope for recycling of nutrients (Khanna and Nair 1977).

Through the leaf fall of the cocoa intercrop in coconut-cocoa system, 50 kg N, 11 kg P_2O_5 and 35 kg K_2O ha^{-1} can be recycled into the system (Varghese *et al.*, 1978). In such a system, the organic carbon content of soil increased by 28 and 54 % in double and single hedge system respectively (Nair and Rao, 1977). A soil store of 28.4 kg N, 44 kg P and 17.3 kg K was estimated in a 30 year old coconut garden having a 5 year old cocoa stand as mixed crop (Khanna and Nair, 1977). On this basis, it was suggested that fertilizer input can be reduced to 165, 70 and 364 kg, N, P and K to coconut-cocoa system instead of the normal dosage of 210, 120 and 469 kg N, P and K respectively. In high density multispecies cropping system, the influence of internal nutrient recycling was such that there was no marked difference in the yield of main crop and component crops in between plots where 33%, 66% and full dose of fertilizers was applied (Srinivasa Reddy *et al.*, 2000). A medium input (66%) was able to sustain coconut productivity. However, the yield of component crops was better with full dose of recommended fertilizers. Thus, the scope of integrated nutrient management in cropping system models involving wide range of crops is enormous.

12.4.10 Economics of cropping / farming system

Adoption of any cropping system by the farming community will ultimately be accepted by its economic advantages. While the monocropping of coconut provides employment for only around 150 mandays ha^{-1} $year^{-1}$ and gave a net income of Rs. 10,400 ha^{-1}, the generation of additional employment to the tune of 130 to 606 mandays ha^{-1} $year^{-1}$ and the net returns ranged from Rs.18,670 in the case of coconut + cassava. In intercropping trials with five crops in a coconut plantation under rainfed conditions in Karnataka, maximum net profit ha^{-1} was obtained with French beans (Rs.13,765) followed by fodder grass (Rs.12,526), sunflower (Rs.12,157), cowpea (Rs.12,036) and ragi (Rs.11,168) besides improvement in coconut yield (Hanumanthappa *et al.*, 1998). Various coconut-based inter/mixed farming systems viz. rice, millet, grain legumes, oilseed crops, root crops, banana, pineapple, chillies [capsicum] and vegetables, mixed cropping with cocoa, black pepper tree spices and mulberry (for sericulture), multistoreyed cropping and mixed farming were evaluated on the basis of their economic viability. It is more profitable therefore, to integrate a number of subsidiary crops and animal components with coconut than to grow it as a monocrop (Das, 1991). The annual cost of cultivation and returns of multistoreyed cropping system consisting of coconut-pepper-cocoa-pineapple recalculated based on the present market prices for the inputs and outputs data of 1976 (Nelliat *et al.*, 1979) presented in table 18 clearly indicates the economic advantage of such systems. The recalculated economics for the earlier yield data from CPCRI, Kasaragod revealed that among the various mixed crop combinations, Coconut-Pepper system was found more remunerative. This system could generate a net return of Rs 45025 ha^{-1} $year^{-1}$ in a coconut garden as compared to Rs 22300 ha^{-1} $year^{-1}$ from coconut monocrop (Srinivasa Reddy and Thomas, 2001). The mixed farming model at CPCRI, Kasaragod (India) generated additional employment to the tune of 850 mandays and ensured good returns without any yield decline in coconut. The output from the 1.04 ha model yielded 11,276 coconuts, 60 kg pepper, 250 kg banana and 14,495 litres of milk. The total revenue from this was Rs 67,705 and net return to the family was Rs 43,654 (Anon., 1990).

Table 18: Labour requirement, expenses and returns from coconut based multistoreyed cropping system (1 ha)

Crops	Labour (mandays)	Yield	Annual cost of cultivation (Rs)	Gross returns (Rs)	Net returns (Rs)
Coconut	157	17500 nuts	22000	43750	21750
Pepper	16	88 kg (dry)	5000	8800	3800
Cocoa (beans)	163	500 kg	5000	10000	5000
Pineapple	30	3710 kg	3000	14840	11840
Total	366	—	35000	79150	42390

Coconut: Rs.2.50 nut^{-1}; Pepper: Rs.100 kg^{-1}; Cocoa: Rs. 20 kg^{-1}; Beans: Rs.4 kg^{-1}.

The profitability of growing vegetables as intercrops in coconut gardens has been reported. The most remunerative combination was snake gourd–ridge gourd–amaranthus system (Rs. 22,217 ha^{-1} $year^{-1}$) followed by amaranthus–bottle gourd–brinjal system (Rs. 20,920 ha^{-1} $year^{-1}$). The introduction of the system resulted in generation of additional employment to the tune of 215 to 365 mandays ha^{-1} $year^{-1}$ (Hegde *et al.*, 1993). In Anaimalai block, Coimbatore district, Tamil Nadu, India, the returns from coconut farming were found to be higher than those from paddy cultivation. The benefit-cost ratio of coconut plantations was higher for plantations with intercropping (Jaganathan, 1992).

The cash flow analysis was performed for the coconut based high density multispecies cropping system for the period from 1983-84 to 1996-97 involving banana, clove and pineapple as component crops (Sairam *et al.*, 1999). The gross margin realised from the system ranged between Rs. 1750 ha^{-1} during 1983-84 to Rs.92, 230 ha^{-1} during 1996-97 The benefit-cost ratio of the system was more than three for full as well as two third levels of fertilizer doses. The economic analysis of coconut based mixed farming system for the period 1989-90 to 1997-98 under optimum management conditions was performed using the experimental data. It was observed that the total cost of the system, which was Rs. 1,30,000 during 1989-90, had increased to Rs. 1,60,500 during 1997-98 and during the same period the gross returns had increased from Rs. 1,79,800 to Rs. 2,67,640. The cash flow analysis performed using a discount rate of 14% realised the benefit-cost ratio (BCR) of 1.29 and the net present worth of the system Rs. 2,27,522. The internal rate of return was 25.44% and the pay back period was four years. These results clearly indicate the economic viability of the system in medium and large coconut holdings under irrigated conditions. Future research and developmental efforts should be initiated to understand and improve the existing status of coconut based farming systems under different agro-climatic and socio-economic environments of all the coconut growing states.

Traditionally, most coconut plantations in Sri Lanka have been maintained as monoculture, although this is a poor system in terms of land productivity. An ongoing study is being conducted of the economic performance of integrated systems and to investigate the reasons for their low rates of adoption. The paper reports on the economic performance of a coconut-based intercropping system as compared to the monocrop system at a site in Kahatawila. Intercrops like black pepper, ginger, and coffee were established in 0.5 acre of an existing mature coconut plantation. The coconut monocrop produced a relatively lower net income $unit^{-1}$ area compared to the intercropping system. Although the intercropping system provides additional income, the return to labour is much greater in the monocrop system because of its low labour requirement. Nevertheless, the return to labour of the intercropping system compares well with the area-wage rate for agricultural labour (Fernando, 1995).

12.5 Coconut based homesteads

Homestead land may be defined as the land owned and occupied by the dwelling unit(s) of a farm household and the immediate surrounding area. Coconut-based cropping systems are *in vogue* in homestead gardens of Kerala from the time immemorial. The terms agroforestry home gardens (Terra, 1954), mixed garden or house garden (Stoler, 1975), compound farm (Lagemann, 1977) and household garden (Vasey, 1985) have been variedly used in literature to denote homestead farms. Fernandez and Nair (1986) defined homegardens as land use practices involving deliberate management of multipurpose trees and shrubs in intimate association with annual and perennial agricultural crops and invariably livestock within the compounds of individual house, the whole crop tree animal unit being intensively managed by family labour. They have been described as subsistence in nature, small in size, most important functions of food production, environment friendly, giving sustainable yields and characterised by an intimacy of plant association. Homesteads are an important component of farming systems but empirical evidence on homestead agricultural production in Bangladesh is limited. A sample of 100 cooperator and 100 non-cooperator farms were surveyed during December 1986 to May 1987. Productivity and income unit^{-1} area from homestead production were found to be higher for the small farm group. Cooperator farmers earned higher returns than non-cooperators, indicating the technological gap between the two groups. Homesteads were in general under-utilized and there is scope for both qualitative and quantitative improvements in Bangladesh (Islam and Rahman, 1989).

Farmers cultivate a host of crops including perennials, annuals and seasonal crops along with coconut, without identifying optimum crop combinations. An economic analysis of the coconut-based cropping system based on data collected from 172 holdings in southern Kerala showed that labour, manure and land area have significant influence on productivity (Job *et al.,* 1993). The study indicated that there is lot of scope to increase the income from coconut based cropping systems by identifying the optimum mix of crops. Salam *et al.* (1991) opined that the home garden agroforestry system as seen in Kerala, though not scientifically laid out, is productive and ensure better efficiency of scarce resources of land, water, nutrients and solar energy. Home gardens are said to be repositories of biodiversity. Nair and Sreedharan (1986) reported 66 cultivated crop species while others documented more than 130 species in a single home garden. The crops though at first glance appear to be haphazardly planted, have definite spatial arrangement within the farm. Nair and Sreedharan (1986) reporting on the homestead gardens of Kerala found that these subsistence-oriented systems were managed mostly by family labour. Chemical fertilizers were not in use and soil physical and biological properties were improved as a result of good nutrient recycling and use of waste materials. It was also pointed out that there was little erosion in such farms.

John and Nair (1998) developed an integrated model for small coconut based homesteads (0.2 ha) by linear programming. The model suitable for southern Kerala comprises 43 enterprises with a cropping intensity of 161.84 per cent provides a net profit of Rs. 37,426 on investing Rs. 25,000 and has benefit: cost ratio of 2:5. Financial analysis of irrigation investments in existing and new plantations of mixed cropping systems of coconuts in smallholding in Kerala revealed that investments in irrigation were financially feasible.

12.6 Synergistic effects in cropping system

The cultivation of different crops in a unit area result in the continuous addition of biomass and higher level of nutrient cycling, which have a positive influence on the physico-chemical and biological properties of soil. As a result, the fertilizer input into the system can be scaled down without affecting the yield of coconut and other component crops. In the high density multi-species cropping systems model at Kasaragod, there was no significant difference in the yield of crops in the full and two-third levels of recommended fertilizers (Srinivasa Reddy *et al.*, 2000). In the system, there was build up of P and K while the levels of N and Mg did not increase as a result of introduction of various crops. The microbial biomass, the organic C, total N, P and K were higher in the root region soils of multistoreyed cropping system when compared to the levels in coconut monocrop (Bopaiah and Shetty, 1991). In the mixed farming system also, a build up of organic carbon, N, P, K and Fe status was noticed (Maheswarappa *et al.*, 1998). Thus, higher productivity is achieved in cropping systems as a result of synergistic interaction among the crop or crop-livestock components.

The microclimate inside a mixed cropping system is characterised by lower maximum temperature, smaller diurnal variation and less evaporative demand compared to pure crop stands. The beneficial effects are reflected on enhanced soil fertility status, enhanced microbial activity and better utilization of natural resources for the benefit of plant growth and sustainable crop productivity. Munna and Singh (2001) evaluated long-term effects of intercropping and bio-litter recycling on soil biological activity and fertility status of sub-tropical soils in 38 and 10-year-old orchard cropping systems involving coconut in Gujarat, India. Under a system of different intercropped fruit trees, the cultivation of guava (*Psidium guajava*) with coconut enhanced the soil microbial activity approximately 2-fold. Soil organic carbon increased from 3.4 to 7.8 and 2.4 to 6.2 g kg^{-1} after 38 and 10 years, respectively, following the establishment of orchards and it was attributed to greater recycling of bio-litters. *Glomus mosseae* was effective in reducing the nematode populations, especially that of *Meloidogyne incognita* and *Radopholus similis* infesting banana, as well as enhancing banana growth and bunch weight (Sosamma *et al.*, 1998). The occurence of *Azospirillum* was investigated in coconut-based farming systems, in Kerala, India, such as high-density multi-species cropping, multistoreyed cropping, mixed cropping with tea and coffee, intercropping with tropical tubers, mixed farming with grasses and in 3 crops, arecanut, *Mimosa invisa* and sugarcane from other plots. The extent of occurrence of *Azospirillum* seemed to depend upon the crop combinations. In a mixed farming system where guinea-grass was one of the component crops, more root fragments of coconut and pepper demonstrated tetrazolium reduction activity than when guinea-grass was absent. *Azospirillum lipoferum* and *Azospirillum brasilense* constituted 42% and 45% of the isolates, respectively, in the coconut-based cropping systems (Ghai and Thomas, 1989).

In case of coconut-vegetable system, the nitrogen budget and balance studies showed that the N-removed was highest for cowpea followed by chilli and snakegourd. At the end of third season, the N balance was observed to be highest in the plot cultured with amaranthus, bottle gourd and brinjal (937.3 kg ha^{-1}) and lowest (785.5 kg ha^{-1}) for cowpea, bhendi and chilli cultured plot (Anon., 1990).

12.6.1 Pest and nematode incidence

The nematode problems and their management in the coconut based multispecies cropping systems on the West coast of South India are reviewed by Koshy *et al.* (1993). A multi-stratified random survey of the plant parasitic nematodes with reference to the coconut based cropping patterns in homesteads of Kerala revealed that *Helicotylenchus multicinctus* was the most frequently occurring species followed by *Meloidogyne incognita, Radopholus similis, Rotylenchulus reniformis* and *Heterodera oryzicola* (Sheela, 1995). The population of these nematodes varied significantly in different crop combinations, soil types and seasons (periods) studied.

Studies on the incidence of stem canker of cocoa caused by *Phytophthora palmivora* under different cropping systems in Daskshina Kannada District, Karnataka, revealed that the incidence and severity of the disease was least in the cocoa-coconut mixed cropping system (1.6% infection) when compared to cocoa-forest plantation (11.8% of plants infected), and cocoa-arecanut mixed cropping system (3.2% infection) (Rao and Mohanan, 1995).

12.7 Benefits of cropping/farming systems

Several advantages of cropping/farming systems have been reported from large number of experiments conducted in different coconut growing countries. Coconut based cropping systems enable maximum utilization of interspaces and solar energy leading to higher income from a unit area. Soil fertility benefits in terms of enhanced microbial activity, organic matter, and nutrient dynamics have been reported providing a better environment for crop growth and would stimulate the natural resistance of the palms against disease causing pathogens and soil borne factors.

Deleterious effects of surface run off and soil erosion will also be reduced in this system. The beneficial effects of changes in the physical, chemical and biological properties of soil become apparent from the yield increase obtained under different cropping systems. Intercropping of high value crops effectively enhance rural employment which has positive effect on rural economy and development. Crop diversification is another important benefit having a positive influence on stability of the environment.

12.8 Drainage

Equally important is the provision for drainage in coconut holdings. It is known fact that coconut fails to thrive well under waterlogged condition. In areas where the natural drainage is poor, it is essential that artificial drainage facilities are provided by cutting deep and wide drains between the rows of palms and raising the levels of the ground around the individual palms (Thampan, 1989).

At the Nileshwar Research Station, surface drains to a depth of 1.5m were provided in a red sandy loam soil where inundation was a problem during rainy season and the water-table used to recede to a depth of about 6-7 m during summer months. The drains provided in between the rows of coconut palm and the crop was also irrigated in the summer months. Following these treatments there is a significant improvement in the yield, which increased from a mean pre-treatment yield of 35.7 nuts to 66.1 nuts $palm^{-1}$ $year^{-1}$ in the post-treatment period.

12.9 Yield, harvesting and storage of nuts

Coconut palms cultivated under proper management conditions, the tall cultivar palms start flowering in about 5-6 years after planting, while the dwarf cultivar begins to flower in the third or fourth year. In both the cases, full bearing is reached only 8-10 years after the commencement of flowering. Then the period of steady yield may continue upto 60 to 65 years or even more depending on the soil, environmental and management conditions. After the end of the peak period the yield begins to decline with the onset of senility. In the coconut palm, the yield is influenced by the inherent characteristics of the palm, agro-climatic conditions and cultural environment such as manuring, irrigation, cultivation, pests and disease control etc. In addition to the influence on the yield in terms of total nuts produced, climate has a profound influence on the output of copra also. Observations made in India showed that the yield of copra from 1000 nuts varied from 139 kg to 181 kg in different months, the yield being higher from February to May and lower from July to November (Anon., 1962). Under optimum agro-climatic conditions, management practices have been found to influence the yield conspicuously both in terms of the number of nuts produced and copra output $palm^{-1}$. Proper manuring and cultural practices can produce an average yield of 60 to 100 nuts palm^{-1} year^{-1} in tall cultivar under rainfed conditions in India. An average yield of 80 to 120 nuts or more can be expected under irrigated conditions. In neglected gardens and in areas, which are unsuitable for coconut cultivation, the average yield may as low as five to 20 nuts palm^{-1} year^{-1}. The average yield in India, in terms of the number of nuts palm^{-1}, is on a par with that of the other coconut growing countries. However, there is considerable variation in the yield in the different coconut growing areas. The reason for these differences can be attributed to the differences in the agro-climatic factors and management practices.

Coconuts generally ripen in about 12 months time after the inflorescence is opened. Only fully matured nuts are to be harvested for getting maximum yield of copra and oil. By harvesting less matured nuts, copra lost to the extent of 6 % in 11 month old nuts, 16 % in 10 months old nuts and 33 % in nine moths old nuts. The maximum quantity of oil is also available when nuts are 12 months old, the reduction in the percentage of oil in 11, 10 and 9 months old nuts being 5, 15 and 33 % respectively (Anon., 1962). There is no appreciable difference in the yield of coir fibre obtained from husks of 12, 11 and 9 months old nuts. However, quality of fibre obtained from the 10 months old nuts has been found superior, being golden brown colour, elastic and good tensile strength.

All the cultivars of coconut palm produce an average of 12 inflorescences in one year. However, some of the inflorescences are likely to abort or may fail to develop into fruit bunches due to environmental changes. Consequently, the number of bunches available for harvest is generally less than 12 in many palms. The frequency of harvest varies from country to country and also within the countries. In West coast areas of India, six to 12 harvests year^{-1} are usually practised. In the properly managed gardens, harvest at monthly intervals is usually adopted. In Sri Lanka and the Philippines harvesting is done six times a year, at bi-monthly intervals (Thampan, 1989).

Experienced climbers climbing the trees commonly do harvesting. They use a small ladder 2 to 3 m long for the purpose and there after invariably uses a rope ring round the feet or ankles for climbing the palms. Cutting notches on the trunk at convenient spacings also are used for climbing. Cutting of notches is not recommended as it may encourage red palm weevils' infestation. The climber on reaching the crown, examines the stages of maturity of the nut bunches and cuts down the mature ones. In some places in India and Sri Lanka, harvesting is done from the ground with the help of a knife attached to a long bamboo pole. With poles, a man can cover at least 250 palms a day, whereas a climber can hardly cover 50 palms day^{-1}. In Malaysia and Thailand, trained monkeys are put in for harvesting purposes. In countries where there is shortage of skilled labour, the nuts are not harvested but allowed to fall of their own and fallen nuts are collected from the ground at frequent intervals (Thampan, 1989).

The harvested nuts are usually stored in heaps under shade or godowns for a few days. Studies have shown that storage of harvested nuts is beneficial only if the nuts are fully ripe. Even in green nuts good quality copra can be obtained immediately after harvest if nuts are fully ripe. In case of immature nuts, the spoilage will be more on storage.

13.0 Integrated disease management in coconut

The coconut palm is affected by a number of diseases, some of which are lethal while others reduce the vigour of the palm causing yield losses. The following is a brief account of the important coconut diseases occurring in India and their management.

13.1 Root (wilt) disease

The coconut root (wilt) disease (RWD) has been known to be present in southern Kerala after the floods in 1882. A comprehensive survey made in 1984/85 showed that the disease was found in a continuous manner in 4,10,000 ha in eight southern districts of Kerala, stretching from Trivandrum in the south to Trichur in the north. The lowest disease intensity of 1.52 per cent was observed in Trivandrum district followed by 2.6 per cent in Trichur district. The highest intensity was noticed in the district of Kottayam (75.63 per cent), followed by that in Alleppey (70.69 per cent) (Jacob Mathew *et al.*, 1998). The annual loss caused by the disease was in the order of 968 million nuts. RWD is also observed in a sparse manner in isolated pockets in the remaining northern districts of Kerala as also in the adjoining districts of Kanyakumari and Coimbatore in the state of Tamil Nadu.

13.1.1 Symptoms

The disease is not fatal, but is a debilitating one. Studies by many workers have contributed to our understanding of the symptoms of the disease. Flaccidity, yellowing and marginal necrosis of the older leaves are observed in association with the disease. Flaccidity, the characteristic bending or ribbing of leaflets is the earliest consistent visual symptom, seen in the central and outer whorls. Yellowing and necrosis occurs in varying intensities in the outer whorl. In advanced stages, loss of colour of the younger leaves also is seen. Flaccidity is regarded as the most frequent and common of the three foliar symptoms associated with the disease irrespective of the age of the palm or soil type (Menon and Pandalai, 1958; Radha and Lal, 1972).

Inflorescence necrosis, production of fewer or no female flowers, pollen sterility etc. render the palm unproductive. Shedding of immature nuts, poor quality nut copra^{-1}, thinner husk, infirm shell, uneven thickness of kernel etc. are also observed.

13.1.2. Etiology

Involvement of biotic agents like fungi, bacteria, viruses, viroids and nematodes in the root (wilt) disease was ruled out after a series of inoculation experiments and electron microscopic studies. Extensive studies have ruled out the role of physiological, nutritional disorders as the primary cause of the disease. Studies using electron microscope showed the presence of phytoplasma (MLO) consistently in the sieve elements of diseased palms and their absence in the healthy, which advocates the phytoplasmal etiology of the disease (Solomon *et al.*, 1983). Remission of the disease symptoms by tetracycline treatment and insect and dodder transmissibility of the disease further supported the phytoplasmal etiology (Pillai *et al.*, 1991; Mathen *et al.*, 1990).

13.1.2.1 Insect transmission

Studies on the role of insects in the disease spread have been conducted systematically through transmission experiments and electron microscopic studies. Among the different insect vectors studied, the banana lace bug (*Stephanitis typica*), and plant hopper (*Proutista moesta*) have the potential to acquire phytoplasma and sustain their propagation in the salivary gland tissues. The vector roles of these two insects were confirmed through transmission experiments under insect proof conditions (Mathen *et al.*, 1990; Solomon *et al.*, 1998).

13.1.3 Disease management

The disease is non-lethal, but debilitating in nature. No curative measure is so far available. However, based on research results accrued in the past, a strategy has been formulated by CPCRI for containing the disease in its present geographical limits and managing the same by improving the condition of the affected palms and thus increasing the yield (to live with the disease). The strategies for the management of the disease are as follows:

13.1.3.1 Eradication in sparsely affected areas

In the sparsely affected areas of northern Kerala and Tamil Nadu, total eradication of all the disease affected palms should be taken up to prevent the spread and contain the disease to the southern Kerala.

13.1.3.2 Management of the disease in southern Kerala

i) *Eradication:* In the heavily disease affected tracts, eradication of all severely affected uneconomic adult palms (those bearing less than ten nuts $year^{-1}$) and all diseased palms in the pre-bearing age and adoption of a package of practices evolved by CPCRI are the strategies recommended for the management of the affected gardens.

ii) *Organic recycling:* Research on mixed farming (raising fodder crops in the interspaces and maintaining milch cows) in a disease affected coconut garden over a period of five years has shown that regular recycling of organic matter (farm yard manure) increased the mean yield of palms by 26 per cent. The response was the highest in palms in the early stages of disease. Considerable decrease in foliar yellowing was observed even though there was no reduction in flaccidity and necrosis. This has also resulted in the significant increase in the status of soil organic carbon, available P, exchangeable Ca, Mg and K in the soil as well as soil microbial activity.

iii) *Mixed cropping:* Studies conducted on mixed cropping with cocoa conducted in a diseased garden for five years under irrigated and recommended doses of fertilizers for both the crops, showed that the yield of coconut increased by 35 per cent. Mixed cropping of cocoa increased soil fertility in the gardens. The deterioration of the palms by the disease was slowed down.

iv) *Intercropping:* Intercropping of tuber crops like yam and elephant foot yam in RWD affected coconut gardens helped to realize 8-15% increase in the mean yield of palms. In these plots the disease index of RWD palms decreased from 37 to 33.3.

v) *Summer irrigation:* Summer irrigation increased water uptake and reduced transpiration rate of RWD palms, thus bringing about a balanced water economy to these palms. When summer irrigation was given @250 litres water $palm^{-1}$ $week^{-1}$, flaccidity and yellowing were reduced significantly resulting in an increase of ten nuts $palm^{-1}$ $year^{-1}$.

vi) *Soil amendments:* The fertilizer trials conducted at Kayangulam, showed that regular additions of Mg at the rate of 3.0 kg magnesium sulphate $palms^{-1}$ $year^{-1}$ along with the normal dose of N, P, K fertilizer right from the time of planting in the main field increased the vegetative growth of young palms at a highly significant level and reduced their age by about 40 per cent. The beneficial effects of Mg were more evident on root (wilt) affected palms than on the healthy. However, application of Mg did not prevent fresh incidence of the disease.

vii) *Cultivar reaction to the disease:* Since this disease cannot be controlled by conventional plant protection measures, development of resistant / tolerant genotypes is a highly practical solution to this disease, though it is a long-term process. A cultivar screening programme to evaluate the yield potential and resistance / tolerance to root (wilt) disease has been in progress for over two decades and so far none of the cultivar / hybrid was found to be tolerant to the root (wilt) disease. However, D (CGD) X T (WCT) hybrids were found to perform better with regard to the yield in the diseased area even though they also took up the infection.

The programme on breeding for resistance / tolerance to coconut root (wilt) disease was initiated with a view to evolve a plant population with field tolerance/ resistance to root (wilt). Accordingly, a large number of palms that had withstood root (wilt) in the 'hot spot' areas were screened and resistant palms identified. Tall x Tall (TxT), Tall x Dwarf (TxD), Dwarf x Tall (DxT) and Dwarf x Dwarf (DxD) crosses and *inter-se* matings were effected among these selected palms. Seedlings raised from such matings were under planted in 'hot spots' to subject them to vigorous natural selection. Disease escapes were subjected to serological test to ensure freedom from root (wilt) pathogen. A higher percentage of hybrids involving disease-free CGD palms as female and WCT as male planted in 1991 have so far not taken up the disease indicating the possibility of using this technique for combating the disease (Jacob *et al.*, 1998).

13.2 Leaf rot

Leaf rot disease is caused by different fungi like *Exserohilum rostratum, Colleltotrichum gloeosporioides* and occurs superimposed on RWD palms (Menon and Pandalai, 1958; Radha and Lal, 1968; Srinivasan and Gunasekaran, 1993, 1994; Varghese, 1934). Nearly 60% of palms in the root (wilt) affected area develop leaf rot infection. Leaf spots appear initially in the spindle leaves and coalesce together to form large blighted areas in the advanced stages. These blighted areas dry up and fall off (Srinivasan and Gunasekaran, 1992).

Trials conducted in 1982-84 showed that sequential spraying with Bordeaux mixture 1%, mancozeb (Indofil M-45) 0.30% and copper oxychloride (Fytolan) 0.5% resulted in 87.8% control of the disease. Similar control was obtained when sequential spraying with the above chemicals was taken up in a large-sized trial plot involving over 5700 palms.

13.2.1 Disease management

Following is the integrated schedule recommended by CPCRI for the control of leaf rot disease: i) Cut and remove rotten portion of the spindle only and the adjacent two innermost fully opened leaves. ii) Pour 300 ml of fungicidal solution of 0.3% hexaconazol (Contaf 5 % EC) or Dithane M-45 around the spindle leaf.

iii) Apply 20 g Phorate 10 G mixed with 200 g fine sand around the base of the spindle leaf (axil filling). Treat all the palms in the garden in this way twice a year in April-May and October-November.

13.3 Bud rot disease

It is one of the most important fatal disease of coconut that affects palms of all ages and cultivars. It has been reported from all the coconut growing regions in the countries. In India, this was first reported in 1906 by Butler. Though this disease is sporadic in nature, epidemics do occur sometimes in some areas.

13.3.1 Symptoms

The earliest visible symptom is the withering of the spindle. In adult palm the spindle (spear leaf) turns dull and bends over. In seedlings, the spindle turns brown and comes off easily with a gentle pull. The base of the spindle is rotten and emits a foul smell. If allowed to degenerate further, the leaves next to the spindle also begin to rot leaving only the fully matured leaves on the crown. In the end, the palm succumbs to the disease. Simultaneously, the infection proceeds to the deeper softer tissues of the cabbage and finally attacks the growing tip. Once the apical meristem is affected, the palm dies. Symptoms of attack of the fungus can be noticed as water-soaked lesions at the base of the petiole of the leaves also (Menon and Pandalai, 1958; Radha and Joseph, 1974).

13.3.2 Etiology

The disease is caused by *Phytophthora palmivora* in our country. *P. faberi* has been reported from Philippines and *P. katsurae* from Cote d'Ivoire. In addition to bud rot, the fungus can attack nuts and cause nut fall (Mahali symptom). The fungus causes dry rot in the tissues and these are then invaded by other fungi and bacteria causing wet-rot.

13.3.3 Epidemiology

The fungus is soil-borne and can survive for a long time in the deeper layers of crown tissues and soil as zoospores. It grows fast with the onset of rain and zoospores and mycelium float. In the case of seedlings, which are planted in pits, the inoculum reaches along with the rain splashes. Sporangia and mycelial bits are carried by the wind driven rain to the crowns of palms. Propagules are also disseminated by pollinating insects and slugs.

Incidence of the disease is governed by the occurrence of 'favourable days'. Days when the minimum temperature lies between 21-24°C coupled with 97-100% RH qualify as 'favourable days'. Availability of favourable days is very important especially in the case of young palms of 5-10 years age (Menon and Pandalai, 1958; Radha and Joseph, 1974). Even though the fungus affects palms of all ages, younger palms are more susceptible. The fungus can infect palmyra (*Borassus flabellifer*), arecanut (*Areca catechu*), oil palm (*Elaeis guineensis*) and also *Washingtonia*. Besides palms, it can affect rubber (*Hevea brasiliensis*), cocoa (*Theobroma caocao*), *Bougainvillea*, *Hibiscus*, jack (*Artocarpus integrifolia*) and breadfruit (*A. incisa*) trees (Menon and Pandalai, 1958; Radha and Joseph, 1974).

13.3.4 Disease control

All palms below the age of 20 years should be sprayed with 1% Bordeaux mixture at the onset of monsoon as a preventive measure.

Once a palm is infected, the entire infected portion should be cut neatly with a sharp knife and burnt. Then the wound should be treated with 10% Bordeaux paste and protected from rain by covering with a polythene sheet or plastic bucket allowing drainage and also proper air circulation. Since some of the dwarf cultivars are sensitive to copper fungicides, an alternate method of keeping small-perforated polythene sachets containing 2-3g. of mancozeb in the top leaf axils is helpful (Nambiar and Rawther, 1993). Improvement of drainage, Rhinoceros beetle control etc. are other measures which would help to reduce the incidence of bud rot. Surveillance is very important to detect infection as early as possible so that curative measures can be taken up.

13.4 Stem bleeding disease

The disease has been reported from all tropical countries where coconut is grown. It was first reported from Sri Lanka (Petch, 1906) and later from India (Sundararaman, 1922) and other countries (Briton Jones, 1940; Menon and Pandalai 1958). In India the disease has been reported from Kerala, Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, Orissa, Goa and Andamans.

13.4.1 Symptoms

The disease is characterized by the exudation of dark reddish brown liquid from the longitudinal cracks in the bark, generally at the base of the trunk. One or more lesions, which are lying close by, may coalesce to form large infection patches. The liquid oozing out dries up and turns black. The tissues below the lesions become rotten and turn yellow first and later black. In the advanced stages of disease, the bleeding patches cover the entire stem (Menon and Pandalai, 1958; Radha, 1962; Nambiar and Rawther, 1993). The leaves in the outer whorl become yellow rather prematurely, droop and dry. The production of bunches is affected adversely. Nut fall is also noticed. The trunk gradually tapers at the apex and crown size becomes reduced in chronic cases.

13.4.2 Etiology

Thielaviopsis paradoxa has been isolated from diseased tissues underlying the bleeding patches of young lesions and also was noticed in the gummy exudation. The fungus was found to reproduce the symptoms on inoculation. Progress of the disease was faster during July to November. Increase in growth cracks, severe summer followed by sudden wetting, imbalanced nutrition, excessive salinity etc. have been reported to be contributory factors of infection. The fungus has also been found sometimes to attack leaves, petioles and nuts (Nambiar and Sastry, 1988).

13.4.3 Control

When diagnosed in the early stage of the disease, the infected tissues can be cut and removed by a chisel. The resulting wound may be dressed with tridemorph (calixin 5%) followed by hot coal tar application after 2-3 days. The chiseled materials should be completely destroyed by burning. The recommended dose of fertilizers and organic manures may be applied and summer irrigation given. Addition of neem-cake at 5 kg palm^{-1} in the basin along with other organics was found to be beneficial. Good drainage facilities may be made in the garden. Trials showed that root feeding of tridemorph thrice a year was beneficial in preventing further spread of lesions on the trunk (Anil Kumar *et al.*, 1992; Ramanujam *et al.*, 1993). Attack by borer insects like *Xyleborus* or *Diocalandra* may be controlled by swabbing with carbaryl (sevin 10% WP). Application of 5 kg neem-cake fortified with *Gliocladium virens* proved to be effective in controlling the stem bleeding disease of coconut (Ramanujam, 1997).

13.5 Basal stem rot disease

The disease, also known as Thanjavur wilt in Tamil Nadu, *Ganoderma* wilt in Andhra Pradesh and 'Anabe roga' in Karnataka is a major constraint in the production of coconut in these states. This disease was first noticed in a severe form in Thanjavur district after the cyclones of 1952 and 1955 and hence the name Thanjavur wilt. Now this disease is widespread in Tamil Nadu occurring in all districts. The disease incidence in Tamil Nadu ranged from 0.6-4.9%, maximum being in Thanjavur district (4.9%) followed by that in Chengulpet district (4.5%). In Kerala, the disease has been found in sporadic form in a few gardens in Palghat districts In Karnataka, the disease is widely prevalent in maidan areas. The disease is also reported to occur in Goa, Maharashtra, Gujarat and Orissa states (Nambiar, 1999).

13.5.1 Symptoms

Withering followed by yellowing and drooping of older leaves is the characteristic initial visible symptom. Even before this, decay of finer roots would have started. The root decay gradually extends up to the bole region and from there to the stem. This is accompanied by exudation of reddish brown viscous fluid from the basal portion of the trunk. The bleeding patch enlarges in size and traverses upwards, to a height of 3-4 metres in certain cases. There is commensurate internal decay just below the bleeding patch. More leaves droop and bunches subtended by these leaves also droop, often resulting in nut fall. The spindle size is reduced and so also the size of the crown. Due to this weakening, the crown topples over in the slightest wind. Dead palms and stumps show the presence of brackets of *Ganoderma*. The disease progresses rapidly in dry areas during summer and in sandy soils.

13.5.2 Etiology

Ganoderma lucidum and *G. applanatum* were isolated from the roots of the diseased palms and their pathogenicity has been established by artificial inoculation.

13.5.3 Epidemiology

Soil moisture stress predisposes the palms to infection. The spread of the disease is fast in dry season. In Andhra, the disease was found to be less in heavy soils, may be due to the high moisture retention capacity of such soils. Trees in the age group of 10-30 yrs. are more susceptible (Satyanarayana *et al.*, 1985). The disease spreads from a central point of infection towards the periphery.

13.5.4 Management of disease

(i) *Phytosanitation :* Palms in the advanced stage of disease and giving uneconomic returns should be cut and removed and the root system along with the bole burnt. The bleeding patch in the stem may be chiseled and protected with tridemorph (5% calixin) and subsequently with hot coal tar.

(ii) *Isolation trenches :* The palms in the early or middle stages of the disease should be isolated from the neighbouring healthy palms by taking trenches 1M deep and 30 cm wide to prevent root contact.

(iii) *Cultural practices :* Avoid repeated ploughing, closer spacing, flood irrigation, and water logging. Grow *Ganoderma* resistant inter/mixed crops like banana in the garden.

(iv) *Nutrient application :* Apply fertilizers @ 500:320:1200 g. N,P,K palm^{-1} year^{-1} and enough organics (at least 50 kg). In addition each palm should be given 5 kg.

neem-cake during September-October.

(v) *Chemical treatment :* The diseased palms may be treated with aureofungin sol. @ 2.0g + 1g copper sulphate in 100 ml. water through root feeding thrice a year in July, October and January. Treatment with calixin 5% was also found to be equally effective. Whenever *Xyleborus* attack is noticed on the stem of affected palms, swabbing with carbaryl (sevin 10 %) WP) may be done.

(vi) *Containing the disease :* Do not transport seedlings from infected area to healthy area. In sporadic cases of occurrence, the severely affected palms should be removed and other infected palms isolated from healthy ones by taking trenches in two circles. The palms in early stages of disease are to be treated with aureofungin sol. Each palm may be given 5 kg neem-cake in addition to the regular fertilizer and organics recommended.

13.6 Crown choke

Chakrabarthy first noticed this disorder in Assam in 1964. This has also been reported from New Guinea, Sri Lanka, Cote d'Ivoire and Philippines.

13.6.1 Symptoms

Emergence of shorter leaves with deformed and crinkled leaflets is the first symptom of the disease. Leaflets often show severe tip necrosis. Number of leaflets reduces gradually and hooking may also be seen. Affected leaflets do not unfurl properly and in many cases give a choked appearance to the frond. As the disease progresses stick-like leafstalks emerge. The inner leaves crowd round the bud, and prevent normal unfurling of the flag leaf. Necrosis may proceed to the deeper tissues and kills the meristem. Premature nut fall is seen and gradual fall in yield is noticed. Inflorescence emergence is hindered resulting in yield loss (Chakraborthy *et al.*, 1970; Rethinam *et al.*, 1990).

13.6.2 Etiology

Symptoms are caused by acute shortage of boron. This affects the calcium-boron ratio. This has to be low for a healthy plant (95) when compared to the affected plant (145) (Baranwal *et al.*, 1989).

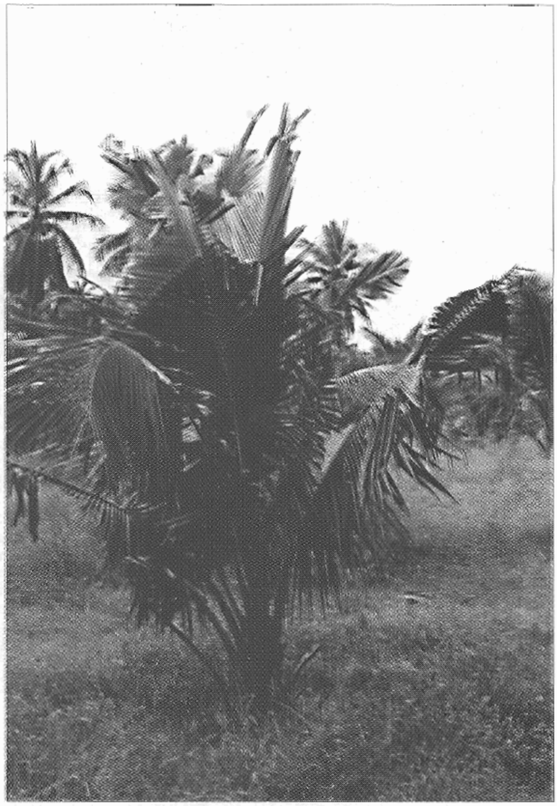
13.6.3 Control

Soil application of borax @ 50g palm^{-1} at half yearly intervals (Feb-March and Aug-Sept.) improves the condition of the palm (Anon., 1989). Making slits in the tight extension of the petioles and opening out the crown would help in the normal emergence of fronds (Chakraborthy *et al.*, 1973).

Budrot affected coconut Palm

Leaf eating caterpiller infested coconut garden

Boron defeciency symptoms in coconut seedling



Rhinoceros beetle infested Palm

Eriophyid mite infected nut

13.7 Grey leaf spot disease

The disease is also called leaf blight. It is widespread in all the coconut growing regions in the tropics. It was first reported from British Guyana (Copeland, 1931) and later from Malaysia, New Hebrides, Sri Lanka, India, and Trinidad etc (Menon and Pandalai, 1958). Recently, the disease has been reported from Nigeria. In India it is found in all the coconut growing tracts.

13.7.1 Symptoms

The symptoms appear on the outer whorl of leaves as minute yellow spots, with a grey brown margin. The lesions may be oval in shape measuring upto 5 cm in length. The centre of the spots turn greyish white while the colour of the margin deepens. Many spots coalesce to form large irregular necrotic patches. Leaves in the advanced stage of infection present blighted appearance. Complete drying and shrivelling is common when the infection is seen. On the upper surface of the leaf the black pycnidia of the fungus appear as minute specks. The disease causes serious damage in nursery plants. However, in adult palms the infection does not cause serious damage (Menon and Pandalai, 1958).

13.7.2 Etiology

The disease is caused by *Pestalotiopsis palmarum*.

13.7.3 Control

Remove severely affected leaves and burn. Spray the foliage with 1% Bordeaux mixture or 0.3% mancozeb. Apply potassic fertilizers and also provide adequate drainage in the gardens. Leaf blight caused reductions in height, leaf production and girth at collar by 10.4, 20.1 and 12.5%, respectively, in coconut seedlings. Nut yield of palms decreased by 10.0-23.6% due to disease incidence. Root feeding with thiophanate-methyl or carbendazim at 2.0% reduced the disease index after three years of application to 18.6 and 20.9%, respectively, compared to 50.5% in the control. The fungicides can also be applied as 0.1% foliar sprays. Spraying a spore suspension of *Trichoderma harzianum* effectively controlled the disease in the field. Potash applied at 2.4 kg combined with 0.52 kg N and 0.32 kg P_2O_5 palm^{-1} year^{-1} reduced the disease intensity and increased nut yield. Farmyard manure or composted coir at 100 kg palm^{-1} year^{-1} also effectively contained the disease (Karthikeyan *et al.*, 2002).

14.0 Integrated pest management in coconut

At various stages of crop growth more than 547 pests have been reported on coconut worldwide. The coconut palm is attacked by 57 species of insects, 12 species of rodents and other vertebrates in India (Vidyasagar and Bhat, 1991). Among the 65 pests recorded in India, the coconut rhinoceros beetle *(Oryctes rhinoceros)*, the red palm weevil *(Rhynchophorous ferrugineus),* the coconut leaf eating caterpillar *(Opisina arenosella),* eriophyid mite *(Aceria guerreronis)* and the cock-chafer beetle *(Leucopholis coneophora)* are the major pests occurring in most of the coconut growing tracts. The other minor pests include scale insects, mealy bugs, coreid bug, defoliating caterpillars and termites, which cause considerable damage at times though generally they are of minor importance.

Integrated pest management is essentially a system of management of pest population utilizing all suitable techniques (such as cultural, chemical, biological) harmoniously and blending them in a compatible manner so as to minimise the pest population to levels below those causing economic injury.

14.1 Management of pests

In order to manage the pests effectively, farmers must be aware of the pests, their seasonal occurrence, clean cultivation, use of biocontrol agents and danger of misuse of pesticides. This can be achieved by providing community level programmes so that management of the pests can be done in a federal approach. In this way we may able to tackle the pest effectively. Application of insecticides by spray, root feeding, stem injection with highly toxic chemicals needs care while administering as well as suitable waiting period must be observed to avoid the pesticide residues in the produce. Adult rhinoceros beetles burrow into the growing point of palms and feed on unopened fronds causing damage to inflorescences and reduction in photosynthetic area, which decreases or delays fruit production. Prolonged attacks can kill mature palms by defoliation and young palms if the growing point is destroyed. The wounds produced by the beetle provides entry points for diseases and the palm weevils, *Rhynchophorus ferrugineus* and *R. vulneratus* (Bedford, 1980).

14.2 Rhinoceros beetle

Rhinoceros beetle *(Oryctes rhinoceros)* is one of the most important pests of coconut and oil palms in Asia. *O. rhinoceros* breeds in decaying organic matter, such as felled rotting palms and usually becomes a major problem in newly planted or replanted oilpalm plantations. Eggs are laid on the breeding sites and the grub feed on these materials for about six months. Pupation takes place in cocoon. The black coloured adult beetle bores holes and feeds on the unopened fronds and spathes. On opening the damaged leaves show the geometrical cuts on leaflets. The beetle causes damage to all ages of palms, seedlings, young and old palms. The longevity of adults was reported as 4.7 months (Nirula, *et al.*, 1955a).

14.2.1 Management

Since the pest breeds in decomposing organic matter, removal of waste materials from the field should be done regularly and good phytosanitation should be maintained in the gardens. Treatment of breeding sites with 0.01% carbaryl 50% WP was effective. In young palms the beetles are extracted from the feeding holes with the help of long rods hooked at the tip (Cherian and Ananthanarayan, 1939; Gressit, 1953; Menon and Pandalai, 1958).

Oryctes species have been reported to be attacked by a number of parasitoids and predators. Thompson (1943) listed five scolid parasites *viz; Campsomeris luctuosa, Scolia procer. S. azurea, S. oryctophaga*, and *S. ruficeps*. The wasps indigenous to Eastern Africa and Madagascar belonging to the family Scolidae *viz.,S. oryctophaga, S. ruficornis, Elis romandi* were introduced to some Pacific islands for the parasitization of *Oryctes* but they failed to establish in the field (Lever, 1979). In India, however, no scolid parasite has been found to parasitize *O. rhinoceros*. In an attempt to reduce the pest population, a predatory bug *Platymeris laevicollis* was introduced into Fiji and New Caledonia from Zanzibar. Each predator can destroy one adult beetle day^{-1} (Vanderplank, 1958). However, the initial success was not sustained in the field for longer duration.

Although the first attempt to control the rhinoceros beetle by biological means was made as early as in 1913 in Samoa (Friedrichs, 1913) by an introduction of a culture of the green muscardine fungus. *Metarhizium anisopliae,* its efficacy remained a mystery because of various factors. Attempts were continued unsuccessfully in many countries like India, Sri Lanka, Mauritius and Malay peninsula. This fungus attacks larvae and adults. In India, the humid conditions with moderate temperatures prevailing during monsoon season in the South-west coast appear to be more suitable for a large scale multiplication of the fungus (Nirula, *et al.*, 1955b).

A virus disease recorded on *O. rhinoceros* from Malaysia (Huger, 1966) was introduced into several South Pacific islands as baculovirus to control the pest population (Marschall, 1970; Zelazny, 1973, 1977a, 1979; Young, 1974; Bedford, 1976). After the introduction, this has rapidly spread and established thereby drastically reducing the population of *O. rhinoceros* below the threshold levels (Hammes and Monsarrat, 1974; Zelazny, 1977a; Bedford, 1980). The occurrence of baculovirus in the natural population of the beetles was reported from the Philippines and Indonesia (Zelazny, 1977b) and India (Mohan, *et al.*, 1989). The pest population has been substantially reduced in Minicoy island, Lakshadweep, India, through the release of baculovirus infected beetles. The leaf and spathe damage as well as fresh incidence of spindle damage which was 56.6%, 31.1% and 39.2%, respectively got reduced to just 7% leaf damage only. On the other hand the disease incidence in beetles enhanced to 60% from zero level (Anon., 1989).

Studies on seasonal incidence of baculovirus, muscardine fungus and bacterial infection on *Oryctes* grubs during 1996-1999 revealed that 5%, 3% 19.7%

respectively, of the grubs were affected in natural conditions (Anon., 1999).

Nematode infections in *Oryctes* seems to be rather common in Africa. Surany (1960) reported that the genus of nematode commonly met with *Oryctes* is *Rhabdites*. Attempts have been made to rear and infest these nematodes in *oryctes* larvae in Fiji and Seychelles with limited success. Isolations of nematodes were made from the third instar grubs of *O. rhinoceros* collected from Agathi island in the Lakshadweep. Suspensions made from the material, when injected into healthy grubs produced mortality (Kurian *et al.*, 1969).

Comparative field trials with pheromone lures obtained from M/S Chem Tica Intrernational, Costa Rica and AgriSense, United Kingdom revealed the superiority of Oryctalure of Chem Tica (Anon., 1999).

14.3 Asian palm weevil

In India, the palm weevil (*Rhynchophorus ferrugineus*) is a serious pest. Adults are attracted to wounded palms. Weevils lay eggs on spindle, tender leaf through injuries caused by rhinoceros beetle. The larvae tunnel into the terminal bud or trunk of the tree and feeds on the inner tissues of crown and upper portion of trunk, leading directly its death. The external symptoms include the presence of small holes on the stem, oozing out of brown viscous liquid, extrusion of chewed up fibres, longitudinal splitting of leaf bases, yellowing and wilting of leaves of the inner and middle whorl. In severe cases the crown of the palm topples. The females are known to be attracted strongly to the fermenting sap oozing out of wounds in the trunk or the leaf bases. In general, palms of 5-20 years are susceptible. Life cycle is completed in three months. Pupation takes place inside the crown. Palms in the age group of 5-20 years are more susceptible to this pest attack. In Kerala, it is reported that nearly 5% palms below the age of 10 years are killed annually by this pest (Lever, 1979).

14.3.1 Management

By injecting the infested trees with carbaryl 1.0% nearly 93% palms were cured (Mathen and Kurian, 1967). Drill a downword slanting hole and inject into the stem at about 1.5 m above ground level and plug with clay (Before treating the palm, harvest the nuts and a waiting period of 45 days must be observed for further harvest of nuts). Subsequently, Rao *et al.* (1973) achieved good success by placing aluminium phosphide tablets inside the damaged portion. Prophylactic treatment of leaf axil filling with mixture of sevidol 8G (carbaryl+r HCH 8G) 25g and sand 200g was advocated. Eco-friendly methods include log trapping with fermented toddy, mud pot trapping with molasses and placement of pheromone sachets in the leaf axils.

A trap for the collection of *Rhynchophorus palmarum* was developed by Maharaj (1965) in Trinidad. When this method consisting of traps with split fresh coconut petioles was tested in one-estate in Sri Lanka 302 red palm weevils *(R. ferrugineus)* were recovered from 10 traps in 141 days (Ekanayake, 1970.) The trapping method was modified with, the addition of sugarcane and yeast to the split petioles.

Aggregation pheromones identified for the Asian palm weevils were 4-methyl-5-monanone for *R. ferrugineus* which is commercially available at M/s Chem Tica International, Costa Rica. Recent field trials in Kerala on the comparative performance of pheromone lures from M/s Chem Tica Intrernational, Costa Rica and AgriSense, United Kingdom revealed that both are equally efficient in catching weevils. Testing of different food baits like pineapple, grapes, sugarcane, plantain, coconut toddy, coconut petiole etc. in pheromone traps, revealed the efficiency of plantain and sugarcane as attractants (Anon., 1999).

14.4 Leaf eating caterpillar

Opisina arenosella is another serious pest of the coconut palm in India, Sri Lanka and Mayanmar. It was first observed in the Eastern part of Sri Lanka from Batticaloa district (Green, 1898). The pest was noted in India for the first time during 1907 on palmyrah palms in Coimbatore, Tamil Nadu. First record of its presence on coconut leaves was from Bapatla, Andhra Pradesh, in 1909. In India, Rao (1924) and Nirula (1956) studied the occurrence of the pest along the East and West coasts. Nirula *et al.* (1951) gave an account of the bionomics, life history and morphology of *O. arenosella* in Kerala.

It is distributed among the coastal and backwater areas. The pest outbreak occurs during summer months. The caterpillars feed on the lower surface of the older leaves and feed on the leaf tissues. (Nirula, 1956; Child, 1974). The caterpillar live in galleries made of silken threads and their faecal matter on the lower surface of the leaflets. During severe cases of infestation all older leaves become dried up and only a few young leaves remain green (Jayaratnam, 1941). The crop yields have been reduced to half in the years following severe outbreak of pest (Lever, 1979). The life cycle is completed in two months. Continuous feeding of the green tissues results in reduction in photosynthetic area and the leaves dry up giving a burnt up appearance. Infestation results in reduced yield.

14.4.1 Management

In sporadic outbreaks cutting and burning the heavily affected outermost 2-3 leaves and spraying the palms with 0.02% dichlorvos was recommended. Root feeding with monocrotophos 36SL (10ml) was effective in severe cases of infestation (Rao *et al.*, 1980). The coconut caterpillar supported about 60 insect natural enemies (Pillai and Nair, 1993) and 26 species of spiders (Sathiamma *et al.*, 1987a). Biological suppression of the pest by releasing parasitoids such as larval, *Goniozus nephantids* and *Bracon hebetor,* pre-pupal, *Elasmus nephantids,* pupal, *Brachymeria nosatoi* at fixed norms proved effective (Sathiamma *et al.*, 1987b) Dosages worked out for the release were 20.5% for *G. nephantidis,* 49.4% for *E. nephantidis* and 31.9% for *B. nosatoi,* when the parasitoids were released individually and 40.4 % when a combined release was made. Carabid beetles, *Parena nigrolineata* and *Calleida splendidula* are recognized as the most potential predators (Pillai and Bhat, 1987). Out of 18 species of predatory spiders of *O. arenosella* larvae, *Sparassus* sp., *Cheira-canthium* sp., *Rhene khandalaensis,* and *Rhene indicus* were important (Sathiamma, *et al.*, 1987a). Among the predators attacking the egg and early larval stages of *O. arenosella,* the anthocorid *Cardiastethus exiguus* and chrysopid, *Mallada astur* were recommended for field release against this pest based on the studies on their feeding potential (Sujatha, 2000).

14.5 Eriophyid mite

In India the first report of eriophyid mite (*Aceria guerreronis*) infesting coconut was from Amballor panchayat of Ernakulam district of Kerala state (Western coast of India) during the first quarter of 1998. From there it has spread to Southern, Northern and Eastern parts of Kerala (Sathiamma et al., 1998). As the dispersal mechanism is predominantly by wind (Julia and Mariau, 1979) the mite has spread from Kerala to its neighbouring coconut growing states of Tamil Nadu, Pondicherry, Karnataka and further to Andhra Pradesh, Maharashtra and Goa. The presence of eriophyid mite is also reported from Andamans and Kalpeni island of Lakshadweep. The adults are 250 μ long and 50 μ wide and complete its life cycle in 7-10 days. They develop on the meristamatic zone of the young nuts covered by the perianth. The feeding injury leads to development of yellowish to white triangular patches beneath the perianth, which enlarges in the due course to brown colour warts with deep fissures on the mesocarp. Severe infestation also leads to premature nut drop. In infested regions the presence of mite was observed throughout the year with maximum population during May (summer) and with a slight reduction in rainy season. The estimated yield loss is reported to be a tune of 20–30 % of copra yield. Eight microbial isolates (*Fusarium moniliforme* [*Gibberella fujikuroi*], *Aspergillus niger, Penicillium* sp., *Aspergillus flavus, Scopulariopsis brevicaulis, Cladophialophora* sp., *Pseudomonas* sp. and *Bacillus* sp.), S. *brevicaulis* and *Cladophialophora* sp. resulted in 27.0 and 14.0% eriophyid mite *(Aceria guerreronis)* mortality, respectively, while the other organisms gave mortalities not higher than 10% (Murali Gopal *et al.*, 2002).

14.5.1 Management

In Kerala, where homestead cultivation under mixed farming with animal husbandry and poultry is in prevalence faulty spray of chemical pesticides will lead to bio magnification. Hence, spraying eco-friendly pesticides like neem formulations containing 0.1 % azadirachtin @ 6 ml lit.$^{-1}$ of water was recommended. Spraying Neemazal resulted in 79.7% reduction in pest infestation (Anon., 1999) The sprayings are to be done during April-May i.e. prior to South-west monsoon, then in August-September during dry spell between South-west and North-east monsoon and in December-January, after North-east monsoon.

14.6 Cockchafer beetle

Leucopholis coneophora and other related species of cockchafers attack roots of coconut and other intercrops, which adversely affects the vigour of the palm and yield. The grub occurs in sandy and sandy loam soils feeding on the root of coconut, result in yellowing of the leaves and loss of yield. Though several species of white grubs are reported to damage coconut, *Leucopholis coneophora* has been considered the most predominant species in the coastal areas of Kerala and Karnataka (Nirula *et al.*, 1952). In the plains *Holotrichia serrata* was reported to be the main root feeder of coconut (Veeresh, 1983). The most common symptoms associated with white grub attack in coconut are yellowing of leaves, immature nut fall, delayed flowering, stunted growth, reduction in yield, etc. The beetles lays eggs in soil, immature grubs feeds on the grass roots and organic matter. The second and third instar grubs are voracious feeders, feeds on growing tender roots. Larval stage lasts for a longer period. Pupates inside the soil and emerges from the soil on receipt of monsoon showers.

14.6.1 Management

Veeresh (1983) reported that application of chlorpyriphos 20 EC (10 ml palm^{-1}), counter 5G, and phorate 10G (20g palm^{-1}) with irrigation gave good control of *H. serrata.* Kurian *et al*, (1983) were of the opinion that *Bacillus popilliae* isolated from *H. serrata* could be used against the white grub species attacking coconut. A scoliid wasp, *Campsomeriella collaris* was observed parasitizing grubs of *Leucopholis* sp. in Kerala (Anon., 1969). A carabid *Pheropsophus sorbrenus* was reported to be predacious both on larvae and adults of white grubs (Veeresh, 1983). Besides crow, striped squirrel also predates on this past. Even dogs, cats and bats have been found feeding on the adult beetles during emergence time (Menon and Pandalai, 1958). Several intercrops *viz.*, tapioca, yam, cacao, etc. serve as host plants for the white grubs. Hence, the control measures should be applied to intercrops also for the effective and long lasting control of the pest.

Sekhar (1958) reported mortality among the pre-pupae of *L. coneophora*, the dissected specimens revealed the presence of nematodes. Entomopathogenic nematodes are being isolated from the infected grubs of *L. coneophora*. *Heterorhabditis* sp. has been screened for the closely related species. *L. burmeisteri* indicated mortality (Anon., 1995).

14.7 Minor pests of coconut

Scales : Although scale insects are considered to be minor pests of coconut in India, they are assuming the status of major pests due to the close planting, poor management practices and scarce rainfall. Several species are associated with coconut of which coconut scale *Aspidiotus destructor* is universally distributed. The insects form a continuous crust and suck the sap from the leaves, flower spikes and young nuts resulting in loss of vigour (Lever, 1979; Jalaluddin and Mohana Sundaram, 1989, Vidyasagar, 1989). It has been found that biological control of this pest is more economical and practical. Successful biological control of *A. destructor* has been achieved by the introduction of a predator *Cryptognatha nodiceps* in Fiji (Taylor and Paine, 1935) and Principe island (Simmonds, 1960). Similarly, two coccinellid beetles *Chilocorus nigritus* from Sri Lanka and *Chilocorus politus* from Java were successfully introduced in Mauritius (Moutia and Mamet, 1946).

Mealy bugs: The mealy bug, a sucking pest occurs in small colonies at the bases of spear leaf, spadix, inflorescence and perianth of tender nuts (Vidyasagar, 1989). *Palmicultor palmarum* and *Pseudococcus cocotis,* are commonly found in India (Anon., 1988). As a result of mealy bug infestation, the tender unopened fronds remain stunted, deformed and suppressed and in severe cases immature nut fall occurs. For the control of the pest spraying with fenthion (0.1 %) or monocrotophos (0.1 %) was found effective (Anon., 1989; Vidyasagar, 1989).

Nut crinklers: Many coreid bugs were recorded in association with coconut (Lever, 1935; Kurian *et al.*, 1972). Among them *Paradasynus rostratus* recorded from India causes damage by feeding on the developing nuts. The symptoms of damage are easily identified by the cracks and gummosis on the nuts. Spraying of the tender nut bunches with carbaryl 0.1 % was reported to give good control of this pest (Visalakshi *et al.*, 1987).

Termites : The termite is an important pest of the coconut seedlings. The common species that attacks coconut in India is *Odontotermes obesus*. The coconut seedlings are either attacked through the base of the seednut or at the collar portion resulting in wilting of the central shoot and ultimate death of the seedling. It had been found that about 20 % of the seedlings in laterite areas were infected by termites (Nirula, *et al.*, 1953).

Several chemicals found effective against termites were parathion, pentachlorophenol, sodium pentachlorophenate and chlordane (Nirula, *et al.*, 1953). It is important to treat the nursery and young palms as and when necessary to ensure healthy growth in the initial years (Lever, 1979).

Other pests: An exotic Hispidae beetle, *Octodonta nipae*, is reported from a forest nursery in Dongfang City, Hainan Province, China, where it damages coconut palms, an important ornamental and fruit crop widely planted in Southern China (Sun *et al.*, 2003). The beetle was first discovered on some ornamental seedlings of *Washingtonia filifera* introduced from a nursery in Guangdong Province. *O. nipae* was promptly eradicated, and no establishment or further spread is detected so far.

15.0 Future thrusts

The research efforts on this difficult to deal with crop led to increase in area, prodction and productivity of coconut. Several coconut palm based products have been developed and marketed in India and in other countries, particularly Philippines. Crop improvement programmes in coconut led to development of hybrids, collection, conservation and catalouguing of germplasm. Collecetion of germplasm using zygotic embryoculture technique and DNA finger printing of germplam are the developments in biotechnology of coconut. Development of crop management strategies suitable to different conditions and high density multispecies cropping sysytem to enhance system productivity have led to increase farm income. Delineation of drought tolerance mechanism, characterization and development of strategies for management of drought are major developments in stress physiology. Studies on palm production physiology and biochemistry in relation to developmental phases led to estimate efficiency for drymatter production and partitioning in relation to nut yield. The research on crop protection led to development of many integrated measures for the control of pests and diseases that attack coconut palm.

Inspite of several developments due to numerous research efforts on this crops, obviously several gaps exist, which need the attention of future efforts for further development of production, productivity and diversified products of coconut in order to increase the income of coconut related farming community. The thrust areas are :

- Strengthening of germplasm collection and characterizetion for different traits for utilization in breeding programme.
- Cryo-preservation of germplasm and development of molecular markers for marker assisted selection (MAS) in breeding programme.
- Development of regeneration protocol.

- Understanding the crop-climate relationship for better management and quality assessment.
- Development of different cropping and farming system packages suitable for different situations.
- Development of theoretical ideotype in coconut for focussed crop improvement.
- Undestanding the abiotic stress tolerance in coconut and screening germplasm for tolerance to different stresses.
- Identification, characterization and conservation of *in situ* field tolerant palms to different stresses and high yielding palms for use in crop improvement programme.
- Physiological and biochemical characterization for productivity potential.
- Development of comprehensive product diversification packages.
- Organic farming of coconut based cropping system and identification of useful and effective biological agents.
- Development of integrated eco-friendly crop protection.
- Formation of effective technology dissemination system.
- Development of database for palms.

16.0 References

Abeywardena, V.C. (1954). *Ceylon Coconut Quart.*, **5:** 94.

Abeywardena, V.C. (1967). *Ceylon Coconut Planters' Review.* **5:** 173-188.

Abeywardena, V.C. (1968). *III Session of FAO Tech. Working Party on Coconut Production, Protection and Processing*, Jakarta, Indonesia.

Abraham, A., Mathew, P.M. and Ninan, C.A. (1961). *Cytologia,* **26:** 327 - 332.

Abraham, A. and Thomas, K.J. (1962). *Indian Coconut J.,* **15:** 84

Abraham, A. and Mathew, P.M. (1963). *Ann. Bot.,* **27:** 505 - 512.

Abraham A, Ninan, C.A. and Gopinath, P. (1965). *Caryologia,* **18:** 395-408.

Adkins, S.W, Samosir, Y.M., Ernawati, A., Godwin, I.D. and Drew, R.A. (1998). *Acta Horticulturae,* **461:** 459 - 465.

Adkins, S.W., Samosir, Y.M., Aluh, N., Wilkins, R., Hetherington, S. and Ogle, H. and Drew, R. (2002). *Acta Horticulturae,* **575:** 107-115.

Aiyadurai, S.G. (1954). *Indian Coconut J.,* **7:** 156-63

Aiyadurai, S.G., and Mohammed Ibrahim, P.A. (1954). *Bull. Indian Central Coconut Committee,* **7:** 179-81.

Albuquerque, S.D.S. (1955). *Bull. Indian Central Coconut Committee,* **9:** 71-75.

Allen, E.F. (1955). *Planters Bull.*, Rubber Res. Inst., Malaysia.

Alviar, N.G, and Cuevas, S.E. (1976). *J. Agric. Econ. and Dev.*, **6:** 184-196.

Ambrose, C (1951a). *Ceylon Coconut Quart.*, **2:** 167- 171.

Ambrose, C. (1951b). *Ceylon Coconut Quart.*, **3:** 73-74.

Anbalagan, R, Shanmugam, N, Bhaskaran, R. and Vijayaraghavan, H. (1987). *Int. symp. on Ganoderma Wilt Disease on Palms and other Perennial Crops.* Tamil Nadu Agricultural University, Coimbatore (Abst.): pp 17-18.

Anilkumar, K.S. and Wahid, P.A. (1988). *Oleagineux* , **43:** 337-342.

Anil Kumar, K.S., Nambiar, K.K.N. and Voleti, S.R. (1992). *CORD*, **8:** 40-47.

Anonymous (1932). *Report (1930-31), Madras Agricultural Stations,* Dept. of Agriculture, Madras, India. pp. 248-266.

Anonymous (1934). *Report (1932-33), Madras Agricultural Stations,* Dept. of Agriculture, Madras, India. pp. 267-308.

Anonymous (1941). *Annual Report.* Coconut Research Institute, Sri Lanka.

Anonymous (1942). *Report (1939-40), Madras Agricultural Stations,* Dept. of Agriculture, Madras, India. pp. 375-384.

Anonymous (1951). *Annual Report (1950-51),* Central Coconut Research Station, Kasaragod, India.

Anonymous (1954a). *Leaflet No.1* (New Series), Coconut Research Institute, Sri Lanka.

Anonymous (1954b). *Leaflet No.2* (New Series), Coconut Research Institute, Sri Lanka.

Anonymous (1955). *Leaflet No.8* (New Series), Coconut Research Institute, Sri Lanka.

Anonymous (1958). *Annual Report 1956,* Institute De Recherches Pour Les Huiles et Oleagineux. Paris.

Anonymous (1960). *Annual Report (1958-59),* Indian Central Coconut Committee, Ernakulam, India.

Anonymous (1962). In: *Report on the Marketing of Coconuts and Coconut Products in India,* pp. 50-52.

Anonymous (1964). *Coconut Bull.*, **18:** 343-345.

Anonymous (1965). *Leaflet No.18.* CRI, Sri Lanka.

Anonymous (1967). *Report Coconut Industry Board,* Jakarta, p. 250

Anonymous (1969). *Annual Report (1969).* Central Plantation Crops Research Institute, Kasaragod, India. pp.101-120

Anonymous (1969). *Report Coconut Industry Board,* Jakarta, p. 280

Anonymous (1972). *Annual Report (1971–72),* Central Plantation Crops Research Institute, Kasaragod, India.

Anonymous (1974). *Annual Report (1973),* Central Plantation Crops Research Institute, Kasaragod, India.

Anonymous (1975). *Annual Report (1974),* Central Plantation Crops Research Institute, Kasaragod, India. pp. 24-27.

Anonymous (1976a). *Annual Report (1975).* Central Plantation Crops Research Institute, Kasaragod, India. pp. 25-28

Anonymous (1976b). *Final Report of The Agrostology Project.* 1970-75, Central Plantation Crops Research Institute, Regional Station, Kayangulam, India.

Anonymous (1977). *Annual Report (1976)*. Central Plantation Crops Research Institute, Kasaragod, India. pp. 31-34.

Anonymous. (1978a). *All India Co-Ordinated Coconut and Arecanut Improvement Project.* Progress Report (1976-77), Central Plantation Crops Research Institute, Kasaragod, India.

Anonymous (1978b). *Coconut Genetic Resources. IBPGR Report,* 784-*IBPGR* Secretariat, Rome, Italy.

Anonymous. (1979a). *Research Report (1977-78).* Kerala Agricultural University, Vellanikkara, Trichur, India. pp. 90-98.

Anonymous (1979b). *Annual Report (1977),* Central Plantation Crops Research Institute, Kasaragod, India. pp. 32-34.

Anonymous. (1982). *Progress Report (1981-82), All India Coordinated Coconut and Arecanut Improvement Project,* Central Plantation Crops Research Institute, Pilicode, India.

Anonymous (1985). *Proc. Seventh Workshop, All India Coordinated Coconut, Arecanut, Spices and Cashew Improvement Projects*, Trivandrum, India. 6-9 Nov. 1985.

Anonymous (1987). *Proc. Eight Biennial Workshop, All India Coordinated Project on Palms,* Orissa University of Agriculture and Technology, Bhubaneshwar, India. 24-27 Oct. 1987.

Anonymous (1988). *Annual Report (1988).* Central Plantation Crops Research Institute, Kasaragod, India. pp. 76-85.

Anonymous (1989). *Annual Report (1988-89).* Central Plantation Crops Research Institute, Kasaragod, India.

Anonymous (1990). *Annual Report (1989-90).* Central Plantation Crops Research Institute, Kasaragod, India. pp. 54-56.

Anonymous (1991). *Proc. Tenth All India Coordinated Project on Palms*, Kasaragod, 26-28 Sep. 1991. Central Plantation Crops Research Institute, Kasaragod, India.

Anonymous (1994). *Annual Report (1993-94).* Central Plantation Crops Research Institute, Kasaragod, India.

Anonymous (1995a). *Annual Report (1994-95).* Central Plantation Crops Research Institute, Kasaragod, India.

Anonymous (1995b). *Annual Report (1995).* Central Plantation Crops Research Institute, Kasaragod, India. pp. 87-94.

Anonymous (1996). *Annual Report (1995 -96).* Central Plantation Crops Research Institute, Kasaragod, India.

Anonymous (1997). *Annual Report (1996-97).* Central Plantation Crops Research Institute, Kasaragod, India.

Anonymous (1998a). *Annual Report (1997).* Central Plantation Crops Research Institute, Kasaragod, India. pp. 25-26.

Anonymous (1998b). *Annual Report (1998), All India Co-Ordinated Research Project on Palms.* Kasaragod, India, pp. 49-54.

Anonymous (1999). *Annual Report (1998).* Central Plantation Crops Research Institute, Kasaragod, India. pp. 86-93.

Appleqvist, L.A. (1968). *Physiol. Plant,* **21:** 455-465.

Areza, M.B., Rillo, E.P, Paloma, M.B.F., Ebert, A.W., Cueto, C.A.& Orense, O.D.(1993). *Philippines J. Coconut Studies.* **18:** 20-23.

Ashburner, G. (1999). In: *Current Advances In Coconut Biotechnology.* (Oropeza, C., Verdeil, J.L. and Ashburner, G.R. Eds.), Kluwer Academic Publishers. pp. 33-44.

Ashburner, G.R., Thompson, W.K. and Halloran, G.M. (1997). *Crop. Sci.*, **37:** 992-997.

Assay Bah, B. and Engelmann, F. (1992a). *Cryo-Letters*, **13:** 67-74.

Assay Bah, B. and Engelmann, F. (1992b). *Cryo-Letters*, **13:** 117-126.

Assay Bah, B. and Engelmann, F. (1993). *Plant Cell, Tissue and Organ Culture*, **33:** 19-24.

Bajaj, Y.P.S. (1984). *Curr. Sci.*, **53:** 1215-1216.

Balasubramaniam, K, Atukorala, T.M.S, Wijesundara, S., Hoover, A.A. and De Silva, M.A.T. (1973). *Ann. Bot.*, **37:** 439-445.

Balasubramaniam, K, Dey, P.M.and Pridham, J.B. (1974). *Trans.Biochem.*, **2:** 1128-1130.

Balasubramaniam, K., Sothary, R.D. and De Silva, M.A.T. (1974) *Ceylon Coconut Quart.*, **25:** 149-152.

Balasubramaniam, K. (1983). In: *Coconut Research & Development* (Nayar, N.M. Ed.), Wiley Eastern Ltd., New Delhi. pp. 221-228.

Balasubramaniam, K. and Alles, N.H. (1989). *Ann. Bot.*, **64:** 253-257.

Baldasseri, L. (1932). *Reseagna Econ. Delle Colonie*, 1034-39.

Banzon, J.A.(1980). *Philippines J. Coconut Studies*, **5:** 31-36.

Banzon, J.A.(1984). *Energy in Agriculture*, **34:** 337-344.

Baptist, N.G. (1956). *Nature*, **178:** 1403-1404.

Baptist, N.G. (1967). *Enzymologia*, **33:** 161-168.

Baptist, N.G. and Perera, B.P.M. (1965). *Arch. Biochem. Biophy.*, **111:** 698-701.

Baranwal, V.K., Manikandan, P. and Ray, A.K. (1989). *J. Plantation Crops*, **17:** 114-120.

Baudouin, L. and Lebrun, P. (2002). *Burotrop Bull.*, **17:** 16–20.

Bavappa, K.V.A, Kailasm, C, Khader, K.B.A, Biddappa, C.C, Khan, H.H, Kasturi Bai, K.V, Ramadasan, A, Sundararaju, P, Bopaiah, B.M, George V Thomas, Misra, L.P, Balasimha, D, Bhat, N.T and Sham Bhat, K. (1986). *J. Plantation Crops*, **14:** 41-47.

Bedford, G.O. (1976). *PANS*, **22:** 11-25

Bedford, G.O. (1980). *Annual Rev. Entomol*, **25:** 309-339.

Belgrave, W.N.C. (1931). *Malay Agric. J.*, **19:** 277-282.

Belgrave, W.N. and Lambourne, J. (1934). *Malay Agric. J.*, **22:** 511-17.

Bengali Baboo and Ramadasan, A.(1986). *J. Plantation Crops*, **14:** 49-51.

Bezard J., Bugant, M. and Clement, G. (1971). *J. Amer. Oil Chem. Soc*, **48:** 134

Bhaskara Rao, E.V.V., Pillai, R.V., and Jacob Mathew, (1991). In. *Coconut Breeding and Management* (Silas, E.G., Aravindakshan, M. Jose, A. Eds.), pp.144-149; Kerala Agricultural University, Vellanikkara, Trichur, India.

Bhaskaran, R., Jaganathan, T and Chandrasekar, G. (1978). In: *Proc. PLACROSYM –I*, Indian Society for Plantation Crops, Central Plantation Crops Research Institute, Kasaragod, India. pp. 351-353.

Bhaskaran, U.P. and Leela, K. (1977). *Indian Coconut J.*, **8:** 1-3.

Bhatnagar, S.P. and Johri, B.M. (1972). In: *Seed Biology* (T.T.Kozlowski. Ed.), Vol.-I. p. 78. Academic Press, New York.

Blake, J. and Eeuwens, C.J. (1982). In: *Tissue Culture of Economically Important Plants. Proc. Int. Symp. Costed.* Singapore, 1981. pp. 145-148 (Abst).

Bomer, A. and Baumann, J. (1920). *Z. Lintersn Nahr. Genussen*, **40:** 97

Bopaiah, B.M and Shetty, H.S. (1991). *Soil Biology Biochem.*, **23:** 89-94.

Braconnier, S. and D'auzec, J. (1985). *Oleagineux*, **40:** 547-551.

Branton, R.L. and Blake, J. (1986). In: *Proc. Int. Cong. Plant Tissue and Cell Culture* (Somers, D.A., Gengenbach, BG., Biesboer, D.O., Hackett W.P., Green, C.E. Eds.), University Minnesota, Minneapolis. U.S.A. p. 399 (Abst.)

Briton Jones (1940). In: *The Diseases of Coconut Palm*, Billiere, Tindall & Cox, London. p. 176

Brunin, C. and Coomans, P. (1973). *Oleagineux*, **28:** 200-234.

Buffard - Morel, J., Verdeil, J.L. and Pannetier, C.(1988). *Eighth Int. Symp. Biotechnol.* Paris, (Abst.). p. 177.

Buffard Morel, J., Verdeil, J.L. and Pannetier, C. (1992). *Canadian J. Bot.*, **70:** 735–741.

Buffard - Morel, J., Verdeil, J.L., Dussert, C., Magnaval, C., Huet, C and Grosemange, F. (1995). In: *Lethal Yellowing: Research and Practical Aspects* (Oropeza, C., Ed.) Kluwer Academic Publi., Netherlands, pp. 217-223.

Bunting, B.(1930). *Malay Agric. J.*, **19:** 277-82.

Burcham, L.T. (1947). *J. Forestry*, **45:** 113-17.

Caray, M. (1924). *Philippines Agric.*, **13:** 229-235.

Cardena, R., Oropeza, C. and Zizumbo, D. (1998). *Euphytica*, **102:** 81-86.

Cardena, R., Ashburner, G.R. and Oropeza, C. (1999). In: *Current Advances in Coconut Biotechnology* (Oropeza, C., Verdeil, J.L. And Ashburner, G.R. Eds.) Kluwer Academic Publishers. pp.145 –155.

Cardena, R., Ashburner, G.R. and Oropeza, C. (2003). *Scientia Horticulturae*, **98:** 257-263.

Carpio, C.B. (1980). *M.Sc Thesis*, University of Birmingham, U.K.

Cecil, S. R and Pillai, N.G. (1978). *Indian Coconut J.*, **8:** 1-3.

Chacko Mathew(1977). *J. Plantation Crops*, **5:** 84-88.

Chakrabarthy, B.K. and Goswami, R.N. (1973). *Coconut Bull.*, **4:** 10-11.

Chakraborthy, B.K., Nath, B. K., Dhar, P. B. and Goswamy, R.N. (1970). *Indian J. Agric. Sci*, **40:** 502-504.

Chan, J.L., Saenz, L., Talavera, C., Hornung, R., Robert, M. and Oropeza, C. (1998). *Plant Cell Rep.*, **17:** 515-521.

Chattopadhyay, P.K. and Mitra, S.K. (1995). *Proc. Nat. Symp. on Sustainable Agriculture in Sub-humid Zone* (Dasgupta, M.K. Ghosh, D.C, Das Gupta, D, Majumdar, D.K, Chattopadhyay, G.N, Ganguli, P.K, Munsi, P.S, Bhattacharya, D. Eds.) March 3-5, 1995. Palli-Siksha Bhavana (Institute of Agriculture), Visva-Bharati; Birbhum, India. pp. 171-172.

Chattopadyay, P.K., Samanta, S.K. and Dasgupta, D. (2002). *Indian Coconut J.*, **33:** 23-27.

Chempakam, B., Rajagopal, V. and Gopalan, A. (1991). *Plant Physiol. and Biochem*, **18:** 21-25.

Chempakam, B., Kasturi Bai, K.V. and Rajagopal, V. (1993). *Plant Physiol. and Biochem.*, **20:** 5-10.

Cherian, M.C. and Ananthanarayan, K.P. (1939). *Indian J. Agric.* Sci., **9:.** 541-559.

Cheyne, O.B.M. (1951). *Ceylon Coconut Quart.*, **2:** 179.

Cheyne, O.B.M. (1952a). *Ceylon Coconut Quart.*, **3:** 73-74

Cheyne, O.B.M. (1952b). *Ceylon Coconut Quart.*, **3:** 123-26

Child, R. (1950). *Emp. J. Exp. Agric.*, **18:** 177-89.

Child, R. (1955). *World Crops*, **7:** 488-492.

Child, R. (1964). *Coconuts*, Longmans, London, p. 216

Child, R. (1974). *Coconuts*, 2nd ed. Longmans, London. p. 335.

Child, R. and Nathanael, W.R.N. (1950). *J. Sci. Food Agric.*, **1:** 326-329.

Chin, H.F., Krishna Pillay, B. and Hor, Y.L. (1989). *Pertanika*, **12:** 183-186.

Chowdhury, D. and Deka, K.K. (1997). *J. Plantation Crops*, **25:** 106-108.

Collin, G. and Hildtech, T.P. (1928). *J. Soc. Chem. Ind.*, London, **47:** 97

Cooke, O.F (1901). *Origin and Distribution Of Cocoa Palm.Contr U S Nat. Herb.*, **7:** 57-97.

Cooke, F.C. (1932). *S.S. and F.M.S. Gen. Cir. Bull.*, **8:** 99.

Cooke, F.C. (1936). *S.S. and F.M.S. Gen. Cir. Bull.*, **23:** 101

Cooke, F.C. (1950). *Ceylon Coconut Quart.*, **20:** 45-66.

Cooke, F.C. (1954). *Ceylon Coconut Quart.*, **5:** 154 -68.

Copeland, E.B. (1906). *Philippines J. Sci.*, **1:** 6-57.

Copeland, E. B. (1931). *The Coconut*, Macmillan & Co., Ltd., London.

Cordova, I., Jones, P., Harrison, N.A. and Oropeza, C. (2003). *Molecular Plant Pathol.*, **4:** 99-108 .

Corley, R.H.V. (1983). *Expt. Agric.*, **19:** 217-237.

Cornelius, J.A. (1973). *Trop. Sci.*, **15:** 15-37.

Croucher, H.H. and Martinez R.S. (1934). *J. Jamaica Agri. Soc.*, **6:** 12-19.

Cutter, C.M, Wilson, K.S. and Freeman, B, (1955). *Amer. J. Bot.*, **42:** 109-115.

D'souza, L and Mallya, S.(1993). In: *Advances in Coconut Research and Development* (Nair, M.K., Khan, H.H., Gopalasundaram, P. Bhaskara Rao, E.V.V. Eds.), Oxford & IBH Publ. Co. Pvt. Ltd., New Delhi, India. pp. 239-241.

D'souza, L, Paily,J and Arokiadoss,V (1988). In: *Proc. Nat. Sem. on Plant Tissue Culture*, 2 - 4 March 1983, Central Plantation Crops Research Institute,, Kasaragod, India. p. 140

Daher, R.F., Pereira M.G., Tupinamba, E.A., Amaral, Junior A.T., Aragao, W.M., Ribeiro F.E., Oliveira, L.O. and Sakiyama N.S. (2002). *Crop Breeding and Appl.Biotech.*, **2:** 431-438.

Das, P.K. (1990). In: *Coconut Based Farming Systems, Proc. XXVII Cocotech Meeting*. (De Silva, S. Ed.), 25-29 June 1990, Manila, Philippines. pp. 539-554.

Das, P.K. (1991). *J. Plantation Crops*, **19:** 191-201.

Dash, D.K., Ray, D.P. and Khan, H.H. (2002). *CORD*, **18:** 1-5.

Date, A. and Meara, M. (1955). *J. Sci. Food Agric*, 6: 162

Davis, T.A. and Pillai, N.G. (1966). *Oleagineux*, **21:** 669-674.

De Candolle, A. (1886). *Origin of Cultivated Plants*. Hafner Publ Co, New York, USA.

De Silva, C.W.S. (1953). *Ceylon Coconut Quart.*, **4:** 137-40.

De Silva, M.A.T. (1968). *Ceylon Coconut Planters' Rev.*, **5:** 108-111.

De Silva, M.A.T., Abeywardena, V., George, G.D. and Balasubramaniam, K. (1973). *Ceylon Coconut Quart.*, **24:** 107-113.

Deshpande, B.R. and Kulkarni, V.G. (1962). *Coconut Bull.*, **16:** 336-338.

Dewi Hayati, P.K., Hartana, A., Suharsono and Aswidinnoor, H. (2000). *Int.Conf. Science and Technol. for Managing Plant Genetic Diversity in the 21st Century*, 12–16, June, 2000, Kuala Lumpur, Malaysia. p. 11.

Dhamodaran S, Ratnambal, M.J., Chempakam, B., Pillai, R.V. and Viraktamath, B.C. (1993). In: *Advances in Coconut Research and Development* (Nair, M.K., Khan, H.H., Gopalasundaram, P. and Bhaskara Rao, E.V.V Eds.) Oxford & IBH Publ. Co. Pvt. Ltd. New Delhi, India. pp. 123-128.

Dix, L. and Van Staden, J. (1882). *Plant Cell Tissue and Organ Culture*, **21:** 239-246.

Duran, Y., Rohde, W., Kullaya, A., Goikoetxea, P. and Ritter, E. (1997). *J. Genet. & Breed.* **51:** 279-288.

Durocher Yvon, F. (1953). *World Crops*, **5:** 437-441.

Dussert, S., Verdeil, J.L., Rival, A., Noirot, M., and Buffard–Morel. J. (1995). *Plant Sci.*, **106:** 185-193.

Dwivedi, R.S., Ray, P.K. and Sunny Ninan. (1979). *J. Nuclear Agric.Biol.*, **8:** 33-35.

Dwivedi, R.S., Chacko Mathew, Michael, K.J., Ray, P.K. and Sumathykutty Amma, B. (1978). *The Indian Nat. Sci.Acad. Symp. on Photosynthesis and Productivity.* Feb. 22-22, Lucknow. pp. 44-46 (Abst).

Dwiwarni, I, Yuhono, J.T. and Kemala, S. (1987). *Pemberitaan-Penelitian-Tanaman-Industri, Indonesia*, **12:** 3-4, 67-73.

Dwyer, R.E.P. (1938), *New guinea Agric. Gaz.* **4:** 24-102

Ebert, A., Taylor, H.F. and Blake, J. (1993). *Plant Cell Tissue and Organ Culture*, **33:** 157-162.

Eden Green.S.J.,and Waters, H.(1982). *Phytopath.*, **72:** 667-672.

Eden, D.R.A. (1953). *The Management of Coconut Garden in Western Samoa. Tech. Paper South Pacific Commiss.*, No. 48.

Eeuwens, C.J. (1976). *Physiol. Plant.*, **36:** 23-28.

Ejedegba , B.O. and Onyeneke , E.C. (2003). *Global J. Pure Appl.Sci.*, **9:** 213-216.

Ekanayake, U.B.M. (1970). In: *Annual Report. C.R.I. Ceylon Coconut Quart.*, **21:** 56-59

Engelmann, F., Dumet, D., Chabrillange, N., Abdelnour Esquivel, A., Assay Bah, B., Dereuddre, J. and Duval, Y. (1995). *Plant Genetic Resources Newsletter*, No. 103, pp. 27-31.

Eroy, M. N. and Dauzat, J. (1997). *Philippines J. Crop Sci.*, **22:** 75.

Escritor, M.L. (1954). *Philippines Agric.*, **38:** 334-354.

Eskafi. F. Basham, H. and McCoy, R. (1986). *Trop. Agric.*, **63:** 225-228.

Espiono, R.B. (1922). *Philippines Agric.*, **11:** 191-200.

Espiono, R.B. and Juliano, J.B. (1924). *Philippines J. Sci.*, **25:** 51-72.

Everard, J.M.D.T., Katz, M. and Gregg, K. (1996). *Trop.Agric. Res*, **8:** 124-135.

Farias Neto J.T. de, Lins, P.M.P. and Muller, A.A.; (2003). *Pesquisa Agropecuaria Brasileira*, **38:** 1237-1241.

Fedrick, W.D. (1953). *Ceylon Coconut Quart.*, **4:** 69-71.

Fernandez, E.C.M. and Nair, P.K.R. (1986). *Agriculture Systems*, **21:** 279-310.

Fernando, N. (1995). *Scottish-Agricultural-Economics-Review*, No. 8, 107-120.

Fernando, S.C. and Gamage, C.K.A. (2000). *Plant Sci.*, **151:** 193-198.

Fernando, W.M.U. and Gajanayake, G. (1997). *Plantations Researche and Developpement.* **52:** 256-261.

Fisher, J.B. and Tsai, J.H. (1978a). *In Vitro,* **114:** 307- 311.

Foale, M.A. (1968). *Aust. J. Agric. Res.,* **19:** 781-789.

Foster, H. (1977). In: *Fertilizer Use and Production of Carbohydrates and Lipids,* International Potash Inst., Berne. pp. 305-310.

Fremod, Y., Ziller, R. and Lamothe, M.N. (1966). *The Coconut Palm.* International Potash Inst., Berne.

Fremond, Y and De Nuce De Lamothe, M. (1966). *Oleagineux,* **26:** 459-464.

Fremond, Y., R., Ziller and Lamothe, M.N. (1966). *The Coconut Palm,* International Potash Inst., Berne.

Fremond, Y. And Ouvrier, M. (1971). *Oleagineux,* **26:** 609-618.

Friedrichs, K. (1913). *Tropenflanze,* **17:** 538

Friend, D. and Corley, R. H. V.(1994). *Expt. Agric.,* **30:** 223-235

Ganarajah, T. (1954). *Ceylon Coconut Quart.,* **5:** 90-93.

Ganesamurthy, K., Natarajan, C., Rajarathinam, S., Vincent, S. and Khan, H.H. (2002a). *J. Plantation Crops.* **30:** 23-25.

Ganesamurthy, K., Natarajan, C., Vaithilingam, R., Giridharan, S. and Khan, H.H. (2002b). *Indian Coconut, J.,* **33:** 31-34.

Geethalakshmi, P., Niral, V and Parthasarathy, V.A. (2000). In: *Nat. Sem. Recent Adv. Plant Biol,* Central Plantation Crops Research Institute, Kasaragod, India, 3-5 Feb, 2000.

Ghai, S.K. and Thomas, G.V. (1989). *Plant and Soil* (Netherlands), **114:** 235-241.

Gopalasundaram, P and Nelliat, E.V. (1979a). In: *Multiple Cropping in Coconut and Arecanut Gardens* (Nelliat, E.V. and Bhat, K.S., Eds.), Central Plantation Crops Research Institute, Kasaragod, India. pp. 6-23.

Gopalasundaram, P and Nelliat, E.V. (1979b). *Coconut Bull.,* **16:** 201-206.

Gorrie, R.M. (1950). *Ceylon Coconut Quart.,* **1:** 11-16.

Green, A.H. and Foale, M.A.(1961). In: *Tenth Pacific Science Congress., Symp. on Tropical Crops Improvement.* South Pacific Commission, Noumea, pp. 65-69.

Green, E.E. (1898). *Trop. Agric.,* **26:** 298-308.

Gressit, J.L. (1953). *Bull. Bernice P. Bishop. Mus.,* No. 212. p. 157.

Griffis, J.L. Jr. and Litz, R.E. (1997). *Proc. Int. Cashew and Coconut Conf.,* Dar es Salaam. pp. 349-357.

Grimwood, B.E. (1975). *FAO Agricultural Development Paper.* **99:** p. 213.

Guzman, E.V. De, Roasario, A.G. Del and Eusebio, E.C. (1971). *The Philippines Agric.,* **53:** 566-579.

Hameed Khan, H., Sakaranarayanan, M.P. and Narayanan, K.B. (1978). In: *Proc. PLACROSYM-I,* Central Plantation Crops Research Institute, Kasaragod, India. pp. 54-79.

Hammes, C. and Monsarrat, P. (1974). *Orstom Ser. Biol.* **22:** 43-111.

Hanumanthappa, M, Indiresh, K.M, Shankar, S and Palanimuthi, V. (1998). In: *Proc. PLACROSYM-XVIII,* Indian Society for Plantation Crops, Central Plantation Crops Research Institute, Kasaragod, India. p. 205.

Harikumar, V.S. and Thomas, G.V. (2003). *Plant Archives.* **3:** 105-108.

Harries, H.C. (1983). *Planter* (Kuala Lampur), **59:** 207-241.

Harries, H.C. (1999). In: *Current Advances in Coconut Biotechnology.* Kluwer Academic Publishers, Netherlands, pp. 431-436.

Harrison, N.A., Myrie, W., Jones, P., Carpio, M.L., Castillo, M., Doyle, M.M. and Oropeza, C. (2002). *Annals Appl.Biol.,* **141:** 183-193.

Hartley, C.W.S. (1977). *The Oil Palm,* 2nd ed., Longman, London.

Hautea, D.M., Santos, G.A., Reano, C.E., Segovia, S.J.E., Galvez, H.F., Bituin. N.O., Carcallas, R.J.U., Rivera, R. and Quilloy, R.B. (2000). *Int.Conf. Science and Technol. for Managing Plant Genetic Diversity in the 21st Century,* 12-16 June, 2000, Kuala Lumpur, Malaysia. p. 12.

Hegde, M.R, And Md. Yusuf. (1993b). *J. Plantation Crops,* **21:** 29-31.

Hegde, M.R, Yusuf, M and Gopalasundaram, P, (1993a). In: *Advances in Coconut Research and Development.* Indian Society for Plantation Crops, Central Plantation Crops Research Institute, Kasaragod, India. pp. 407-412.

Henderson, F.C. (1956). Report Dept. Agri. Stock & Fish., Port Moresby. Papua And New Guinea Report.

Herran, A., Estioko, L., Becker, D., Rodriguez, M.J.B., Rohde, W. and Ritter, E. (2000).*Theor. Appl. Genet.,* **101:** 292-300.

Hocher, V., Verdeil, J.L., Grosemange, F., Huet, C., Bourdeix, R., n'cho, Y., Sangare, A., Hornung, R., Jacobsen, H.J., Rillo, E., Oropeza, C. and Hamon, S. (1998). *Cahiers Agric.,* **7:** 499-505.

Hore, J.K., Bandopadhyay, A. and Ghosh, D.K. (2003). *Indian Coconut J.,* **34:** 10-13.

Hornung, R. (1995). *Plantations Researche and Developpement,* **50:** 38-41

Huger, A.M. (1966). *J. Invertebrate Pathol,* **8:** 38-51.

Hunter, H., and Leake, H.M. (1933). In: *Recent Advances in Agricultural Plant Breeding,* 362-81

Islam, M.M and Rahman, M.M. (1989). *Economic Affairs,* Calcutta, **34:** 89-99.

Iyer R.D. (1993a). In: *Advances in Coconut Research and Development* (Nair, M.K, Khan, H.H., Gopalasundaram, P., Bhaskara Rao, E.V.V. Eds.), Oxford & IBH Publ Co Pvt Ltd., New Delhi, India, pp. 31-32.

Iyer, R.D. (1993b). In: *Advances in Coconut Research and Development* (Nair, M.K, Khan, H.H, Gopalasundaram, P., Bhaskara Rao, E.V.V. Eds.) Oxford & IBH Publ Co. Pvt Ltd., New Delhi, India. pp. 149-159

Iyer RD (1995). *J. Plantation Crops,* **23:** 1-18.

Iyer, R.D, Bhaskara Rao E.V.V and Govindakutty, M.P. (1979). *Indian Fmg.,* **28:** 3-5.

Iyer, R.D, Kuruvinashetti, M.S, Mini, P. S, Prakash, P and Raju, C.R (1982). *Int. Cong. on Plant Tissue & Cell Culture,* Tokyo, Japan.

Iyer, R.D. and Damodaran, S. (1994). In: *Advances in Horticulture.Vol.9, Plantation and Spice Crops.* Part I (Chadha, K.L and. Rethinam, P. Eds.). Malhotra Publishing House, New Delhi. pp. 217-242.

Iyer, R.D. and Parthasarathy, V.A. (2000). In: *Biotechnology in Horticultural and Plantation Crops* (Chadha, K.L., Ravindran, P.N. and Leela Sahijram. Eds.), Malhotra Publishing House, New Delhi. pp. 286-302.

Jack, H.W.and Sands, W.N. (1924). *Malay Agric. J.,* **17:** 140-70.

Jacks, G.V. (1936). *Imp. Bur. Soil Sci. Tech. Comm.*. **34:** 36-37.

Jacob Mathew, Rawther, T.S.S and Pillai, N. G. (1998). In: *Coconut Root (Wilt) Disease* (Nampoothiri K.U.K. and Koshy P.K. Eds.), Central Plantation Crops Research Institute, Kasaragod, India. pp. 1-7.

Jacob Mathew, Amarnath, C.H., Vijayakumar, K. Yusuf, M. and Balkrishnan, T.K. (1988). *CORD*, **4:** 48-55.

Jacob, P.M and Rawther, T.S.S (1991). In: *Coconut Root (Wilt) Disease* (Nair, M.K, Nambiar, K.K.N, Koshy, P.K and Jayasankar, N.P .Eds.), Monograph No. 3, Central Plantation Crops Research Institute, Kasaragod, India, pp. 67-71.

Jacob, P. M., Nair, R. V and Rawther, T. S. S. (1998). In: *Coconut Root (Wilt) Disease* (Nampoothiri, K. U. K and. Koshy, P. K. Eds.), Central Plantation Crops Research Institute, Kasaragod, India. pp. 97-104.

Jagadeesan, M and Padmanabhan, D (1982). In: *Proc. PLACROSYM-V*, Indian Society for Plantation Crops, Central Plantation Crops Research Institute, Kasaragod, India. Dec. 15-18, p. 22.

Jaganathan, N.(1992). *Indian Coconut J.*, **23:** 7-13.

Jagoe, R.B. (1938). *Malay Agric. J.*, **26:** 369-75.

Janaki Ammal, E.K. (1945). In: *Chromosome Atlas of Cultivated Plants*. (Darlington, C.D. and Janaki Ammal, E.K. Eds.), Allen & Unwin Ltd, London, U.K.

Jalaluddin, M and Mohanasundaram, M. (1989). *Indian Coconut J.*, **19:** 14-19.

Jamaluddeen, K and Jacob, V.J. (1983). *J. Plantation Crops*, **11:** 39-46.

Jamieson, G.S.(1943). *Vegetable Fats and Oils*. New york. p. 147.

Janistyn, B. (1989). *Phytochem.*, **28:** 329-331.

Jayalakshmy, A, Arumugham, C.S. and Narayanan, C. and Mathew, A.G. (1988). *Oleagineux*, **43:** 409-414.

Jayalekshmy ,V.G. and Rangaswamy, S.R.S. (2002). *J. Plantation Crops*. **30:** 18-22.

Jayaratnam, T. J. (1941). *Trop. Agric.*, (Sri Lanka). **96:** 3-21.

Jayasekara, C. and Mathes D.T. (1992). *Indian coconut J.*, **23:** 7-13

Jayathilake, G.S. (1974). *Ceylon Coconut Quart.*, **25:** 160-163.

Job, E, Asan, R..B and Ramasubramonian, P. (1993). *Indian Coconut J.*, **24:** 2-4.

John C.M. and Jacob, K. (1959). In: *First Conf. of Coconut Research Workers In India.*, Indian Central Coconut Committee, Ernakulam.

John, C. M. (1949). *Indian Coconut J.* **2:** 63-76.

John, C.M. (1951). *Indian Coconut J*, **5:** 42-52.

John, C.M. (1952). In: *Coconut Cultivation*. Indian Central Coconut Committee, Ernakulam.

John, C.M. and Menon, K.P.V. (1947). *Joint Report of Work on the Improvement of Coconuts*,. Indian Central Coconut Committee, Ernakulam.

John, C.M. and Narayanan, G.V. (1942). *Madras. Agric. J.*, **17:** 140-70.

John, C.M. and Varghese, E.J. (1951). *Indian Coconut J.*, **5:** 31-41.

John, J. and Nair, M.A. (1998). *Indian Coconut J.*, **29:** 4-7.

Johns, R. (1938). *East Africa Agric. J.*, **3:** 186-94.

Jones, L.H., (1983). *Oil Palm News*. **17:** 1-8.

Joseph, P.A., Potty, N.N., Ashokan, P.K and Nayar, N.K. (1993). *Indian Coconut J.*, **24:** 7-9.

Julia, J.F. and Mariau, D. (1979). *Oleagineux,* **34:** 181-189.

Juliano, J.B. (1926). *Philippines J. Sci.,* **30:** 187-200.

Kalamai, A and Sree Rangaswamy (1990). *Indian Coconut J.*, **20:** 9-10.

Kamala Devi, C.B., Velayudham, M.(1978). In: *Proc. PLACROSYM I.* (Nelliat, E. V., Ed.), Central Plantation Crops Research Institute, Kasaragod, India. pp. 340-346.

Kamaladevi, C.B., Nelliat, E.V. and Pillai N.G. (1974). *J. Plantation Crops,* **1** (suppl.): 67-69.

Kanapathy, K. (1976). *Malay Agric. J.*, **50:** 322-339.

Kannan, K and Nambiar, K.P.P. (1976). *Coconut Bull.*, **5:** 1-3.

Kapadia MN (1981). *Indian Coconut J.*, **12:** 4-5.

Karp, A. (1999). In: *Current Advances in Coconut Biotechnology* (Oropeza, C., Verdeil, J.L. and Ashburner, G.R. Eds.) Kluwer Academic Publishers. pp. 121-129.

Kartha, A.R.S (1963). *J. Sci. Food & Agric.* **14:** 515-519.

Kartha, A.R.S. and Narayanan, R. (1956). *Indian J. Agric. Sci.* **26:** 319-327.

Kartha, A.R.S., SethI, A.S. and Narayanan, R. (1959). *J. Sci. Ind. Res.* **18:** 172-175.

Kartha, ARS. (1981). *J. Plantation Crops,* **9:** 125-127.

Kartha, ARS. (1964). *J. Sci. Food & Agri.*, **15:** 299-302.

Karthikeyan, M., Sarala, L., Karunanithi, K. and Rajarethinam, S. (2002). *Indian Coconut J.*, **32:** 6-7.

Karun, A, Sajini, K.K. and Iyer, R.D. (1996). *J. Plantation Crops,* **24** (suppl.): 586-593.

Karun, A. And Sajini, K.K.(1994). *Curr. Sci.*, **67:** 118-120.

Karunaratne, S. and Periyperuma, K. (1989). *Plant Sci.*, **62:** 247-253.

Karunaratne, S., Gamage, S and Kovoor, A. (1991). *J. Plant Physiol,* **139:** 27-31.

Karunaratne, S., Kurukulaarachchi, C. and Gamage, C. (1985). *COCOS,* **3:** 1-8.

Kasturi Bai, K.V. (1993). *Ph.D. Thesis*, Mangalore University, Mangalore. India. p. 257.

Kasturi Bai, K.V. and Ramadasan, A.(1978). In: *Proc. PLACROSYM I* (Nelliat, E.V. Ed.), Central Plantation Crops Research Institute, Kasaragod, India. pp. 321-330.

Kasturi Bai, K.V. and Ramadasan, A. (1982). *J. Plantation Crops.* **10:** 124-126.

Kasturi Bai, K.V. and Ramadasan, A. (1983). In: *Coconut Research and Development* (Nayar, N.M. Ed.), Wiley Eastern Limited. pp. 203-209.

Kasturi Bai, K.V. and Ramadasan, A. (1990). *J. Plantation Crops,* **18:** 130-133.

Kasturi Bai, K. V., Rajagopal, V. (2000). *Indian J. Plant Physiol,* 320-323.

Kasturi Bai, K. V. and Khan, H.H. (2002). *Indian J. Hort.* **59:** 185-190.

Kasturi Bai, K.V., Ramadasan, A. and Satheesan, K.V. (1981). *J. Indian Bot. Soc.*, **60:** 352-354.

Kasturi Bai, K.V., Voleti, S.R. and Rajagopal, V.(1988). *Agri. Forest.Meteorol.* **43:** 193-199.

Kasturi Bai, K. V., Rajagopal, V and Balasimha, D. (1998). *Plant Physiol. Biochem.* **25:** 163-166.

Kasturi Bai, K. V., Rajagopal, V. and Ratnambal,M.J.(2001). *J. Plant Biol.* **28:** 161-164.

Kasturi Bai, K. V., Rajagopal, V and Balasimha, D.and Gopalasundaram, P. (1997). *CORD,* **13:** 45-58.

Kasturi Bai, K.V., Rajagopal, V., Prabha, C.D., Ratnambal, M.J. and George, M.V. (1996a). *J. Plantation Crops*. **24:** 23-28.

Kasturi Bai, K.V.,Rajagopal, V., Chempakam, B. and Prabha, C.D. (1996b). *J. Plantation crops*, **24**(Suppl): 548-554.

Kasturi Bai, K. V., Srinivasa Reddy, D.V., Ratnambal, M.J. and Laxman, R.H. (2002). *CORD* (in press).

Katherine, W.S. and Cutler Jr. V.M. (1952). *Amer. J. Bot.*, **39:** 37-58.

Khan, H.H., Gopalasundaram, P., Joshi, O.P. and Nelliat, E.V. (1986). *Fert. Res*, **10:** 185-190.

Khan, H.H.,Biddappa, C.C. and Cecil, S.R. (1990). *Indian Coconut J.*, **20:** 2-7.

Khan, H.H.(1993). In: *Fertilizer Management in Commercial Crops* (Tandon, HLS. Ed.), VIII. Fertilizer Development and Consultation Organization, New Delhi, India. p. 176 .

Khanna, P.K. and Nair, P.K.R. (1977). *Malaysian Soc. Soil. Sci.* Kuala Lampar.

Korikanthimath, V.S, Ankegowda, S.J, Yadukumar, N, Rajendra Hegde, Hosmani, M.M and Hegde, R. (1997). *Annals Of Plant Physiology*, **11:** 107-110.

Korikanthimath, V.S, Rajendra Hegde, Ravindra Mulge, and Hosmani, M.M. (2000). *Crop Res.*, (Hisar). **20:** 343-349.

Koshy, P.K, Sosamma, V.K and Sundararaju, P. (1993). In: *Advances in Coconut Research and Development*, pp. 465-475.

Koshy, P.K. and Kumaran, P.M. (1997). *ICAR News*. Indian Council of Agricultural Research, New Delhi. **3:** 2.

Krishnaji, N., Mukherjee, Nelliat, E.V., Nair, P.K.R, Jacob Mathew and Varghese, P.T. (1976). *Working Paper No. 41*. Centre for Development Studies, Thiruvananthapuram, India.

Krishnamurthy, M.N. and Chandrasekhara, N. (1979). *J.Food Sci. Technol.*, **16:** 74-75.

Krishnamurthy M.N., and Chandrasekhara N. (1983). *J. Food Sci. Technol.*, **20:** 206-209.

Kumar, P.P., Raju, C.R., Chandramohanan, M. and Iyer, R.D. (1985). *Plant Sci.*, **40:** 203-207.

Kurian, C., Antony, J., Pillai, G.B., and George, E. (1969). *Final Report of the PL 480 Project on 'Methods of Control of Coconut Rhinoceros Beetle Oryctes Rhinoceros L.'* Submitted to US Dept. of Agric. p. 32. .

Kurian, C., Pillai, G.B., Abraham, V.A. and Mathen, K. (1972). *Curr. Sci*,. **41:** 37.

Kurian, C., Pillai, G.B., Antony, J., Abraham, V.A. and Natarajan, P. (1983). In: *Coconut Research and Development* (Nayar, N.M. Ed.), Wiley Eastern Ltd. New Delhi. pp. 361-375.

Kurup V.V.G.K., (1989). *M. phil Dissertation* , Mangalore University, Mangalore, India. p. 75.

Kurup, V.V.G.K., Voleti, S.R. and Rajagopal, V. (1993). *J. Plantation Crops*, **2:** 71-80.

Kuruvinashetti, M.S and Iyer, R.D (1979). *Fifth FAO Technical Working Party on Coconut Production Protection and Processing*, Manila, Philippines.

Kuruvinashetti, M.S and Iyer, R.D (1980). In: *Proc. Nat. Symp. on Tissue Culture, Genetic Manipulation and Somatic Hybridization of Plant Cells* (Rao, P.S., Heble, M.R. and Chadha, M.S. Eds.), BARC, Bombay, India.

Kushwah, B.L., Nelliat, E.V., Markose, V.T. and Sunny, A.F. (1973). *Indian J. Agron*, **18:** 71-74.

Kuttappan, M. (1971). *Coconut Bull.*, **1:** 2-4.

Lagemann, J. (1977). *Traditional Farming in Eastern Nigeria*, Weltforum Verlag, Munchen.

Lakshmanachar, M.S.(1963). *Indian Coconut Bull.*, **16:** 370-372.

Lalitha Bai, E.K, Prasanna Kumari, K.T, Viswanathan, T.V, and Rekha, K. (1996). *South Indian Hort.*, **43:** 154-155.

Latiffah ,Z., Harikrishna, K., Tan, S.G., Tan, S.H., Abdullah, F. and Ho, Y.W. (2002). *Annals Appl. Biol.*, **141:** 133-142.

Leach, B.J., Foale, M.A. and Ashburner, G.R. (2003). *Genetic Resources and Crop Evolution*, **50:** 627-638.

Lebrun, P., Grivet, L. and Baudouin, L.(1998a). *Plantations, Researche and Developpement*, **5:** 233 - 245.

Lebrun, P., Grivet, L. and Baudouin, L. (1999). In: *Current Advances in Coconut Biotechnology* (Oropeza, C., Verdeil, J.L. And Ashburner, G.R. Eds.), Kluwer Academic Publishers. pp. 73-87.

Lebrun, P., n'cho, Y.P., Seguin, M., Grivet, L. and Baudouin, L. (1998b). *Euphytica*, **101:** 103-108.

Lebrun, P., Baudouin, L., Bourdeix, R., Konan, J.L., Barker, J.H.A., Aldam, C., Herran, A. and Riter, E. (2001). *Genome*, **44:** 962-970.

Leela, K. and Bhaskaran, U.P. (1978). In: *PLACROSYM-I*, Indian Society for Plantation Crops, Central Plantation Crops Research Institute, Kasaragod, India.pp. 393-398.

Leon, R., Sanchez, G., Aqlpizar, D., Escamilla, A., Santamaria, J. and Oropeza, C. (1993). In: *Advances in Coconut Development and Research* (Nair, M.K., Khan, H.H., Gopalasundaram, P. and Bhaskara Rao, E.V.V. Eds.), Oxford & IBH, Publ. Co. Pvt. Ltd., New Delhi. pp. 621-628.

Lever, R.J.A.W. (1979). *Pests of the Coconut Palm*, FAO Plant Production and Protection Series No. 18. p.190.

Lim, J.R., and Banzon, J.A. (1983). *Philippines, J. Crop. Sci.*, **8:** 8-12.

Lindquist K (1960). *Hereditas*, **46:** 75-157.

Liyanage, D.V. (1950). *Trop. Agric.*, **106:** 151-55.

Liyanage, D.V. (1952). *Annual Report of Coconut Research Scheme (1950)*. Ceylon Govt. Sessional paper. **14:** 22-30.

Liyanage, D.V. (1953a). *Ceylon Coconut Quart.*, **4:** 59-60.

Liyanage, D.V. (1953b). *Ceylon Coconut Quart.*, **4:** 127-29

Liyanage, D.V. (1953c). *Ceylon Coconut* Quart., **4:** 127-129.

Liyanage, D.V. (1955a). *Annual Report of Coconut Research Institute (1953)*. Ceylon Govt. Sessional Paper, **25:** 27-30.

Liyanage, D.V., (1955b). *Planting Material for Coconuts*. Paper Presented at the Coconut Conference, 29th August, 1955 Bandirippuwa Estate, Lunuwila Coconut Research Institute, Ceylon.

Liyanage, D.V. and Abeywardena, V. (1957a). *Trop. Agric.*, **113:** 1-16.

Liyanage, D.V. and Abeywardena (1957b). *Trop. Agric.*, **113:** 325-340.

Liyanage, M. De S., Jayasundara, H.P.S., Fernando, D.N.S, And Fernando, M.T.N. (1993). *J. Asian Farming Systems Association*, **1:** 579-588.

Liyanage, M. De S., and Gunathilake, H.A.J. (1998). In: *Proc Int. Cashew and Coconut Conf.*

Trees for Life - The Key to Development, (Topper, C.P., Caligari, P.D.S, Kullaya, A.K. Eds.)

Loomis, R.S. And Williams, W.S. (1973). *Crop Sci.* **3:** 67-72.

Lubina, R. (1990). *M.Phil. Thesis* Mangalore University, Mangalore, India. p. 70.

Lumige, L.C. (1969). *Philippines J. Plant, Sci.*, 34.

Maceda, F.S. (1933). *Philippines Agric.*, **22:** 430-41.

Magat, S.S., Cadigal, V.L., and Habana, J.A. (1975). *Oleagineux*, **30:** 413-418.

Magat, SS and Margate, RZ (1990). *CORD* VI: 30-51.

Magnaval, C., Noirot, M., Verdeil, J.L., Blattes, A., Huet, C., Grosdemange, F. and Buffard Morel, J. (1995). *J. Plant Physiol.*, **146:** 155-161.

Magnaval, C., Noirot, M., Verdeil, J.L., Blattes, A., Huet, C., Grosdemange, F. and Buffard-Morel, J. (1997). *J. Plant Physiol.*, **150:** 719–728.

•Maharaj, S.(1965) *Trop. Agric.*, **42:** 373-375.

Maheswarappa, H.P. (1997). *Ph.D. Thesis*, University of Agricultural Sciences, Bangalore, India.

Maheswarappa, H.P. and Anithakumari, P. (2002). *Indian J. Arecanut, Spices and Medicinal Plants.* **4:** 82-83.

Maheswarappa, H.P, Hegde, M.R, Dhanapal, R And Biddappa, C.C. (1998). *J. Plantation Crops,* **26:** 139-143.

Manikandan, P., Joshi, O.P., Khan, H.H and Biddappa, C.C. (1986). J. *Plantation Crops*, **14:** 134-138.

Manjula, C. (1990). *M.Phil.Thesis.* Mangalore University, India. p. 79.

Manjula, C., Chempakam, B. and RajagopaL,V.(1993). *J. Plantation Crops*, **21**(Suppl): 313-321.

Manjula, C., Chempakam, B and Rajagopal, V. (1995). *Plant Physiol. & Biochem.* **22:** 169-172.

Manjunath, B.L, Balbatti, M.S and Dhandar, D.G. (1998). In: *Proc. PLACROSYM-XII*, Indian Society for plantation Crops, Central Plantation Crops Research Institute, Kasaragod, India.

Manna, S., Mathew, B., Hasan, M.A. and Chattopadhyay, P.K. (2003). *Indian Coconut J.*, **33:** 15-17.

Marar, M.M.K. and Pandalai, K.M. (1957). *Indian J. Meteorol. Geophys*, **B:** 1-11.

Marar, M.M.K. and Pandalai, K.M. (1961). *Indian Coconut J.*, **4:** 110-122.

Marar, M.M.K. and Pappachan, G. (1964). *Indian Coconut J.*, **17:** 137-141.

Marechal, H (1928). *Fiji Agric. J.*, **1:** 16-45.

Markose, V.T. and Nelliat, E.V. (1975). *J. Plantation Crops*, **3:** 16-19.

Marschall, K.J. (1970). *Nature*, **225:** 288-289.

Martin, E.B. (1955). *Trop. Agric.*, **32:** 162-169.

Martius, C.F.P. Von. (1850). *Historia Naturatus Palmarum*, Leipsig 3. Munich Germany.

Mathai, G., Mathew, A.V. and Kunju, V.M. (1985). *Indian Phytopath.*, **38:** 561-562.

Mathai G., Mathew, J. and Balakrishnan, B. (1991). In:*Coconut Breeding and Management* (Silas, E.G, Aravindakshan, M. and Jose, A., Eds.), Kerala Agricultural University, Vellanikkara, Trichur, India. pp. 161-162.

Mathen, K. and Kurian, C. (1967). *Indian J. Agric. Sci.*, **36:** *265*

Mathen, K., Rajan, P., Nair, C. P. R., Sasikala, M., Gunasekaran, M., Govindan Kutty, M. and Solomon, J. J. (1990). *Trop. Agric.*, **67:** 69-73.

Mathew, C. and Ramadasan, A. (1964). *Indian Coconut. J.*, **17:** 114-119.

Mathew, J. and Shafee, M. (1979). In: *Multiple Cropping in Coconut Garden.* (Nelliat, E.V. and Shama Bhat, K. Eds.), *Technical Bull. No. 3.* Central Plantation Crops Research Institute, Kasaragod, India. pp. 42-46,

Mathew, P.A., Nagabhushanam, S. and Dhandar, D.G. (1993). In: *Advances in Coconut Research and Development*, Oxford & IBH Pub. Co. Pvt. Ltd., New Delhi. pp. 437-439.

McCoy, R.E., Howard, F.W., Tsai, J.H., Donselman, H.M., Thomas, D.L., Basham, H.G., Atilano, R.A., Eskafi, F.M., Britt, L. and Collins, M.E. (1983). *University Florida Agric.Exp. Sta. Bull No.834.*

McDonough, J and Zimmermann,.J (1979). *Principles.* **66:** 1038-1042.

Meerow, A.W., Wisser, R.J., Brown, J.S., Kuhn, D.N., Schnell, R.J. and Broschat, T.K. (2003). *Theor. Appl.Genet.*, **106:** 715-726.

Mendiola, N.B. (1926). *A Manual of Plant Breeding for the Tropics*, Manila.

Menon, K.P.V. and Nair, U.K. (1952). *Indian Coconut J.*, **5:** 81-100.

Menon, K.P.A. and Pandalai, K.M. (1958). *The Coconut Palm - a Monograph.* Indian Central Coconut Committee, Ernakulum.

Menon, K.P.V. and K.M. Pandalai, (1960). *The Coconut Palm - a Monograph.* Indian Central Coconut Committee, Ernakulam.

Menon, K.S. and Nayar, T.V.R. (1978). In: *Proc. PLACROSYM-I*, Central Plantation Crops Research Institute, Kasaragod, India. pp. 416-424.

Menon, K.S., Thommen, K.J and Sukumaran, A.S (1981). In: *Review of Research on Coconut Root (Wilt) Disease*, Central Plantation Crops Research Institute, Kayangulam, India. pp. 78-82.

Meunier, J., Benoit, G., Ghesquiere, M., Jay, M., and Bourdeix, R. (1992). In: *IBPGR Workshop on Coconut Genetic Resources*, Cipanas, Indonesia, 8-11 Oct. 1992. IBPGR, Rome, Italy.

Michael, K.J (1964). *Indian Coconut J.*, **17:** 85-92.

Michael, K.J (1977). In: *Annual Report (1976).* Central Plantation Crops Research Institute, Kasaragod, India.

Michael, K.J. (1978). *J. Plantation Crops.* **6:** 1-3.

Milburn, J.A and Davis, T.A. (1973). *Physiol. Plant*, **29:** 415-420.

Mkumbo, K.E. and Hornung, R.K.W. (1997). *Proc. Int. Cashew and Coconut Conf.*, Dar-es-Salaam, pp. 358-361.

Mohan, K.S., Jayapal, S. P. and Pillai, G.B. (1989). *J. Plantation Crops,* **16**(suppl.): 163-170.

Mondal, H., Mandal, R.K. and Biswas, B.B. (1970a). *Plant Cell Physiol,*. **11:** 177-181.

Mondal, H.,Mandal, R.K. and Biswas, B.B. (1972). *Eur.J. Biochem*, **25:** 463-470.

Mondal, H, Mondal, R.K. and Biswas, B.B. (1970). *Nucleus*, 23: 10 - 18.

Monera, O.D. and Del Rosario, E.J. (1982). *Annual Trop. Res.*, **4:** 47-54.

Moutia, L.A. and Mamet, R. (1946). *Bull. Entomol. Res.*, **36:** 439-472.

Mujer, C.V. and Ramirez, D.A. (1980), *Philippines J. Biol.*, **9:** 25-30.

Mujer, C.V. Mendoza, E.M.T. and Ramirez, D.A. (1983). *Phytochem.*, **22:** 1335-1340.

Mujer, C.V., Ramirez, D.A. and Mendoza, E.M.T. (1984a) *Phytochem.* **23:** 893-894.

Mujer, C.V., Ramirez, D.A. and Mendoza, E.M.T. (1984b). *Phytochem,* **23:** 251-1254.

Muliyar, M.K. and Nelliat, E.V. (1971). *Oleagineux;* **26:** 687-691.

Munna, M.C. and Singh, M.V. (2001). *Bioresource Technology*, **76:** 143-150.

Murali Gopal, Saleena, A. and McCoy, C.W. (2002). *Curr. Sci.,* **82:** 22-24.

Murashige, T. and Skoog, F. (1962) *Physiol.Plant,* **15:** 473- 497.

Murray, D.B., and Smith, M.N.L. (1952). *Trop. Agric.*, **21:** 180-195.

Murray, D.V. (1977). In: *Ecophysiology of Tropical Crops* (Alvim, T.A and Kozlowski, T.T. Eds.), Academic Press, New York. pp. 384-407.

Nagaraju, V., Guohao, H.E,. Parthasarathy, V.A. and. Prakash, C.S. (2002). *J. Plantation Crops.* (Accepted).

Nagwekar, D.D., Sawant, V.S., Joshi, G.D. and Khan, H.H. (2002). *Indian Coconut J.,* **32:** 23-25.

Nagwekar, D.D., Haldankar, P.M., Desai, A.G., Gunjate, R.T. and Rajput, J.C. (1997). *J. Plantation Crops,* **25:** 209-211.

Nagwekar, D.D., Sawant, V.S., Desai, V.S., Mahadik, M.V., Khan, H.H., Joshi, G.D. and Jambhale, N.D. (2003). *Indian Coconut J.,* **34:** 3-5.

Nair, G.S, Sudhadevi, P.K and Alice Kurian. (1991). In: *Recent Adv. Med. Arom. and Spices Crops.* Vol.I, (Raychaudhuri, S.P., Ed.), Today and Tomorrow's Printers and Pub., New Delhi. pp. 163-165.

Nair, M.K., and Nampoothiri, K.U.K. (1993). In: *Advances in Coconut Research and Development.* (Nair, M.K., Khan, H.H., Gopalasundaram, P., Bhaskara Rao E.V.V., Eds.), Oxford & IBH Publishing House, New Delhi.

Nair M.K. (1994). In: *Advances in Horticulture* Vol 9. Plantation and Spice Crops, Part I (Chadha, K.L. and Rethinam, P. Eds.), Malhotra Publishing House, New Delhi.

Nair, M.K., Khan, H.H. and Gopalasundaram, P. (1995). *Indian Coconut J.,* **26:** 3-19.

Nair, M.K., Koshy, P.K. Jacob, P.M., Nair, R.V., Bhaskara Rao, E.V.V., Nampoothiri, K.U.K. and Iyer, R.D. (1996). *Indian Coconut J.*, **27:** 2-5.

Nair, P.K.R. (1976). *Financing Agriculture,* Bombay, **7:** 3-8.

Nair, P.K.R. (1979). *Intensive Multiple Cropping with Coconuts in India,* Verlag Paul Parrey, Berlin and Hamburg. p. 135.

Nair, P.K.R. (1993). *An Introduction Of Agroforestry*, Kluwer Academic Pub., Dordrecht, Netherlands. 499.

Nair, P.K.R, Varma, R, and Nelliat, E.V. (1974). *Indian Fmg,* **24:** 11-13.

Nair, P.K.R, and Bavappa, K.V.A. (1975). *J. Root Crops,* **1:** 93-94.

Nair, P.K.R. and Balakrishnan, T.K. (1976). *Indian J. Agric. Sci.*, **46:** 453-462.

Nair, P.K.R. (1977). *Gartenbauwissenschaft,* **42:** 145-150.

Nair, P.K.R. and Thomas Varghese, P. (1976). *Indian Fmg*, **25:** 17-21.

Nair, P.K.R and Balakrishnan, T.K. (1977). *Agric. Met.* **18:** 455-462.

Nair, S.K and Rao, N.S.S. (1977). *Plant and Soil*, **46:** 511-519.

Nair, A.G.R. and. Sankara Subramanian, S. (1963). *Indian coconut J.*, **16:** 154-157.

Nair, M.A. and Sreedharan, C.(1986). *Agroforestry Systems,* **4:** 339-363.

Nair, P.K.R, Varma, R, Nelliat, E.V. and Bavappa, K.V.A. (1975). *Indian J. Agric. Sci.* **45:** 165-171.

Nambiar, C.K.B., Khan, H.H., Joshi, O.P and Pillai, N.G. (1983). *J. Plantation Crops,* **11:** 24-32.

Nambiar, K.K.N. and Rawther, T.S.S. (1993). In: *Advances in Coconut Research and Development*(Nair, M.K:, Gopalsundaram, P., Khan, H.H. and Bhaskara Rao, E.V.V., Eds.), Oxford & IBH Publ. Co. Pvt. Ltd., New Delhi. pp. 546-561.

Nambiar, K.K.N. (1999). In: *IPM Systems in Agriculture,* Vol. 5. Oil Seeds (Rajeev. K. Upadhayay, K. G., Mukerji and Rajak, R.L., Eds.), Aditya Books Pvt. Ltd., New Delhi. pp. 493- 515.

Nambiar, M.C. (1978). In: *Proc. PLACROSYM-I,* Indian Society for Plantation Crops, Kasaragod, India. pp. 444-445.

Nambiar, M.C. and Prasannakumari (1964). *Indian Coconut J.*, **27:** 93-100.

Nambiar, M.C., Thankamma Pillai, P.K. and Vijayakumar, G (1970). *Indian J Genet.,* **30:** 744-752.

Nambiar, M.R. and Swaminathan, M.S. (1960). *Indian J. Genet.*, **20:** 200-211.

Naresh Kumar, S. (1998). In: *Harvest and Post Harvest Technology of Plantation Crops* (Bosco SJD *et al.,* Eds.), Central Plantation Crops Research Institute, Kasaragod, India. pp. 158-164.

Naresh Kumar, S. and Chempakam., B. (2000). In: *Nat. Sem. on Recent Advances in Plant Biology-an interdisciplinary approach to unravel plant functions*, Central Plantation Crops Research Institute, Kasaragod, India from 3-5 Feb, 2000. Abs No.VI 4.

Naresh Kumar, S. and RajagopaL,V (2000). *ICAR NEWS*, Oct-Dec. **6:** 16

Naresh Kumar, S., Chempakam, B.and Rajagopal, V. (2000). *Indian Coconut J.*, **31:** 25-28.

Naresh Kumar, S., Rajagopal, V. and Anitha Karun. (2000) In: *Recent Advances in Plantation Crops Research* (Muraleedharan, N. and Raj Kumar, R. Eds), *Proc. PLACROSYM XIII,* Indian Society for Plantation Crops, Central Plantation Crops Research Instittue, Kasaragod, India. pp 225-229.

Naresh Kumar, S., Rajagopal, V. and Anitha Karun. (2001). *CORD,* **18:** 1-12.

Naresh Kumar, S., Rajagopal, V., Siju Thomas, T. and Cherian, V.K. (2003). In: *Abs II. Int. Cong. on Plant Physiology,* 8-13th Jan., 2003. Abst No. S13/P25.

Naresh Kumar, S., Rajagopal,V, Laxman, R.H; Dhanapal,R. and Maheswarappa, H. P. (2000c). In: *Proc. PLACROSYM XIV – Plantation Crops Research and Development in the New Millennium* (Rethinam, P., Khan, H.H., Reddy, V.M., Mandal, P.K. and Suresh, K., Eds.), Indian Society for Plantation Crops, Central Plantation Crops Research Institute, Kasaragod, India. pp. 116-120.

Naresh Kumar, S., Rajagopal, V,. Cherian, VK, Siju Thomas, T., Sreenivasulu, B., Nagvekar, D., Hanumanthappa H., Vijayakumar, K., Ratheesh Narayan, M.K. and Amarnath, C.H. (2002b) (*communicated*).

Nascente, A.S. and Sa, L.F.de (2002). *Pesquisa Agropecuaria and Desenvolvimento Sustentavel* , **1:** 45-51.

Nathanael, W.R.N. (1952). *Ceylon Coconut Quart.,* **3:** 193-199.

Nathanael, W.R.N. (1967). *Ceylon Coconut Quart.,* **18:** 15-35.

Nathaniel, W.R.N. (1969). *Fertilizer,* **35:** 11-17.

Neera Bhalla-Sarin, Bagga, S., Sopory, S.K. and Guha-Mukherjee, S. (1986). *Plant Cell Rep.* **5:** 322-324.

Neera Bhalla- Sarin and Bagga, S. (1988). In: *Proc. Nat. Sem. on Plant Tissue Culture,* ICAR, New Delhi. pp. 132-137.

Nelliat, E.V. (1956). *Bull. Indian Central Coconut Committee,* **9:** 213-214.

Nelliat, E.V. (1973). *J. Plantation Crops,* **1**(suppl.): 70-80.

Nelliat , E.V. (1979). In: *Multiple Cropping in Coconut and Arecanut Gardens.* (Nelliat, E.V. and Bhat, K.S. Eds.), Tech. Bull. Central Plantation Crops Research Institute, Kasaragod, Kerala. pp. 3-5.

Nelliat, E.V. (1984). In: *Proc. PLACROSYM–V,* Indian Society for Plantation Crops, Central Plantation Crops Research Institute, Kasaragod, India. 379-387.

Nelliat, E.V., And Muliyar, M.K. (1971). In: *Proc. Int. Symp. on Soil Fertility Evaluation,* 575-583. Indian Society of Soil Science, New Delhi.

Nelliat, E.V and Krishnaji, N. (1976). *Indian Fmg,* **27:** 9-12.

Nelliat, E.V. and Padmaja, P.K. (1978). In: *Proc. PLACROSYM-I* (Nelliat, E.V. Ed.). Indian Society for Plantation Crops, Central Plantation Crops Research Institute, Kasaragod, India. pp. 186-199.

Nelliat, E.V., Nair, P.K.R. and Kushwaha, B.L. (1976a). *J.Plantation Crops,* **4:** 16-20.

Nelliat, E.V., Shama Bhat, K. and Nair, R.B. (1976b). *Annual Report (1976),* Central Plantation Crops Research Institute, Kasaragod, India. pp. 27-28.

Nelliat, E.V., Bavappa, K.V.A and Nair, P.K.R. (1974). *World Crops,* **26:** 262-266.

Nelliat, E.V., Gopalasundaram, P., Thomas Varghese, P and Sivaraman, K. (1979). In: *Multiple Cropping in Coconut and Arecanut Gardens.* Tech. Bull. (Nelliat , E.V., and Shama Bhat, K., Eds.), Central Plantation Crops Research Institute, Kasaragod, Kerala. India. pp. 28-34.

Nelliat, E.V. (1972). *J. Plantation Crops,* **I** (suppl.): 70-80.

Ninan, C.A. and Satyabalain, K (1963). *Indian Coconut J.,* **I6:** 109

Ninan,C.A. and Raveendranath, TG (1965). *Caryologa,* **18:** 619-623.

Ninan,C.A. and Raveendranath, TG (1972). *Coconut Bull.,* **3:** 2-4.

Ninan, C.A. and Nambiar, M.C (1974). In: *Advancing Frontiers in Cytogenetics* (P. Kachroo, Ed.), Hindustan Publ. Corp., New Delhi, India. pp. 175-188.

Ninan, CA., Pillai, RV and Josy Joseph (1960). *Indian Coconut J.,* **23:** 129-134.

Nirula, K.K. (1956). *Indian Coconut J.,* **9:** 101-103.

Nirula, K.K., Antony, J. and Menon, K.P.V. (1951). *Indian Coconut J.,* **4:** 217-223.

Nirula, K.K., Antony, J. and Menon, K.P.V. (1952). *Indian Coconut J.,* **5:** 137-140.

Nirula, K.K., Antony, J. and Menon, K.P.V. (1953). *Indian Coconut J.,* **7:** 26-34

Nirula, K.K., Radha, K. and Menon, K.P.V. (1955a). *Indian Coconut J.,* **8:** 1-20.

Nirula, K.K., Radha, K. and Menon, K.P.V. (1955b). *Indian Coconut J.,* **9:** *3-10.*

Ochs, R., and Ollagnier, M. (1977). In: *Fertilizer Use and Production of Carbohydrates and Lipids,* 269-293. International Potash Inst. Berne.

Ollagnier, M. and Ochs, R. (1971). *Oleagineux,* **26:** 1-15.

Ollagnier, M. and Ochs, R. (1972). *Oleagineux,* **27:** 193-198.

Ollagnier, M., Ochs, R. and Daniel, C. (1976). *The Chlorine Nutrition of Oil Palm and Coconut-Application of Fertilization* IRHO, Paris.

Ollagnier, M., Ochs, R., Pomier, M. and de Taffin G. (1983). *Oleagineux,* **38:** 309-321.

Oo, K.C. and Stumpf, P.K. (1979) *Lipids,* **14:** 132-143.

Oropez, C., Verdeil, J.L., Ashburner, G.R., Cardena, R. and Sanatamaria, J.M. (Eds.), *Current Advances In Coconut Biotechnology (1999),* Kluwer Academic Publishers, Netherlands.

Oropeza, C. and. Taylor, H.F. (1994). In: *Physiology, Growth and Development of Plants in Culture* (Lumsden, P.J., Nicholas, J.R. And Davies, W.J., Eds.), Kluwer Academic Publishers, Netherlands. pp. 284-288.

Ouverier, M. and Ochs, R. (1978). *Oleagineux,* **33:** 437-443.

Padmaja, G., Sumathi Kutty Amma, B., Mathew, C., Ray, P.K. and Dwivedi, R.S. (1980). *Indian J. Expt. Biol.,* **18:** 1209-1211.

Padmaja, G. and Sumathykutty Amma, B. (1979). *J. Plantation Crops,* **7:** 101-104.

Padmaja, G., Sumathykutty Amma, B., Chacko Mathew, Nambiar, P.T.N. and Dwivedi, R.S. (1981). *Indian J. plant Physiol.,* **24:** 42-46.

Padua-Resurreccion, A.N. and Banzon, J.A. (1979). *Philippines J. Coconut Studies,* **4:** 1-16.

Pagden, H.T. (1936). *Coconut Quart.,* **1:** 7-938.

Pagden, H.T. (1936). *Malaysian Agric. J.,* **24:** 128-38.

Pandalai, K.M. (1953). *Indian Coconut J.,* **6:** 89-93.

Pandalai, K.M., Sankarasubramoney, H. and Menon, K.P.V. (1953). *Indian Coconut J.,* **7:** 20-25.

Pandarakalam, J.C. (1956). *Indian Fmg.,* **6:** 43-45.

Park, Malcolm. (1934). *Trop. Agric.,* **83:** 141.

Parthasarathy, V.A. (1999) In. *Improvement of Plantation Crops* (Ratnambal, M.J., Kumaran, P.M., Muralidharan, Niral, V. and Arunachalam, V., Eds.), Central Plantation Crops Research Institute, Kasaragod, India. pp.160-163.

Parthasarathy, V.A. (2001). *Deputation Report,* Central Plantation Crops Research Institute, Kasaragod, India. p. 55.

Parthasarathy, V.A. and Bose, T.K. (2001). In: *Biotechnology of Horticultural Crops.* Vol.-I. p. 175.

Parthasarathy, V.A., Bose, T.K., Deka, P.C., Das, P., Mitra, S.K. And Mohandas, S., Eds.), Naya Prokash, Calcutta, pp. 585-594.

Parthasarathy, V.A., Geethalakshmi, P. and Niral, V. (2004). *Acta Bot.Croatia,* **63:** 69-74.

Patel, J.S. (1937). *Proc Assoc. Biol,* **5:** 1-16.

Patel, J.S. (1938). *Coconut – A Monograph,* Govt. Press. Madras.

Patil, J.L, Haldnkar, P.M, Jamadagni, B.M And Salvi, M.J. (1991). *Indian Coconut J.,* **19:** 1671-69.

Patil, J.L., Haldankar, P.M., Jamadagni, B.M. and Salvi, M.J. (1992). *J. Plantation Crops,* **20:** 167-169.

Peng, Fangren, Huang, Baolong, Tay, Juhana, Lim, Nam, Peng, F.R., Huang, B.L., Tay, J.H., And Lim, N. (1996). *J. Nanjing Forestry University,* **20:** 68-72.

Perera, L. (2001). *CORD,* **17:** 35-51.

Perera, L., R.R.A. and Jayatileke, R. (1996). *COCOS,* **11:** 69-78.

Perera, L., Russell, J.R., Provan, J., Mcnicol, J.W. and Powell, W. (1998). *Theor. Appl. Genet.*, **96:** 545-550.

Perera, L., Russel, R., Provan, J. and Powell, W. (1999). *Mol. Ecol.*, **8:** 335-346.

Perera, L.,Russell, J.R.,Provan, J. and Powell, W. (2000a). *Genome*, **43:** 15-21.

Perera, L., Russell, J.R., Provan, J. and Powell, W. (2000b). *Int. Conf. Science and Technol. for Managing Plant Genetic Diversity in ihe 21st Century*, 12-16 June, 2000, Kuala Lumpur, Malaysia. p.15 (Abst).

Perera, L., Russell, J.R., Provan, J. and Powell, W. (2000c). *Euphytica*, **102:** 381- 389.

Perera, L., Peries, R.R.A., Padmasiri, M.H.L. (2002). *Plant Genetic Resources Newslett.*, **131:** 70-72.

Perera, L., Russell, J.R., Provan, J. and Powell, W. (2003). *Euphytica*, **132:** 121-128.

Perez Zamora, O. (2003). *Terra* **21:** 401-408.

Peries, O. S., Liyanage, A. De S., Mahindapala, R. and Subasinghe, S.M.P. (1975). *Ceylon Coconut Planters Rev.*, **3:** 37-40.

Peries, R.R.A. and Everard, J.M.D.T. (1991). *COCOS*, **9:** 40-46.

Persly, G.J. (1992). *Replanting the Tree of Life: Towards an International Agenda for Coconut Palm Research.* CAB, Oxford, UK. p. 156.

Petch, T. (1906). *Trop. Agric.*, **27:** 489-491.

Pieris, W.V.D. (1934). *Trop. Agric.*, **82:** 75-97

Pieris, W.V.D. (1945). In: *Bull. No.6*, The Coconut Research Scheme, Ceylon.

Pillai, T.N.Y (1967). *Curr. Sci.*, **36:** 667-668.

Pillai, G.B. and Bhat, S.K. (1987).. *Indian Coconut J.*, **17:** 6-10.

Pillai, G.B. and Nair, K.R (1993). *Indian Coconut J.*, **3:** 2-9.

PillaI, N.G. (1964). *Indian Coconut J.*, **17:** 109-113.

Pillai, N.G., and Davis, T.A. (1963). *Indian Coconut J.*, **16:** 81-87.

Pillai, N.G and Shanta, P. 1965. *Curr. Sci.*, **34:** 636-637.

Pillai, N.G., Sukumaran, C.K. and Pandalai, K.M. (1959). *Proc. 1st Conf. Coconut Res. Workers*, Trivandrum, India. pp. 132-151.

Pillai, N. G., Chowdappa, P., Solomon, J. J. and Mathew, J. (1991). *J. Plantation Crops*, **19:** 14-20.

Pillai, N.G., Wahid, P.A., Kamala Devi, C.B., Ramanandan, P.L., Cecil, R., Amma, P.G.K., Mathew, A.S. and Nambiar, C.K.B. (1975): In: *FAO Technical Working Party on Coconut Production, Protection and Processing*, Kingston, Jamaica.

Pillai, N.K. (1919). *Agric. J. India*, **14:** 608-25.

PillaI, R.V., Nair, R.B., Mathew, C., Bavappa, K.V.A. and Ramadasan, A. (1973). *J. Plantation Crops*, **1**(suppl.): 89-92.

Poduval, M., Hasan, Md. Abu and Chattopadhyay, P.K. (1998), *Indian Coconut J.*, **28:** 3-6

Pomier, M. (1964). *Oleagineux*, **19:** 615-620.

Pomier, M. and de Taffin G. (1982). *Oleagineux*, **37:** 55-62.

Potty, N.N, Ashokan, P.K and Balakrishnan, T.C, (1979). *Agric. Res. J. Kerala*, **17:** 130-132.

Pramod, P.V., Nair, R.V., Thomas, R.J., Mathews C., and Pillai, S. (2003).*Indian Coconut J.*, **33:** 9-11.

Premaratne, W.H.E, Silva, M.P. De, De Silva, M.P; Jager. A. De and Verhaegh, A. (1991). *First Int. Symp. on Horticultural Economics in Developing Countries*, Alemaya, Ethiopia, 16-23 July 1989. *Acta Horticulturae*. No. 270, 381-387.

Pulgar Vidal, J. (1953). *Agric. Trop.*, **10:** 37-44.

Purseglove, J.W. (1972). *Tropical Crops. Monocotyledons 2.* Longmans, London.

Quencez, P. and de Taffin, G. (1981). *Oleagineux,* **36:** 1-7.

Radha, K. (1962). *Coconut Bull.* **16:** 347-350.

Radha, K. and Lal, S. B. (1968) 3rd Session *FAO Tech. Working Party on Coconut Production Protection and Processing,* Jakarta. pp. 1-5.

Radha, K. and Lal, S.B. (1972). *Indian J. Agric. Sci.,* **42:** 410-13.

Radha, K. and Joseph, T. (1974). *Final Report, PL 480 Scheme.* p. 32.

Radley, M. and Dear, R. (1958). *Nature,* 182: 1098-1099.

Rajagopal, V. (1991). *J. Plantation Crops,* **19:** 91-101.

Rajagopal, V. and Ramadasan, A. (1999). *Advances in Plant Physiology and Biochemistry of Coconut Palm.* APCC. Pub., Jakarta. p. 124.

Rajagopal, V.and Naresh Kumar, S., (2001). In: *Nat. Sem. on role of plant physiology for sustaining quality and quanity of food production in relation to environment.* 5-7 Dec., 2001, University of Agricultural Sciences, Dharwad, India. pp. 31-36.

Rajagopal, V. and Kasturi Bai, K.V. (2002). *BUROTROP Bull.* **17:** 21-22.

Rajagopal, V. and Sumathykuthyamma, B. (1989). *CORD,* **5:** 77-88.

Rajagopal, V., Sumathykutty Amma, B. and Patil, K.D. (1987a). *New Phytol,* **105:** 289-293.

Rajagopal, V. Patil, K.D. and Sumathykutty Amma, B. (1987). *Indian Coconut J.,* **18:** 3-5.

Rajagopal, V., Kasturi Bai, K.V. and Voleti, S.R. (1990). *Oleagineux,* **45:** 215-223.

Rajagopal, V; Shivashankar, S. and Jacob Mathew. (1996). *Plantations, Researche and Developpement.* **3:** 251-255.

Rajagopal, V., Kasturi Bai, K.V. and Naresh Kumar, S. (2002) In: *Proc. PLACROSYM XIV – Plantation Crops Research and Development in the New Millennium* (Rethinam, P., Khan, H.H., Reddy, V.M., Mandal, P.K. and Suresh, K., Eds.) pp 30-35.

Rajagopal, V., Patil, K.D. and Sumathykutty Amma, B., (1986). *J. Exp. Bot,.* **37:** 1398-1405.

Rajagopal, V., Kasturi Bai, K.V. and Naresh Kumar, S. (2000b). In: *Extended Summaries Vol. 2. of Int: Conf. on Managing Natural Resources for Sustainable Agricultural Production in the 21st Century* held at New Delhi, 14-18 Feb, 2000 Vol **2:** Agro-biodiversity:778-779.

Rajagopal, V., Kasturi Bai, K.V., Voleti, S.R. and Shivashankar, S. (1988a). *Plant Physiol. and Biochem.,* **25:** 80-86.

Rajagopal, V., Shivashankar, S., Kasturi Bai, K.V., and Voleti, S.R. (1988b). *Plant Physiol. and Biochem.,* **15:** 80-86.

Rajagopal, V., Chempakam, B., Robert Cecil, S. and Kamalakshy Amma, P.G. (1989). *Plant Physiol and Biochem.,* **16:** 52-56.

Rajagopal, V., Ramadasan, A., Kasturi Bai, K.V. and Balasimha, D. (1989b). *Irrig. Sci.,* **10:** 73-81.

Rajagopal, V., Voleti, S.R., Kasturi Bai, K.V. and Shivashankar, S. (1991a). In: *Coconut Breeding and Management.* (Silas, E.G., Arvindakshan, M. and Jose, A., Eds.), Kerala Agricultural University, Vellanikkara, Trichur, India. pp. 136-143.

Rajagopal, V., Kasturi Bai, K.V. and Voleti, S.R. (1990). *Oleagineux*, **45:** 215-223.

Rajagopal, V., Voleti, S.R., Kasturi Bai, K.V. and Shivashankar, S. (1991b). In: *Coconut Breeding and Management* (Silas, E.G., Arvindakshan, M. and Jose, A., Eds.), Kerala Agricultural University, Vellanikkara, Trichur India. pp. 322-324.

Rajagopal, V., Kasturi Bai, K.V., Pillai, R.V. and Vijayakumar, K. (1992). *J. Plantation Crops*, **20**(suppl.): 277-283.

Rajagopal, V., Naresh Kumar, S., Kasturi Bai, K.V. and. Laxman, R.H. (2000a), *J. Plant Biology*, **27:** 27-32.

Rajagopal, V., Naresh Kumar, S., Siju Thomas, T., Vinu, K. Cherian, Ratheesh Narayanan, M.K.,·Ananda, K.S,. Nagvekar, D., Hanumanthappa, M., Vincent, S. and Sreenivasulu, B. (2000). In: *Nat. Sem. on Recent Advances in Plant Biology-An interdisciplinary approach to unravel plant functions*, Central Plantation Crops Research Institute, Kasaragod, from 3-5 Feb., Abs. No. III 3.

Rajagopalan, A., Viswanathan, T.V. and Nirmala Devi, S. (1992). *J. Plantation Crops*, **20** (suppl.): 50-51.

Rajapakse, G. (1950). *Ceylon Coconut Quart*, **1:** 7-9.

Raju, C.R, Prakash Kumar, P, Mini Chandramohan and Iyer, R.D. (1984). *J. Plantation Crops*, **12:** 75-78.

Raju, C.R., Prakash Kumar, P., Mini Chandramohan and Iyer, R.D. (1982). *Abst Nat. Sem. On Plant Propogation*, Calcutta, 27-29 Dec 1982, Bidhan Chandra Krishi Viswavidyalaya & Soc. Adv Hort., Kalyani, India. pp. 100-101.

Ramadasan, A.(1964). In: *Proc. 2nd Session FAO Working Party on Coconut Production Protection and Processing*, Colombo. pp. 257-272.

Ramadasan, A. and Lal, S.B. (1966). *Coconut Bull.* (India), **20:** 173-175.

Ramadasan, A. and Mathew, C. (1977). *J. Plantation Crops*, **5:** 125-126.

Ramadasan, A. and Satheesan, K.V. (1980). *J. Plantation Crops*, **8:** 55-57.

Ramadasan, A. and Jacob Mathew, (1987). *J. Plantation Crops*, **15:** 59-63.

Ramadasan, A., Balakrishnan, T.K. and RajagopaL, V. (1991). *Indian Coconut J.*, **21:** 2-5.

Ramadasan, A., Satheesan, K.V. and Balakrishnan, R. (1980). *Indian J. Agric. Sci.*, **50:** 553-554.

Ramadasan, K, Abdullah, I., Teoh., K.C., Vanialingam, T. and Chan, E. (1978). *Planter*, **54:** 329-342.

Ramakrishnan, T.S. and Ramakrishnan, K. (1949). *Curr. Sci.*, **18:** 342-344.

Ramanujam, B. (1997). *Ph. D Thesis* , Mangalore University, Mangalore, India. 228p

Ramanujam, B., Nambiar, K.K.N. and Anilkumar. (1993). In: *Advances in Coconut Research and Development* (Nair, M.K, Gopalsundaram, P, Khan., H. H and. Bhaskaro Rao, E. V. V., Eds.), Oxford & IBH Publ. Co. Pvt .Ltd., New Delhi. pp. 615-616.

Ranasinghe, C.S., Weerakoon, L.K., Liyanage, Y.M.H. and Mathes, D.T. (1999). *CORD*, **15:** 46-67.

Rao, A.G., Rao P.R., Thammiraju, N.B., Rao K.L., Krishnamurthy, B.H. and Murthy, S.M. (1980). *Indian Coconut J.*, **11:** 3-5.

Rao, G.K.R. and Mohanan, R.C. (1995) *Indian Cocoa Arecanut and Spices J.* **19:** 35-37.

Rao, G.S.L.H.V.P. (1985). *Indian Coconut J.*, **15:** 3-6.

Rao, G.S.L.H.V.P. (1986). *Indian Coconut J.*, **17:** 11-13.

Rao, G.S.L.H.V.P. (1991). In: *Coconut Breeding and Management*. (Silas, E.G., Arvindakshan, M. and Jose, A., Eds.), Kerala Agricultural University, Vellanikkara, Trichur., pp. 150-155.

Rao, P.V.S., Subramanian, T.R. and Abraham, E.V. (1973). *J. Plantation Crops*, **1:** 26-27.

Rao, Y.R. (1924). In: *Report on the Proc. of the 5th Entomology Meeting*, Pusa, pp. 92-98.

Ratanambal, M.J. (1995a). *Deputation Report* (IPGRI Trainers Course on Coconut Breeding Research Techniques), September 19-29, 1995, Monado, Indonesia.

Ratnambal, M.J., Nair, M.K., Muralidharan, K, Kumaran, P.M., Bhaskara Rao, E.V.V. and Pillai, R.V. (1995b). *Coconut Descriptor*, Central Plantation Crops Research Institute, Kasaragod, India.

Raveendranath T.G., Nair, P.N. and Ninan, C.A (1975). *Coconut Bull.*, **6:** 2.

Raveendranath, T.G. and Ninan, C.A. (1973). *J. Plantation Crops*, **1:** 17 - 22.

Ray, P.K., Dwivedi, R.S., and Sunny Ninan (1979). In: *Proc. PLACROSYM-I* Indian Society for Plantation Crops, Kasaragod, India. pp. 331-339.

Reddy, D.V.S., Upadhyay, A.K., Gopalasundaram, P. and Khan, H.H. (2002). *Nutrient Cycling in Agroecosystems*. **62:** 131-138.

Reddy, A.G.S, Nataraj, T. Gopal, M and Naidu, R. (1998). *Indian Coffee*, **62:** 17-22.

Reddy, D.V.S. Naresh Kumar, S. and Prabhu, S.R. (2001) *J. Plantation Crops*, **29:** 62-65

Rethinam, P. (1989). *Research Highlights of AICRP on Palms (1972-79)*. Central Plantation Crops Research Institute, Kasaragod, India. pp. 11-12.

Rethinam, P., Roy, A.K., Baranwal, V.K., Chakrabothy, B.K. and Nambiar, K.K.N. (1990), *Indian Coconut J.*, **20:** 1-4.

Reynolds, S.G. (1995). *Pasture-Cattle-Coconut Systems*. Food and Agriculture Organisation of United Nations, Bangkok, Thailand. p. 668.

Rival, A., Triques, K., Beule, T., Nato, A., Lavergn, D., Santamaria, J., Verdeil, J.L., Hocher, V., Oropeza, C. and Hamon, S. (1999). In: *Plant Biotechnology and In Vitro Biology in the 21st Century*, (Altaman, A. *et al.*, Eds.), Kluwer Academic Publishers, Netherlands. pp. 437-440.

Rockwood, M.S. (1953). *Ceylon Coconut Quart.*, **4:** 13-15

Rodriguez, F.M., Laurena, A.C., Laureles, L.R., Santos, G.A., and Mendoza, E.M.T (1998). *Phillpines J. Crop Sci.* **23:** 84.

Rohde, W. (1993). In: *European Research Working for Coconut*, Montpellier, France, Sept. 2-6th Sept. 1993. pp.41-51.

Rohde, W. (1996). *J. Genet. & Breed.*, **50:** 249-261.

Rohde, W., Kullaya, A., Rodriguez J. and Ritter, E. (1995). *J.Genet & Breed.*, **49:** 179-186.

Rohde, W., Becker, D., Kullaya, A., Rodriguez, J., Herran, A. and Ritter, E. (1999). In: *Current Advances in Coconut Biotechnology* (Oropeza, C., Verdeil, J.L. and Ashburner, G.R., Eds,), Kluwer Academic Publishers. pp. 99-120.

Romney, D.H. and Smith, R.W. (1965). *Proc. Amer. Soc. Hort. Sci. Caribbean Reg., XIII Ann. Meet.*, pp. 177-187.

Rosario, E.J.DEL. (1980). *Philippines J. Crop Sci.*, **5:** 67-75.

Rosario, A.G. Del and Guzman, E.V. De (1976). *Philippines J. Sci.*, **105:** 215-222.

Rosario, A.G. Del. (1984). *Tissue Culture of Coconut Inflorescence*, Res. Bull. Natl. Res.

Council, Philippines. **39:** 205-222.

Roychaudhury, R. and Biswas, B.B. (1962) *Sci. and Cult.*, **28:** 591-592.

Ruehrmund, M.E., (1959). *Candy Ind.*, **112:** 11.

Sadasivan, V. (1951). *Archives of Biochemistry,* **30:** 159-163

Sahasranaman, K.N. (1961). *Coconut Bull.,* **15:** 49-52.

Sahasranaman, K.N. (1964). *Coconut Bull.,* **18:** 128-130.

Sahasranaman, K.N. and Pillai, N.G. (1976). *Intensive Agric.,* **14:** 6-10.

Sahasranaman, K.N., Pillai, N.G., Jayasankar, N.P., Potti, V.P., Varkey, Thomas, Kamalakshy Amma, P.G. and Radha, K. (1983). In: *Coconut Research and Development* (Nayar, N.M., Ed.), Wiley Eastern, New Delhi. p. 160-163.

Sahoo, S.C., Lenka, P.C. and Dash, D.K. (2002). *Orissa J. Hort.,* **30:** 130-132.

Sairam, C.V, Gopalasundaram, P, Srinivasa Reddy, D.V., Subramanian, P., Umamaheswari, L. and Hegde, M.R. (1999). *J. Plantation Crops,* **27:** 37-44.

Salam, M.A., Sreekumar, D, Mohanakumaran, N. and Sathees Babu, K. (1991). *Indian Coconut J.,* **22:** 4-12.

Salgado, M.L.M. (1938). *Trop Agric.* (Ceylon), **90:** 30-33.

Salgado, M.L.M. (1948). *Ceylon Coconut Res. Stn. Bull. No. 6.* Sri Lanka.

Salgado, M.L.M. (1950). *Ceylon Coconut Quart.,* **1:** 23-26.

Salgado, M.L.M., (1951). *Ceylon Coconut Quart.,* **2:** 161-64.

Salter, P.J. and Goode, J.E. (1967). *Res. Review No.2,* Common Wealth Bureau of Horticultural and Plantation Crops.

Samosir, Y.M.S., Godwin, I.D. and Adkins, S.W. (1998). *Acta Horticulturae,* **461:** 467-473.

Samosir, Y.M.S., Godwin, I.D. and Adkins, S.W. (1999). In: *Current Advances In Coconut Biotechnology.* (Oropeza, C., Verdeil, J.L. And Ashburner, G.R., Eds.), Kluwer Academic Publishers. pp. 341–354.

Sampson, H.C. (1923). *The Coconut Palm,* John Bale, Sons & Danielsson Ltd, London.

Samson, A.S., Khaun D, R.N., Cater, C.M. and Mattil, K.F. (1971). *J. Food Sci,* **36:** 725-728.

Sandoval, A., Hocher, V. and Verdeil, J.L. (2003). *Plant Cell Rep.,* **22:** 25-31.

Sankaranarayanan, M.P. and Velayuthum, M. (1976). *Coconut Bull.,* **7:** 13-14.

Sankarasubramoney, H., Pandalai, K.M. and Menon, K.P.V. (1954). *Indian Coconut J.,* **8:** 5-25.

Santamaria J.M., Talavera, C., Lavergne, D., Trabels I.S., Verdeil, J.L., Huet, C., Rival, A., Hamon, S. and Nato, A. 1999. In: *Current Advances in Coconut Biotechnology.* (Oropeza, C., Ashburner, R., Verdeil, J.L., Zizumbo. D., Eds). Kluwer Academic Press, Dordrecht, Netherlands. pp. 371-381.

Santos, A.L. dos., Monnerat, P.H. and Alves E.A.B.(2003). *Pesquisa Agropecuaria and Desenvolvimento Sustentavel.* **1:** 165-171.

Satheesan, K.V., Narasimhayya, G. and Ramadasan, A. (1983). *J. Plantation Crops,* **11:** 47-49.

Sathiamma, B., Jayapal, S.P. and Pillai, G.B. (1987a). *Entomon,* **12:** 45-47.

Sathiamma, B., Nair, C.P.R. and Koshy, P.K. (1998). *Indian Coconut J.,* **29:** 1-3

Sathiamma. B., Pillai G.B. Abraham, J., Bhat, S. K., Jayapal, S.P. and Nair, K.R. (1987b). *J. Plantation Crops.* **15:** 118-122.

Satyabalan, K. and Rajagopal, K. (1987). *J. Plantation Crops*, **15:** 23-30.

Satyanarayana, Y., Ramapandu, S., Rajamannar, M. and Chiranjeevi, V. (1985). *Indian Coconut J.*, **16:** 3-5.

Sayed, P.M. and Narayana, G.V. (1953). *Indian Coconut J.*, **6:** 102-25

Sekhar P.S. (1958). *Indian Coconut J.*, **11:** 67-80.

Selvaratnam, E.M. (1952). *Nature* (London), **69:** 714-715.

Sen, B C. (1956). *Bull. Coconut* (Indian Central Coconut Committee), **10:** 43-45.

Sethi, A.S. and Kartha, A.R.S. (1956). *J. Sci. Indust. Res,*. **15B:** 105-106.

Shanthamalliah, N.R., Venkatesha Gowda, T.N., Krishnamanohar, R., Shivayogishwara, B., and Balakrishna, P. (1982b). In: *Proc. PLACROSYM-V,* Central Plantation Crops Research Institute, Kasaragod, India. December. 15-18, 1982.

Shanthamalliah, N.R., Venkatesha Gowda, T.N., Krishnamanohar, R. and Shivayogishwera, B., (1982a). In: *Proc. PLACROSYM-V*, Central Plantation Crops Research Institute, Kasaragod, India. pp. 402-404.

Sharma, A.K. and Sarkar, S.K (1956). *Genetica*, **28:** 361-488.

Sheela, M.S. (1995). *Indian Coconut J.*, **26:** 5-6

Shirke S.V., Kendurkar, S.V., Apte, A.V., Phadke, C.H., Nadgauda, R.S. and Mascarenhas, A.F. (1993). In: *Advances in Coconut Research and Development* (Nair, M.K., Gopalsundaram, P., Khan., H.H. and Bhaskaro Rao, E.V.V., Eds.), Oxford and IBH Publ. Co. Pvt. Ltd., New Delhi, pp. 235-237

Shivashankar, S., (1988). *Plant Physiol. and Biochem.*, **15:** 87-92.

Shivashankar, S. (1990). *Ph.D. Thesis*, Mysore University, Mysore, India.

Shivashankar, S. (1992). *J.Plantation Crops,* **20** (suppl.): 267-273.

Shivashankar, S. and Kasturi Bai, K.V. (1988). *Philippines J.Coconut studies,* **12:** 24-29.

Shivashankar, S. and George,K.M. (1993). *J. Plantation Crops*, **21**(suppl.): 355-359.

Shivashankar, S. and Nagaraja, K.V. (1996). *Plant Physiol. and Biochem,* **23:** 21-26.

Shivashankar, S., Kasturi Bai,K.V. and Vijayakumar, K. (1986). *Philippins J. Coconut studies,* **11:** 9-12.

Shivashankar, S., Kasturi Bai, K.V. and Rajagopal, V. (1991). *Trop. Agric,* **68:** 106-110.

Sierra, Z.N. and Balleza, C.F. (1972). *National Institute of Science and Technology, Annual Report*, (1971-1972), p. 3.

Simmonds, F. J. (1960). *Bull. Entomol. Res.* **51:** 223-237.

Singh, R.P. and Kartha, A.R.S. (1978). *Indian J. Agric. Sci.* **45:** 389-391

Siqueira, E.R. De and Inoue, M. T. (1992). *Pesquisa Agropecuaria Brasileira*, **27:** 639-646.

Smith, A.C. (1932). *Malaysian Agric. J.*, **20:** 118-22.

Smith, A.C. (1933). *Malaysian Agric. J.*, **21:** 265-71

Smith, G.W. (1966). *J. Appl. Eco.,* **3:** 687-697.

Solomon, J.J., Govindankutty, M.P. and Nienhaus, F. (1983). *Z. Pflkrankh. Pflschutz.* **90:** 295-297.

Solomon, J.J., Nair, C.P.R., Rajan, P., Srinivasan, N., Govindankutty, M.P., Mathen, K. and Pillai, N.G. (1998). In: *Coconut Root (Wilt) Disease* (Nampoothiri K.U.K. and Koshy, P.K., Eds.), Central Plantation Crops Research Institute, Kasaragod, India. pp. 33-44.

Sosamma, V.K., Koshy, P.K., Samuel, R. and Mehta, U.K. (1998). In: *Proc. Third Int. Symp. Afro-Asian Society of Nematologists,* Sugarcane Breeding Institute (ICAR), Coimbatore, India. April 16-19, 1998, pp. 94-97.

Southern, P.J. (1967). *Papua and New Guinea Agric. J.,* **19:** 38-44.

Southern, P.J. (1969). *Oleagineux,* **24:** 211-220.

Spencer, F.M. (1963). *South Pacific Bull.,* **13:** 32- 36.

Srinivasa Reddy, D.V. (1998). In: *Proc. PLACROYSM XIIII*·(Absract), Dec. 16-18, 1998, Coimbatore, India.

Srinivasa Reddy, D.V. and Biddappa, C.C. (2000). *J. Plantation Crops,* **28:** 1-16.

Srinivasa Reddy, D.V. and Arunachalam, V. (2002). *Indian Coconut J.,* **32:** 1-3.

Srinivasa Reddy, D.V., Ratnambal, M.J. and Gopalasundaram, P. (1996). *Indian Coconut J.,* **27:** 5-7.

Srinivasa Reddy, D.V, Biddappa C.C and Gopalasundaram, P. (1998a). *Indian Coconut J.,* **29:** 6-8.

Srinivasa Reddy, D.V., Subramanian, P. and Gopalasundaram, P. (2000b). *Abstract No.12, (PLACROSYM XIV), Int. Conf. on Plantation Crops,* held at Hyderabad from Dec. 15-18, 2000.

Srinivasa Reddy, D.V. and George V. Thomas. (2001). In: *Mixed Cropping of Black Pepper in Coconut and Arecanut Gardens. Technical Bulletin No. 42.* Central Plantation Crops Research Institute, Kasaragod, India. p. 20.

Srinivasa Reddy, D.V., Naresh Kumar, S. and Prabhu, S.R. (2001). *J. Plantation Crops,* **29:** 62-65.

Srinivasa Reddy, D.V., Dhanpal, R., Palaniswamy, C. and Maheshwarappa, H.P. (1998b). *J. Plantation Crops,* **26:** 57-60.

Srinivasa Reddy, D.V., Upadhyay, A.K., Gopalasundaram, P. and Khan, H.H. (2001). *Nutrient Cycling in Agro ecosystems,* Netherlands. **59:** 1-8

Srinivasan, K.S. Indira, K. and Chandrasekharan, M.R. (1964). *Indian J. Biochem.* pp. 146-148.

Srinivasan, N. and Gunasekaran, M. (1992). *Indian Coconut J.,* **23:** 2-6

Srinivasan, N. and Gunasekaran, M. (1993). *Indian Coconut J.,* **23:** 2-7

Srinivasan, N. and Gunasekaran, M. (1994a). *CORD,* **10:** 34-50

Srinivasan, N. and Gunasekaran, M. (1994b). *Philippines J. Coconut Studies,* **19:** 26-27.

Stebbins GL (1950). *Variation and Evolution in Plants,* Oxford & IBH Publ Co, Bombay India.

Stoler, A. (1975). *Ph.D. Thesis,* Colombia University, New York, USA.

Sujatha, A. (2000). *Ph.D. Thesis,* Mysore University, Mysore, India. p. 215

Sumangala Nambiar S. (1991). In: *Coconut Breeding and Management* (Silas, E.G., Arvindakshan, M. and Jose, A. Eds.) Kerala Agricultural University, Vellanikkara, Trichur, India.

Sumathykutty Amma, B. (1964). *Curr. Sci.* **33:** 49-50.

Sumathykutty Amma, B. and Patil, K.D. (1985). *J. Plantation Crops,* **12:** 182-184.

Sunderaraman, S. (1922). *Agric. Res. Inst., Pusa Bull.,* p. 127.

Sun-J.H., Yu, P.Y. and Zhang, Y.Z. and Wang, X.J. (2003). *Entomological Knowledge.* **40:** 286-287.

Surany, P. (1960). *Diseases and Biological Control of Rhinoceros Beetles (Oryctes Spp.) South Pacific Commission Tech. Paper No. 182*. p. 62.

Swain, S.C., Sahoo, S.C., Panda, J.M. and Rath, S. (2002). *The Horticultural J.*, **15:** 17-21.

Swaminathan, M.S. and Nambiar, M.C(1961). *Nature*, **292:** 85-86.

Swaminathan, M.S. (1983) In: *Coconut Research and Development* (Nayar, N.M. Ed.), Wiley Eastern Ltd., New Delhi India, pp. 3-11.

Taffin, G. De, Zakra, N., Pomier, M., Braconnier, S., Weaver, R.W. and De-Taffin, G. (1991). *Oleagineux*, **46:** 489-500.

Taylor, T.H.C. and Paine, R. W. (1935). *Bull. Entomol. Res.* **26:** 1-102.

Tempany, H. (1954). *World Crops* **6:** 62-65.

Terra, G.T.A. (1954). *Malaysian J. Trop. Geography*, **4:** 33-34.

Teulat, B., Aldam, C., Trhin, R., Lebrun, P., Barker, J.H.A., Arnold, G.M., Karp, A., Baudouin, L. and Rognaon, F. (2000). *Theor. Appl. Genet.* **100:** 764-771.

Thampan, P.K. (1972). *Coconut Culture in India*, Green Villa Pub. House, Cochin (India).

Thampan, P.K. (1976). *The Coconut Palm and its Products*. Green Villa Pub. House, Cochin (India).

Thampan, P.K. (1984). *Profitable Coconut Growing*. Coconut Development Board, Cochin. p. 72.

Thampan, P.K. (1989). *Hand book on Coconut Palm*. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi. p. 311.

Thankamma Pillai P.K., Vijayakumar, G. and Ravindran, P.N. (1983) In: *Coconut Research and Development* (Nayar, N.M. Ed.), Wiley Eastern Ltd., New Delhi India.

Thankamma Pillai, P.K and Vijayakumar, G (1972). *Indian Genet.*, **32:** 303

Thomas, George V., Prabhu, S.R., Reeny, M.Z and Bopaiah, B.M. (1998). *World J. Microbiol. and Biotech.*, **14:** 879-882.

Thomas, George, V. and Shantaram, M.V. (1984). *Plant & Soil*, **80:** 373-380.

Thomas, George, V. and Shantaram, M.V. (1986). In: *Workshop on Beneficial Microbes in Tree Crops Management*, Central Plantation Crops Research Institute, Kasaragod, India. Sept. 8-9, 1986. p. 8.

Thomas, K.M. (1974) *East African Agri. J.*, **40:** 152-156.

Thompson. W. R. (1943). *A Catalogue of the Parasites and Predators of Insect Pests*. Commonwealth Bureau Biol. Control, Ottawa, Canada.

Triques, K., Rival, A., Beule, T., Puard, M., Roy, J., Natao, A., Lavergne, D., Havaux, M., Verdeil, J.L., Sangare, A. and Hamon, S. (1997c). *Plant Sci.*, **127:** 39-51.

Triques, K., Rival, A., Beule, T., Puard, M., Roy, J., Nato, A., Lavergne, D., Havaux, M., Verdeil, J.L., Sangare, A. and Hamon, S. (1997a). *Plant Sci.*, **127:** 39-51

Triques, K., Rival, A., Beule, T., Dussert, S., Hocher, V., VerdeiL, J.L. and Hamon, S. (1997b). *Plant Cell, Tissue and Organ Culture*, **49:** 227-231.

Tulecke, W., Weinstein, L.H. Rutner, A. and Laurencot, J.R.H.J.(1961). *Contr. Boyce Thomp.Inst.* **21:** 115-128.

Twyford, I.T. and Wright, A.C.S.(1965). *The Soil Resourses of the Fiji Islands*.Vol.I, Govt. of Fiji, Suva, pp. 142-168.

Uexxkul, H.R., Von. (1972). *Oleagineux*, **27:** 13-19.

Ultaman, P. (1949). *Curr. Sci.* **7:** 251-252.

Ummar Kutty, O.V (1955). *Indian Coconut, J.,* **8:** 74-78.

Upadhyay, A., Jose, J., Manimekalai, R. and Parthasarathy, V.A. (2002). In: *Managing Plant Genetic Resources*, (Engels, J.M.M., Brown, A.H.D. And Jackson, M.T. Eds.), CAB International, Oxford, London. pp. 61-66.

Upadhyay, A., Jayadev,K., Manimekalai,R. and Parthasarathy,V.A. (2004). *Scientia Horticulturae*, **99:** 353-362.

Van Overbeek, J., Conklin, M.E. and Blakeslee, A.F. (1941). *Science*, **94:** 350-351.

Vanderbelt, J. (1945). *Nature,* **156:** 174-175.

Vanderplank, F. L. (1958). J. *Entomol. Soc. South Africa,* **29:** 309-314.

Varghese, E.J., Krishna Marar, M.M., and Thomas, P.K. (1953). *Indian Coconut J.*, **6:** 49-56.

Varghese, M. K. (1934). *Disease of Coconut Palm*. Department of Agriculture and Fisheries, Travancore. p. 105.

Varghese, P.T., Nair, P.K.R., Nelliat, E.V., Rama Varma and Gopalasundaram, P. (1978). In: *Proc. (PLACROSYM–I)* (Nelliat, E.V. *et al*, Eds.), Indian Society for Plantation Crops, Central Plantation Crops Research Institute, Kasaragod, India. pp. 399-415.

Varghese, P.T., Nelliat, E.V., Rama Varma and Balakrishnan, T.K. (1978). In: *Proc. (PLACROSYM –I)* (Nelliat, E.V. *et al.*, Eds.), Indian Society for Plantation Crops, Central Plantation Crops Research Institute, Kasaragod, India. pp. 383-392.

Vasey, D.E. (1985). *Food and Nutrition Bull.,* **7:** 37-43.

Veeresh, G.K. (1983). In: *Coconut Research and Development* (Nayar, N.M., Ed.), Wiley Eastern Ltd., New Delhi. pp. 385-391.

Venkatasubbayya, K.V. (1945). *Proc. Indian Acad. Sci.,* **B 22 :** 193-207.

Verdeil, J.L. and Buffard Morel, J. (1995). In: *Biotechnology in Agriculture and Forestry* (Bajaj, Y.P.S. Ed) Vol.30:299- 317.

Verdeil, J.L., Baudouin, L., Hocher, V., Bourdeix, R., n'cho, Y.P., Sangare, A., Rilo, E., Oropeza, C and Hamon, S. (1998). *Plantations, Researche and Developpement,* **52:** 339- 342.

Verdeil, J.L., Huet C., Grosdemange, R. and Buffard-Morel, J. (1994). *Plant Cell Rep.* **13:** 218-221.

Vidyasagar, P. S. P. V. (1989). *Extension Folder No. 16*, Central Plantation Crops Research Institute, Kasaragod, India. p. 4.

Vidyasagar, P.S.P.V. and Bhat, S.K. (1991). *J. Plantation Crops,* **19:** 163-182.

Vijayaraghavan, H., Raveendran, T.S. and Ramanathan, T. (1989). *Indian Coconut J.*, **20:** 1-5.

Visalakshi, A., Beevi, S.N. Pillai, K.S., Nair, K.K.R. and Das, N.M. (1987). *Entomon,* **12:** 395-396.

Viswanathan, R., Guruswamy, S.N. and Aseervatham, J.R. (1966). *Madras Agric. J.*, **53:** 429-432.

Viswanathan, T.V., Radhakrishnan, V.V., Reghunath, B.R. and Prasannakumari, K.T. (1992). *Indian J. Agric. Sci.,* **62:** 616-617.

Viswanathan, T.V., Reghunath, B.R, Radhakrishnan, V.V., Prasannakumari, K.T. and Sosamma Cheriyan. (1993). *Indian Perfumer,* **37:** 12-13.

Voleti, S.R, Shivashankar, S. and Rajagopal. V. (1988), *J.Plantation Crops*, **18** (suppl.): 104-107.

Voleti, S.R., Kasturi Bai, K.V., Nambiar, C.K.B. and Rajagopal, V. (1993). *Oleagineux*, **46:** 505 - 509.

Wadt, L.H.O., Sakiyama, N.S., Pereira, M.G., Tupinamba, E.A., Ribeiro, F.E. and Aragao, W.M. (1999). In: *Current Advances in Coconut Biotechnology*. (Oropeza, C., Verdeil, J.L. And Ashburner, G.R., Eds.) Kluwer Academic Publishers. pp. 89-97.

Wernigg, A.T. (1932). *Trop. Agric.*, **79:** 349-352.

Wickremasuriya, C.A. (1968). *Ceylon Coconut Quart.*, **19:** 152-160.

Wilshaw, R.G.H. (1941. *Malay Agric. J.*, **29:** 267-72.

Wilson, K.S. and Cutter, Jr. V.M. (1952b). *Amer. J. Bot.*, **39:** 57-58.

Wilson, K.S. and Cutter Jr. V.M. (1955). *Amer. J. Bot.*, **42:** 116-119.

Wuidart, W(1981). *Oleagineux*. **36:** 367-376.

Young, E.C. (1974). *J. Invertebrate Pathol.*, **24:** 82—92.

Zelazny, B. (1973). *J. Invertebrate Pathol.*, **22:** 122-126.

Zelazny, B. (1977a). *J. Invertebrate Pathol.*, **29:** 210- 215.

Zelazny, B. (1977b). *FAO Plant Prot. Bull.* **25:** 73-77

Zelazny, B (1979). *J. Invertabrate Pathol.*, **33:** 106-107.

Ziller, R. (1960). *Oleagineux*, **15:** 73-81.

Ziller, R. and Fremond, A. (1961). *Oleagineux*. **16:** 293-302.

Zizumbo Villarreal, D., Cardena Lopez, R. and Pinero, D.(2002). *Genetic Resources and Crop Evolution*. **49:** 237-245.