Coconut Based Cropping/Farming Systems

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FOREWORD

The coconut (*Cocos nucifera* L) palm, venerated as Tree of life, bestows multiple benefits to humankind by providing food, medicine, health drink, shelter, fuel, timber, fibre and an array of industrial products. As a crop of small and marginal farmers in India, the income derived from small holdings is not sufficient enough to sustain the livelihood of even the small farm families. Efficient utilization of resources such as solar radiation, soil, water and labour becomes important for sustainability in a perennial crop like coconut, where the land remains committed to the same crop for several decades. Coconut as a monocrop is a poor resource user and the growth habit and planting pattern of the palm offers immense scope for raising compatible crops in the inter and intra spaces and integrating animal husbandry and subsidiary income generating enterprises.

In India, research on Coconut Based Cropping Systems (CBCS) was initiated during the thirties and was further intensified in the seventies with the establishment of Central Plantation Crops Research Institute at Kasaragod. Several cropping system models have been developed in the institute with crop diversification and intensification to increase the per palm productivity as well as productivity of unit holding in a system approach. The components of the production systems and management practices are selected in such a way to achieve high productivity, profitability and sustainability of the existing coconut gardens by efficient utilization of both on farm and off farm inputs and by regulating the production process to safeguard environment. In depth studies undertaken in an inter-disciplinary mode enabled to generate enormous information on crop compatibility, light utilization, nutrient transformation, complementary and synergistic interactions, dynamics of microbial community and activities, plant health dimensions and the economic viability.

This book on **'Coconut based cropping / farming system'** is a comprehensive compilation of results emanated from research on coconut based cropping / farming systems at CPCRI over several decades. I am confident that it will be useful for farmers, researchers, developmental officials, extension personnel and policy makers. I complement the authors for their efforts in compiling the voluminous information and bringing out in the form of a book.

(H. P. Singh)

Date: 1st December, 2010

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Relevance and opportunities in coconut based cropping/farming systems

R. Dhanapal

Introduction

Coconut is a traditional plantation crop of India and assumes the status of a high value commercial crop. In India, most of the acreage under coconut palm (90%) lies in the four southern states i.e., Kerala, Tamil Nadu, Karnataka and Andhra Pradesh. Kerala ranks first in area (53.76%) and production (45%) followed by Tamil Nadu, Karnataka and Andhra Pradesh. Coconut is mostly a crop of small farmers in India, the average size of a holding being 0.22 ha. More than 90% of the five million coconut holdings in the country are less than one ha in size (Thampan, 1988). The income derived from such small holdings is not sufficient to sustain even the small families. In traditional coconut growing states in India, with mono cropping, the farm yields are poor and farmers are under employed spending only 100 and 120 man-days, under rainfed and irrigated systems of cultivation, respectively. The farm production and productivity are not sustainable. Coconut gardens offer excellent opportunities to exploit the inter-space potential for maximizing returns per unit area. Coconut based cropping/farming systems involving cultivation of compatible crops in the interspaces of coconut and integration with other enterprises like dairying offer considerable scope for increasing production and productivity per unit area, time and inputs by more efficient utilization of resources like sunlight, soil, water and labour. In humid tropics, higher efficiency of utilisation of the basic resources of crop production viz. land, solar radiation and water can be achieved by adopting intensive cropping systems (Nelliat, 1973).

2. Coconut based cropping/farming system

Cropping/farming system aims at crop diversification and intensive cropping in the inter space available in coconut to increase the per palm productivity as well as productivity of unit holding in a system approach wherein the available farm resources like soil and water/rainfall resource, farm labour, agricultural inputs (seeds, fertilizers, agro-chemicals) etc. are utilized to produce both nuts, food and non-food agricultural products from the farm, in a business or profitable way. Under such a cropping/farming system, all the management practices and component production systems should be able to maintain high productivity, profitability and sustainability of the existing coconut palms to maximize economic yield of the farm. Sustainability is the main objectivity of farming system, where production process is optimized through efficient utilization of the inputs in safeguarding the environment.

3. Scope and opportunities for growing intercrops in coconut

3.1. Resource use in coconut

Crown shape and length of coconut leaves necessitate a wider spacing of 7.5 x 7.5 m giving a population of about 175 palms per ha. However, experimental evidences have shown that a sole crop of coconut at this spacing does not fully utilize the available basic resources of crop production, viz., soil, solar energy, water and nutrients.

3.2. Rooting pattern

Coconut palm, like all other monocots, has a typical adventitious root system. Under favourable conditions, as many as 4,000 to 7,000 roots are found in the middle aged palm. 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. Anil Kumar and Wahid (1988) observed that more than 80% of the root activity was confined to a lateral distance of 2m from the trunk. Further studies on adult palm grown under coastal sandy soil confirmed that the mean number of roots produced were 5072. Over 95% of the roots were found in the top 0-120 cm depth out of which 18.9 and 63% of roots were confined to the top 0-30 cm and 31-90 cm depth, respectively. With respect to the lateral spread, percentage of roots emerging from the bole were confined to 2 m radius and only 12.2 and 7.5% of roots were extended up to 3 m and 4 m radius, respectively (Maheswarappa *et al.,* 2000). Thus, the active root zone of coconut is confined to 25% of the available land area and the remaining area could be profitably exploited for raising subsidiary crops. A high efficiency in the use of available soil moisture and nutrients can be achieved by growing intercrops outside 2 m radius around the base of palms.

3.3. Canopy structure and light utilization

The venetian structure of coconut crown and the orientation of leaves allow part of the incident solar radiation to pass through the canopy and fall on the ground. The light intensity at ground level was always higher than 6700 lux at all the periods of the year (Nair, 1979).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 extinction coefficient of around 0.65 for PAR. Age and spacing of coconut palms, soil fertility, varietal characteristics, leaf area and time of the day influence the light penetration through the canopy. With the movement of sun and that 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.

The amount of light transmitted ranges from 5% in a five to ten year old D x T hybrid at a density of 560 palms/ha to about 90% in a 60-70 year old plantation at a density of 120 palms/ha. Nair and Balakrishnan (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 apparent coverage of ground and shade cast by the canopy and the magnitude of radiation transmitted through the canopy vary according to the age of palms as shown in Fig.1 (Nelliat *et al.,* 1974). Besides age, spacing, soil fertility, varietal characteristics and time of the day also influence the light penetration.

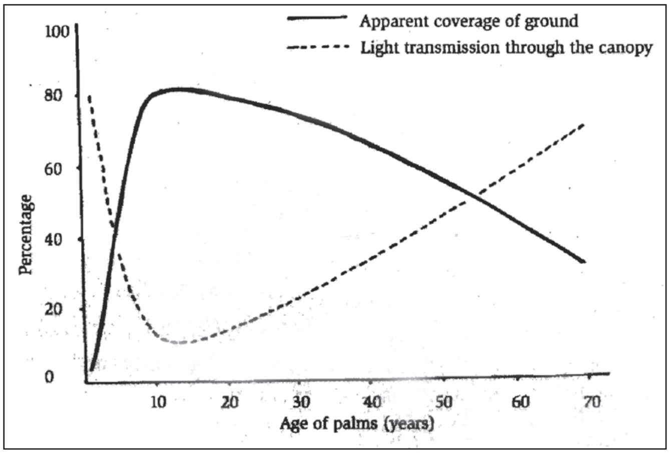

Fig.1 : Apparent coverage of ground by coconut canopies of various age groups (Source: Nelliat *et al.,* 1974)

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.

a. **Planting till full development of canopy (about 5- 8 years):** A major portion of the solar energy is not being intercepted by coconut leaves, good transmission initially, as the palm canopy develops with age, the percentage of utilisation increases progressively during the pre-bearing period, with a corresponding decrease in transmission of light. Suitable for growing annuals/biennials. The suitable crops are cereals, grain legumes, vegetables, spice crops, fruit crops like banana, pineapple etc.

b. **Young palms (8 to 25 years):** Maximum ground coverage and low canopy- moderate to poor light availability- not congenial for multiple cropping. The suitable intercrops are black pepper, chillies, beverage crops like cocoa, coffee, fruit crops like rambutan, mangosteen, citrus etc.

c. **Mature trees (more than 25 years):** Increase in trunk height; reduction in crown size - light transmission increasing with age (high light levels) - the amount of slant rays of sun falling on the ground increases and consequently, the apparent coverage of ground by the canopy of coconut decreases progressively. Ideal for raising annual and / or perennial crops as multiple and multi-storeyed cropping models.

4. Criteria for selection of inter crops

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 which 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 facilities and labour availability.

It is not very necessary always to fulfill all these exacting requirements to have successful crop combinations. But one must ensure that the correct crop is chosen. In most cases failure of inter/mixed cropping is due to the wrong choice of the crop(s).

5. Coconut based cropping/ farming systems research in India

Coconut based cropping/farming systems have received priority in the research programmes in India in recent years. The systems cover inter cropping, mixed cropping, multi-storeyed cropping and mixed farming in coconut holdings.

Intercropping: Growing annuals/biennials in the interspaces of coconut

Mixed cropping: Growing perennials 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 levels (e.g. 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: Other subsidiary enterprises such as livestock, poultry, rabbitary etc. are raised with the help of fodder or pasture grown in the coconut garden.

6. Relevance of Coconut Based Cropping Systems in India

The practice of CBCS can provide:

1. Food security through food sufficiency;
2. Nutritional foods rich in vitamins and minerals (nutrients);
3. Employment generation from farm diversification; and
4. Ecological stability (environmental protection).

6.1. Social benefits: Social benefits are the food and nutritional functions of fresh nuts of coconut and coconut products, and crops produced under CBCS. With CBCS, the same coconut lands can be used to produce various crops: 1) cereals (as source of carbohydrates, protein, fats and oils); 2) root crops (as source of carbohydrates and minerals); 3) legumes (as source of protein and vegetable fats and oils); 4) fruit crops (as rich source of vitamins and minerals, and carbohydrates); 5) leafy and fruit vegetables (as rich source of vitamins, minerals and dietary fibres); 6) spice crops (food flavouring, and vitamins and minerals); 7) coffee and cocoa (beverage and stimulants); 8) natural fibre crops (clothing materials and paper and packaging); 9) wood and timber (housing materials, pulp and paper)

6.2. Ecological benefits: Compared to the ecological conditions of the long-term mono cropping those of lands under CBCS are more favourable and stable for intensive and sustainable agricultural production. This is highly attributed to more efficient utilization of the land resources as a result of: 1) maximization of solar energy capture; 2) optimization of soil moisture use and retention capacities; 3) enhancement of soil fertility build up due to higher biomass generation over time; and 4) minimal soil erosion and nutrient losses largely attributed to effective and efficient crop canopies and root systems. (Magat, 2007).

Thus, totals CBCS environmental value = (Soil conservation + Farm diversification + Nutrient recycling + Fuel energy)

Generally, the value of the coconut based agro ecosystem is based on the direct use as food, raw materials and fuel, but the services rendered by the ecosystem should also be covered. Thus, a more comprehensive functions and services of coconut based ecosystems are given below:

Ecosystem functions	Ecosystem services	Ecosystem services in CBCS
Regulation of atmospheric chemical composition	Gas regulation	CO_2 plant uptake (C sequestration)
Storage and retention of water	Water supply	Improvement of water infiltration and moisture retention
Retention of soil within an ecosystem	Erosion control, sediment retention, & nutrient losses	Prevention of soil loss by runoff, storage of transported silt and clay

Soil formation process	Soil formation	Weathering of rocks and accumulation of organic matter
Soil water conservation & suppression of weeds	Weed control, reduction of soil evaporation & nutrient recycling	Coconut fronds, husk etc. including nitrogen fixation by legumes grown between trees help in weed growth suppression and conservation of soil and moisture
Stabilization of ecosystem integrity in response to environmental stress	Disturbance regulation	Variability of farmers incomes resulting from typhoon damages (by changing the vegetation structure and pattern through intercropping)

(Source: Constanza *et al.* 1997 cited by UPLB and PCA (2002))

6.3. Soil and water conservation: Ground cover minimizes the direct impact of rainfall and the separation of soil aggregates under a coconut environment, which can control soil erosion by 70- 90%, compared to bare soil or un-cropped condition. The micro climate in coconut garden allows other crops or plants to grow favourably between the spaces of palms. The presence of undergrowth vegetation in coconut plantations minimizes soil and water loss through surface runoff. An adequate ground cover can also increase rainwater infiltration and storage, eventually increasing water supply of the entire area. The runoff and soil loss under grass plots and coconut mono crop recorded at CPCRI, RC, Kidu farm are given below:

Parameter	**Control plot**		**Grass plot with drip irrigation**		**Grass plot with farmers' irrigation practice**	
	10th June to 10th July	11th July to 10th August	10th June to 10th July	11th July to 10th August	10th June to 10th July	11th July to 10th August
Rainfall (mm)	779.50	981.00	779.50	981.00	779.50	981.00
Run off (mm)	89.15	145.72	6.62	14.23	6.02	13.94
% run off	11.53	14.85	0.80	1.45	0.77	1.42
Soil loss (t/ha)	3.12	2.84	0.49	0.89	0.42	0.90

(Dhanapal *et al.* 2002)

6.4. Better retention of water: Because of the shade under coconut stand and full canopy coverage evaporative demand is very much reduced and intercropping allows a better retention of water in the soil for a longer period.

6.5. Coconut as a shade tree: Some of the crops require partial shade especially medicinal plant.

6.6. Farm diversification: The diversity in CBCS is very similar to that of plant or crop community diversity in relation with the plant genetic resources conservation and management. In coconut mono-cropping system only about 25% of the soil mass is normally utilized by the crop, the remaining 75% serves as the land resource or habitat for intercrops or other compatible plants in the system. The ecological value of the opportunity provided by coconut to grow an intercrop or several intercrops in mixed and multistorey CBCS is the mean value of the products of intercrops that could stabilize economic incomes of farmers, considering the common fluctuation of copra or nut prices.

6.7. Nutrient recycling: In coconut based farming system there is lot of opportunity for organic recycling. Since CBCS involves growing lot of crops and produces considerable quantity of biomass which could be effectively recycled and put back in to the system.

7. Conclusion

In coconut farming, with or without higher price of nut or copra, the coconut based cropping systems guided by the modern and productive concept and application of basic principles involved, the social, environmental and economic or monetary benefits are substantially enhanced and become highly attractive to coconut farmers.

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Coconut based inter cropping and mixed cropping systems

H. P. Maheswarappa, C. Palaniswami, R. Dhanapal and P. Subramanian

Introduction

Coconut (*Cocos nucifera* L.) is a versatile crop providing food, medicine, health drink, shelter, fuel, timber and fibre. The income derived from such small holdings is not sufficient to sustain even the small families. In addition, coconut as a monocrop provides employment only for about 135 man days/ha under rainfed conditions and 175 man days per ha under irrigated conditions. Consequently the family labour remains unemployed for larger part of the year. In perennial crops like coconut, where the land remains committed to the same crop for several decades, one of the feasible ways of increasing the production is to raise additional crops in the interspaces. Coconut based cropping systems (CBCS) involving cultivation of compatible crops in the interspaces of coconut offer considerable scope for increasing productivity per unit area, time and inputs by more efficient utilization of resources like sunlight, soil, water and labour. Unlike in annuals, the potential for increasing productivity per unit area of land, time and inputs is considerably higher in perennial crops (Bavappa and Jacob, 1982). An agronomically desirable system should ensure that all the components of production are exploited at optimal level ensuring that the long term production capability of the system as a whole is not affected. Study of the response of component crops and the environment of the farming system under a given situation using various parameters is of utmost importance for understanding the dynamics of the systems and making mid-term corrections for their improvement. Though the yields obtained from the tropical perennial plantation crops are high, further yield increases could be achieved by improvements in light interception, conversion efficiency and harvest index (Corley, 1985). He also indicated that minimizing stress with irrigation or fertiliser application increases conversion efficiency in oil palm, coconut, cocoa and rubber. Increase in planting density to achieve early ground cover, careful management of shade and use of varieties with greater tolerance of exposure to full sun light, reduced maintenance respiration and better harvest index are the other factors suggested by Corley as pathways for increasing yield. The interaction effects in intercropping systems are more complex than monocultures or sequential systems since they vary as widely as over storey crops with coffee and cocoa or legume grass pasture mixture (Allen *et al.,* 1976). Intercropping is popular because of many advantages like, increased productivity per unit area, better use of available resources (land, labour, time, light, water and nutrients), reduction in damage caused by pests, diseases and weeds and socio-economic factors (greater stability, economics, human nutrition and biological aspects) (Vandermeer, 1989). The desirable characters of crops to be grown under or between a tree crops have been described by Allen (1955) and Hartley (1977).

Earlier workers have also reviewed the research carried out on coconut based intercropping and cropping system in India (Nair, 1979; Rethinam and Venugopal, 1994; Reddy and Biddappa, 2000). In this review elaborate work on the system approach, its impact on soil characters, socio-economic benefits and recycling of biomass from cropping system are presented and discussed.

2. Research work on coconut based cropping systems

In India, research on CBCSs was initiated during the thirties at the Coconut Research Stations at Kasaragod, Pilicode and Nileshwar and was intensified in the seventies with the establishment of Central Plantation Crops Research Institute at Kasaragod and AICRP on Palms with centers in different coconut growing states. A number of CBCSs involving annuals, biennials, perennials and combinations of both annuals and perennials have been developed to suit the farmers' needs, availability of resources like labour, rainfall, irrigation facilities, finance soil characteristics and market demand. The crops found suitable for raising as subsidiary crops in coconut gardens include tuber crops, rhizomatous spices, cereals, pulses, oilseeds, fruit crops, vegetables, and medicinal and aromatic plants among the annuals and beverage crops and spices among the perennials.

3. Management of the cropping systems

3.1. Selection of suitable component crops

The success of a crop mixing programme under coconuts depends very much on the selection of compatible crop combinations in which each crop will exploit a distinct and different zone of atmosphere and soil so that individual competition for moisture, nutrients, space and solar radiation will be the minimum. When the individual crops in the system utilise mutually exclusive rooting zones, the demand for additional nutrients and moisture need not necessarily be directly proportional to the cropping intensity adopted. Differential root activity under crop mixing not only enables better utilisation of the native and added nutrients but also prevents loss of nutrients from leaching and mobility (Thampan, 1980).

A large variety of crops have been found suitable for growing under irrigated and rainfed conditions in coconut garden. The important successful crops among them are listed in Table 1.

Unlike in annual crops, intercropping in coconut need not affect the productivity of the main crop. The selection of crops should be such that they make best use of the natural resources without unduly competing with coconut. Although the intercrops may not compete with coconut for light, they are likely to compete for soil moisture and nutrients. If these two inputs are supplied as per the requirements of various crops, there will not be any adverse effect on coconut yield.

Table 1. Annual and perennial crops grown in coconut garden as mixed crops

Crops	References
1. Tubers/Root crops and Rhizomatous spices Cassava, Elephant foot yam, Sweet potato, Greater yam, Lesser yam, Chinese potato, Colocasia, Ginger, Turmeric, Potato	Nair (1979), Varghese *et al.*(1978b), Ramakrishnan Nayar and Sadanandan (1990), Maheswarappa *et.al* (2003)
2. Cereals and millets Rice, Pearlmillet, Fingermillet, Baragu, wheat	Gopalasundaram and Nelliat (1979)
3. Pulses and Oilseeds Cowpea, Green gram, Black gram, Redgram, Ground nut, Soybean, Bengalgram, Sunflower	Gopalasundaram and Nelliat (1979), Potty (1978), Hegde and Yusuf (1993)
4. Vegetable crops Chillies, Potato, French bean, Snake gourd, Amaranthus, Brinjal, Bottle gourd, Ridge gourd, Coccinia, Dolichos bean, Tomato,	Rethinam (1989), Hegde *et al.* (1993),
5. Fruit crops Banana, Pineapple, Papaya, Guava, Lemon, Lime	Nelliat *et al.* (1974), Nair (1977), Gopalasundaram and Nelliat (1979), Gopalasundaram *et al.* (1993), Maheswarappa *et al.* (2003a), Subramanian *et al.* (2009)
6. Fodder crops Pusa Giant, Hybrid napier-NB-21 and BH18, Guinea grass, Stylosanthes, Fodder cowpea, Mochi (*Lab-lab purpureum*), Hybrid napier PBN-16, Hybrid napier DHN 3 + Centrosema, Hybrid bajra napier (CO-3), Hybrid napier + *Stylosanthes gracilis*	Ramakrishnan Nayar and Sahasranaman (1978), Jacob Mathew and Shaffee (1979), Sahasranaman *et al.* (1983), Maheswarappa and Hegde (1995), CPCRI (2004), Subramanian *et al.* (2007)
7. Medicinal and Aromatic crops Chittadalodakam (*Adhatoda beddomei*), Karimkurinji (*Nilgirianthus ciliatus*), Nagadanthi (*Baliospermum montanum*), Vetiver (*Vetiveria zizanioides*), Indian long pepper (*Piper longum*)	Maheswarappa *et al.* (2008a), CPCRI (2008), CPCRI (2003)

8. Flowering crops Heliconia, Anthurium, Jasminum sp.	CPCRI (2003), Arunachalam and Reddy (2007)
9. Tree crops *Acacia mangium, Acacia auriculoformis, Casuarina equisetifolia, Ailanthus* sp., *Tectona grandis, Tamarindus indica, Erythrina indica*	CPCRI (1989)
6. Spices/Tree spices Black pepper, Vanilla, Nutmeg, Cinnamon, Clove,	Nelliat *et al.* (1974), Nair (1977), CPCRI, (1984), Maheswarappa and Anitha Kumari (2002), Maheswarappa *et al.* (2003b), CPCRI (2009)
7. Cocoa	Nelliat *et al.* (1974), Nair (1977), Abdul Khader *et al.* (1984), Bavappa *et al.* (1986), Nair *et al.* (1975)
8. Mulberry	CPCRI (2002)

The success or failure of a coconut based farming system is often decided by the choice of the system components. Studies on the shade response of different intercrops revealed sweet potato as shade sensitive, coleus and colocasia as shade tolerant and ginger and turmeric as shade loving. Attempts have also been made to identify varieties suitable for multiple cropping situations in crops like banana, pepper, ginger and turmeric.

3.2. Irrigation

Water requirement of any crop is very much influenced by the evaporative demand of the climate. When other crops are introduced under coconuts there will be a perceptible change in the microclimate of the area favouring a reduced rate of evapotranspiration. Consequently, the overall water use efficiency increases in a multi-cropping system and under certain situation, the combined water requirement of all the crops in the system may remain almost the same to that of coconut alone in the same area (Thampan, 1980). In a mixed cropping trial conducted at the CPCRI, Kasaragod, India, involving a crop combination of coconut, cocoa, pepper and pineapple, the observation over a period of seven years revealed that there was considerable reduction in the irrigation requirement once the crop-mix got established. Crop growth and productivity were not affected when irrigation was given at wider intervals as compared to the frequency adopted during the initial years of the trial (Nelliat, 1978). Mixed cropping in coconut should be practiced only with assured water supply conditions during summer months. Sprinkler irrigation or perfo sprays is most suitable for the inter or mixed cropping systems where the entire area is required to be wetted. As the water is conveyed through pipes, irrigation efficiency in sprinkler or perfo-spray is high compared to flood or basin irrigation. The quantity of water applied should be at least equal to 75% of the open pan evaporation. In the mixed farming system, wherein fodder grasses and legumes are grown in the interspaces, overhead sprinkler will be an ideal choice (Maheswarappa *et al.*, 1998). However, in multi-storeyed or high density cropping systems, where a large number of tall perennial plants are included, perfo-spray is preferable. During the initial years, when the canopy size of mixed crops is small, banana can be raised in the space available which will serve as the shade for mixed crop seedlings and also gives additional returns to the grower. In mixed cropping, since a number of crops are grown over a given area of land, a greater depletion of the plant nutrients may occur in the soil. Hence, it is necessary that recommended dose of fertilizers for each crop be applied individually to all the crops in the system. As far as possible the crop residues should be recycled to the plot by way of mulch or by incorporation into the soil. This also provides conducive environment for the multiplication and activity of beneficial micro-organisms. Irrigation through perfo irrigation was the best method for adoption in mixed cropping system for uniform distribution of water to all the crops. Water to a depth of 20 mm at the IW/CPE ratio of 1.0 is optimum for higher productivity in the system (Reddy *et al.*, 2002 and Maheswarappa *et al.*, 2003b).

3.3. Weed management

Maheswarappa *et al.* (2003b) have reported that crops like pineapple are prone to be infested with weeds during early growth stages and need more labour for wedding. Under HDMSCS, weeds grown in the interspaces are slashed and left in the field itself which will be contributing for recycling (CPCRI, 2003, CPCRI, 2004).

4. Resource use, productivity, socio-economic and other benefits of coconut based intercropping and mixed cropping systems

Intercropping as applied to plantation crops refers to growing annuals in the interspaces of the main crop. Studies on intercropping with special reference to plantation crops have received scientific attention only in the recent past. The emphasis was that the yield of the main crop of coconut should not decrease due to the growing of intercrops. Studies on intercropping in coconut stands were initiated in the thirties at the Coconut Research Station (CRS), Kasaragod and Pilicode (Kerala, India).

The desirability of raising annuals or perennials in the interspaces of coconut and the advantage arising out of such practices was earlier recognised by Nelliat (1973). Gopalasundaram and Nelliat (1979) have reviewed the work on intercropping with different crops in coconut garden in India.

Tuber crops

Many tropical tubers like cassava, elephant foot yam, colocasia, chinese potato, sweet potato, greater yam and lesser yam are among the most popular intercrops raised in coconut gardens (Gopalasundaram and Nelliat, 1979 ; Hegde *et al.,*1990). The tuber crops partially meet the food requirements of a farm family and almost always find a place in the homestead gardens of Kerala (Varghese *et al.,* 1978b). In an intercropping trial of coconut with tuber crops at CPCRI, Kasaragod, India there was a general reduction in the yield of coconut when the intercrop alone was manured, but no such reduction was noticed when both the intercrop and the main crop were manured (Varghese *et al.,*1978b). There was increase in yield of coconut in the plot intercropped with elephant foot yam and yam under root (wilt) affected coconut garden. The cost benefit analysis showed that coconut + tapioca combination gave the highest net return per rupee invested (Sethumadhava Menon and Ramakrishnan Nayar, 1978).

Rhizomatous spice crops

Ginger and turmeric are the important spice crops commonly intercropped in coconut gardens (Varghese *et al.,* 1978b ; Hegde *et al.,* 1990). Better performance under the partially shaded conditions, assured market demand, easy processing and long storage life are some of the factors that favour growing of the spice crops. Among nine varieties of turmeric tried as intercrop in coconut, Sugantham, Wynad Local and T. Sunder performed well yielding 18.9, 18.1 and 17.4 tonnes / ha of fresh rhizomes under rainfed condition (Potty *et al.,* 1979). Later studies have indicated that the varieties VK 31, VK 116 and Vandimitta are also suitable for intercropping in coconut gardens.

Millets and Cereals

Experiments conducted at Pilicode (Kerala) during the late thirties and early forties have shown that millets like varagu (*Paspalum scrobiculatum*), pearl millet (*Pennisetum typhoides*) and finger millet (*Eleusine coracana*) performed well as intercrops in coconut garden. Sowing of these crops is preferably taken up at the beginning of the south-west monsoon season or just after the receipt of summer rains. However, due to lack of demand, these crops are not popular at present. Rice being the staple food crop of Kerala attempts were made to identify suitable upland varieties for intercropping in coconut at CPCRI, Kasaragod (Gopalasundaram and Nelliat, 1979).

Oilseeds

Groundnut and soybean have been reported to be compatible intercrops with coconut. At Pilicode the groundnut variety TMV-2, yielded as much as 1326 kg pods and 1448 kg haulms/ha and was highly profitable. Studies at Kasaragod have shown that soybean can be successfully grown as an intercrop during the post-rainy period under irrigated conditions. The variety PK-472 had recorded the highest yield of 980 kg/ha. Soybean cv. CO1 raised as an intercrop in 40 and 60 year old coconut gardens yielded 610 and 750 kg/ha respectively (Hegde and Yusuf, 1993) and growing soybean did not affect the yield of coconut.

Vegetables

Only limited work has been done on intercropping vegetables in coconut gardens. Rising of chillies, potato and beans was found to be a profitable practice in maidan areas of Karnataka. Experiments at Kasaragod have indicated the suitability of vegetables like snake gourd, bottle gourd, brinjal, coccinia and bitter gourd as compatible crops with coconut (Hegde *et al.*, 1993).

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

A number of perennials like cocoa, clove, nutmeg, coffee, pepper, mulberry, jack, breadfruit, mango, sapota, papaya and timber yielding trees can be grown in association with coconut. Studies carried out at CPCRI and elsewhere have revealed that cocoa, pepper, clove and nutmeg are the most compatible crops with coconut and can be grown as mixed crops in the west coast region.

Cocoa

The combination of cocoa and coconut has been found to be the most remunerative and mutually beneficial among the different crop combinations. Cocoa, being a shade loving plant, is quite ideal in coconut gardens where the shade cast by the adult palms is optimum for its growth. There is no serious competition for nutrients and moisture between the two crops because of the mutually exclusive rooting zones. Coconut is a monocot while cocoa is a dicot. This situation is again favourable in nutrient utilisation as there is a difference in the preference for certain nutrient elements by dicots and monocots (Thampan, 1980). Cocoa has been found to be suitable for mixed cropping with coconut in South India (Nair *et al.*, 1975). In a mixed crop experiment at CPCRI, Kasaragod, the average increase in the yield of coconut under 'single hedge', and 'double hedge' with cocoa, worked out to be 68 and 115.9 per cent, respectively over the pre-experimental yield of the corresponding groups (Table 2) (Nair *et al.*, 1975). Nair and Gopalasundaram (1990) have reported that the increase in coconut yield under coconut monocrop was only 57.4% whereas, it was 91.2% and 125.6%, respectively under single hedge and double hedge system of mixed cropping with cocoa. Further it was reported that a significant decrease in per plant yield in cocoa when resorted to double hedge planting as compared to the single hedge system between coconut rows. Yield of cocoa was significantly more in the singe hedge system (25.5 pods/plant) compared to the double hedge system (13 pods /plant) (Nair and Gopalasundaram, 1990). The additional increase in yield of coconut under mixed cropping with cocoa could be due to the synergistic effect of crop combination. Nair and Varghese (1976) found an increase up to 55 per cent in coconut yield when mixed with cocoa as compared to pure crop of coconut.

Table 2. Total productivity of coconut and cocoa mixed cropping

Treatment	Plant population/ha		Mean yield of coconut (Nuts/palm/year)			Cocoa (pods/ plant/ yr)
	Coconut	Cocoa	Pre-Exptl. Period	Exptl period (1972-87)	Increase (%)	(1985-87)
Coconut sole crop	175	-	68	107	57.4	-
Coconut + single hedge cocoa	175	350	57	109	91.2	25.5
Coconut + double hedge cocoa	175	650	39	88	125.6	13.0

(Nair and Gopalasundaram, 1990)

Varghese *et al.* (1978a) have reported the amount of shed leaves collected at fortnightly intervals for one year period amounted to 818 kg and 1785 kg/ha/year (oven dry), respectively under single and double hedge systems of cocoa. The organic carbon content and the soil fertility improved considerably under the mixed crop and was reflected in the enhanced yield of coconut (Table 3). Based on the nutrient composition of the cocoa leaves, under the double hedge system, about 50 kg N, 11 kg P_2O_5 and 35 kg K_2O/ha/year were returned to the soil through leaf fall.

Table 3. Organic carbon content in the soil during 1978

Treatment	Organic carbon (%)		
	Pre-experimental period	Experimental period	
	0-30cm	0-15cm	15-30cm
1. Unirrigated coconut	0.2-0.3	0.36	0.27
2. Irrigated coconut	0.2-0.3	0.56	0.56
3. Coconut + cocoa in single hedge + pineapple + pepper	0.2-0.3	0.61	0.56
4. Coconut + cocoa in double hedge + pineapple + pepper	0.2-0.3	0.70	0.58

(Varghese *et.al.*, 1978)

Nair and Balakrishnan (1976) have measured the intensity of light falling on the ground at different times of the day in a coconut-cacao crop mix during different seasons of the year at CPCRI, Kasaragod, India. Results indicated that during the peak bright hours of the day (10.00-14.00 hr.), an average of 44% light was intercepted by coconut in a pure palm stand. Of the 56% sunlight available for cacao, the crop was able to intercept 63%

when it was planted in a single hedge and at least 76% when planted in double hedges as a mixed crop with coconut. But the light available for cacao on a per plant basis was less in double hedge, and this could be one of the reasons for lesser yield per plant in double hedge than in single hedge.

Experiments on mixed cropping of coconut and cocoa under unirrigated conditions at Pilicode, Kerala have shown that cocoa as mixed crop had not influenced the productivity and bearing habit of coconut. The double hedge system of cultivation of cocoa in the interspaces of coconut (spaced at 9 x 9 m apart) was found to be superior to the single hedge with respect to the yield and economic return obtained per ha. Even in the double hedge system of raising cocoa under coconut, no crop or plant competition was observed (Abdul Khader *et al.,* 1984).

Nair and Gopalasundaram (1990) have reported that under multi-storeyed cropping system, pepper and cocoa performed better and during the first six years, pineapple could yield to the tune of 1.2 kg fruit /plant and later could not perform well due to shading of cocoa. The coconut yield (nuts per palm per year) was increased to 115 (1985-87) from pre-experimental yield of 45.6. Economic analysis has shown that this combination could generate a net return of Rs. 30,000/per ha/year as compared to Rs. 17,100/per ha /year from middle aged irrigated coconut mono crop. This system provides employment for 335 mandays/ha/year and gives B:C ratio of 1.76. While working out economics of cocoa mixed cropping with coconut in India, Das (1984) has reported that the coconut-cocoa system as a whole promises a higher net return compared to coconut monoculture.

Nair and Rao (1977a and b) reported the intense microbial activity in the rhizosphere of coconut with cocoa as mixed crop. The dominant N-fixing bacterium in the rhizospheres of coconut and cocoa as well as on the root surface of coconut was a specific of *Beijerinckia* (Table 4). Several micro organisms like *Pseudomonas* sp. and *Aspergillus niger* isolated have the ability to solubilise tricalcium phosphate. Among the bacterium isolated, an isolate of *Escherichia* sp. was found closely associated with the root surface. Among the many rhizosphere fungi tested, two isolates, *Aspergillus flavus* and *A. fumigatus*, produced Gibberellin like substances (GLS).

Beneficial changes in ecoclimatic parameters have been reported in coconut + cocoa combination compared to monocrop (Nair and Balakrishnan, 1977). Their studies revealed that the microclimate inside a crop mix is more equitable than that in monocropped stands. The crop mixes recorded lower mean maximum temperature (Table 5), higher relative humidity and reduced evaporative demand. Varghese *et al.* (1978) have reported that soil temperature at 30 and 60 cm depths was 3 to 6°C lower and the variation in the mean

Table 4. Number and nature of micro-organisms (per g dry rhizosphere soil in the rhizosphere of coconut under mixed cropping with cocoa) during July 1974

Nature of isolates	Non rhiosphere soil	Mixed cropping with cacao				
		Coconut without Cacao	Single hedge		Double hedge	
			Coconut	Cacao	Coconut	Cacao
Total bacteria (10^6)	48	140	152	80	200	104
Total *Beijerinckia* (10^3)	0	3	3	5	4	9
Total phosphate - solubilising bacteria (10^6)	0	3	4	2	4	8
Total *Actinomycetes* (10^6)	1	2	2	3	4	5
Total fungi (10^4)	10	22	76	11	90	14

(Nair and Rao, 1977a)

Table 5. Average air temperature variations (November 1975 to May 1976) at two heights expressed as deviation from the corresponding values at ground level

Height above ground (cm)	Deviations (± 0 C)				
	*1	*2	*3	*4	*5
8h00: 100	-0.4	-0.1	+ 0.3	+ 0.5	+ 0.5
200	-0.8	0	+ 0.2	+ 0.7	+ 1.0
14h30: 100	-2.1	-1.3	-0.8	+ 0.2	-0.1
200	-2.8	-1.9	-1.3	+ 0.3	+ 0.3

(Nair and Balakrishnan, 1977)

monthly soil temperature was the least in the mixed cropping system of coconut + cocoa compared to the monoculture of coconut.

*1 Open area. *2 Unirrigated coconut *3 Irrigated coconut *4 Coconut + cocoa, at 30 cm from base of cocoa *5 Coconut + cocoa, centre of four cocoa

The increase in annual productivity of coconut by following mixed cropping of cocoa has been reported by many workers (Nelliat *et al.*, 1974; Nair, 1977; Varghese *et al.*, 1978; Kamalakshi Amma *et al.,* 1982; Abdul Khader *et al.,* 1984 and Nair and Gopalasundram, 1990).

Perennial Spices

Among the perennial spices, pepper is an important spice crop which is commonly cultivated in coconut garden. The review of work done on pepper mixed cropping with coconut plantations in different agro climatic zones of the country has established its suitability as a remunerative crop in various cropping models (Reddy and Thomas, 2001). As early as 1971-72, Panniyur-1 variety of pepper planted as mixed crop and trailed on palms aged over 60 years in one ha plot at CPCRI, Kasaragod yielded a mean of 2 kg dry pepper /vine/year (CPCRI, 1977). The highest yield was 5.5 kg pepper/vine/year (CPCRI, 1977). Among the various mixed crop combinations studied at CPCRI, Kasaragod, economics of coconut-pepper system was found to be more remunerative. This system could generate a net return of Rs.26,200/ha/year in a mixed cropped coconut garden as compared to Rs.22,300/ha/year from coconut mono crop. While evaluating the performance of six varieties of pepper in the multi-storeyed cropping system Potty *et al.,* (1979) suggested that Karimunda and Panniyur-1 varieties perform better under mixed cropping situations.

Experiments of CPCRI, Kasaragod on coconut mixed with pepper, clove, nutmeg and cocoa indicated that clove could yield 3 kg dry flowers, nutmeg average 1.5 to 2.0 kg mace and 8 to 12 kg nuts. The highest net return was obtained with coconut + nutmeg cropping system (Rs. 94,300/ per ha) followed by coconut + clove (Rs. 46,800/- per ha) compared to coconut + pepper (Rs. 26,200/-) and coconut + cocoa (Rs. 31,400/-). The net return under coconut alone was only Rs. 22,300/per ha (Nair *et al.,* 1991).

In 1970's, CPCRI has developed a multi-storeyed cropping model, the most productive and remunerative combination of coconut-pepper (trailed on coconut palms)-cocoa-pineapple system. These crops developed their canopies at varying heights, simulating the features of a multi-storeyed building. Nelliat *et al.* (1979) reported the beneficial effect of growing cocoa, pepper, clove, nutmeg and cinnamon in terms of higher productivity and net return per unit land.

A field experiment was undertaken at CPCRI, Kasaragod to study the performance of different varieties of pepper as mixed crop in coconut garden under irrigated condition during 2003 to 2008. In general, *Phytophthora* slow wilt disease incidence was observed in Panniyur-2, Panniyur-3, Kottanadan, OPKM, HP 34 and HP 813 varieties/hybrids. In severe cases, the vines were uprooted and gap filled with disease free cuttings during 2003. The growth observations recorded during December 2007 indicated that the height of vines differed significantly among the varieties/hybrids and Collection 1041 recorded the maximum height (5.2 m) followed by HP 105 (5.1 m). The lowest height was recorded in HP 34 (2.9 m) hybrid. Number of laterals (in 1 m column height) differed significantly and collection 1041 recorded significantly higher number of laterals (56.6) and the lowest was recorded in HP 34 hybrid (15.06) (Maheswarappa *et al.,* 2008b). The dry pepper yield obtained during 2006-07 was significantly higher in Collection 1041 (1.1 kg/vine) followed by Panchami (0.82 kg/vine) and HP 813 (0.78 kg/vine). The variety OPKM recorded significantly the lowest yield (0.25 kg/vine). From the preliminary data on growth and yield of different varieties, it can be derived that varieties like Collection 1041 (Thevam), Panchami, Sreekara, HP 813, Panniyur- 1 and Panniyur- 4 are found to perform well in the coconut garden. More data are to be collected to arrive at final conclusions.

Table 6. Yield of cocoa, pineapple and spices in coconut garden under multistoreyed cropping

Crop combination with coconut	Coconut (nuts/palm/year)			Yield of mixed crops				
				Pineapple during 1983-84 (kg/ha)	Cocoa (pods/ tree) during 1984	Pepper (kg/vine) during 1983-84	Cinnamon (g/ plant) during 1982-83	
	Pre-Expt. (1969-72)	During 1983 - 84	Percentage increase during the last 10 years over pre- Expt. (1974-84)				Quils	Quillings
Cocoa SH + pepper + pineapple	45.3	101.2	123	777	59	1.23	-	-
Cocoa DH + pepper + pineapple	36.1	89.6	148	102	35	0.68	-	-
Cinnamon in SH + Pineapple + pepper	25.1	88.2	251	1196	-	1.46	162	115
Cinnamon in DH + Pineapple + pepper	40.1	81.3	103	565	-	1.60	85	49
Cinnamon DH	40.8	96.2	136	-	-	-	115	36

SH: Single hedge, DH: Double hedge (CPCRI,1984 and 1985)

In an experiment started in 1972 on coconut based multi storeyed cropping system with cocoa in single and double hedge system, pepper and pineapple, the yield of coconut increased markedly during the experimental period compared to the pre-experimental yield in all the five crop combinations (Table 6) (CPCRI, 1984 and 1985).

Research findings have indicated that under coconut based HDMSCS and mixed farming systems, pepper variety Panniyur -1 has performed better and yielded 1.2 to 1.66 kg/vine/ year and the yield was higher under 2/3rd recommended fertilizer dose (1.66 kg/vine) (CPCRI, 2004, Palaniswami *et al.*, 2007). Clove yield ranged from 1.0 to 1.55 kg dry clove per tree under coconut based HDMSCS (Reddy *et al.*, 2002) and was the highest under 2/3rd recommended fertilizer dose (Palaniswami *et al.*, 2007). Harvesting is a major problem in clove and hence, there is a need to breed short statured varieties. Banana (kadali var.) yield ranged from 3.9 kg to 5.76 kg/bunch and was the highest under full dose of fertiliser recommended (Palaniswami *et al.*, 2007). Nutmeg yielded on an average 1.0 to 1.2 kg mace and 7 to 8 kg seed/ tree/ year under coconut based HDMSCS in root (wilt) affected area (Maheswarappa and Anitha Kumari, 2005). In coconut based HDMSCS, the recyclable biomass available was the highest under 2/3rd of recommended fertiliser treatment in different crops compared to the other fertiliser treatments (Subramanian *et al.*, 2005) (Table 7).

Table 7. Total annual biomass available for recycling from 1 ha of coconut based HDMSCS under different fertilizer levels (t/ha)

Amount of biomass removal/ crops	Coconut	Clove	Banana	Pineapple	Total
Full	15.80	0.666	1.295	0.435	18.196
Two-third	16.46	0.676	0.962	0.399	18.497
One -third	14.11	0.619	0.927	0.387	16.043
One-fourth	12.50	0.524	0.738	0.351	14.133
One-fifth	11.65	0.392	0.575	0.263	12.832
Control (no fertilisers)	11.60	0.349	0.503	0.215	12.667

(Subramanian *et al.*, 2005)

Nambiar *et al.* (1989) have reported that under HDMSCS, the P fractions increased and there was general increase in all the fractions of K over a period of three years cropped with different species.

Associative N_2 fixing *Azospirillum* spp. was found colonising the roots of coconut and black pepper in varying intensities under different cropping systems such as HDMSCS, multi-storeyed cropping and mixed farming (Ghai and Thomas, 1989). The isolates of *Azospirillum* from coconut and black pepper exhibited significant level of nitrogenase activity, which indicated contribution of substantial amounts of N_2 to the cropping system by way of biological nitrogen fixation. The isolates from coconut roots were identified as *Azospirillum brasilense* and those from black pepper as *Azospirillum lipoferum* based on biochemical and morphological features of the isolates.

Under the experiment on evaluation of vanilla as a mixed in coconut garden, the number of inflorescences produced and fresh bean yield were significantly higher with application of vermicompost (5 kg/vine) + biofertilizers (25g/vine) and cow dung slurry (6 t/ha) application, respectively compared to the other treatments. The fresh bean yield (1.18 kg/vine) was significantly higher with cow dung slurry application, which was on par with application of vermicompost @5 kg/vine, vermicompost @5 kg/vine + biofertiliser application and biogas slurry application (6 t/ha). Absolute control recorded significantly lower fresh bean yield (0.42 kg/vine) (CPCRI, 2009).

Medicinal and aromatic plants

At present there is an increasing demand for medicinal and aromatic plants which are mostly collected from their natural sources. By this relentless collection without replacement, most of them are either extinct or in imminent danger of extinction. Therefore, attempts have been made to study the possibility of growing medicinal and aromatic plants as intercepts in coconut plantations.

Performance of different medicinal plants like Orila (*Desmodium gangeticum*), Moovila (*Pseudartheia viscida*) and Coleus (*Coleus aromaticum*) (herbs of 8 months duration), Chittadalodakam (*Adhatoda beddomei*), Karimkurinji (*Nilgirianthus ciliatus*) and Nagadanthi (*Baliospermum montanum*) (shrubs of 18 months duration) was evaluated as inter/mixed crops at CPCRI, Kasaragod during 2003 to 2006 in 30 years old coconut garden spaced at 7.5 m x 7.5 m. The crops were cultivated as per the package with only organic manure in the form of vermicompost. Among the annuals tried, *Coleus aromaticum* could not establish well in the coconut garden. Mean of two seasons yield indicated that orila recorded dry root yield of 764.3 kg/ha, whereas, moovila produced dry root yield of 590.8 kg/ha (Maheswarappa *et al.,* 2008a). Among the biennials, the dry root and stem yield of Nilgirianthus was 2,483.3 and 17,338.3 kg/ha, respectively. The dry root and stem yield in case of Chittdalodakam was 1,725.5 kg/ha and 9,037.8 kg/ha, respectively. Nagadanthi produced 9,264.5 kg/ha of dry roots. Among the annuals, Orila recorded the highest net return (Rs. 12,929/ha) in 8 months and among the biennials, the highest net return obtained was with Nilgirianthus (Rs.1,93,049/ha) in 18 months. In the same way, the coconut equivalent of intercrops yield was also the highest in the case of Nilgirianthus.

Field experiment on evaluation of Indian long pepper under different organic treatments viz., vermicompost (VC) alone, VC + biofertiliser and VC + vermiwash when grown as mixed crop in coconut garden revealed that the number of branches were almost similar in all the organic treatments. The dry spike yield obtained under VC + vermiwash (123.1 kg/ha during the second year of planting) was higher compared to vermicompost alone (103.8 kg/ha) and VC + biofertiliser (115.5kg/ha) treatments (CPCRI, 2009). When Vetiver (*Vetiveria zizanioides*) was grown as mixed crop in coconut garden, the number of tillers produced (56.2 nos.) and dry weight of roots (116 g/plant) was higher in VC + vermiwash treatment (CPCRI, 2008). Under the feasibility studies on medicinal tree crops, it was found that bael tree (*Bilva*) (*Aegle marmelos*) has grown to a height of 4.7 m with the girth of 14.7 cm four years after planting. Sappan wood (Pathimugham (*Caesalpenia sappan*) tree had height of 4.9 m with girth of 14.4 cm. Asokam (*Saraca asoca*) tree had grown to a height of 2.4 m with a girth of 6.1 cm. Coomb tree (Kumizhu) (*Gmelina arborea*) had a girth of 45.0 cm (CPCRI, 2008). There was no adverse impact on the yield of main crop of coconut due to inter/mixed cropping of any of the medicinal crops.

Fruit crops

Banana is a highly profitable mixed crop in areas with good irrigation facilities. Experiments were conducted at CPCRI, Kasaragod to screen and find out the banana varieties best suited for intercropping. Varieties like Grosmichel and Peda pacha were the highest yielders followed by Dwarf Cavendish (Gopalasundaram and Nelliat, 1979). Under HDMSCS model at different levels of recommended fertilizer doses, banana (Kadali) has performed well and yielded on an average of 8-10 kg fruit/ bunch (Reddy *et al.,* 2002). Under the same system, there was increase in the population of bacteria whereas count of fungi and actinomycetes was low and population of 'P' solubilisers was maximum in the banana root rhizosphere (CPCRI, 2004). Microbial biomass and phosphatase activity was higher at $2/3^{rd}$ of recommended fertilizer and full dose of fertilizer in the rhizosphere of banana (CPCRI, 2001). Under HDMSCS at Kasaragod, banana (variety Kadali) and pineapple (variety Mauritius) produced on an average 5.8 kg per bunch and 0.9 kg fruit, respectively (Palaniswami *et al.,* 2007).

Experimental results of evaluation of performance of pineapple and banana as mixed crop in coconut garden under littoral sandy soil revealed that these crops responded well to application of coir pith and burial of coconut husk treatments and resulted in higher yield compared to control. Intercropping with pineapple or banana had positive impact on coconut yield (Subramanian *et al.,* 2009).

In farmers' garden, Nendran banana could be profitably cultivated as an intercrop in coconut garden in the early phase of coconut growth and yield obtained was 10-12 kg/ plant to provide net profit of Rs. 6,400/- from 0.1 ha coconut garden in Pallikkara, Kasaragod (Thamban and Arulraj, 2007).

Fodder Crops

Under Kasaragod condition, Guinea grass and Hybrid napier (NB 21) were found to grow well in coconut garden in red sandy loam soil, and the yield of Hybrid napier was higher under irrigated condition (52 tonnes/ha) (Maheswarappa *et al.,* 2001).

Experimental results of evaluation of performance of Hybrid Bajra Napier (Co3) as mixed crop in coconut garden revealed that it can be successfully grown in coconut gardens in coastal sandy soil by adopting suitable soil moisture conservation measures. Burial of one layer of dried coconut husk in trenches and planting of grass resulted in higher fresh fodder yield (96.83 t/ha) (Subramanian *et al.*, 2007) (Table 8).

Table 8. Effect of different treatments on fresh fodder yield (t/ha/year)

Treatment	Fodder yield
Coconut husk burial in the planting zone of the grass	96.83
5 cm thickness of coir pith application in the planting zone	90.20
Control.	62.85
CD (P = 0.05)	6.68

(Subramanian *et al.,* 2007)

Other crops

Cultivation of mulberry and rearing of silk worm has been successfully demonstrated in coconut garden (CPCRI, 2002). Among the flower crops, Heliconia and Anthurium grown in coconut garden had a good vase life. Of the five *Jasminum* genotypes tried in coconut shade, *J. pubescence* was found to grow well than all other genotypes tested (CPCRI, 2003). Arunachalam and Reddy (2007) analyzed the role of eight foliar traits of juvenile plants of five different species of *Jasminum* grown under coconut shade. The results revealed the shade tolerant *J. pubescence* produced more number of nodes and longer shoots in all the three seasons studied. *J. grandiflorum* produced longer leaves and internodal distance than other species tested. Winter season shoots were longer with more number of nodes and longer internodal distances than rainy season.

The experience based on survey conducted in coconut gardens of Kasaragod district of Kerala, India by Dhanapal *et al.* (2000) indicated that mixed cropping of arecanut and coconut simultaneously resulted in reduction in yield of coconut. In the case of arecanut planting as a mixed crop in coconut garden having palms of age 5-8 years, the yield of arecanut was only 30 to 40% of the normal yield whereas, areacanut mixed cropping in coconut gardens with palms more than 20 years of age did not affect the yield of coconut but there was 10-15% reduction in the yield of arecanut.

Coconut- agro forestry system

To mitigate the poor physico-chemical properties of coastal sandy soil, investigations have been conducted on the effect of growing *Gliricidia* in between the coconut rows with different planting densities and pruning intensities (Subramanian *et al.* 2000). Coconut growth was not adversely affected when *Gliricidia* was grown. A high biomass yield of 8t/ha was obtained with three prunings per year from three rows of *Gliricidia*. These prunings could meet 90% of N, 25% of P and 15% of K requirement of coconut palms.

An agro-forestry experiment with different tree species was initiated at CPCRI during 1983 in a coconut plantation planted during 1965 at 8 x 8 m spacing in non replicated manner. Data on nut yield has shown that with high population of subabul, casuarina and eucalyptus, the coconut yield wass adversely affected, whereas, Ailanthus tree, though slow growing, appears to be compatible with coconut and had not affected the yield of coconut (Table 9) (CPCRI, 1989).

Table 9. Yield of coconut as influenced by agro - forestry system

Tree crop combination	Nut yield/palm/year	
	Pre Experimental (1979-83)	Experimental period (1986-88)
Coconut alone	118	50
Coconut + Ailanthus	95	99
Coconut + *Eucalyptus citriodora*	109	99
Coconut + subabul	81	39
Coconut + casuarina	58	14
Coconut + *E. teriticornis* + subabul	78	28
Coconut + casuarina + subabul	19	9
Coconut + mango	58	79
Coconut + Jack	29	45

(CPCRI, 1989)

5. Future research areas

i. Need for screening high value horticultural crops/varieties and selecting best suited ones for maximising output and income of the system.

ii. Studies on effect of irrigation, integrated nutrient management, nutrient availability and uptake in the system, organic management and weed management and plant protection of the entire cropping system.

iii. Studies on the microclimatic changes and carbon sequestration in the system.

6. Conclusion

Coconut based cropping systems, involving cultivation of compatible crops in the interspaces of coconut offer considerable scope for increasing productivity per unit area, time and inputs by more efficient utilization of resources like sunlight, soil, water and labour. From the above review it is clear that mixed cropping in coconut garden is beneficial in terms of sustainable production and productivity over the years. Such diversification in coconut helps to conserve natural resources and protect environment. With many ecological and social benefit of mixed cropping a change in shift of mono cropping to specialise mixed cropping system with more diversified cropping is highly beneficial.

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Cropping system for coastal sandy soil management

P. Subramanian, R. Dhanapal and C. Palaniswami

Introduction

Soil forms the basic natural resource that determines the availability of nutrients and water, the most important inputs, which decide the productivity of coconut palm to a great extent. As coconut palms are committed to soil for many decades, unless the quality of soil is maintained and regularly improved, it is obvious that the yield levels cannot be sustained or improved. Whatever impressive may be the genetic potential of coconut palms; satisfactory yields can be expected only if they are cultivated in a suitable environment with proper management practices. Coconut palm is known for its adaptability to a wide range of soils and varying soil environment. In India, coconut is being grown in different soil types. However, alluvial, laterite, sandy and red sandy loam forms the major soil types occupied by coconut. The coastal sandy soil, which occurs all along the coastal tract of the West and East coasts of the Peninsular India lying mostly in Kerala, Karnataka, Tamil Nadu, Andhra Pradesh, Orissa and Maharashtra, is the most predominant soil type with respect to coconut cultivation. The general weather prevailing along the coast is

Table 1. Physico- chemical properties of coastal sandy soils

Content	Range
Clay (%)	0.6-10.8
Silt (%)	0.0-7.8
Sand (%)	87.2-95.4
pH	5.52-8.3
Organic carbon (%)	0.00-0.46
CEC (me/100g)	0.4-5.4
Available nitrogen (kg ha^{-1})	30 to 60
Available phosphorus (kg ha^{-1})	10 to 25
Available potassium (kg ha^{-1})	5 to 25
Physical constants	
Field capacity (%)	3.8 to 7.2
Permanent wilting point (%)	0.42 to 2.12
In situ bulk density $g.cm^{-3}$	1.56 to 1.82

conducive for growing coconut. However, coconut productivity is very low in the coastal sandy soils ranging from 20 to 40 nuts/palm/year, mainly due to poor physico - chemical properties of the soil (Table 1).

Reasons for lower productivity of coconut under coastal sandy soil

- Poor water holding capacity.
- Excessive infiltration (due to the porosity of sands).
- Easy leaching of nutrients leading to low nutrient retentive capacity and low availability of NPK and micronutrients.
- Because of low clay and organic matter content, the soil has small specific surface area.
- Low cation exchange capacity.
- Low organic carbon content.

Under these conditions, sustainable crop production could be achieved through adoption of cropping systems which were successfully established by CPCRI. The results of work carried out at CPCRI, Kasaragod are discussed hereunder.

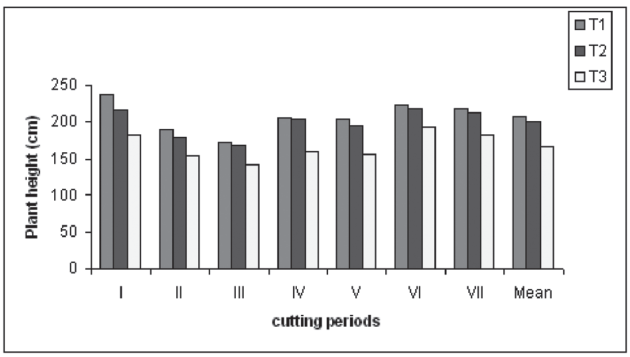
2. Cropping system approach with soil moisture conservation measures

To improve the coconut productivity, many approaches are available. One among them is the cropping system approach. Coconut is highly amenable for cultivating intercrops because of its wider spacing (7.5 x 7.5 m) used for planting. Even though coconut is a widely spaced crop, the interspaces cannot be utilized for growing of intercrops in sandy soils under normal conditions on account of poor water retention, soil fertility status etc. However, by adopting proper soil and water conservation measures, intercropping can be practiced in the coconut garden under coastal sandy soil.

Under this circumstance waste/usufruct materials from coconut palm viz., husk and coir pith come handy for rectifying this situation. From a well-managed coconut garden, about 14-16 tonnes/ha/year of dry material is available in various forms (leaves, spathe, bunch waste and husk etc.), of which 50% contribution is from husk and coir pith. These wastes/usufructs available *in situ* can be used as moisture conservation materials and a source of nutrient for the crops. Results based on the experiments conducted at CPCRI revealed that fodder grass, vegetable crops (amaranthus, pumpkin and ash gourd) and fruit crops (banana and pineapple) could be successfully grown as intercrops in coconut gardens under coastal sandy soil by adopting appropriate soil moisture conservation measures viz., husk and coir pith application in the planting zone. In addition to the extra income realized by intercropping, it has a complementary impact on coconut productivity. This leads to the overall improvement in the productivity of the system as a whole.

2.1.Growing fodder grass as intercrop

Subramanian *et al.* (2007) established that fodder grass can be successfully grown as an intercrop in coconut gardens under coastal sandy soils by adopting appropriate soil moisture conservation measures. The results revealed that the husk and coir pith application had significantly influenced the plant height of Co 3 grass during different periods of cutting (Fig. 1). Higher plant height (ranging from 172 to 237 cm during different cutting periods with a mean of 237 cm) was recorded in the treatment where husk was applied in the planting zone and it was comparable with coir pith application and both the treatments significantly differed from the control (143 to 183 cm with a mean of 168 cm). Similar type of response was obtained in no. of tillers /clump(Fig. 2). The highest number of tillers/ clump (13.3 to 42) was obtained in the treatment where husk was applied in the planting zone and it was on par with the treatment where coir pith was applied in the planting zone and it significantly differed from the control treatment. Higher plant height and more



T1: Coconut husk burial in the planting zone of the grass, T2: 5 cm thickness of coir pith application in the planting zone and T3: control

Fig. 1. Plant height as influenced by different treatments

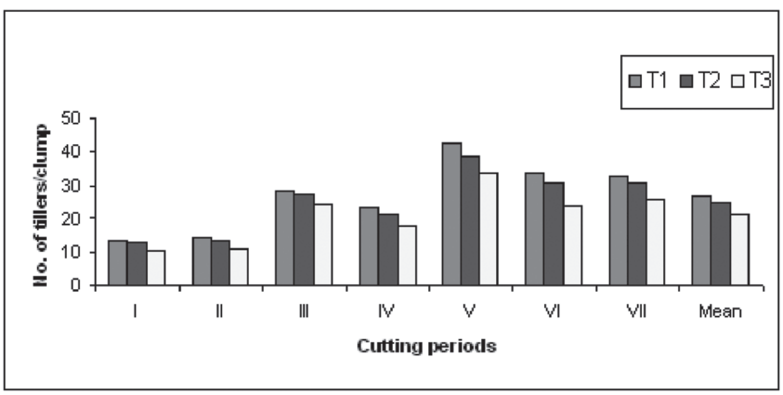


Fig. 2. No. of tillers/clumps as influenced by different treatments

no. of tillers/clump in the husk/coir pith treatment is mainly due to congenial conditions prevailing in the rooting zone.

Higher fresh and dry fodder yield was obtained under husk application during each cutting and it was on par with coir pith application and significantly differed from the control treatment (Table 2). Higher fresh fodder yield realized is mainly due to the beneficial effects of higher soil moisture and nutrient availability and enhanced biological activities in the rhizosphere. Further, husk contains considerable amount of potassium and is made available to the plant when it decomposes (Subramanian *et al.,* 2007). Both the crude protein content and protein yield also were the highest when amendments were used. Findings of the study proved that fodder grass Co3 can be successfully grown as an intercrop in coconut garden under coastal sandy soil. From one hectare of coconut garden around 96 tonnes of fresh fodder could be produced in a year (Table 2). This is sufficient to supply fresh fodder for 8-10 milch animals.

Table 2. Effect of conservation measures on fodder yield and crude protein content and yield

Treatment	Fresh fodder (t/ha/year)	Crude protein content(%)	Crude protein yield (t/ha/year)
T_1: Coconut husk burial in the grass planting zone	96.83	11.83	2.28
T_2: 5 cm thick coir pith application in the grass planting zone	90.20	12.13	2.22
T_3: Control	62.85	11.47	1.48
CD (P = 0.05)	6.61	NS	0.30

2.1.1. Economics

A farmer integrating coconut + fodder grass (1 ha) and dairy (6-8 milch animals) in the coconut based mixed farming system under coastal sandy soil situations can realize a net profit of approximately Rs.1 lakh/ha/year. The maximum profit that could be realized is from dairy followed by coconut. Besides, the farmer can get 20 to 25 tonnes of cow dung, cowshed washings and urine that could be effectively recycled for biogas production and later the slurry pumped to the garden for increasing the productivity of the system.

2.2. Pumpkin as intercrop

Pumpkin can also be grown successfully as an intercrops in coconut garden in coastal sandy soil using husk/coir pith as amendments (Subramanian *et al.,* 2006 a). (Table 3).

Application of coir pith and husk had significantly influenced the growth and yield parameters. Higher fruit yield was obtained under coir pith application (10.12 t/ha) and it was on par with husk application (9.46 t/ha) and significantly superior to the control treatment (6.21 t/ha). Higher fruit yield under husk and coir pith application is mainly due beneficial effects in the pits viz., higher soil moisture and increased nutrient availability and enhanced biological activities in the rhizosphere. Coir pith and husk have very high water holding capacity of 5 to 6 times their weight. It has been found that by incorporation of 2 per cent weight of coir pith with sandy soil, the water holding capacity of the latter is increased by 40 per cent. By adopting soil moisture conservation measures and growing vegetables such as pumpkin and ash gourd, farmers could relalize an additional net income of Rs 35,000/ha/season.

Table 3. Effect of different treatments on growth and yield parameters of pumpkin

Treatments	Vine length (cm)	No. of fruits/ vine	Fruit diameter (cm)	Fruit length (cm)	Average fruit wt. (kg/fruit)	Fruit yield (t/ha)
T_1	632	2.8	60.6	27.4	1.94	9.46
T_2	656	2.8	62.6	29.0	2.10	10.12
T_3	542	1.9	51.3	23.6	1.26	6.21
CD (P = 0.05)	62	0.2	8.0	NS	0.40	0.87

T_1: Coconut husk burial in the pits, T_2: 5 cm thickness of coir pith application in the pits and T_3: Control, NS = Not significant

2.3 Pineapple as intercrop

Pineapple suckers grown under husk/coir pith incorporation produced higher yield of fruits (Subramanian *et al.*, 2009). The results (Table 4) showed that husk and coir pith application as amendments had significantly influenced fruit size and fruit weight. Higher fruit yield was obtained under husk application from one hectare of coconut garden and it was on par with coir pith application and significantly differed from the control treatment (Table 5).

Table 4. Effect of different treatments on yield parameters of pineapple as intercrop in coconut under coastal sandy soil

Treatment	Total fruit length(cm)	Fruit length(cm)	Crown length(cm)	Circumference (cm)		
				Bottom	Middle	Top
T_1	34.8	18.5	16.25	33.08	37.65	31.60
T_2	33.6	18.16	15.48	32.66	36.37	30.09
T_3	28.5	15.84	14.89	29.06	35.28	28.61
S.Ed	1.3	0.6	0.87	0.42	0.52	0.49
CD (P = 0.05)	2.7	1.32	NS	0.91	1.14	1.08

T_1: Coconut husk burial in the pits, T_2: 10 cm thickness of coir pith application in the pits and T_3: Control, NS = Not significant

Table 5. Effect of different treatments on yield of pineapple as intercrop in coconut under coastal sandy soil

Treatment	Individual fruit wt (g)			Fruit yield(kg/ha)			
	First crop	Second crop	Third crop	First crop	Second crop	Third crop	Average
T_1	1773	1643	1612	16241	15278	14673	15397
T_2	1657	1508	1542	14800	14642	13466	14302
T_3	996	1012	972	8896	7650	7417	7987
S.Ed	81	76	62	666	710	512	550
CD (0.05)	177	166	135	1451	1546	1118	1198

T_1: Coconut husk burial in the trenches, T_2: 10 cm thickness of coir pith application in the trenches and T_3: Control

3. Impact of cropping systems on coconut productivity

The impact of growing fodder grass, vegetables and fruit crops on coconut productivity revealed complementary effect of vegetable and pineapple as intercrops. Cropping systems and soil conservation measures had a positive impact on coconut yield (Table 6). Adopting intercropping systems viz., coconut + pineapple, coconut + vegetable and coconut + fodder grass resulted in increased yield of coconut compared to monocropping of coconut under coastal sandy soil situations. Similarly soil moisture conservation measures play beneficial role on coconut yield.

Table 6. Effect of cropping systems and soil moisture conservation measures on coconut yield*

Treatment	Coconut yield (nuts/palm/year)
Cropping systems	
Coconut + vegetable intercropping	**98**
Coconut + pineapple intercropping	**100**
Coconut + fodder grass intercropping	**89**
Coconut monocropping	**91**
Soil conservation measures	
Coconut husk burial	**108**
Coir pith application	**100**
Control	**72**

**Average of 3 years yield data*

4. Economics of coconut based cropping system

The economic analysis of coconut based intercropping system under coastal sandy soil indicated that all the cropping systems had realized higher net returns as compared to monocrop. The net returns had ranged from Rs. 45,771/ha/year in the case of coconut monocrop to Rs. 1,03,010/ha/year in the case of coconut + pineapple intercropping system. The percentage increase in the case of net returns over coconut monocrop ranged from 128 in the case of coconut + pineapple inter cropping system to 40 in the case of coconut + ash gourd intercropping system (Subramanian *et al.,* 2009).

5. Alley cropping/intercropping of glyricidia in coconut gardens

Glyricidia has great potential as a multipurpose tree in agro forestry, which fits well in marginal and sub marginal soils. Experimental results from CPCRI have proved that glyricidia can be successfully grown as intercrop in coconut gardens in coastal sandy soil (where no other green manure crop can establish), and supply green manure continuously (Subramanian *et al.,* 2000).

Three rows of glyricidia in between two rows of coconut with three prunings per year resulted in higher biomass yield of 7,970 kg/ ha. The loppings were cut into small pieces and incorporated into the soil as green manure. The coconut growth was not affected by intercropping with glyricidia. Application of glyricidia prunings from the interspace of one hectare of coconut garden to the coconut palms could meet a major portion of nitrogen (88 per cent), part of phosphorus (27 per cent) and potassium (13 per cent) requirement of coconut palms (Table 7). The *in situ* planting of Nitrogen fixing tree species like glyricidia between coconut rows can even supply micronutrients such as Copper, Zinc and Boron. Further advantages are *in situ* availability, easy decomposability and low cost of the green

Table 7. Nutrient substitution through glyricidia loppings in coconut

Nutrient	N	P	K
Coconut			
Fertilizer recommendation (g/palm/year)	500	320	1200
Total fertilizer needs (kg/ha)	87.5	21.0	210
Glyricidia			
Nutrient content of loppings (%) (on dry wt. basis)	3.38	0.247	1.165
Nutrient availability through glyricidia biomass from 1 ha of glyricidia intercropped coconut garden (kg)	77.74	5.68	26.80
Fertilizer nutrient substitution by glyricidia % nutrient substitution	**88.0**	**27.0**	**13.0**

manure(Subramanian *et al.,* 2006b). In addition to these, the microclimatic conditions in the coconut garden are also improved.

6. Glyricidia as green manure

The poor soil fertility status of coastal sandy soil can be improved by addition of green manure of glyricidia (Subramanian *et al.,* 2005). The results of a field experiment on substitution of nitrogenous fertilizer with glyricidia green manure in coconut under coastal littoral sandy soil at CPCRI, Kasaragod revealed that the treatment of incorporating glyricidia as green manure had higher levels of available soil nitrogen as compared to application of inorganic fertilizers alone. The available soil phosphorus levels showed no significant differences, though the available soil potassium content in the different treatments was non significant, higher level of available potassium was observed with increased dosage of incorporation of glyricidia green manure and the highest available potassium content was observed in the treatments where 75% and 100% nitrogen was substituted through organics (Table 8 and 9). Glyricidia as green manure also improved the soil moisture availability and the soil moisture content was increased with the quantity of glyricidia applied (Fig. 3 and 4). Application of glyricidia along with inorganic fertilizers was found to increase the nut yield of coconut. When 50% N was substituted by glyricidia (25 kg of glyricidia green leaves) along with 50% of N and 100 per cent of P and K through chemical fertilizers, higher coconut yield of 52 nuts per palm per year was recorded (44 percentage increase over control). The cost benefit ratio was also most favourable in this treatment (1: 1.82).

Table 8. Effect of different treatments on the organic carbon content of the soil

Treatment	Organic carbon (%)	
	0-25 cm	25-50 cm
T_1 : Control (Inorganic fertiliser alone)	0.25	0.24
T_2 : 25% N by *Glyricidia* + 75% N and full PK by Inorganics	0.45	0.25
T_3 : 50% N by *Glyricidia* + 50% N and full PK by inorganics	0.43	0.26
T_4: 75% N by *Glyricidia* + 25% N and full PK by inorganics	0.44	0.33
T_5 : 100% N *Glyricidia* + Full PK by inorganics	0.56	0.31
SE_d	0.08	0.06
CD(P = 0.05)	0.17	NS

Table 9. Effect of glyricidia green manuring on available soil nutrient status in coconut basin at two depths

Treatment	Nutrients (ppm)					
	N (0-25cm)	N (25-50cm)	P (0-25cm)	P (25-50cm)	K (0-25cm)	K (25-50cm)
T_1: Control (Inorganic fertiliser alone)	38.4	31.2	89.82	65.21	35.77	23.08
T_2: 25% N by glyricidia + 75% N and full PK by Inorganics	44.5	33.4	107.96	46.5	42.69	27.69
T_3: 50% N by glyricidia + 50% N and full PK by inorganics	46.3	36.4	107.88	28.62	41.54	25.38
T_4: 75% N by glyricidia + 25% N and full PK by inorganics	47.0	37.9	104.24	40.09	43.84	35.77
T_5: 100% N by gliricidia + Full PK by inorganics	49.0	38.2	93.88	33.62	43.84	30.00
Sed	1.56	7.68	23.006	19.813	4.682	5.312
CD (P=0.05)	3.40	NS	NS	NS	NS	NS

NS= Not significant

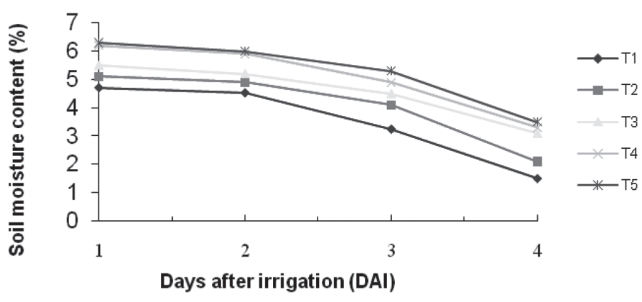


Fig. 3. Effect of different treatments on soil moisture content(%) (0-25 cm)

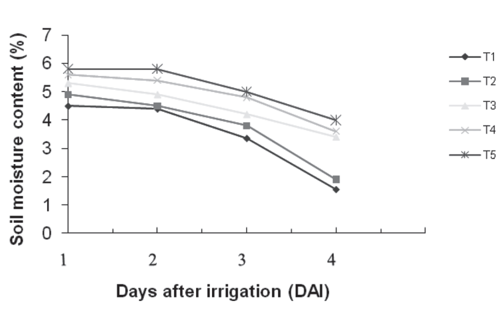


Fig. 4. Effect of different treatments on soil moisture content(%) (25-50 cm)

For glyricidia green manure incorporation, 1.8 m radius basin should be opened at a depth of 20 cm around the bole and 25 kg of green manure and the required inorganic fertilizers are applied and covered with the excavated soil during the first fortnight of September.

7. Conclusion

Coconut palms grown under coastal sandy soil conditions generally will produce only 20-40 nuts/palm/year. To make coconut cultivation economically viable and sustainable under coastal sandy soil, more emphasis should be given for improving the physical and chemical conditions of soil. In this regard, CPCRI has successfully developed cropping system approach with moisture conservation practices using husk/coir pith for growing different intercrops and alley cropping of glyricidia. All these techniques need to be adopted in an integrated manner to improve the productivity of the system. By adopting such agro techniques in the coastal sandy soil, we can expect a significant improvement in yield as evident from the results of the experiments conducted at CPCRI.

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Coconut based mixed farming system

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Introduction

Coconut in India is predominantly cultivated in small and marginal holdings. About 98% of the coconut holdings in the country are less than 2.0 ha in size and more than 90% of them are less than 1.0 ha in extent. Most of these holdings neither provide gainful employment opportunities for the family labour throughout the year nor generate sufficient income to meet the family requirement. Coconut palm when grown as a monocrop, does not fully utilize the resources viz., soil. nutrients, moisture and solar radiation available in the coconut garden. Hence, there is ample scope for the integration of crops and animals in coconut growers are more exposed to economic risks and uncertainties owing to the rapid price fluctuations. In this context it is needless to emphasize the importance of crop / enterprise diversification in coconut gardens.

Coconut based cropping/farming systems, involving cultivation of compatible crops in the interspaces of coconut and integration with other enterprises like dairying offer considerable scope for increasing production and productivity per unit area, time and inputs by more efficient utilization of resources like sunlight, soil, water and labour. Majority of the coconut growing soils are poor in soil fertility and needs external inputs to enhance productivity. So to keep coconut growing is more profitable and sustainable coconut based farming is one of the option. Coconut based integrated farming is an ecologically sustainable system which helps the farmer to realize more income.

2. Mixed farming

Mixed farming in coconut garden involves integration of fodder crops in the interspaces of coconut, maintenance of animal components like dairy, poultry, sericulture, fishery etc., and recycling the by-products obtained.

2.1. Advantages of mixed farming

- Fodder crops grown in the interspaces of adult plantations come up well, because the fodders are mostly surface feeders.
- Providing a crop cover requiring minimum inter cultural operations will be the best for sustaining soil fertility.
- Grass roots, because they traverse the soil extensively, are also considered the best conservers of soil nitrogen. The carbon nitrogen ratio of grass roots is wide, and hence their debris decomposes slowly. Any small amount of mineral nitrogen

released in this process is appropriated again by the live roots. The same is the course of events that occurs in the case of added fertilizer nitrogen to a considerable degree.

- Legumes do not have an extensive root system as the grasses. The agronomic advantage of inclusion of legumes lies in fixation of molecular nitrogen symbiotically. This indicates that an efficient crop combination which will utilize the space, light, nutrients and moisture, without adversely affecting coconut will contribute to very high net returns.
- The high employment potential that can be generated by adopting this practice is another advantageous factor. The labour requirement of plantation with coconut alone, in a year is around 150 man days per hectare. In a mixed farm, it goes up to about 900 man days per hectare.
- Mixed farming or alternate husbandry in coconut garden can solve the deficiency in milk production to some extent. Most of the coconut growers own less than one hectare of land and the income from their land is insufficient to maintain a decent standard of living. Further, since coconut cultivation does not require intensive utilization of labour, both the cultivator and his family can utilise their spare time for other useful work like dairying without much difficulty and improve their economy.
- Besides, cultivation of fodder grasses and fodder legumes enriches the soil by adding more organic matter and nitrogen. It also checks soil erosion. All these contribute indirectly to increasing the yield of the coconut palms.
- Mixed farming has greater significance in the disease affected tract.
- Understorey weed control
- Stability through diversification
- Prolonged economic life of the plantation
- Irrigation water is utilized more efficiently than when the interspace is left fallow

There are several environmental factors which play an important role in this integration system, viz; competition, shade tolerance, trampling and soil compaction, cattle damage to young trees, tree spacing and effect of pastures/fodder crops on nut yield.

3. Coconut based integrated farming system experiment at CPCRI

Coconut based integrated farming system research was started at CPCRI, Kasaragod in 1972 and Kayamkulam during 1970. At Kasaragod, initially experiments were conducted by intercropping fodder grass in a 60 year old coconut with integration of dairy unit. The experiment was continued for a period of 16 years (1972-1988). During 1988 to 1999 the experiments was conducted with the integration of coconut and components viz. Coconut + fodder grass, dairy unit (five to six Jersey and Holstein Friesian cross breed cows, poultry unit (100 layers and 100 broiler in each batch and 100 number quail layer birds), biogas unit, aquaculture and sericulture (which was integrated with the system during 1999)(Maheswarappa *et al.*, 2001).Thereafter this experiment with the same components except sericulture was maintained under NATP from 2000 to 2003 (Khan *et al.*, 2002) and the details are presented in Table 1. From 2004 on wards the experiment was continued with the fodder grass variety NB 21 was replaced by of Hybrid Bajra Napier Co3 and introduction of azolla cultivation unit. Similarly mixed farming unit was started in the root (wilt) affected area at Kayamkulam during 1972 and the results are discussed hereunder.

Table 1. Components of integrated farming system maintained at Kasaragod during 2000-2003

	Components	Area (ha)/Numbers
1	Coconut + Fodder grass	0.69
2	Coconut + Mulberry	0.24
3	Pepper (in coconut palm)	120
4	Banana (in border rows)	60
5	Dairy (Milch cows)	6
6	Broiler birds (4-6 batches/year - 100 batches)	400
7	Quail birds	100 layers
8	Fish pond	625 m^2 area
	Coconut (Monocrop)	0.17

3.1.Performance of different components of the mixed farming system

a) Forage grass and legumes in coconut interspaces

Cultivated fodders show a considerable degree of shade tolerance and compatibility as intercrop of coconut. The ability of perennial fodder grasses to prevent nutrient losses through their ramified root system and that of legumes to add nitrogen to the soil are added advantages to the nature of association with coconut. Coconut offers considerable scope for raising shade tolerant forage crops in the interspaces and integrating animal enterprises. Fodder grasses like hybrid napier (Pusa Giant and NB 21), Guinea grass and Guatemala grass yield about 50 to 60 t fresh fodder/ha/year under coconut shade (Jacob

Mathew and Shaffee, 1977), which is sufficient to maintain five cross-bred milch cows. Among the legumes, Brazilean lucerne and cowpea perform well yielding about 30 t/ha (Sahasranaman and Pillai, 1976). Nayar and Sahasranaman (1978) evaluated the performance of four fodder crops (two genotypes of hybrid Napier, viz. Pusa Giant and NB 21) Guinea grass (Maekuenii) and legume *Stylosanthes gracilis*, under rainfed and irrigated conditions in the interspace of coconut at Central Plantation Crops Research Institute, Regional Station, Kayamgulam and found that the graminaceous fodders Pusa Giant, NB 21 and Guinea grasses were on par in herbage yield but gave significantly higher yield than the legume *Stylosanthes*, both under rainfed and irrigated conditions. The increase in yield of fresh fodder due to irrigation was the highest in the case of NB 21 (55%) followed by Pusa Giant (44%) (Table 2). Hence, depending upon the availability of irrigation facilities, one of these graminaceous fodder crops could be selected for growing in coconut stands. *Mimosa invisa* was observed to be toxic to the animals, when fed alone, in large quantities (Anonymous, 1976).

Table 2. Effect of irrigation on forage yield of fodder crops

Fodder crops	Yield (t/ha/yr)			Percentage increase in yield due to irrigation
	Rainfed	Irrigated	Mean	
Pusa Giant	37.07	53.21	45.14	44.00
N B 21	41.61	64.43	53.02	55.00
Guinea grass	46.91	51.51	49.21	9.80
Stylosanthes	20.82	17.28	19.05	-
Mean	36.60	46.60	41.60	

CD(P = 0.05) comparison between fodder crops -10.59

Maheswarappa *et al.* (2001) reported that Hybrid Napier grass NB 21 and Guinea grass (*Panicum maximum*) are the most productive yielding about 50 tonnes of fresh fodder per ha per year. Guinea grass has the capacity to withstand prolonged cloudy weather conditions prevailing in Malabar region during the rainy season. Subramanaian *et al.* (2008) found that Bajra Napier hybrid - Co3 grown as intercrop in coconut garden under red sandy loam soil resulted in significantly higher fodder yield with the application of 50% NPK through vermicompost and farm yard manure + 50 per cent NPK through chemical fertilizer(117 ton/ha/year) and was comparable with fully organic treatments(106 t/ha/year) and significantly differed from chemical fertilizers alone (96 t/ha/year). In coastal sandy soil when hybrid bajr napier grown as intercrop with moisture conservation measures resulted in the green fodder yield of 92 t/ha/year (Subramanian *et al.*, 2009).

b) Dairy

During 1989 to 2003 five to six milch animals of Jersey cross breed (first lactation) were maintained in the system. From 2004 onwards eight animals were maintained. The cattle shed were constructed to accommodate about 8 cows with an area of about 2.5 m^2 per animal. The cattle-shed consisted of separate room for calves, storeroom and milk distribution room. All the operations connected with the mixed farming system such as management of fodder grasses, milking, cleaning the cows and cowshed and feeding of animals were managed by the family. Additional labour was provided only for replanting of grass slips, fertiliser application and harvesting of coconuts. In the present mixed farming unit eight cows (seven Holstein Friesian and one Jersey cross breed) are maintained under this system so that 5 animals could yield milk throughout the year.

Cows were given on an average 30 kg green fodder daily. This was supplemented with the concentrates as per schedule given in the Table 3. Ready made concentrates can be purchased from market and used for feeding cattle. However, to provide good quality concentrate, preparation is to be done in the farm itself by purchasing raw material from the market viz., maize flour, wheat bran, rice bran, groundnut cake, gingelly oil cake, mineral mixture and salt.

The milk production for the period 1989 to 2003 was in the range of 5948 to 13153 liters per annum (Maheswarappa *et al.,* 2000 and Khan *et al.,* 2002).

Table 3. Feed schedule for dairy cattle

Animals	Concentrate	Fresh grass(kg)	Paddy straw(kg)
Dry cows	1.5	25-30	1
Milking animals	1 kg for every 2.5 to 3.0 litres of milk	30	2
Pregnant animals	2.5 kg from 7th month onwards	30	2
Calves	1 kg	5	1

c) Biogas from cattle manure

About 40% of the dry weight of cattle waste is constituted of carbon. Left in aerobic atmosphere, most of it undergoes microbial oxidation to carbon dioxide. Storing the produce in an aerobic medium results in microbial reduction of the carboneaeous fraction to methane. It is this principle that is used in the partially controlled decomposition process in the biogas plant. Manure from four animals can generate fuel gas enough for a family. Though the cost of installation of the plant is a bit high, it requires no running expenditure and the gas is safe and innocuous. A bio gas plant has been installed at Kasaragod and it was observed that about 50 kg cow dung is necessary to generate sufficient biogas. With an average daily biogas requirement of 0.56 m^3 per person, the total biogas needed to meet the fuel requirement of a family consisting of five members will be 2.85 m^3. Vidhan Singh *et al.* (2002) conducted the studies on the possibility of utilizing pith for biogas production. It was found that coconut pith in combination with cowdung gives higher methane content in biogas, while alone it does not produce any gas. The best combination was found to be with 80% cowdung and 20% coconut pith (Table 4).

Table 4. Average production of biogas in different treatments

Treatment	Average production (l/day)	
	For the entire experiment	For the range of temp. 30-33°C
100% Cowdung	879.23	933.85
80% cowdung + 20% coir pith	929.61	970.35
60% cowdung + 40% coir pith	653.74	708.45
40% cowdung + 60% coir pith	438.06	460.80
20% cowdung + 80% coir pith	332.32	332.45
CD (P = 0.05)	86.69	131.50
C.V.(%)	4.84	6.95

d) Poultry

i) Broilers

Broilers and quail birds were integrated in to the coconut based mixed farming system during 1989. The broilers, layers and quails were reared in the deep litter system. Coir pith, waste material obtained after extraction of coir from husk was spread to a height of 5 cm evenly on the floor to conserve the droppings and to prevent loss of nutrients and it formed the bedding. This coir pith material is enriched with poultry dropping and resulted in the production of very good organic manure. A separate brooding chamber was fabricated to take care of chicks in the initial stages. One Day-old broiler chicks were kept in brooding chamber for 14 days and then transferred to the shed. Broiler and layer birds were given concentrates in the following feeding schedule (Table 5).

Table 5. Feed requirement of broiler (g/day)

Days	Upto 3 days	4-7	2nd week	3rd week	4th week	5th week	6th week	7th week	8th week
Feed	10	20	40	60	80	100	120	120	120

The birds were provided feed in the linear feeder. For layers also a similar feeding schedule as above was followed and vaccination against Mereck and Ranikhet disease was done one day after and 21 days after hatching, respectively. Japanese quails were given 20 g concentrates per bird per day. Drinking water was provided with the help of suspended drinking bowl. On an average 645 kg of broiler birds was produced from the system per annum (Khan *et al.,* 2002). According to Hedge *et al.,* (1992) broiler farming is the most profitable enterprise. The total income realized from a 100 bird unit, by maintaining round the year (5 batches) was Rs.4,250. Layer unit gave a net return of Rs. 2700. In addition to this 2 tonnes of coir pith manure which is enriched with poultry droppings (Maheswarappa *et al.,* 1998).

ii) Japanese quails

Japanese quail is hardy birds that thrive well in cages or deep litter system of rearing and are inexpensive to keep. The brown-coloured Japanese quail (*Coturnix coturnix japonica*) is bred for commercial Quail production. They are relatively small in body size. They are adaptable to intensive systems of poultry husbandry. Because of their low volume, they are fit for high density rearing. It is blessed with the unique characteristics of fast growth, early sexual maturity, high rate of egg production, short generation interval and shorter incubation period that make it very suitable as an alternative farming animal. They are fairly resistant to disease, and less worries for vaccination. With shorter reproduction cycle and earlier marketing age, it offers fast monetary circulation ultimately yielding quicker returns. Egg production starts when the female quail reaches six to seven weeks of age and it touches 85% production by the end of 10 weeks. Sexing is not done in one-day-old quail chicks. Only after 4 weeks of age, the female can be differentiated from the males. Females are larger than males and they have black spots on face, neck and in the breast region. Male / female ratio in the parent stock should be 1:2 or less. Quails start laying eggs at the age of 6 weeks, quails lay most of the eggs during evening hours (between 3 to 6 PM). Eggs should be collected very frequently and carefully, as shells of eggs are very thin and they break very easily. With proper care, hens should lay 200 eggs in their first year of lay. Life expectancy is 2 years. The quails require an area of $0.5m^2$ per bird. Clean, fresh water should be provided at all times. Japanese quail requires 14-18 hours of light per day to maintain maximum egg production and fertility. This means that supplementary lighting must be provided in the autumn, winter and spring months. Adult Japanese quails eat between 14 g and 18 g of food per day. By integration of this into the coconut based mixed farming system, farmer will addition returns to the tune of Rs.1120 per annum (Hegde *et al.,* 1992).

e) *Rabbitry*

Ten female and four male Russian chinchilla were maintained. Rabbits were housed in a cage system providing an area of 0.9x0.6x0.75M per animal. They were fed with tender grass, banana leaves, erythrina leaves, tridax weed and amaranthus. Some of these crops were cultivated in the unit in an area of about 200 m^2. In addition to green leaves, about 150-200 g concentrate was given to each animal. Drinking water was provided in small cups. The production was in the range of 10 to 87.5 kg per annum (Maheswarappa *et al.,* 2000).

f) *Aquaculture*

Another enterprise, which can be profitable in Kerala. With the modern management techniques evolved and the existing vast water resources, the state can bring about substantial increase in fish production through fresh water fish culture. A fishpond with the dimension of 27.5 m length, 22.5 m width and 1.5 m depth was constructed. The soil being sandy and porous and to curtail percolation loss, the pond was lined with silpaulin sheets. Preferably clayey or laterite soil is to be filled upto 10 cm at the bottom of the pond. This soil layer will help to facilitate natural recycling of the food material and to arrest the temperature fluctuations during hot days. The pond water is maintained with the help of internal water source. To facilitate in draining of water from the pond whenever needed an outlet pipe is provided at 1 ft. below the embarkment so as to drain the excess water. Both the outlets and the drainpipes are fixed with strainers so that fish dose not escape. As the pond is lined with silpaulin sheet, there will not be natural ecosystem. Hence artificial aeration is a must. For this, 1 HP blower was installed through which air is pumped in to the pond at 12 different [points for proper aeration all through the pond.

In the semi intensive system as the natural food available in the pond will not be sufficient for the fish, it is necessary to supplement it with cowdung, chemical manure and artificial feed. First installment is to be applied into the pond about 24 hours before releasing the fish. If any point of time, algal growth is more, application of manure is to be broadcasted all over the pond whereas cowdung may be dumped in the corner of the pond. About the 4-6 cm fingerlings of four selected species viz. catla (*Catla catla*), Rohu (*Sebeo rohita*), Mrighal (*Cirrhinus mrighla*) and grass carp (*Cteneopharyngodon idellus*) were left in the pond. Generally 1000 fingerlings can be accommodated in 625 m^2. The density of the population depends according to the level of management and the number of species of fishes that are to be left. Use of concentrates helps in quick growth of fish. It is recommended to give mixture of groundnut cake and rice bran in 1: 1 ratio at the rate of 1 to 3 per cent of body weight of fish. These materials are to be mashed thoroughly and made into ball with the help of water and suspended at minimum four places in the pond. Since poultry droppings were available in the system, around 1 kg of poultry droppings were also applied everyday to the pond. This also helps to provide ready-made food for the fish. For grass carp variety, green grass was applied every day.

Normally fish is to be harvested from pond after 10 to 12 months period. Maximum weight of the fish at the end of one year varies from 900 to 1200 g per fish depending upon the variety. In the present study the weight ranged from 810 g in case of mrighal to 1180 g in the case of grass carp (Table 6). It is desirable to harvest the fishes at periodical intervals so that the remaining ones in the pond can attain good weight. On an average 400 kg could be harvested.

Table 6. Growth of different varieties of fish (average weight in g/length in cm)

Varieties	Growth of fishes over a period of time				
	After I month	After 3 months	After 5 months	After 8 months	After 12 months
Rohu	13/8.0	86/17	150/23	470/30	850/35
Catla	15/6.5	88/15	250/23	550/30	900/45
Mrighal	12/5.0	82/14.5	145/20	450/25	810/30
Grass carp	25/8.4	90/19.5	275/20	900/36	1180/42

(Singh *et al.*, 1994).

3.2. Nutrient input into the system

In addition to inorganic inputs to the coconut palms and the grass grown in the interspaces, the production components of the system viz., the animal activities contribute considerable quantities of animal biomass in the form of cow dung, poultry manure and urine and cowshed washings. Of these production, cowdung alone accounts for 14 tons, contributing to 98 kg nitrogen, 70 kg phosphorus and 105 kg potash. Similarly poultry droppings can be recycled in to the system. The coir pith bedding material in the poultry sheds analysed 1.85% N, 2.04% P and 1.87% K. The leaflets of dried fronds of coconut are separated and used for vermicomposting employing the earthworm *Eudrilus* sp. Out of a total quantity of 6 tonnes of dried fronds, leaflets accounts for 2.1 tons which yield the vermicompost in about 3 months with a recovery of 70% and approximate nutrient content of 1.8% N, 0.3% P and 0.6% K. The petiole of the coconut frond is used for fuel. These innovative methods contribute to 155.06 kg nitrogen, 76.72 kg phosphorus and 141 kg potash. The requirement of inorganic inputs for one ha of coconut, fodder grass unit viz., 210 kg N, 38.5 kg P and 173.8 kg K, can be supplemented to the extent of 74.29, 100 and 81.78% of N. P, and K through recycling of animal and plant wastes in one hectare of coconut garden (Table 7). Reducing chemical load into the agriculture system by recycling on farm wastes in an eco friendly way to improves of soil health and aids in sustaining productivity (Khan *et al.,* 2002).

Table 7. Nutrient inflow in coconut based mixed farming system

Items	Quantity	N (kg)	P (kg)	K (kg)
A) Nutrient contribution by the components of the system				
Cow dung	14 tons	98.00	70.00	105.00
Poultry	295 kg	1.92	2.36	2.08
Cows urine and cowshed washings	50000 litres	30.00	-	28.00
Total		**129.92**	**72.36**	**135.08**
B) Nutrient substitution through recycling of the coconut fronds (without petiole)				
Coconut Leaves (vermicompost)	1.45 tons	26.14	4.36	6.94
Total (A + B)		**155.06**	**76.72**	**141.02**
C) Inorganic addition to the system				
i) Coconut palms	0.5:0.32: 1.2	79.00	22.12	157.37
ii) Grass	160: 20: 20	131.2	16.4	16.4
Total (i + ii)		**210.2**	**38.52**	**173.77**
Percent supplementation of inorganics through waste recycling				
Percent supplementation		**74.29**	**Entire**	**81.78**

* kg/ha

4. Impact of mixed farming system

a) Soil physical properties

Mixed farming system generally improves soil physical properties besides improving the productivity of coconut. Maheswarappa *et al.* (1998) observed that there was improvement in soil physical properties by adopting mixed farming system. Increase in maximum water holding capacity of soil (from 24.0 to 33.6%), improvement in porosity of soil (38.2 and 39% to 44.5 and 46.0%) and reduction in bulk density of soil (1.54 g cc^{-1} to 1.40 g cc^{-1}) both in coconut manuring circles (basins) and grass cultured plot was noticed. Palaniswami *et al.* (2010) also reported higherwater holding capacity, reduction in the bulk density and higher hydraulic conductivity under mixed farming treatments compared to monocropping of coconut (Table 8). However, Nayar and Sahasranaman (1978) observed that mixed farming had little effect on the size of soil aggregates when observed after a period of five years.

Table 8. Effect of mixed farming practices on soil physical properties

Treatments	Water holding capacity (%)	Bulk Density (g cm^{-3})	Hydraulic Conductivity (mm $second^{-1}$)
T_1-monocrop + Recommended fertilizer	19	1.56	0.0037
T_2- mixed farming + 50% Organic + 50% Inorganic	19	1.23	0.0064
T_3- mixed farming + 100% organic	21	1.41	0.0044
T_4- mixed farming + 100% Inorganic	18	1.56	0.0105

b) Soil chemical properties

Biddappa *et al.* (1993) and Maheshwarappa *et al.* (1998) reported higher organic carbon, N, P and K status under grass cultured plot. The secondary and micronutrient status of soils showed the reverse trend as that of N, P and K. Among the grass cultures tried, guinea grass recoded higher available N, P and K compared to Coconut + hybrid napier bajra intercropping. They also observed that the soils under mixed farming generally showed relatively lower values of available Ca, Mg, Mn, Cu and Zn whereas there was marginal increase in available Fe status. Similar significant increases in the organic carbon, available P, exchangeable Ca and Mg contents were noticed in the soil samples drawn at depths of 0-50 and 50-100 cm at root affected area (Sahasranaman *et al.,* 1976). Increase in the available K was noticed only at 50-100 cm depth. No significant change in available N and pH was observed after five years of mixed farming. Bopiah and Shetty (1991) also observed that the organic carbon and total N contents of the soil were higher in the mixed farming system than in the coconut monocropping system. The addition of slurry from the biogas plant added considerable organic matter into the system, thereby increasing the various microbial and biochemical properties of the soil. The total P and available P were slightly higher in the mixed farming system (Table 9).

c) Soil biological properties

Intercropping of fodder hybrid napier with coconut palms resulted in the proliferation of total bacteria and nitrogen fixing organisms in the coconut rhizosphere, irrespective of the condition of the palm. Compared to the palms in the control plot, crop mixing enhanced phosphate solubilizing bacteria in root region of root (wilt) affected coconut palms harbouring significantly higher numbers. (Potty and Jayasankar, 1976; Potty *et al.,* 1977). In the root (wilt) affected area, beneficial microflora increase was observed by adopting mixed farming practice over a period of five years. The highest number of soil bacteria

Table 9. Chemical composition of soils of coconut-based mixed farming and coconut monocropping

Crop	Depth (cm)	pH	Organic C(%)	Total N(%)	Total P(%)	Available P(μg g^{1} soil)	Total K(%)	Available K(μg g^{-1} soil)
Coconut (MF)	0-25	6.50	0.71	0.068	0.50	22	0.15	88
	26-50	5.10	0.50	0.053	0.36	18	0.23	97
	51-100	5.00	0.26	0.029	0.21	16	0.23	50
Napier grass (MF)	0-25	5.35	0.36	0.038	0.30	170	0.13	23
	26-50	5.30	0.19	0.021	0.35	18	0.23	32
	51-100	5.43	0.18	0.018	0.12	2	0.20	24
Coconut, monocrop	0-25	5.55	0.22	0.020	0.42	13	0.18	60
	26-50	5.28	0.15	0.015	0.31	12	0.19	56
	51-100	4.44	0.10	0.011	0.28	8	0.22	40
Coconut, monocrop interspace	0-25	5.48	0.18	0.018	0.30	10	0.17	27
	26-50	4.93	0.09	0.010	0.52	1	0.21	13
	51-100	4.80	0.06	0.006	0.40	1	0.17	23

*Average of three replications

was observed in *Stylosanthes gracilis* plots. But the nitrogen fixing organisms were maximum in the hybrid napier + *Centrocema pubescense* plots. The hybrid napier + *S. gracilis* combination proved to be the best among the combined treatments because of low level of denitrifiers and comparatively high proliferation of nitirifies (Sahasranaman *et al.*, 1983).

Bopaiah and Shetty (1991) found that bacterial counts were higher in the roots of coconut and Napier grass of mixed farming than in coconut monocropping. The microcroflora and enzyme activities decreased with the increase in soil depth. Urease, dehydrogenase and phosphatase enzyme were greater in the rhizosphere soil than in the root zone soil. The bacteria and fungi counts were more in the root region of grass-cultured plots compared to coconut monocrop. The actinomycetes count did not show much variation between mixed farming and monocropping system. The N_2 fixer and phosphate solublizing bacteria were more in the mixed farming system as compared to monocropping system. The increased microbial count and beneficial microorganisms could be due to addition of dairy and poultry wastes resulting in higher organic carbon content of the soil in the mixed farming system. Microbial biomass and activities of soil enzymes (phosphatase and dehydrogenase) indicated that the soil biological activity was more in the farming system when compared to the monocrop of coconut. Microbial biomass was high in the system where organic recycling is practiced. This microbial biomass is considered among the most labile pools of organic matter and thus, serves as the reservoir of organic matter Phosphatase activity related to hydrolyzing P compounds and liberates inorganic P for absorption by plants (Table 10). The dehydrogenase activity is remarkably high compared to monocropped basins indicating microbial oxidative activity. Higher biomass carbon in the root zone of coconut/ Napier grass in the mixed farming than in coconut in the monocropping system (Table 11).

Thomas *et al.* (2010) studied the microbial distribution in the coconut basin and the interspaces in the coconut garden and population of bacteria, fungi and actinomycetes were found to be very high in the mixed farming with 100% organic farming treatment

Table 10. Microbial activity in coconut - grass system

Treatments	**Coconut**		**Grass**	
Depth	0-25(cm)	25-50(cm)	0-25(cm)	25-50(cm)
Microbial biomass(µg C / g soil)				
Monocrop	151.06	89.36	187.5	113.33
Mixed farming	**181.98**	**114.80**	**219.59**	**142.77**
Phosphatase (µg p-nitrophenol /g soil /h)				
Monocrop	31.16	15.43	39.16	15.67
Mixed farming	**41.23**	**27.15**	**47.29**	**21.94**
Dehydrogenase (µg formazan / g soil / h)				
Monocrop	5.02	2.66	7.14	4.18
Mixed farming	**9.36**	**6.51**	**14.46**	**10.03**
Bacteria x10^6				
Monocrop	2.27	2.73	1.27	0.67
Mixed farming	**8.03**	**3.23**	**8.73**	**1.87**
Fungi x10^3				
Monocrop	2.27	3.03	0.47	0.77
Mixed farming	**9.33**	**8.55**	**2.45**	**3.22**
Actinomycetes x10^5				
Monocrop	3.**67**	**4.0**	**4.33**	**2.33**
Mixed farming	**9.50**	**2.89**	**5.23**	**2.45**

Table 11. Soil microbial biomass in the root zone of coconut-based mixed farming (MF) and coconut mono-cropping systems

System	**Soil microbial biomass (µg C g^{-1} soil)**	
	0-10 days	**10-20 days**
Coconut (MF)	187.80	27.80
Napier grass (MF)	177.95	41.88
Coconut monocropping	111.22	19.46
Lsd (P = 0.05)	70.74	28.50

followed by the 50% organic substituted treatment and the population was low in inorganic fertilizer alone applied treatments (Table 12).

Table 12. Microbial activity in the coconut based mixed farming system

Treatments	Bacteria (10^5 cfu/g soil)		Fungi (10^3 cfu/g soil)		Actinomycetes (10^5 cfu/g soil)	
	Coconut basin	Inter space	Coconut	Inter space	Coconut	Inter space
T_1-monocrop + Recommended fertilizer	13.45	10	6.86	4.16	9.62	6.16
T_2- mixed farming + 50% Organic + 50% Inorganic	18.22	21.64	6.6	7.23	7.83	8.35
T_3- mixed farming + 100% organic	23.17	29.22	18.16	19.31	11.33	14.26
T_4- mixed farming + 100% Inorganic	11.76	14.66	7.12	8.35	7.00	12.94

d) Leaf nutrient status

Higher major and secondary nutrients content in the index leaf of coconut was studied under mixed farming compared to monocropping of coconut from 1989 to 2008 at Kasaragod (Table 13). This is due to beneficial effect of mixed farming system in improving the soil physical, chemical and biological environment which favoured the higher uptake from the

Table 13. Effect of mixed farming on leaf nutrient status (per cent) at Kasaragod

Period		N	P	K	Ca	Mg	Reference
Mixed farming unit at Kasaragod							
Pre-treatment (1988-89)		1.65	0.19	0.99	0.26	0.14	Maheswarappa *et al.* (1998)
1995-96		2.23	0.23	1.35	0.41	0.46	
1999-2000	**Monocrop**	1.87	0.15	1.36	-	-	Khan *et al.* (2008)
	Coconut + guinea grass	1.82	0.14	1.74	-	-	
2007-08	**Monocrop**	1.83	0.12	1.01	0.39	0.19	Palaniswami *et al.* (2008)
	Coconut + Hybrid bajra napier Co3	1.92	0.13	1.14	0.52	0.20	
Mixed farming unit at Kayamkulam							
Pre-treatment (1971)		1.63	0.15	0.92	0.23	0.17	Sahasranaman *et al.* (1983)
Post-treatment (1974)		1.84	0.18	1.46	0.42	0.22	

soil nutrients pool. Similar increase in leaf nutrient status especially potash of coconut has been reported by Sahasranaman *et al.* (1983) in root (wilt) affected garden when mixed farming was adopted.

5. Impact of mixed farming on disease symptoms of root (wilt) affected palms

In the mixed farming plot, amelioration of the foliar yellowing of the root (wilt) affected palms was reported by Sahasranaman *et al.* (1976). But progressive increase in the other symptoms of the disease, viz., flaccidity and necrosis was observed (Anonymous, 1976) indicating that the practice had little curative effect on the disease. Study of the root growth of the palms in the mixed farming area (with grass and irrigation) and control (without grass and no irrigation) indicated regeneration of roots in the former (CPCRI, 1976).

6. Yield of coconut

The effect of mixed farming on the yield of coconuts has been doubted, because grasses are vigorous growing and exhaust the nutrients. The data from the experiment for the period 1972-78 at Kasaragod showed that, when the management practices for both crops were adequate, the yield of the main crop did not decline. The mean annual yield obtained per palm during the pre-experimental (1969-72) and experimental (1972-78) periods were 64.7 and 69.5 nuts, respectively, showing an increase of 7.4%, which was substantial, considering the age of the plantation. Since the palms were already under good management, as reflected in the high pre-experimental yield, and age of the palms, the response obtained was significant. The palms in an adjoining plot of almost same age and good management, had shown a decline of 15.8% in yield, for the corresponding period. Hence, the net response in yield of coconuts, due to mixed farming practice was over 23%. Vikraman Nair *et al.,* (1976) observed that a minimum of 25% increase in yield can be obtained by such adopting mixed farming. Jacob Matthew and Mohamed Shaffee (1979) found that mixed farming in coconut had synergistic effects, increasing the coconut yield compared with coconut monocropping. In the root (wilt) affected area, a 28% increase in nut yield was obtained by adopting mixed farming practice over a period of five years (Sahasranaman *et al.,* 1983). It was also reported that the increase in yield was the highest in palms of the disease early group (disease index 11-25) and the lowest in palms of the disease advanced group (disease index above 51). Increase in production of inflorescences as well as female flowers was also reported (Anonymous, 1983).

The data obtained from the field experiment on mixed farming initiated in 1975 also indicated that the production of female flowers, percentage of female flower set and the yield of coconut were not adversely affected by raising fodder crops in the interspaces of coconut palms, both under rainfed and irrigated conditions.

Jacob Matthew and Mohamed Shaffee (1979) found that mixed farming in coconut had synergistic effects, increasing the coconut yield compared with coconut monocropping. Maheswarappa *et al.* (2001) reported an yield of 112.3 nuts / palm / year in WCT palms with mixed farming when compared to pre-experimental yield of 58.6 nuts / palms / year, whereas for Laccadive Ordinary the respective figures were 163.5 and 101.7 nuts / palm / year.

7. Economics of mixed farming system

Since a large majority of coconut growers are marginal farmers the income from a sole crop of coconut is insufficient to make a satisfactory living. Economic analysis of the project on mixed farming at CPCRI, Kayamkulam revealed that the annual net profit per hectare increased from Rs. 86 in the case of coconut alone (pre experimental period) to 2780 from coconut and dairying (CPCRI, 1976). Sahasranaman *et al.* (1976) reported that the economics of mixed farming unit maintained at Kayamkulam showed that by maintaining eight milch cow in 1.3 ha , a profit of Rs. 6693 was obtained in five years from the dairy alone with a cost benefit ratio of 1:1.06. But when the income from coconuts was also taken into account the profit went upto Rs. 18,064/- with a cost benefit ratio of 1:1.15. If the dairy work is done by the owner family, the cost benefit ratio will go up further to 1:1.37, providing the farmer family with employment worth of Rs.424/ month (Table 14). Based on the mixed farming out put data for the period 1972 to1988, the economics of this system when worked out at 1988 prices, showed a net return of Rs. 29,500/ha/year against a net return of Rs. 17,000/ha/year for coconut sole crop raised under irrigation with the similar age group of palms in Kerala situation (Das, 1989). The economic analysis of mixed farming system maintained at CPCRI, Kasaragod for the period,1989-90 to 1997-98, realized a net return between Rs 49,700 and Rs. 126,900 (Table 15) (Maheswarappa *et al.* 2000).The cash flow analysis performed using a discount rate of 14% realized the benefit: cost of 1.36, the net present worth of the system was Rs. 286,500, the internal rate of return was 27.44% and the pay back period was 5 years (Maheswarappa *et al.* 2001). Economic analysis of the mixed farming system maintained at CPCRI for the period 2007-08 recorded a net income of Rs.1,37164/ha and the maximum income was realized from dairy unit followed by coconut (CPCRI, 2008). Coconut, milk yield and broiler's sale accounted for 83 per cent of the revenue generated from the system.

8. Employment generation

The annual labour requirement of a pure coconut plantation of one hectare was about 150 man days, of which about 50 per cent was for harvesting of coconuts. Under mixed farming practices not only the farmer family (husband and wife) was getting employment round the year, it could provide additional 100-150 mandays work for outside labour. Total

Table14. Economics of mixed farming in coconut gardens (Rs. /ha)

A. Krishnapuram		
(a)Capital expenditure for five years (1970-1975)		
Total expenditure	26,213.02	
Total appreciation	1,300.00	
Total depreciation	4,016.10	
(b)Income, expenditure, and cost benefit ratios for the experimental period		
	Dairy	Dairy + Coconut
Total income	1,19,596.95	1,35,010.44
Total expenditure	1,12,903.34	1,16,946.49
Cost benefit ratio(Hired labour)	1 : 1.06	1 :1.15
Expenditure (Substracting labour charges)	87,441.09	
Cost benefit ratio* if family itself attended to agrostology work	1:1.37	
B. Kasaragod		
a) Capital expenditure	1975-76	1972-76
Total expenditure	5,211.00	39,790.00
Total appreciation	5,251.00	15,121.00
Total depreciation	3,275.00	10,496 00
(b) Income, expenditure, and cost benefit ratios for the experimental period		
Total income	36,577.55	1,24,547.04
Total expenditure	24,477.65	80,603.46
Cost benefit ratio	1 :1.50	l : 1,50
Total income for the farmer family for labour & management	12,099.90	43,943.58
Wages earned by the farmer family	7,921,50	21,094.81

❖ Note : The owners* family will get an employment worth Rs. 424.00/ month from the mixed forming.

employment in a normal year was about 800-850 man days, and in years when grass slips were to be planted /replanted, their employment potential rose to about 1000 mandays. (Sahasranaman *et al.,* 1983).

Table 15. **Economic returns of coconut based mixed farming system at Kasaragod (Rs. / ha) (1989-90 to 1997-1998)**

Year	Total variable	Annuity	Total return	Gross return	Net return
1989-90	94300	36400	130700	184500	53800
1990-91	93500	36400	129900	188300	58400
1991-92	118700	36400	155100	190600	35500
1992-93	122000	36400	158400	191900	33500
1993-94	139700	36400	176100	231700	55600
1994-95	138800	36400	175200	254300	79100
1995-96	159300	36400	195700	284700	89000
1996-97	164300	36400	200700	290100	89400
1997-98	130600	36400	167000	293900	126900

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Coconut based cropping systems in root (wilt) diseased areas

V. Krishnakumar and H. P. Maheswarappa

Introduction

Out of the total area of 1.94 million ha under cultivation in India, coconut in Kerala occupies an area of 8.2 lakh ha and produces 5,641 million nuts with 6,889 nuts/ha (2007-08), which is 11% lower than Indian productivity. The productivity of coconut in Kerala is also low compared to the other south Indian states (except Karnataka). Many reasons have been attributed to this condition, the most predominant being the prevalence of root (wilt) disease, which is non-lethal and debilitating. This disease was first noticed in a very limited extend around 1882 from Erattupetta area of Meenachil taluk and subsequently from Kaviyoor and Kalluppara areas of Thiruvalla taluk (Kottayam district) and Kayamkulam of Karthikappally taluk (Alappuzha district) (Pillai, 1911). Since then, this disease has spread in all directions from the original foci of infection and is reported to be present in a contiguous manner in eight southern districts and isolated pockets in other northern districts in Kerala. This disease is also reported from neighbouring districts of Tamil Nadu and Karnataka bordering Kerala state and some parts of Goa.

Most coconut gardens in the eight districts (between Thrissur in the north and Thiruvananthapuram in the south), covering an area of about 4.1 lakh ha (2006-07), which is 46.90% of the total coconut area in Kerala are affected by root (wilt) disease. The percentage share of coconut production form these districts is 47.40 and the rest comes from the six other districts (where the disease is not occurring in a wide spread manner). The net return from the disease affected area is comparatively low due to the poor yield of coconut and also due to the additional expenditure to be incurred on plant protection operations to combat the leaf rot disease, which is often found to be superimposed with root (wilt) disease. Improving yield from root (wilt) disease affected coconut gardens all on a sudden is not possible as there is no effective prophylactic or curative measure for this disease as it is caused by phytoplasma. If the diseased palms are left unattended, the disease will advance and cause drastic reduction in nut yield. It has been reported that the reduction in yield of root (wilt) affected palms is proportional to the intensity of the disease and it varies from 10 to 80% (Anon.,1976a). In such a situation where the income from the main crop is declining, the agronomic strategy has to be oriented to evolve a suitable inter/mixed/multi-storeyed cropping programme, which will ensure a reasonable income to the farmer from the land.

The land area available for cultivation (size of holding) is comparatively low in Kerala and hence, the scope of bringing more area under cultivation is remote. In order to enhance productivity per unit land area, we have to make maximum use of limited resources without affecting the ecological balance in any manner. The ideal approach for small farmers towards this would be to increase the cropping intensity, which can be achieved through two ways, the first being the time concept where instead of taking only one crop, more crops per year are cultivated and harvested and the second being space concept, where all the available space in between the main crop is used for cultivation of various crops.

In root (wilt) disease affected areas, the negative effects of coconut monoculture system of cultivation and either no application or inadequate inorganic fertilizers without ensuring a natural organic recycling process have already shown adverse effect in progressive decline in yield and soil fertility. Adoption of cropping system approach has the advantages of improving farm income and family nutrition, besides offering agro biomass for recycling that helps in build up of organic matter content of soil, which is the site of all major biological activities.

In any cropping system model, careful attention should be given for management of different crops in order to exploit their genetic potential and available resources such as water, sun light, nutrients etc. Crops are classified into four groups (Table 1) based on their reaction to sunlight/shade (Vikraman Nair *et al.*, 2003). The crops should also be identified based on the reactions to intensity of sunlight/shade available in the coconut gardens.

Planting of crops with varying rooting habit at appropriate spacing would not only help avoid competition for water and nutrients, but enhance their use efficiency as well.

Table 1. Classification of crops based on tolerance to sunlight/shade for intercropping

Sl. no.	Parameter	Effect on production/remarks	Example of crops
1	Non-tolerant to even slight shade	Drastic decline in yield even under slight shade. Cannot be grown successfully as intercrop	Paddy, Bhendi, sweet potato, leguminous plants, ground nut
2	Non-tolerant to shade	Yield decline increases with intensity of shade. Can be grown in border areas where more sunlight is available	Coleus, Brinjal, Tomato, Chilli, Dioscorea, Nendran banana
3	Tolerant to shade	Slight reduction in yield due to shade. Can be grown successfully when 50% sunlight is available	Colocasia, Amorphophallus, Banana varieties other than nendran
4	Shade loving	Yield increases to some extent with increase in shade. More ideal as intercrop than sole crop	Ginger, Turmeric, Arrow root, Kacholam

Table 2. Management practices for intercropping in coconut garden

Intercrop	Time of planting	Method of planting, spacing	Manures		Duration (months)
			FYM (t/ha)	NPK (kg/ha)	
Tuber crops					
Elephant foot yam	March-April	Pits 90 x 90cm	20	26:20:33	8
Greater yam	April-May	Pits 90 x 90cm	9	80:60:80	8
Lesser yam	April-May	Pits 75 x 75 cm	8	60:30:60	7
White yam	April-May	Pits 90 x 90cm	9	80:60:80	8
Cassava	May-June	Mounds 90 x 90cm	9	50:50:100	8-10
Vegetables					
Chilli	May-June (rainfed) Sept-Oct. (irrigated)	Transplant in shallow trenches / pits or on ridges 45 x 45 cm	20-25	75:40:25	
Brinjal	May-June (rainfed) Sept-Oct. (irrigated)	Transplant in shallow trenches / pits or on ridges 60x60 cm for non-branching 60x 75-90 cm for branching types	20-25	75:40:25	
Spices					
Ginger	First fortnight of April	Small pits at a depth of 4-5 cm. 25 x 25 cm	30	75:50:50	8-9
Turmeric	First fortnight of April	small pits in the beds in rows 25 x 25 cm	40	30:30:60	7-9
Banana	April-May (Rain fed) Aug.-Sept. (Irrigated)	Pits Poovan/ Palaynakodan- 2.1x 2.1m Robusta- 2.4 x1.8 m	10 kg/plant as basal	60-200 : 160-200 : 320-400 (in different split doses)	
Pineapple	May-June	Trenches (convenient length and 90 cm width and 15-30 cm depth) Double rows at 70 x 30 cm	25	320:160:320	
Beverage					
Cocoa	May-June	Pits Single row between coconut palms at the centre	15-20 kg/plant	100:40: 140 g / tree / year	

In coconut garden when intercrops are to be planted, care should be taken to plant them (except for pepper) at least 2 m away from the radius of coconut. Nutrients and water should be applied for each crop separately as per schedule. Coconut based cropping system is an important and most relevant activity in the present day context of sustaining income from unit area. The details of agro management practices to be followed for various intercrops are given in Table 2.

Various studies on coconut based cropping systems in root (wilt) diseased areas have been conducted at the Regional Station of Central Plantation Crops Research Institute, Kayamkulam since the early 1970s.

2. Effect of intercropping on yield of coconut palms

Menon and Nayar (1978) studied the effect of intercropping with tuber crops like tapioca (*Manihot esculenta* Crantz), elephant foot yam (*Amorphophallus companulatus* Bume) and yam (*Dioscorea alata* Linn.) for three years from 1975 on the yield and disease intensity of 16 year old West Coast Tall coconut palms planted at 7.5 x 7.5 m in root (wilt) prevalent area. The intercrops were grown under rainfed condition by leaving an area of 2 m radius around the base of palms. The overall response of palms indicated that there was no reduction in yield of coconut palms due to intercropping. But there was variation in response in yield of palms in different disease intensity groups. A slight increase in the overall mean yield was noticed in the plot where elephant foot yam was cultivated (11.81%) followed by the plot where yam was raised (2.28%) (Table3). The estimated net response in nut yield of root (wilt) affected palms was to the extent of 5, 18 and 8 per cent with tapioca, elephant foot yam and yam, respectively.

Table 3. Effect of intercropping in root (wilt) affected coconut gardens -yield of coconut palms

Treatment	No. of nuts/palm*		Percentage increase / decrease over pre-exptl. period	Estimated net response (%)
	Pre-exptl. period	Post-exptl. period		
Mono crop of coconut(control)	40.96	38.62	-5.76	
Tapioca	49.75	48.85	-1.80	+ 4.96
Elephant foot yam	52.49	58.69	+ 11.81	+ 17.57
Yam	57.01	58.31	+ 2.28	+ 8.04

* Overall mean under different disease indices (Apparently healthy, Disease early, Disease middle and Disease advanced categories)

Further analysis indicated a positive response in yield of coconut palms of the apparently healthy group. However, in the case of disease advanced group, decrease in yield was noticed both in the intercropped and non-intercropped areas. They also reported that as the disease advances and the palms cross the middle index group, recuperating capacity of palms get diminished resulting in reduction in yield.

The effect of mixed cropping of Forestero variety of cocoa in 16 year old root (wilt) disease affected West Coast Tall coconut palms during 1975 to 1978 was evaluated by Kamalakshy Amma *et al*. (1982). The treatments included three systems of planting viz., single hedge- one row of cocoa in between coconut (500 plants/ha); double hedge-two rows of cocoa (700 plants/ha) and mixed single-cocoa planted in between the rows of coconut in triangular system (744 plants/ha). It was found that the yield of coconut in root(wilt) affected garden could be increased by 27 to 35 per cent by mixed cropping with cocoa as compared to that of mono cropping of coconut (Table 4). The maximum yield of 62 nuts/palm/year was obtained when double hedge system was adopted.

Table 4. Effect of mixed cropping of cocoa in root (wilt) disease affected coconut garden

Treatment	Disease index		Increase in coconut yield over pre-experimental period (%)	Economics (based on 1978 price)	
	Pre-expt.	Post-expt.		Gross return (Rs./ha)	Net return (Rs./ha)
Mono crop of coconut	35	34	5.1	6457	3607
Coconut + cocoa (Single hedge)	33	30	27.1	13457	8357
Coconut + cocoa (Double hedge)	28	26	32.8	16625	11065
Coconut + cocoa (Mixed single hedge)	32	30	35.0	16835	10175

3. High Density Multispecies Cropping System in root (wilt) disease affected area

High Density Multispecies Cropping System models consist of a large number of crop species that include annuals, biennials and perennials with very high plant density. The crops selected will have large, medium, and small canopy architecture and are planted in a systematic manner to exploit space both in the vertical and horizontal dimensions. The disturbance to soil is to be kept to the minimum (only slash weeding is done) and all the biomass (other than the economic part) produced is also to be recycled within the system. Cash, food and fodder crops are generally included in the cropping system. The annual crops are removed as the canopy size of perennial crops increases.

An experiment on high density multispecies cropping system with coconut and various component crops has been in progress at the Regional Station of Central Plantation Crops Research Institute, Kayamkulam since 1998 onwards. Crops included in the system were coconut, nutmeg, banana, pine apple and tuber crops (amorphophallus, dioscorea and colocasia). Various agro management practices as given below were adopted in the system.

- Growing cowpea (*Vigna unguiculata*) as green manure crop in coconut basin during April-May and incorporating biomass when the plants attained maximum vegetative growth.
- Application of composted coir pith @ 50 kg per palm during September-October (this practice was discontinued from 2004-05 and all the bio mass was vermicomposted and applied to coconut palms in one portion of the field along with half of the dose of recommended fertilizers and rest of the palms with full dose of fertilizers).
- Application of recommended dose of fertilizers for coconut (500:300:1000 g NPK/ palm/year) in two split doses- one-third during April-May and the remaining during September-October along with $MgSO_4$@1.0 kg/year.
- Adoption of need based plant protection measures for control of leaf rot disease of coconut palms.
- Mulching coconut basins during summer months and irrigating coconut and other plants through perfo irrigation.
- Adoption of recommended package of practices for component crops as per the Kerala Agricultural University.

The results of various studies on HDMSCS (Table 5) indicated that there was improvement in coconut yield over the years. The average yield obtained during the five year periods of 1994-98, 1999-03 and 2004-08 were 62, 65 and 62 nuts/palm, respectively compared to the pre-experimental yield of 30 nuts /palm (Maheswarappa, 2008 and Krishnakumar and Maheswarappa,2010). The increase in yield of coconut was mainly due to improvement in

Table 5. Average yield of coconut and component crops in HDMSCS

Period	Coconut (nuts/year)*	Banana (kg)	Pepper (kg)	Pineapple (kg)	Nutmeg & Mace (kg)	Amorpho phallus (kg)	Dioscorea (kg)	Colocasia (kg)
1994-98	6181(62)	849	26	318	13	312	270	223
1999-03	6453(65)	1,053	28	242	30	273	300	378
2004-08	5547(62)	904	23	321	16	1250**	—	—

* Figure in parenthesis is no. of nuts/palm/year ** yield during 2008 only

chemical and microbiological characteristics of soil coupled with effective management of leaf rot disease, which enhanced growth and yield of coconut. Integrated agro management practices for coconut and changes in microclimate due to inter/ mixed cropping with banana, pineapple and nutmeg plants occupying different vertical spaces in the system are also attributed as the reasons for improvement in health and yield of coconut palms.

4. Yield of component crops

From the intercropping studies, Menon and Nayar (1978) reported that yield of tuber was the highest in the case of tapioca (Table 6). Among the varieties of tapioca cultivated, H-165 gave an average yield of 15.93 t of tuber/ha/year. Elephant foot yam and Yam gave considerably low yield during the second and third years. The high yield of tapioca when grown as intercrop was maintained in all the years which was an indication that in spite of successive cropping, there may not be substantial reduction in the yield of intercrops. Tapioca gave the maximum output per ha, whereas this was not so in the case of elephant foot yam and yam, which necessitated suitable crop rotation for these two intercrops.

Table 6. Intercropping in root (wilt) affected coconut gardens -mean yield of intercrops

Intercrop	Mean yield (t/ha)
Tapioca H-165	15.93
Tapioca M-4	6.66
Tapioca H-226	7.50
Elephant foot yam(local)	5.36
Yam (local)	5.45

Yield of cocoa was the maximum when cultivated in mixed single hedge system (238 kg) followed by double hedge (196 kg) and single hedge (110 kg) of planting (Kamalakshy Amma *et al*.,1982).

From the studies on HDMSCS in root (wilt) disease affected area, Maheswarappa *et al*. (2003) noticed differential performance of banana varieties. The highest average yield was given by Karpooravalli (22-25kg/bunch) followed by Palayankodan (20-24 kg/ bunch). The performance of other varieties ranged from 15-20 kg for Poovan; 14-19 kg for Njalipoovan; 13-18 kg for Nendran and 12-17 kg/bunch for Robusta. Average yield of pepper varied from 1.0 to 1.2 kg dry pepper/plant. Among the pepper varieties trailed on coconut, Karimunda and Panniyur-I performed better with an average yield of 1 to 1.2 kg /vine/year (Maheshwarappa and Anitha Kumari, 2005). Yield of pineapple ranged from 1.0 to 2.0 kg fruit/plant. Tuber crops such as dioscorea (5.5-7.0 kg/plant), amorphophallus (7.5-10.0 kg /plant) and colocasia (3.0-4.0 kg/plant) also performed very well in the system and provided additional yield. .

5. Effect of intercropping on root (wilt) disease intensity

Inter /multiple cropping and mixed farming systems in root (wilt) affected coconut gardens have been found to exert ameliorating effect on the disease affected palms. The effect of intercropping on palms under different disease intensity groups was studied by Menon and Nayar(1978) and the results are given in Table 7.

Table 7. Effect of intercropping on palms under different disease intensity groups (% of total)

Group	Disease index	Control		Tapioca		Elephant foot yam		Yam	
		1975	1977	1975	1977	1975	1977	1975	1977
Apparently healthy	0-10	13.33	—	18.36	10.22	12.00	13.00	5.26	16.66
Disease early	11-25	26.67	26.66	20.40	18.36	20.80	22.00	21.05	22.23
Disease middle	26-50	40.00	40.82	40.82	51.02	42.38	30.00	60.52	41.66
Disease advanced	> 51	20.00	33.33	20.40	20.40	23.82	35.00	13.17	19.45

It was found that all the apparently healthy palms in the mono cropped control plot developed the disease during the course of study. In general, there was not much difference in percentage of palms in various disease categories due to intercropping except an increase in the case of disease middle category for tapioca and apparently healthy for yam.

The mean disease index (Fig.1) in the monocropped plot increased from 34.23 to 36.13 indicating an advancement of disease intensity. In the case of palms intercropped with tapioca, the increase was little more conspicuous and it was from 32.1 to 37.25.

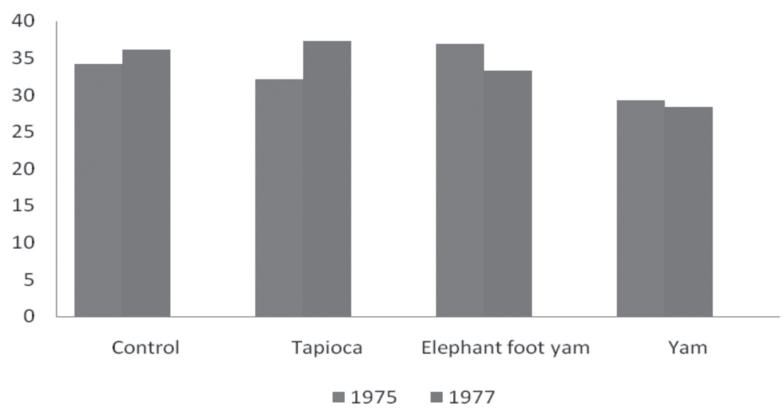

Fig.1. Mean disease index of root (wilt) diseased coconut palms during 1975(pre) and 1977(post) experimental period under intercropping (Menon and Nayar, 1978)

There was a slight reduction in mean disease index score of palms intercropped with elephant foot yam from 36.95 to 33.25, but the percentage under the disease advanced group increased during the experimental period. Reduction, though negligible, in the overall mean disease index of palms from 29.3 to 28.4 in the area intercropped with yam was also observed.

No further deterioration in the disease condition of the palms was observed by Kamalakshy Amma *et al*. (1982) when different systems of mixed cropping of cocoa was adopted in root (wilt) disease affected area. They have attributed this to the beneficial interaction and effect of intense microbial activity in the rhizosphere of coconut and the increased activity of nitrogen fixers and phosphorus solubilizers.

Antony (1983) studied the effect of intercropping with cassava, elephant foot yam, colocasia, greater yam, ginger and turmeric and found that there was no significant change in disease indices and yield in affected palms under rainfed conditions. Maheswarappa *et al.* (2005) from the HDMSCS studies at CPCRI, Regional Station from 1998 to 2002 noticed reduction in root (wilt) disease index after four years to the extent of 2.9 in disease early, 5.6 in disease middle and 6.4 in disease advanced palms due the integrated management practices (Table 8).

Table 8. Root (wilt) disease index of coconut palms as influenced by integrated nutrient management practices

Disease index	During June, 1998	During July, 2002	Increase(+) Decrease(-)
Disease Early(<20) (33 palms)	15.1	12.2	-2.9
Disease Middle(20-50) (59m palms)	41.4	35.8	-5.6
Disease Advanced (>50) (8 palms)	60.8	54.4	-6.4

6. Economics of inter/mixed cropping /HDMSCS

Growing all the three tuber crops as intercrops was found to be profitable, but tapioca gave the maximum profit (Menon and Nayar, 1978). Intercropping with tapioca gave about 50% more income compared to the other tuber crops. The slight reduction in yield of coconuts was more than compensated by the total output from the tapioca plot. Thus, intercropping was more profitable than monocropping of coconut. They also revealed that coconut and tapioca H-165 gave the highest net return of Rs.7,415 followed by coconut and elephant foot yam (Rs.5,890) and coconut and yam(Rs.5,650) while coconut alone gave only Rs.2,520/ha. Coconut+ tapioca combination gave the highest net return per rupee invested 1:1.47, followed by coconut + elephant foot yam (1:1.16) and coconut + yam(1:1.08) whereas, mono cropping gave the ratio of 1:0.90.

Maximum net return was from double hedge of planting accommodating 700 cocoa plants/ha(Rs.11,065/-) followed by mixed single hedge accommodating 744 plants/ ha(Rs.10,175/-) and single hedge system accommodating 500 plants/ha(Rs.8,357/-). The net return from plots adopting mono cropping of coconut was Rs.3,607/- (Kamalakshy Amma *et al.*, 1983).

Anithakumari and Rema Bai(2002) worked out the economics of coconut and other intercrops in HDMSCS in root (wilt) disease affected coconut garden (Table 9) by taking a unit population of various component crops including coconut and found that the net return ranged from Rs.900/- (for 100 plants of elephant foot yam) to Rs.18,000/- (for 500 plants of banana). The highest return per plant was for coconut (Rs.89) followed by banana (Rs.36) and dioscorea (Rs.12) indicating the economic benefit of intercropping in coconut garden. They have also studied the monetary return including BC ratio from different crop combinations (Table 10) and found that raising banana as intercrop with coconut gave the highest gross and net returns of Rs.1,08,100 and Rs.55,675/ha, respectively with BC ratio of 2.06. Though the gross and net return was low in the case of pine apple than tuber crops, a higher BC ratio was possible because of the lower gross cost of production.

Table 9. Economics of intercropping in HDMSCS (on unit plant population basis)

Crops	No. of plants	Total expenditure(Rs.)	Total return(Rs.)	Net return(Rs.)	Returns/plant (Rs.)
Coconut	115	14,145	24,380	10,235	89
Banana	500	17,000	35,000	18,000	36
Elephant foot yam	100	2,100	30,000	900	9
Dioscorea	100	1,500	2,700	1,200	12
Pineapple	3000	12,000	24,000	12,000	4

Table 10. Returns from different crop combinations with coconut (1 ha) in root (wilt) disease affected area

Crop combination	Gross cost (Rs.)	Gross return (Rs.)	Net return (Rs.)	BC ratio
Mono crop of coconut	21,525	38,100	16,575	1.77
Coconut + banana	52,425	1,08,100	55,675	2.06
Coconut + Elephant foot yam	48,525	77,100	28,575	1.60
Coconut + Dioscorea	40,870	73,200	32,330	1.79
Coconut + pineapple	33,400	62,100	28,700	1.86

From the HDMSCS, Maheswarappa and Anithakumari (2005) observed that the total cost of Rs.28,950/-during the initial year (1993-94) went up to Rs.38,945/ha during 2002-03, mainly because of the increase in labour wages. Among the components of cost of production, labour wage alone constituted 56% of total cost, indicating that labour requirement is high in HDMSCS, wherein replanting of annual crops is an essential operation. In the system, crops like pine apple requires more labour for weeding and fertilizer application. The total return of Rs.54,920/- from the HDMSCS during 1993-94 increased to Rs.84,430/ha during 2000-01.The net return obtained from the system was Rs.25,970/- and Rs.47,180/ha during the same periods.

Cash flow analysis at a discount rate of 12% gave a BC ratio and net present worth of 2.28 and 1,80,106, respectively indicating the additional return and economic worthiness of HDMSCS in root(wilt) disease affected area. By adopting the system, there will be stabilized income for coconut farmers even during lower price prevailing for coconut.

The HDMSCS experiment was continued from 2004 to 2008 by dividing the coconut planted area into two parts and coconut palms in one half of the plot were applied with 100% recommended dose of fertilizers (500:300:1000 g NPK/palm/year) and the remaining with half the dose of fertilizers + organic manures in the form of vermicompost produced *in situ* using all the coconut leaves by *Eudrilus* sp.of earthworms. The fertilizers were applied in two split doses (one-third during May-June and two-third during August-September) every year. Sowing of green manure cowpea (*Vigna unguiculata*) seed in the basins of coconut palms that received both fertilizers and organic manures was done during May and incorporated once they attained maximum vegetative growth. The plant population maintained in the field is given in Table 11.

Table 11. Year wise plant population density of main and component crops under HDMSCS in different years

Crop	2004-05	2005-06	2006-07	2007-08
Coconut (West coast tall)	96	95	90	82
Nut meg(Local)	70	70	70	70
Black pepper (Karimuda trained on coconut palms)	108	60	42	35
Banana (different varieties such as Njalipoovan , Nendran, Robusta, Red Banana, Palayankodan)	350	318	250	20 (Others removed)
Pine apple(Kew)	675	660	500	400
Elephant foot yam (Gajendra)				900 plants

Spacing adopted for different crops:

Coconut: 7.5 x 7.5 m; Nutmeg: 7.5 x 7.5 m (in the centre of four coconut palms)

Pine apple: 60 x 45 cm; Banana: 2.5 m in between coconut palms leaving about 2 m from coconut basin; Elephant foot yam: 90 cm x 90 cm (planted in between coconut palms after removal of banana)

Economic analysis indicated that net return of the system varied from Rs.16,114/- during 2005-06 to Rs.35,383/- during 2007-08 (Table 12). The share of main crop of coconut in the gross return for different years varied between 49 to 70%, the highest being during the second year and the lowest during third year, because of lower price per coconut obtained during that year. The analysis also showed that the profit (net return/ha) has increased by 33% during 2007-08 when compared to the profit obtained during the first year (2004-05). The contribution of inter/mixed crop in the HDMSCS varied from 30% during 2005-06 to 51% during 2006-07 indicating that any fall in price of main crop (coconut) could be compensated to a great extent by other crops of the system. These results highlight the fact that crop diversification could help the farmers to realize better returns even if the price of one commodity gets reduced in any year.

Table 12. Details of return (Rs./ha) from HDMSCS

Crops /Particulars	2004-05	2005-06	2006-07	2007-08
Coconut[1]	33,567	31,564	25,157	38,920
Banana[2]	19,428	9,000	14,040	900
Pineapple[3]	570	1,300	2,575	2,575
Black Pepper[4]	1,265	1,740	2,100	1,800
Nutmeg[3]	1,270	800	2,000	930
Mace[3]	2,080	520	880	560
Elephant foot yam[3]	-	-	-	14,380
Total returns from main product	58,180	44,924	46,752	60,065
Returns from by products	1,500	1,500	1,500	1,500
Total return	59,680	46,424	48,252	61,565
Net return	26,570	16,114	26,172	35,383

[1]Average price of coconut for 2004-05 was Rs.5.51/nut, for 2005-06 was Rs.5.82/nut, for 2006-07 was Rs.4.93/nut and for 2007-08 was Rs.7.00/nut.

[2]Average price of banana for different years was Rs.12/kg

[3]Average price of pine apple, nut meg, mace, elephant foot yam and were Rs.5, Rs.100, Rs.400 and Rs.10 /kg, respectively

[4]Average price of black pepper for 2004-05 was Rs.55, for 2005-06 was Rs.60 and for 2006-08 was Rs.100/kg

7. Mixed farming in root (wilt) diseased area

Grasses such as Hybrid Napier, *Stylosanthes gracilis, Peuraria javanica, Centrosema pubescence* either alone or Hybrid Napier in combination with the other three were raised as intercrop in root (wilt) disease affected coconut garden over a period of five years (1971 to 1975).A dairy unit with 4-8 Swiss Brown cows were also maintained during different years of the study. In the root (wilt) affected area, an overall increase of 28% in nut yield (Table 13) was obtained by adopting mixed farming practice (Sahasranaman *et al.*, 1983). Further analysis of the data shows that the increase in nut yield was more than 25% in the case of palms falling in the disease indices categories of 0-10 and 11-25 indicating that intercropping fodder crops by adopting recommended agromanagement practices helps to improve the yield of disease affected palms. Though amelioration of yellowing of root (wilt) disease affected palms was possible, progressive increase in other symptoms of the disease such as flaccidity and necrosis was observed (Anon, 1976 b) indicating that the practice had little curative effect on the disease. Study on the root growth of palms in the mixed farming area (with grass and irrigation) and control (without grass and no irrigation) indicated regeneration of roots in the former (Anon, 1976 b).

Table 13. Effect of intercropping fodder and mixed farming on nut yield

Disease index	Control plot (nut yield/ per palm/year)			Experimental plot (nut yield/ per palm/year)			Estimated response %
	Pre-expt.	Post-expt.	Percentage increase/ decrease	Pre-expt.	Post-expt.	Percentage increase /decrease	
0-10	58.3	62.4	+ 7.0	50.3	68.4	36.0	29.0
11-25	31.1	29.2	— 6.1	33.7	42.3	25.5	31.6
26-50	20.9	18.1	—13.4	22.5	25.4	8.9	22.3
51 and above	19.5	21.4	+ 9.8	19.0	23.7	24.7	14.9
Overall	30.5	29.9	—2.0	31.4	39.6	26.1	28.1

8. Recyclable biomass from HDMSCS

Quantity of recyclable biomass generated in the system ranged from 9.1 t/ha (during 2002) to 17.6 t/ha (during 2004) (Maheswarappa, 2008). Biomass generation was higher during 2001 and 2004 due replanting of banana and pineapple. The entire bio mass was converted into vermicompost using *Eudrilus* sp. of earthworm and the recovery ranged from 70 to 72%. The average nutrient content was 1.4% N, 0.2% P and 0.36% K and thus the total contribution of N, P and K into the crop production system was 70.1 to 142.1 kg, 10.0 to 20.3 kg and 18.0 to 36.5 kg, respectively during different years with a mean recovery of 70%.

9. Soil nutrient status/ properties

A general increase in soil pH towards the surface soil was noticed due to mixed cropping cocoa in root (wilt) disease affected coconut garden (Kamalakshy Amma *et al.*, 1983). There was also a build up in the soil nutrient status which was more pronounced at 4 m than at 1.5 m away from the base of palm. The quantity of shed leaves of cocoa might have contributed to the added soil fertility. Status of nutrients was low in double hedge system, perhaps due to the effective utilization of nutrients and higher yields of crops per unit area.

The water holding capacity of top 0-25 cm soil from the root region of coconut and different crops in HDMSCS was found to be higher (37.4 to 38.5%) when compared to coconut mono crop (35.3 to 35.8%) (Maheswarappa *et al.*, 2005). They attributed this to the positive effect of integrated cropping system including nutrient management for coconut and other crops. It was found that organic carbon, pH, status of total N, available P and K as well as micro nutrients (Fe, Cu and Zn) of soil under HDMSCS was also high than mono crop of coconut (Table 14).

Table 14. Soil nutrient status (0-25 cm) in basins of coconut and intercrops

Location	Major nutrients*			Secondary nutrients* (Available)		Micro nutrients* (Available)				Org.C (%)	pH
	Total N	Av.P	Av.K	Ca	Mg	Fe	Mn	Cu	Zn		
Coconut basin (HDMSCS)	447	96	124	94	45	36.26	2.74	2.96	13.41	0.32	6.3
Coconut basin (mono crop)	401	88	109	96	49	21.00	2.83	1.24	8.90	0.14	6.0

* Content in ppm

The soil nutrient status in basins of component crops under the HDMSCS during the pre and post experiment period is presented in Table 15. It could be seen that there is an improvement in the nutrient status of soil by inter/mixed cropping with banana, nutmeg and pineapple, mainly due to the integrated nutrient management including recycling of biomass in the field.

10. Microbial population

Observations on the microflora of coconut palms under mixed cropping with fodder crops in the root (wilt) disease affected region revealed higher values of total bacteria and

Table 15. Soil nutrient status in basins of component crops

Crop	Org. C (%)		Total N (ppm)		Av.P (ppm)		Av.K (ppm)		Av.Ca (ppm)		Av.Mg (ppm)	
	Pre*	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Banana 1	0.30	0.31	337	350	85	86.2	137	139	95	99	40	46
2	0.23	0.28	280	295	76	76.4	129	129	88	92	36	39
Nutmeg 1	0.29	0.32	410	420	83	86.5	114	124	104	112	39	43
2	0.18	0.29	300	315	75	79.2	128	129	89	97	36	38
Pineapple 1	0.29	0.45	270	277	118	115	97	101	83	89	41	45

(* Maheswarappa *et al.*, 2005) Soil depth 1 = 0-25 cm 2 = 25-50 cm

ratios of nitrogen fixing organisms to denitrifiers in coconut soils cultivated with *Stylosanthes graciclis* alone or in combination with Hybrid Napier (Sahasrananam *et al.*, 1983). Mixed cropping of Hybrid Napier with root (wilt) disease affected palms resulted in the proliferation of total bacteria and nitrogen fixing organisms in the coconut rhizosphere irrespective of the disease condition of the palms. Compared to the mono cropped coconut palms, raising Hybrid Naiper as a mixed crop enhanced phosphate solubilising bacteria in the root region. Potty and Jayasankar (1983) found that the trend was, however, reversed after the application of chemical fertilizers (Table 16).

Table 16. Influence of crop mixing Hybrid Napier grass on the coconut rhizosphere microflora, before and after application of chemical fertilizers

Organisms	Coconut + Hybrid Napier grass				Mono crop of coconut			
	Pre-application		Post-application		Pre-application		Post-application	
	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased	Healthy	Diseased
Total Bacteria	51.84	21.25	21.83	10.28	27.00	5.51	5.15	7.81
Total Fungi	37.62	29.45	28.67	206.71	6.76	76.22	1.05	20.48
N-fixing Bacteria	84.20	35.86	9.92	8.25	35.86	8.71	3.47	7.88
Phosphate solubilising								
Actinomycetes	4.95	2.33	0.83	1.30	1.45	3.04	0.33	0.55
Bacteria	8.15	130.78	0.61	0.87	8.85	3.95	0.63	0.93
Fungi	6.58	5.26	1.12	1.21	2.40	2.40	1.52	1.46

Physiological classification of Actinomycetes isolated from the root (wilt) disease affected coconut palms under mixed cropping with Hybrid Napier(Ag.I), *Centrosema pubescens* (Ag II), *Stylosanthes gracilis* (Ag III) and coconut alone (Check plot) yielded positive indications (Potty,1977). Various traits studied were phosphate solubilization (P), nitrate reduction (N), cellulose digestion (C), gelatine hydrolysis (G) and starch hydrolysis (S). A distinct difference was noticed in the combinations PG, PS, PC and PN between the crop mixed and control plots. In Ag III treatment GS, GC and GN combinations were absent in the isolates. In the combinations among three different characters, PGS, PGC, PSN and PCN were not observed in any of the isolates from Ag II treatment. All the combinations of four different characters were absent in Ag II treatment. The results indicated the possibility of altering the microflora of coconut rhizosphere by appropriate inter and mixed cropping.

Antony (1983) enumerated the population of different micro organisms including nitrogen fixing and phosphate solubilising bacteria at the time of harvest during the first two years of intercropping tuber/rhizome crops. Enzymatic activities like hydrogenase, invertase, urease and phosphatise were estimated at the time of planting, during vegetative phase and and at harvest during third year. Beneficial influence on the number of asymbiotic nitrogen fixing bacteria was noticed both on the coconut root surface and non-rhizosphere soils. It was also found that intercropping significantly stimulated phosphatise activity in the non-rhizosphere soils.

Influence of inter/mixed cropping on the endomycorrhizal symbiosis in coconut was studied by Thomas (1988). It was observed that soil samples from coconut basins and interspaces from the plots interc ropped with Hybrid Napier had higher spore counts of VAM in surface as well as deep layers compared with those of mono cropping and cocoa-mixed plots. Different methods of cultivation of cocoa such as single hedge system, double hedge system and mixed single hedge did not cause any marked variation in the distribution of spores in the coconut basin. The spore population was 72.3% and 83.5% less at 25-50 cm and at 50-100 cm depth, respectively in the coconut basins than at 0-25 cm (surface soil). It was noticed that the degree of mycorrhizal colonisation in roots varied with plant species and the intensity of infection was high in Hybrid Napier (82.1%) but low (58.7%) in cocoa roots.

11. Future research areas

i. Studies on requirement of cultural operations such as tillage, irrigation, weed management and integrated plant protection of the entire cropping system

ii. Need for screening crops/varieties and selecting best suited ones for maximising output and income of the system

iii. Studies on nutrient requirement and balance of the system to arrive at common fertilizer schedule

iv. Work out the complementary, competitive, supplementary and allelopathic effect of various component crops over a period of time.

v. Study the soil moisture relationship, microclimatic changes, carbon sequestration and nutrient availability and uptake in the system

12. Conclusion

Intensification and diversification of small, marginal and sub marginal farmers are critical for realizing income and livelihood to farmers. A technical change would be essential to shift from pursuing an exploitative mono cropping or specialized farming system to more diversified farming system with complimentary allied sector activities such as dairy, poultry etc. Farm diversification helps to conserve natural resources and protect environment. Diversification of farm income sources could be a viable option for farmers in improving the livelihood choices and total income from unit area.

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Nutrient management in coconut based high density multispecies cropping system

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Introduction

The soil resource base of the coconut growing regions is poor and hence, there is a need to improve the crop growing environment to ensure timely and adequate availability of the nutrients to the crops. Nutrient management in coconut based high density multi species cropping system (HDMSCS) would be a complex task as this will involve the interplay of various factors viz. nutrient recycling, fertilizer additions, differential crop responses, nutrient uptake and soil environment. Thus, there is a need to consider the system as a unit.

Concept of coconut based high density multi species cropping system was initiated during 1983 at CPCRI Kasaragod involving 17 different species (Bavappa *et al.,* 1986). They have reported that there was differences in the yield under 1/3rd, 2/3rd and full dose of recommended NPK fertilizer application. Yields were higher under 2/3rd and full dose of recommended fertilizer application. Again in 1993-94, the model was modified with clove, banana and pineapple as component crops with 6 fertiliser doses like Full, 2/3rd, 1/3rd, 1/4th, 1/5th and No fertilizer treatments. Five years averaged yield data (1995-99) indicated that, the yield of different crops and coconut was higher under 2/3rd of recommended NPK application (Reddy *et al.,* 2002). The same model was modified during 1999 with addition of two crops like black pepper (Panniyur 1), and coffee (Cauvery var.) and keeping the 6 doses of fertilizer treatments as mentioned above and including recycling of biomass in the form of vermicompost for all the crops. The cropping system layout is shown in Fig. 1. Fertilizers were applied in two splits for coconut i.e. 1/3rd immediately after the onset of South - West monsoon (May-June) and remaining 2/3rd dose and organics (Vermicompost) at the post-monsoon period (September-October). Perfo irrigation (modified form of sprinkler irrigation) was given during the dry period (December-May) at IW/CPE ratio of 1.00. The performance of coffee was not satisfactory and hence it was removed from the system.

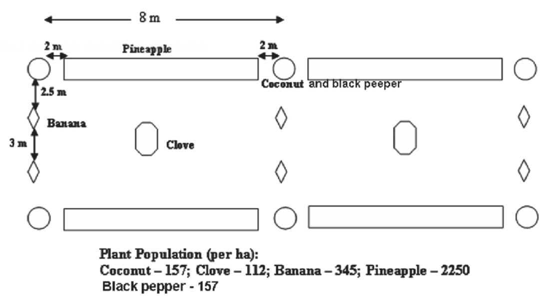


Fig.1. Planting pattern of coconut and other component crops

2. Plant nutrient status

The nutrient status of the plant was monitored and it was found that in general lower dose of fertilizer treatment recorded numerically higher values for coconut leaf P, Zn, Cu, Fe, Mn and Mg content due to the concentration effect (Table 1). In the case of coconut, the N content was above the critical level (1.8%) upto 1/3rd of the fertilizer level and declined with the further reduction in fertilizer dose. In fact, at lower doses, the N content was below the critical level, suggesting that the fertilizer levels below 1/3rd of the recommended dose are insufficient to meet the crop needs. Foliar P and K levels in coconut, though optimum in all the treatments, were higher at fertilizer levels of 1/3rd, 2/3rd and full doses, but declined thereafter with reduction in fertilizer levels. In respect of component crops, the economic and biomass yields were higher with the higher fertilizer levels, the foliar nutrient contents for P and K did not vary much among the fertilizer levels (Table 1). While in tissue, N content increased with the increasing fertilizer level and there is substantial yield variation in the component crops. The relationship between coconut leaf nutrient status and nut yield is given in Fig.2. There was linear relationship between the coconut yield and leaf K content ($P < 0.01$) indicating that the soil could respond to potassium application. Coconut leaf Mn showed second order relationship with the nut yield suggesting dilution effect of Mn in the palm at higher production level.

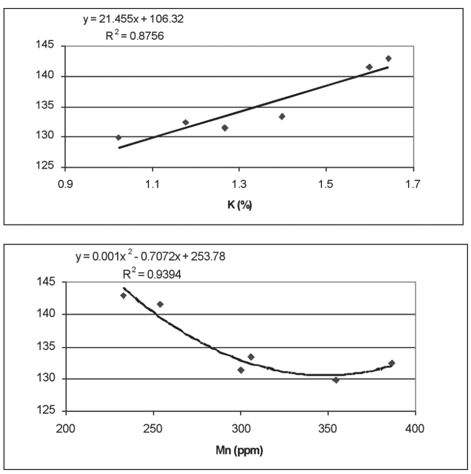


Fig. 2. Relationship between coconut leaf nutrient content and nut yield

3. Soil nutrient status

Soil total N, organic carbon content, available P, K, Ca, Mg and micronutrients of the surface soil recorded higher values than the subsurface soil of coconut and component crops. The soil nutrient status under various fertilizer treatments is given in Table 2. The

Table 1. Foliar nutrient content of coconut and component crops

Crop/ Treatment	N (%)	P (%)	K (%)	Crop/ Treatment	N (%)	P (%)	K (%)
COCONUT				**BANANA**			
Control	1.82	0.140	1.026	Control	1.82	0.170	2.644
1/5th	1.79	0.147	0.982	1/5th	1.79	0.186	2.351
1/4th	1.82	0.142	1.161	1/4th	1.83	0.178	2.323
1/3rd	2.00	0.131	0.897	1/3rd	1.88	0.171	2.493
2/3rd	1.90	0.126	0.848	2/3rd	2.06	0.143	2.219
Full	1.93	0.143	1.161	Full	2.59	0.173	2.436
CLOVE				**PINEAPPLE**			
Control	0.98	0.138	1.026	Control	0.77	0.261	3.029
1/5th	0.95	0.097	0.941	1/5th	0.73	0.258	2.639
1/4th	1.12	0.109	0.897	1/4th	0.69	0.235	2.786
1/3rd	1.29	0.099	0.898	1/3rd	0.78	0.216	2.436
2/3rd	1.25	0.082	1.193	2/3rd	0.70	0.214	2.438
Full	1.25	0.062	1.209	Full	0.75	0.188	2.379

Table 1. Foliar nutrient content of coconut and component crops (continued..)

Crop/ Treatment	Ca(%)	Mg(%)	Zn(ppm)	Cu(ppm)	Mn(ppm)	Fe(ppm)
COCONUT						
Control	0.40	0.22	24.50	5.95	354.50	233.15
1/5th	0.34	0.19	29.15	6.05	386.75	265.30
1/4th	0.35	0.21	27.05	7.25	300.25	145.50
1/3rd	0.48	0.23	21.80	7.50	253.75	175.05
2/3rd	0.53	0.20	18.40	6.30	232.50	122.70
Full	0.53	0.19	16.40	6.65	306.00	125.00
CLOVE						
Control	0.74	0.18	11.50	12.40	1122.25	217.65
1/5th	0.83	0.18	85.80	20.60	1017.50	182.40
1/4th	0.83	0.21	13.30	10.65	857.25	253.65
1/3rd	0.72	0.18	10.50	4.90	913.25	230.00
2/3rd	0.66	0.21	11.85	4.45	1121.25	225.80
Full	0.57	0.18	8.50	5.20	852.50	204.15

BANANA						
Control	0.49	0.26	21.40	10.10	819.75	204.95
1/5th	0.59	0.31	26.35	13.15	907.50	737.70
1/4th	0.46	0.29	16.20	10.95	679.25	327.35
1/3rd	0.50	0.30	18.45	12.50	785.50	200.20
2/3rd	0.45	0.32	16.30	10.45	919.75	275.90
Full	0.43	0.31	15.60	7.60	405.50	173.00
PINEAPPLE						
Control	0.38	0.26	11.65	7.85	142.00	152.50
1/5th	0.35	0.31	12.00	7.85	159.25	168.15
1/4th	0.38	0.25	9.45	7.40	226.25	146.95
1/3rd	0.34	0.30	9.40	12.25	205.00	191.05
2/3rd	0.37	0.23	5.70	7.80	171.75	189.90
Full	0.31	0.25	4.90	10.10	166.00	146.30

organic matter status declined with the increased fertilizer addition. In fact, in coconut rhizosphere, the highest organic matter content (0.712%) was found in the no fertilizer treatment, which declined to 0.512% in the treatment of full dose of fertilizers. The increasing fertilizer levels led to higher active root biomass production. The exudates so secreted by the roots led to the proliferation of microbes, which decomposed the organic matter leading to reduction in the organic matter content at higher fertilizer levels. The total N content in the soil increased appreciably with increasing fertilizer levels. At lower fertilizer levels, the organic matter content in the soil was high, still, the total N content was lower suggesting high C:N ratio of the organic matter. Similar trends were observed in all the component crops except in the case of pineapple, where the organic matter content was higher at higher fertilizer levels. The available P and K status of soil increased with increasing fertilizer levels in the entire main as well as component crops. Thus, P and K when applied to soil have a tendency to get fixed, which becomes slowly available to the crop later on. There was quadratic relationship between the soil available K and coconut yield and leaf K content ($P < 01$, Fig.3).

4. Biomass production and nutrient recycling

The nutrient cycle comprises the supply, uptake and the loss of nutrients to the environment. Biomass recycling returns nutrients to the agroecosystems that would otherwise be lost to the environment. Growing different intercrops and recycling of crop residues in the form of vermicompost are nutrient recycling techniques.

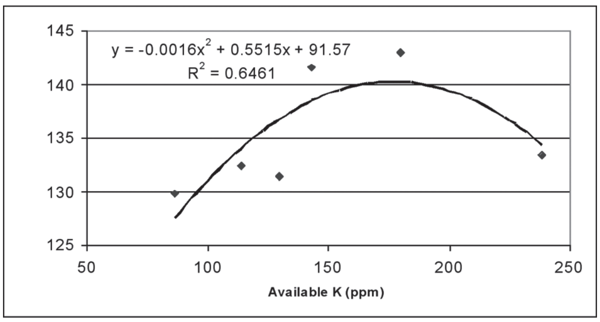
Table 2. Soil nutrient status of the coconut based cropping system

Treatments	Org. Matter (%)	Total N (ppm)	Available P (ppm)	Available K (ppm)
Coconut (Average of three depths)				
No fertilizer	0.712	265	98.71	76.71
1/5th	0.700	365	161.73	96.80
1/4th	0.702	755	165.67	117.24
1/3rd	0.519	1435	220.44	112.36
2/3rd	0.523	1410	285.57	161.21
Full	0.512	1460	342.65	229.60
Clove (Average of two depths)				
No fertilizer	0.736	175	48.13	62.71
1/5th	0.706	300	49.93	74.88
1/4th	0.699	345	57.29	88.99
1/3rd	0.621	1360	59.07	124.57
2/3rd	0.632	1195	76.25	168.54
Full	0.615	1280	93.78	161.21
Banana (Average of two depths)				
No fertilizer	0.741	290	28.86	42.01
1/5th	0.723	230	29.81	75.49
1/4th	0.714	515	25.54	97.59
1/3rd	0.563	1050	29.15	109.79
2/3rd	0.598	1215	29.55	162.43
Full	0.576	1250	32.81	236.92
Pineapple				
No fertilizer	0.623	340	27.34	29.92
1/5th	0.617	280	21.03	42.61
1/4th	0.599	410	41.84	63.31
1/3rd	0.589	530	42.33	65.75
2/3rd	0.732	600	47.29	77.92
Full	0.741	620	50.27	121.75

Table 2. Soil nutrient status of the coconut based cropping system (continued...)

	Ca (ppm)	Mg (ppm)	Fe (ppm)	Cu (ppm)	Zn (ppm)	Mn (ppm)
Coconut (Average of three depths)						
Control	93.99	23.72	86.99	0.67	1.46	33.71
1/5th	91.76	17.32	78.13	0.35	1.00	35.49
1/4th	99.07	15.86	113.10	0.91	2.04	53.69
1/3rd	68.75	16.61	87.21	0.55	1.41	57.98
2/3rd	76.44	13.35	78.29	0.65	1.13	49.61
Full	71.68	12.96	97.71	0.78	1.16	51.29
Clove(Average of two depths)						
Control	107.16	15.09	90.19	0.91	1.48	54.31
1/5th	94.78	8.35	108.22	1.28	1.72	55.25
1/4th	90.58	17.14	115.18	0.87	2.18	61.22
1/3rd	103.51	25.43	81.36	1.16	2.44	66.15
2/3rd	117.61	28.43	91.20	0.83	1.59	46.02
Full	75.32	25.98	103.86	1.07	1.53	44.15

Banana (Average of three depths)						
Control	81.51	17.59	76.80	0.87	1.28	33.74
1/5th	65.20	15.17	93.83	0.95	1.21	56.65
1/4th	88.75	27.62	97.90	1.11	1.56	40.01
1/3rd	96.17	31.39	81.89	0.74	1.35	68.79
2/3rd	100.54	40.34	103.45	0.81	1.73	80.53
Full	101.30	33.36	73.97	1.03	2.31	47.62
Pineapple						
Control	168.87	32.41	98.88	1.58	2.57	29.21
1/5th	105.25	31.56	91.42	1.12	2.22	52.86
1/4th	121.94	50.37	60.45	0.95	2.39	59.27
1/3rd	165.34	48.13	66.24	1.36	2.74	58.25
2/3rd	136.91	34.65	99.82	1.05	2.43	41.97
Full	131.92	29.05	101.30	1.12	2.18	39.46



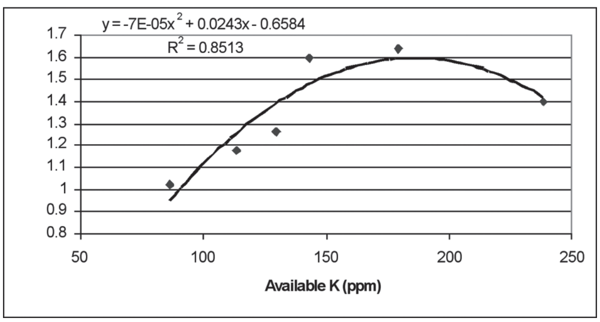


Fig. 3. Relationship between soil available K with coconut yield and leaf K content

The highest coconut biomass was obtained at full dose treatment (23.51 t/ha), which declined to 19 t/ha in the control treatment (Table 3). The total nutrient exhaust ranged from 130.45, 18.29 and 172.64 kg of N, P and K, respectively per ha in the full dose to 97.11, 13.06 and 125.45 kg of N, P and K, respectively per ha in the no fertilizer treatment plot. The extent of nutrient recycling in terms of leaflets, petioles, bunches, spathe and husk was the highest in full dose treatment (Fig. 4).

Table 3. Biomass production and nutrient export in coconut from the system (on dry wt. basis)

Fertilizer treatments	Biomass (t/ha)	N (kg/ha)		P (kg/ha)		K(kg/ha)	
		Exhaust	Recycled	Exhaust	Recycled	Exhaust	Recycled
Full	23.51	130.43	70.58	18.29	8.55	172.64	114.26
2/3rd	22.71	130.29	69.58	18.09	7.54	182.35	121.11
1/3rd	22.29	121.29	61.71	16.81	6.86	176.74	113.09
1/4th	20.72	103.21	47.87	17.86	8.19	142.49	90.97
1/5th	20.24	98.03	47.78	15.38	6.82	134.03	92.31
Control	19.05	97.11	48.92	13.06	5.44	125.45	87.84

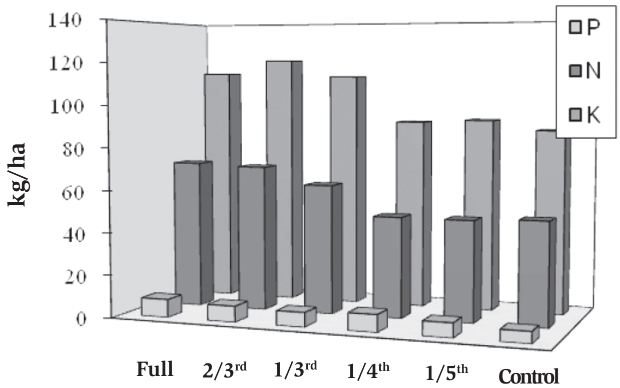


Fig. 4. Extent of nutrient recycling (kg/ha) under different fertilizer levels

Yield

In the coconut based HDMSCS, the coconut yield (mean of six years) ranged from 127 nuts/palm/year under no fertilizer control treatment to 147 nuts/palm/year at 2/3rd and 1/3rd of the recommended fertilizer dose (Table 4). The productivity of palms declined with the reduction in fertilizer levels beyond 1/3rd of the recommended fertilizer treatment. The yield of clove trees also varied with the fertilizer treatments and it ranged from 1.00 under

Table 4. Output from 1.2 ha coconut based cropping system model at Kasaragod (mean of six years)

Treatment	Coconut (No.)	Pineapple (kg/fruit)	Clove (dry kg/tree)	Banana (kg / bunch)	Black pepper (kg / bush)
Full dose	145	0.89	1.44	5.76	0.87
2/3rd rec. dose	147	0.70	1.55	5.43	1.66
1/3rd rec. dose	147	0.57	1.22	4.70	0.90
1/4th rec. dose	137	0.43	1.12	4.36	1.06
1/5th rec. dose	129	0.48	1.00	3.91	0.42
No fert.- Control	127	0.45	1.32	3.86	0.46

1/5th or rec. dose to 1.55 kg/tree/year at 2/3rd of rec. dose. The average weight of banana bunch and pineapple fruit were the highest with the full recommended dose of fertilizers (5.76 kg/ bunch and 890 g/fruit), respectively. The pepper yield was higher with 2/3rd of recommended dose of fertilizer (1.66 kg/bush) and was lowest with 1/5th of reecommended dose and no fertilizer control.

5. Fertiliser response function of coconut

In the experiment, there is no factorial combination of fertilizer treatment and the NPK recommended dose is taken as one and the other treatments were transformed accordingly. The quadratic response fitted showed significant correlation coefficient (Fig.5). The optimum fertilizer requirement was worked out to be 359 g N, 229 g P_2O_5 and 860 g K_2O per palm per year, which gave the yield of 151.77 nuts/year.

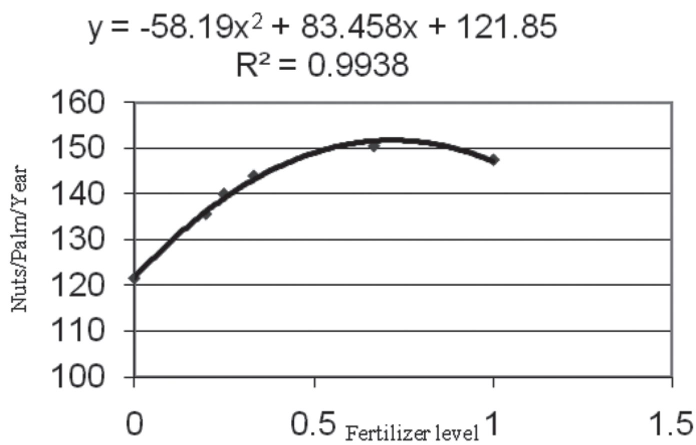


Fig.5. Fertilizer response function for coconut

6. Energy balance in the cropping system

Although the energy of sunlight is a fundamental input to agriculture, the energy balance of agricultural systems depends on the additional energy supplied from non-renewable sources. Sustainable agriculture practices can improve the energy balance and ensure that it remains positive - there is more energy coming out than going in. Agricultural productivity is closely linked with the energy inputs. The measure of energy flow in crop production systems provides a good indicator of the technological aspects of crop production system in agriculture. For sustainability in energy management, the efforts have to be double pronged, firstly efficient use of commercial energies and secondly harnessing renewable energy sources as supplementary and substituting commercial energy sources.

Balance : Total energy input/total energy output, including transport where relevant

Ratio : Renewable over non-renewable energy inputs

Energy balancing in agriculture requires consideration of the energy consumption, on-farm energy fluxes and energy output. The non-renewable energy input into the system ranged from 29,633 to 39,694 MJ/ha. The energy values from the economic output are between 7,824 to 15,064 MJ/ha (Table 5). The use efficiency was the highest in the treatments receiving full dose of fertilizers (0.38).

Table 5. Energy balance in HDMSCS

Treatments	Fertiliser and Pesticide (MJ/ha)	Irrigation (MJ/ha)	Total input (MJ/ha)	Economic out put (MJ/ha)	Energy efficiency
Control	2,562	27,070	29,633	7,824	0.264
1/5th	3,549	27,070	30,620	7,875	0.257
1/4th	3,796	27,070	30,867	8,939	0.289
1/3rd	4,207	27,070	31,278	8,637	0.276
2/3rd	8,415	27,070	35,486	11,306	0.318
Full	12,623	27,070	39,694	15,064	0.379

7. N-mineralisation

Nitrogen (N) is mineralized when microorganisms convert N in soil organic matter to ammonia, nitrate, and nitrite. *In situ* N-mineralisation was determined as the difference between extractable N in incubated and initial soil samples. Soil samples were taken from two 20 cm PVC tubes with a diameter of 5 cm that were inserted vertically into the topsoil (10 cm). In general, the rate of N- mineralisation was higher in coconut basin area (2.2 ppm -N per day) upto 1/3rd of recommended fertiliser dose(Fig. 6). However, in lower dose of fertilizer, clove soil had higher N- mineralisation rate (3.43 ppm -N per day).

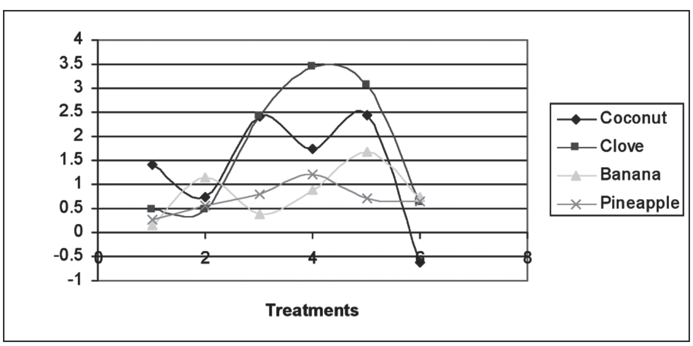


Fig. 6. *In situ* N- mineralisation in different root zone soils of coconut based cropping system

8. Soil organic carbon sequestration

There is a critical need for best management practices that enhance SOC sequestration. At the local and regional levels, increased SOC contributes positively to soil tilth, fertility, and water-holding capacity and thereby increases crop production, promotes sustainability and enhances land value for producers. At the global level, increased sequestration of C in agricultural soils has the potential to mitigate. In the integrated nutrient experiment, after organic recycling there was soil carbon buildup in coconut basin while in area of pineapple soil carbon store was depleted (Fig.7).

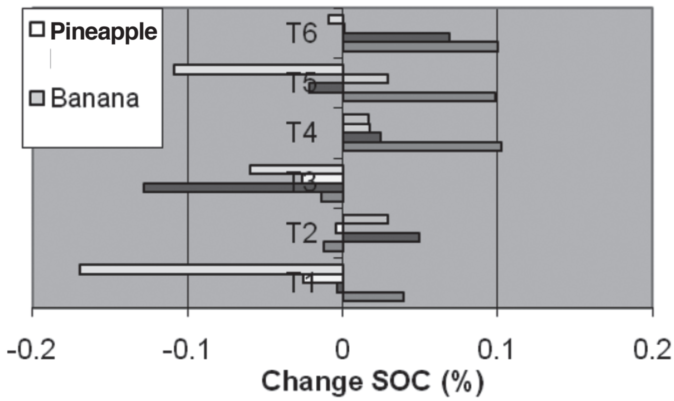


Fig. 7. Change in SOC in the coconut based cropping system

9. Yield sustainability

Sustainability of yield in the coconut can be estimated by quantifying yield variation over the years. This can be done by similar sequence matching technique. Similar sequence matching algorithms are classified into whole matching and subsequence matching. Whole matching finds data sequences that are similar to a query sequence, where the lengths of data sequences and the query sequence are all identical. Subsequence matching finds subsequences, contained in data sequences that are similar to a query sequence of an arbitrary length.

The proposed algorithm enables finding a data sequence that has a fluctuation pattern similar to the query sequence even though they are not close to each other before the normalization transform. By this, we can compare the yield fluctuation pattern between the treatments in coconut over the years.

Given a sequence $\vec{x} = (x_i)$ $(0 \quad i < n)$ of the length n(1), the *normalized sequence* $v(\vec{x}) = (\tilde{x}_i)$ is defined as follows:

$$\tilde{x}_i = \frac{x_i - \mu(\vec{x})}{\sigma(\vec{X})}$$

where $\mu(\vec{X})$ and $\sigma(\vec{X}_i)$ are the mean and standard deviation of the sequence $\vec{X}$, respectively.

Summery of notations

Notation	Definition
$\vec{S} = (s_i)$	Yield data over the years $\vec{S} = (s_0,\ldots, s_{N-1})(0 \le i \le N)$
$\vec{X} = (x_i)$	A subsequence contained in the data sequence $\vec{S}$ $\vec{X} = (x_0,\ldots, x_{N-1})(0 \le i < n \le N)$
$\vec{T} = (t_i)$	The sequence to be compared $\vec{T} = (t_0,\ldots, t_{n-1})(0 \le i < n)$
$\vec{d}\ (\vec{X},\vec{T})$	Euclidean distance between two sequences $\vec{X}$ and $\vec{T}$

$$d\ (\vec{X},\vec{T}) = \left\{\sum (x_i - x_i)^2\right\}^{/2} \left(Len(\vec{X}) = Len\ (\vec{T})\right)$$

Amplitude($\vec{X}$) $w = \max(\vec{X}) - \min(\vec{X})$

It was observed that the control treatment came closer to the other treatments after organic recycling. Without application of recycled organics there was higher year to year yield variation in the control treatment compared to the other fertiliser treatments. As indicated by the mean euclidean distance of control with other treatments was 1.39 prior to organic recycling while it was 0.87 after organic recycling (Table 6). There was decrease in amplitude after the introduction of organic recycling in the normalized sequence (Fig. 8). In the control pre experiment, amplitude of 1.98 had reduced to 1.77 during post experiment. This clearly indicates that the decrease in the year to year yield variation. However, the amplitude decrease was more perceptible in control treatment compared to other treatments.

Table 6. Euclidean distance of normalized subsequence

Pre experiment	**Full**	**2/3rd**	**1/3rd**	**1/4th**	**1/5th**	**Control**
Full	-	0.9415	0.2647	1.0225	0.4370	1.1245
2/3rd	0.9415	-	0.7244	0.9311	0.8487	1.7641
1/3rd	0.2647	0.7244	-	0.9681	0.5194	1.3481
1/4th	1.0225	0.9311	0.9681	-	0.8482	1.6880
1/5th	0.4370	0.8487	0.5194	0.8482	-	1.0147
Control	1.1245	1.7641	1.3481	1.6880	1.0147	-
Post experiment						
Full	-	1.0020	0.5122	0.8162	1.0047	1.1507
2/3rd	1.0020	-	0.7617	0.8161	0.7414	1.3105
1/3rd	0.5122	0.7617	-	0.3152	0.5050	0.7629
1/4th	0.8162	0.8161	0.3152	-	0.2357	0.5335
1/5th	1.0047	0.7414	0.5050	0.2357	-	0.6137
Control	1.1507	1.3105	0.7629	0.5335	0.6137	-

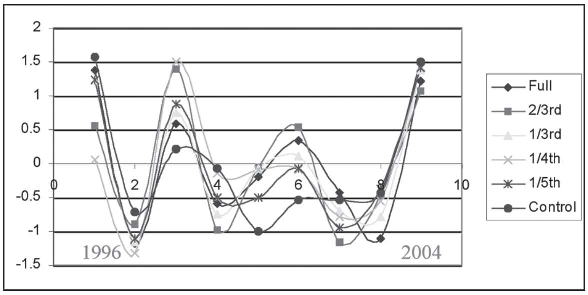


Fig. 8. Pre and post organic recycling normalised yield difference in sequence

10. Potassium dynamics in coconut based cropping system under red sandy loam soil

The potassium adsorption varied with the fertilizer regimes (Table 7) and it declined with increasing fertilizer levels. The adsorption was more in the fertilizer treatment. Fertilizer at 250 ppm of applied K (221.05 ppm) and this declined appreciably to 51.63 ppm at full dose of recommended fertilizer levels. At 500 and 750 ppm K levels, K adsorption was high at no fertilizer and $1/5^{th}$ of the recommended dose but declined at $1/4^{th}$ of the recommended dose, which increased at further increase in fertilizer regimes. But at 1000 ppm K level, no particular trend was observed. The fertilizer treatment at $1/4^{th}$ of the recommended dose showed lower adsorbed K values in the treatments 500, 750 and 1000 ppm K levels compared to the other treatments. In the case of treatments such as no fertilizer, $1/5^{th}$ and $1/4^{th}$ of the recommended doses, the adsorbed K increased up to 750 ppm K level, and there upon it showed a decline at 1000 ppm K level. In the case of other three higher fertilizer regimes, the adsorption of K increased to 500 ppm K level, beyond which there was decline in K adsorption. Within the K levels, the potassium adsorption declined with increasing fertilizer level upto $1/4^{th}$ of the recommended dose. However, beyond this level, the K adsorption increased with the increasing fertilizer level.

The perusal of Table 7 reveals that adsorption of K was more in the lower fertilizer regimes (no fertilizer, $1/5^{th}$ and $1/4^{th}$ of the recommended dose), which may be on account

Table 7. Adsorption of potassium (ppm) in soil under different fertilizer regimes

Fertilizer regime	Levels of K added (ppm)				
	0	250	500	750	1000
No Fertilizer	0	221.05	1259.47	1298.89	861.28
$1/5^{th}$	0	136.81	1259.47	1359.11	649.13
$1/4^{th}$	0	94.45	1110.78	1118.25	578.11
$1/3^{rd}$	0	93.98	1211.00	1178.46	791.18
$2/3^{rd}$	0	94.45	1260.41	1218.26	791.18
Full	0	51.63	1260.41	1238.21	575.29

of lower K application rates. Variation was also observed in K adsorption between fertilizer regimes vis-a-vis K treatments, which could be attributed to the variation in saturation of exchange complex with K. Interestingly, within the K levels, the potassium adsorption declined with increasing fertilizer level upto $1/4^{th}$ of the recommended dose. However, beyond this level, the K adsorption increased with the increasing fertilizer level. In the case of higher fertilizer regimes, the increased adsorption may be attributed to added phosphatic fertilizers, which contributes phosphate ions, which is capable of neutralizing positive charges of Fe hydroxides in the clay fraction generating electronegative sites that can be occupied by K^+. With the application of phosphatic fertilizer, there is buildup of available P in the soil. The P tends to accumulate, as the crop requirement for P is less. In fact, it has already been established that soil test values of 20 ppm of air dry soil available P is sufficient to maintain the P nutrition of coconut. The available P status of the soil ranged between 98 ppm (No fertilizer level) and 343 ppm (Full dose of recommended fertilizer).

On fitting the adsorption versus equilibrium concentration values, quadratic function gave the best fit compared to Langmuir and Freundlich equations. Adsorption maxima were calculated from the quadratic function. Adsorption maxima varied with the fertilizer regime (Table 8). The adsorption maxima increased up to one-fifth of the recommended dose and there upon, it declined at $1/4^{th}$ of the recommended dose, further, which it increased with the increasing fertilizer regimes. This variation can be attributed to the increased P application as stated above that contributes phosphate ions, which is capable of neutralizing positive charges of Fe hydroxides in the clay fraction generating electronegative sites that can be occupied by K^+ ions. The soil solution K level required for optimum K nutrition of the coconut ranged between 651 to 697 ppm under various fertilizer regimes. This suggests that a minimum soil solution K level in the vicinity of 650ppm or above is required to meet the K demands of the crop. On plotting the fertilizer regime against soil solution K level, 4th degree polynomial curve gave the best fit (Fig. 9).

Table 8: Effect of fertilizer regime on adsorption K maxima and soil solution K level

Fertilizer regime	Adsorption K maxima (ppm)	Optimum soil solution K (ppm)
No Fertilizer	1399.50	691.65
$1/5^{th}$	1452.20	665.71
$1/4^{th}$	1237.17	687.86
$1/3^{rd}$	1325.20	697.97
$2/3^{rd}$	1352.01	686.27
Full	1373.28	651.57

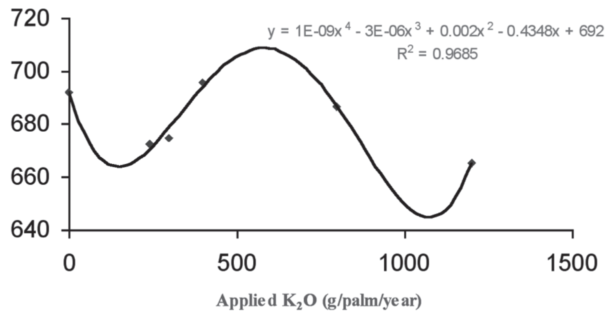


Fig. 9. Minimum soil solution K level as affected by fertilizer regime in the coconut based cropping system

11. Nutrient release pattern from vermicompost

Nutrient release pattern from vermicompost (VC) was studied in a column with two soil types of red sandy loam and littoral sand involving four levels of VC viz., 0, 2, 6 and 8 g per column(T0, T1, T2 and T3). After 186 days of column study on N- mineralisation pattern of VC treated soil, it was observed that the double exponential model(eq-1) fitted to N mineralised gave R^2 value of 0.99 significant at 1%. Rational function model (eq-2) of cumulative N mineralized and days of incubation gave R^2 value of 0.99 significant at 1%. However, comparison of root mean squared error (RMSE) observed that the Rational function model had a lower value (Table 9).

$$X_t = X_1(1 - e^{-k1t}) + X_2(1-e^{-k2t}) \qquad \text{eq-1}$$

where X_t = mineralizable N (mg g^{-1} soil), X_1 = labile N pool (mg g^{-1} soil), X_2 = stable N (mg g^{-1} soil), k_1, k_2 = mineralization rates of the labile and stable pools, respectively (day^{-1}) and t = time of incubation (days)

$$y = \frac{a}{1+\frac{b}{x}} + \frac{a}{1+\frac{b}{x}} \qquad \text{eq-2}$$

where the curve has a horizontal asymptote at Y = a + c. Parameters b and d control the rate at which the curve approaches its asymptote, x time of incubation (days).

12. Nutrient Budget

In Coconut based HDMSCS experiment at Kasaragod, an annual nutrient budget and balance of N, P, K, and Mg was worked out for three consecutive years (Bavappa *et al.,* 1986). It was observed that while there has been no build up of N and Mg, the levels of P and K doubled by the third year.

Table 9. Mineralisation potential(Np -ppm) of littoral sand (S)and red sandy loam soils(R)

	T0S	T1S	T2S	T3S	TOR	T1R	T2R	T3R
Rational model								
Np	229.89	295.89	404.64	425.05	235.26	322.45	394.42	457.61
RMSE	1.14	2.10	2.09	1.38	1.63	2.77	1.95	1.20
R^2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Exponential Model								
Np	181.88	250.86	304.13	319.27	195.95	279.25	307.30	356.67
RMSE	2.31	4.86	4.21	3.14	3.13	6.23	4.73	4.50
R^2	1.00	0.99	1.00	1.00	1.00	0.99	1.00	1.00

12.1. Spatial variability: Grid soil samples were collected during 1997 from Ist generation Coconut- clove - banana - pineapple HDMSCS model. The soil samples were analysed for av. P and av. K and spatial analysis of these nutrients shows that the variation along east-west direction is more than the north-south direction. Anisotrophy exists. Among the treatments quantitative variation of semivariance differs.

12.2. Nutrient reserve: The nutrient reserves in terms of av. P and av. K increased with increasing fertilizer levels. The least of 328 kg K/ha and 339 kg P /ha was found in control treatment (No fertilizer) whereas, it was 527 kg P /ha 572 kg K/ha in the case of the plot treated with full dose of recommended fertilizers.

12.3. Moisture depletion pattern: The moisture depletion was monitored in the coconut based HDMSCS during March and April by installing neutron probe access tubes laterally at 0.5 m interval from coconut bole in the 1st generation experimental plots. It was found that the depletion was more in coconut and clove basins than in banana and pineapple root zones. Soil moisture content in the lower depth (25 - 50 cm) was less (12.9%) than that at 0-25 cm depth (15.9%) at all the distances except at 0.5 m from bole of coconut.

13. HDMSCS-demonstration plot Hill block

In the HDMSCS experiment at Hill block started during 2000-01, the inter crop yields were as follows: banana 2.66 kg/bunch, black pepper 1.25 kg/vine and pineapple 1.03 kg/fruit. The estimated total income ranged from Rs 1,52,531/ha in coconut-black pepper-pineapple to Rs 1,57,910/ha in coconut-black pepper-banana. The maximum net return of Rs. 1,12,310 was obtained in coconut-black pepper-banana with B:C ratio of 3.46.

14. Second generation coconut based models

14.1. Nutrient reserve: In the 2nd generation HDMSCS experiment, grid soil samples were taken at 1 m intervals and at two depths in the coconut monoculture, coconut-clove-banana and coconut-pineapple-cocoa models. The soil samples were analysed for organic carbon, total-N, av. P and K. The total nutrient reserves upto 0.5 m soil depth was computed. Compared to monoculture, there was depletion of org.C and total N in the coconut-clove-banana and coconut-pineapple-cocoa models, while the av. K built upto 177 and 164 kg/ha, respectively in the models. However, the available P was depleted in coconut-pineapple-cocoa model whereas, coconut-clove-banana was enriched by 109 kg P/ha compared to the coconut monoculture.

14.2. Spatial variability: The spatial variability of these nutrients in 2nd generation HDMSCS models was studied during 1997. On, computation and plotting of semivariogram, anisotrophy in the distribution of N, P, K and org. C at two depths was observed. In the monoculture, surface soil variation for total-N was minimum at 90° angle, while it was maximum at 45° angle. The semivariance of 45° angle increased upto 5 lag distance (m) and then decreased thereafter due to clove in the center of coconut-clove-banana model. The same trend was observed in coconut-pineapple-cocoa model. However, there was no decrease in semi variance at 45°angle after 5 lag distance.

14.3. Moisture depletion: In the 2nd generation HDMSCS model of coconut-clove-banana, subsoil moisture (12.4%) was less than that of top soil (13.4%) near the coconut while at 1.5 m and 2.0 m distance from coconut and clove, top soil moisture was low. In the coconut monoculture and coconut- cocoa- pineapple models, the moisture content did not vary with the soil depth.

15. Conclusion

Integrated nutrient management by using 2/3rd recommended fertiliser dose along with recycling of biomass by vermicomposting gives the best economic benefit in a sustainable manner. The system is more sustainable and production and productivity will increase without affecting the ecosystem. There is a positive impact through improvement of soil health by recycling of waste products in the system as organic manures. Further it will be eco-friendly with nature which will enable to increase the production and productivity of the system.

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Microbial interactions in coconut based cropping/arming systems

George V. Thomas, Murali Gopal and Alka Gupta

Introduction

Microbial community and fauna in a coconut garden under monocropping are likely to be constant and the introduction of other annuals and perennials could induce a shift in soil biology, which in turn could benefit the crop community. The abundance of beneficial root and soil organisms can suppress pathogens, improve plant nutrition, promote growth, and increase productivity. Although many factors can affect soil microbial communities, including soil characteristics, environmental conditions and crop management strategies, one of the most important factors driving changes in soil microbiology is the particular plant species present. It is known that specific crop grown can greatly affect soil microorganisms (Curl and Truelove, 1986). Microbial growth is carbon limited, and therefore the presence of organic matter has great influence on microbial population (Lynch and Whipps, 1990; Wardle, 1992). The variety of organic compounds released by plants through root exudates has been postulated to be a key factor influencing the diversity of microorganisms in the rhizosphere of different plant species (Grayston *et al.*, 1996).

The basis of success of coconut palm-based cropping and farming systems has long been a topic of investigation of the scientific community. There has also been scientific curiosity to understand the basic processes and alterations in soil biota leading to better performance of coconut palms with reduced chemical fertilizer dose. Soil microorganisms play an important role in nutrient acquisition of plants and are critical determinants of soil nutrient status, crop health and overall crop productivity (Glick, 1995). With the increasing emphasis on environmentally friendly, low input agriculture practice, there is ever growing interest in the management of soil microbial communities to enhance plant growth and soil microbiological foundations of coconut based cropping system approach (Thomas and Prabhu, 2003).

2. Rhizosphere as a zone of intense microbial activity

Rhizosphere is the region of soil subject to the influence of plant root and is the site of organic deposition and the generator habitat and resource heterogeneity for soil organisms. The rhizosphere harbours a higher and more active microbial biomass than surrounding bulk soil. Plants modify their rhizosphere through nutrient, moisture and O_2 uptake from the rhizosphere, rhizodeposition and production of root exudates. Processes in the rhizosphere influence plant disease, plant nutrition and root architecture by affecting the dynamics of microbial populations and communities.

3. Organic compounds in root region soils

The organic compounds in the soils are released from the decomposition of animal and plant residues by micro-organisms and from plant root exudates. The substances include sugars, aminoacids, organic acids, phenols, vitamins, nucleotides and many other organic compounds (Bopaiah *et al.,*1991). Total sugars were significantly higher in the root zone soils of coconut based mixed farming and coconut based multi-storeyed cropping systems when compared to monocrop of coconut (Table 1). Amino acids and phenol content were higher in the soils of multi-storeyed cropping system compared to monocrop of coconut. Raffinose, lactose, maltose and glucose were the sugars identified in all the systems. Among the amino acids, serine/glycine, glutamic acid, alanine, phenyl alanine, valine and isoleucine were present in all the cropping systems. Succinic acid was the organic acid reported from the root zone soils. The presence of these organic compounds influences the microflora in the root zone of the crops.

Table 1. Sugars, aminoacids and phenols in the root region soils of coconut based cropping / farming systems

Cropping system	Total sugars	Reducing sugars	Amino acids	Phenols
Coconut multistoreyed cropping	27.59 ± 2.39	4.19 ± 0.38	1.47 ± 0.38	0.24 ± 0.08
Coconut mixed farming	27.32 ± 3.27	4.32 ± 0.78	1.18 ± 0.10	0.10 ± 0.05
Coconut monocropping	20.08 ± 1.89	4.65 ± 0.58	1.24 ± 0.18	0.12 ± 0.04
CD (P = 0.05)	7.57	1.66	0.90	0.19

Average six values ± SEM, All values are in $\mu g\ g^{-1}$ dry weight of soil

Amino acids constitute an important component of organic fraction in root exudates of coconut and component crops in the cropping system (Kavitha, 2009). The concentration of total amino acids varied in root exudates of coconut and component crops in relation to the fertilizer treatments. The total amino acid content was 282.90 $\mu mol.g^{-1}$ root in coconut and it varied from 253.35 to 303$\mu mol.g^{-1}$ root in root exudates of component crops viz. clove, banana and pineapple of the high density multispecies cropping system. The amino acids recovered from the root exudates of coconut and component crops showed various proportions of acidic (aspargine, glutamine, glutamic acid), basic (histidine) and neutral amino acid (phenyl alanine, tyrosine, alanine, valine, leucine, isoleucine and threonine).

4. Plant beneficial microbes and function specific microbes

Bopaiah (1990) studied the microflora, enzyme activities, carbon and nitrogen mineralisation at three soil depths in the root zone and interspaces of coconut palms. The bacteria and fungi were more in the root zone soils as compared to their respective interspace soils. Activities of soil enzymes such as urease, phosphatase and dehydrogenase were greater in the root zone soils of coconut as compared to the interspace soils. The palm forms symbiotic association with VAM fungi belonging to the four genera viz., *Glomus, Gigaspora, Sclerocystis* and *Acaulospora*. Bacteria and fungi capable of solubilising insoluble phosphates are also found in large numbers in rhizosphere of coconut (Thomas *et al.*, 1991).

Coconut based cropping systems and farming systems have been shown to have enhanced microbial activity (Ghai and Thomas, 1989; Bopaiah and Shetty, 1991). Coconut and mixed crops harbour rich diversity of beneficial microbes (Table 2).

Table 2. Microbial diversity in the rhizosphere of coconut and component crops in cropping system

Crop	Microorganisms reported	Reference
Coconut	*Trichoderma* sp., *Aspergillus* sp., *Pencillium* sp., *Rhizopus* sp., *Pseudomonas* sp., *Arthobacter* sp., *Beijerinkia* sp., *Bacillus* sp., *Pseudomonas* sp., *Bacillus* sp., *Azospirillum* sp., *Azospirillum amazonense. Beijerinckia indica, Azoarcus* sp., *Bacillus* sp., *Burkholderia* sp., *Herbaspirillum frisingense, Arthrobacter* sp.	Bopaiah (1994) Thomas (1985) Merilyn and George (1992) George (1990), Thomas and Prabhu (1998), Prabhu *et al.* (1998) Thomas and Prabhu (2003)
Cocoa	*Aspergillus* sp., *Penicillium* sp., *Escherichia* sp., *Aspergillus flavus, Aspergillus fumigatus.*	Subba Rao (1983), Fresquez and Sabey (1989)
Banana and pineapple	*Trichoderma sp., Mortiella* sp., *Gliocladium* sp., *Fusarium* sp., *Penicillim* sp., *Chaetonium* sp., *Pythium* sp., *Humicola* sp., *Burkholderia* sp., *Cylindrocladium* sp., *Pseudomonas* sp.	Watanabe (1971) Weber *et al.* (1999)

5. Biological nitrogen fixing bacteria

The baceteria, which have potential for reducing gaseous atmospheric nitrogen to a biologically stable form, have rhizospheric associations and associative symbiotic root associations with the coconut palm. *Beijerinckia indica* possessing traits such as biological nitrogen fixation, production of polysaccharides and plant growth promoting properties has been found to have consistent rhizospheric association with coconut (Merilyn and Thomas, 1991). *Azotobacter* has also been reported to be a component of rhizosphere community. Associative symbiotic bacteria belonging to *Azospirillum* with species diversity of *A. lipoferum, A. brasilense, A. amazonense* have been reported from endorhizosphere and rhizosphere regions of not only coconut, but also several component crops in the cropping system (Ghai and Thomas, 1989). Nitrogen fixation efficiency of the bacteria based on the Acetylene Reduction Assay (ARA) in the range of 2.71 to 78.94 nM C_2H_4 tube^{-1}h^{-1} in case of *Beijerinckia* isolates and ARA of 10.05 nM C_2H_4 ml^{-1} media h^{-1} in case of *Azospirillum* isolates have been reported (Thomas *et al.*, 1991) (Table 3).

Table 3. Occurrence of nitrogen fixing bacteria in the roots and rhizosphere soils of coconut

Location/Expt.	Bacteria	Population per g soil	*In vitro* Nitrogen Fixation	Reference
Coconut-cocoa mixed cropping Kasaragod	*Beijerinckia*	2.0 – 6.0x10^3	--	Nair and Subba Rao (1977)
Coconut-hybrid napier intercropping, Kayangulam	N_2 fixers	1.20 – 1.77x10^4	--	Potty, George and Jayasankar (1977)
Mixed cropping in tree spices, Kasaragod	”	1.43 – 3.96x10^5	--	Rohini Iyer (1983)
Coconut Plantations, Kerala	*Beijerinckia*	9x10^4	--	
	Azotobacter	6x10^4	--	Subba Rao (1983)
Basin management with green manures, Kayangulam	N_2 fixers	50.11 – 74.99x10^4	--	Thomas (1987)
Coconut based multi-storeyed cropping, Kasaragod	*Beijerinckia*	4.28x10^3	7.0-15.6mg/g C source	Bopaiah (1998)
Coconut based mixed farming, Kasaragod	*Beijerinckia*	4.18x10^3	8.4-12.2mg/g C	Bopaiah (1998)
Farmers gardens in different locations in Kerala	*Beijerinckia*	1.00x8.77x10^3	2.71-78.94 nMC_2H_4 tube^{-1}h^{-1}	Merilyn and Thomas (1991a)
Coconut in different cropping systems,				
Kasaragod	*Azospirillum*	17-25% roots	10.05 nMC_2H_4 ml^{-1} media h^{-1}	Ghai and Thomas (1989)

6. Phosphate mobilisers

Studies on the distribution of phosphate-solubilizing bacteria in coconut plantation soils revealed that clayey soils harboured less population than laterite, alluvial and sandy soils. *Pseudomonas* sp., *Micrococcus* sp., *Micrococcus roseus, Bacillus subtilis, Corynebacterium* sp. and *Alcaligenes* sp. were the phosphate-solubilizing bacteria encountered in coconut soils. *In vitro* estimation of the phosphate-solubilizing ability of the isolates revealed solubilization of 19.5 to 54 per cent of the insoluble phosphates supplied in the culture broth. Inoculation of soils with efficient phosphate-solubilizing bacteria after addition of farm yard manure and rock phosphate released more available P from insoluble P sources. *M. roseus* and *B. subtilis* possessed better capacity to survive in unamended soils, as compared to the other phosphate-solubilizing bacteria tested and have a great potential as inoculants in crop plants for better utilization of insoluble P-sources (Thomas and Shantaram, 1986).

7. Microbial association in cropping system

Microbiological investigations have been carried out in different cropping systems of coconut and the results revealed proliferation of microflora, and biological activities at higher level in cropping/farming systems.

7.1 Coconut hybrid napier intercropping

Intercropping of fodder hybrid napier with coconut palms resulted in the proliferation of total bacteria and nitrogen fixing organisms in the rhizosphere of apparently healthy and root (wilt) diseased coconut palms compared to the palms in the control plot (Potty *et al.*, 1977). Crop mixing enhanced phosphate solubilizing bacteria in root region of the palm with root (wilt) affected coconut palms harbouring significantly higher numbers. The trend was however reversed after the application of inorganic fertilizers.

7.2 Coconut-cocoa mixed cropping

Mixed cropping of cocoa in coconut plantations improved the microbial activity in the rhizosphere of coconut which may be attributed to an increase in organic matter content of soil due to periodic shedding of cocoa leaves. When compared to coconut cultivation without cocoa, mixed cropping of coconut with cocoa stimulated the population of bacteria and fungi in the rhizosphere of coconut, including the nitrogen fixing and phosphate solubilising bacteria. The occurrence of indole acetic acid producing *Escherichia* sp. on the root surface of coconut and the appearance of gibberellin(like-substance) producing *Aspergillus flavus* and *A. fumigatus* in the rhizosphere were also reported in the root region of plantation crops under mixed cropping (Nair and Subba Rao, 1977).

Two efficient phosphate solubilising microorganisms, viz., *Pseudomonas* sp. and *Aspergillus niger* were isolated from the rhizosphere of coconut and cacoa. They were capable of solubilising 49.0 % and 49.7 % inorganic phosphate. The incidence of phosphate solubilising microorganisms and available phosphorus in different rhizosphere soils were directly related (Nair and Subba Rao, 1977).

7.3 High density multispecies cropping system

High density multispecies cropping system involve growing a large number of crops at very high population per unit area to maximize production and economic returns from the plantations. An in depth study of microbial interactions, biochemical changes and nutrient transformations by the microflora was undertaken. Augmentation of microbial activity as reflected by enhanced population of heterotrophic microflora and population of function specific microbes such as nitrogen fixers and phosphate solubilisers were reported in the cropping system when compared to that in the monocrop of coconut. The increase in microflora is attributed to physico-chemical conditions induced in the rhizosphere, root exudates patterns and heterogenieity and quantity of carbon source entering through root exudates and litter fall.

Spores of vesicular-arbuscular (VA) mycorrhizal fungi were reported in all the soil samples collected from the root zones of plants forming a coconut-based multistoreyed cropping system, namely coconut, cacao, cinnamon and black pepper. Their numbers ranged widely from plant to plant (8-420 spores/100 g soil) and varied remarkably from sample to sample of the same crop. Of the eight species found, *Gigaspora gigantia, G. gilmorei. Glomus fasciculatus* (clusters), and *G. macrocarpa* were the most common, *G. microcarpa* and a flat unidentified spore type were less frequent, whereas *Sclerocystis* sp. and a white unidentified spore type were rare. Usually more than two VA species occurred at the root zone of each crop. Root samples of all the hosts showed extensive infection (80- 98%) with internal and external hyphae, and characteristic vesicles and arbuscules (Ramesh, 1982).

Soil microbial biomass carbon was significantly higher in coconut root region soils when compared to that in other crops. Microbial biomass carbon was also influenced by the fertilizer levels with medium levels supported higher biomass carbon contents (Kavitha, 2009). The ratio of microbial biomass to total carbon was high in root region soils of coconut indicating higher contribution of microbial biomass to total carbon. The metablic efficiency of the microbial biomass was characteristically lower when full dose of recommended fertilizers were applied. Soil microbial biomass carbon content was negatively correlated with metabolic quotient.

7.4 Mixed farming system

Soil microflora, enzyme activities and microbial biomass in the root zone and rhizosphere of coconut-based mixed farming system showed considerable increase when compared to coconut monocropping systems (Table 4 and 5). Bacterial counts were higher in the rhizosphere of coconut and napier grass of mixed farming than in coconut monocropping. Urease, dehydrogenase and phosphatase enzyme activities were greater in the rhizosphere soil than in the root zone soil. The soil microbial biomass and the concentration of N and available P and K were higher in the mixed farming system (Bopaiah and Shekara Shetty, 1991).

Microbial biomass exerts an influence on soil carbon and nutrient cycling, both through the oxidation of soil organic matter and mineral nutrients. Soil microbial biomass was significanly higher in the root region soil of coconut and hybrid napier when compared to that in monocropping systems (Table 6).

Table 4. Microflora (CFU g^{-1} cropping systems soil) in the root zone and rhizosphere of mixed farming and monocropping systems of coconut

Crop	Root zone[a]				Rhizosphere[b]		
	Depth (cm)	Bacteria ($x 10^6$)	Fungi ($x 10^3$)	Actinomycetes ($x 10^5$)	Bacteria ($x 10^6$)	Fungi ($x 10^3$)	Actinomycetes ($x 10^5$)
Coconut (MF)	0-25	8.03	9.33	9.50	12.25	4.55	2.05
	26-50	3.23	8.55	2.89			
	51-100	3.03	2.45	2.50			
Napier grass (MF)	0-25	8.73	3.22	5.23	9.28	2.92	0.30
	26-50	1.87	2.33	2.45			
	51-100	1.30	1.56	1.11			
Coconut, monocrop	0-25	2.27	2.27	3.67	8.87	4.87	0.31
	26-50	2.73	3.03	4.00			
	51-100	1.43	1.07	1.67			
Coconut, monocrop interspace	0-25	1.27	0.47	4.33			
	26-50	0.67	0.77	2.33			
	51-100	0.37	0.77	2.00			
LSD (P = 0.05)					5.50	4.49	0.39
Crop		0.54	0.72	1.34			
Depth		0.47	0.62	1.16			
Crop x depth		0.94	1.24	2.32			

[a]Average of three replications. [b]Average of five replications.

Table 5. Soil enzyme activities in the mixed farming and monocropping systems of coconut

Crop	Depth cm	Root zone[a]			Rhizosphere[b]			
						Dehydrogenase[2]		
		Urease[1]	Dehydrohenase[2]	Phosphatase[3]	Urease[a]	Without glucose	With glucose	Phosphatase[3]
Coconut (MF)	0-25	7.61	2.74	147.67	9.04	2.61	6.13	161.7
	26-50	6.55	1.28	59.67	-	-	-	
	51-100	4.78	-	29.67	-	-	-	
Napier grass (MF)	0-25	8.42	3.38	81.33	8.54	4.71	12.5	136.0
	26-50	6.32	1.95	38.00	2.92-			
	51-100	2.55	-	15.67				
Coconut, monocrop	0-25	7.67	2.87	69.33	5.41	2.82	6.04	133.6
	26-50	5.44	1.46	54.33	-	-	-	
	51-100	2.04	-	34.67	-	-	-	
Coconut, monocrop interspace	0-25	3.62	1.89	29.83	-	-	-	
	26-50	3.80	0.83	24.30	-	-	-	
	51-100	1.96	-	15.17				
LSD (P = 0.05)					3.29	2.77	2.10	30.42
Crop		0.96	0.21	17.79				
Depth		0.83	0.15	15.40				
Crop x depth		1.66	0.29	30.81				

[a] Average of three replications; [b] average of five replications; [1]urease as µg of $NH4^{+}$ g^{-1} soil h^{-1}, [2]dehydrogenase as µg of Formazon/g of soil h^{-1} and [3]phosphatise as µg p-nitrophenol g^{-1} of soil h^{-1}

Basin management with leguminous cover crops

In situ cultivation and incorporation of green manure legumes in coconut basins improved the microbial activity in the root region of coconut in a slightly acidic laterite soil. Populations of bacteria, fungi, actionomyoetes, asymbiotic nitrogen fixing and phosphate solubilising bacteria were significantly increased during the maximum vegetative phase and at 30 days of incorporation of green manures. However, such a proliferation in microflora was not observed at 60 days of incorporation. Dehydrogenase activity also exhibited a similar trend, whereas the activity of urease enzyme did not increase to any significant level. The number of endomycorrhizal chlamydospores in the root region soil and the intensity of mycorrhizal infection in roots of coconut were high in green manured basins. In general, *Pueraria phaseoloides* had a better beneficial influence on microbial characteristics of coconut root region as compared to *Mimosa invisa* and *Calopogonium mucunoides* (Thomas, 1987).

Table 6. Soil biomass in rhizosphere of crops in the mixed farming system

System	Soil biomass (mg C g^{-1} soil)	
	0-10 days	10-20 days
Coconut (MF)	187.80	27.80
Napier grass (MF)	177.95	41.88
Coconut monocropping	111.22	19.46
LSD (P = 0.05)	70.74	28.50

8. Amplification of microbes in relation to crop residue recycling

Large quantities of crop residues are available in coconut based cropping systems. Recycling crop residues in cropping system has been carried out using an epigeic strain of earthworm belonging to *Eudrilus* sp. Vermicomposting system could serve as a source of beneficial microbes in the cropping system. The coconut leaf vermicompost contained significantly high population of fungi, free-living nitrogen fixers, phosphate solubilizers, fluorescent pseudomonads, and silicate solubilizers (Gopal *et al.,* 2009).

9. Comparative study in different cropping systems

The population of phosphate solubilising bacteria were higher in coconut based high density multispecies cropping, multi-storeyed cropping and mixed farming systems as compared to that in coconut monocrop. *Bacillus, Pseudomonas* and *Micrococcus* and *Aspergillus, Fusarium* and *Penicillium* were the genera of P-solubilizing bacteria and fungi identified. *Bacillus polymyxa* (45.2%), *Bacillus subtilis* (40.8%) and *Pseudomonas* *striata* (43.3%) were the bacteria which showed greater P-solubilizing ability under *in vitro* conditions. Among the fungi, *Aspergillus niger* (2 isolates) and *Penicillium citrinum* have recorded higher P-solubilizing ability. *Aspergillus niger* and *Penicillium citrinum* have shown greater competitive saprophytic ability, while *Bacillus subtilis*, *Bacillus polymyxa* and *Pseudomonas striata* showed better survival in sandy loam soil (Bopaiah and Thomas, 1993).

A study on 26 crops including plantation crops and intercrops in different cropping system revealed occurrence of *Azospirillum* in different levels in coconut-based farming systems, such as high-density multispecies cropping (15 crops), multi-storeyed cropping (3 crops), mixed cropping with tea and coffee (2 crops), intercropping with tropical tubers (5 crops), mixed farming with grasses (3 crops) and in 3 crops, arecanut, and sugarcane from other plots. Incidence of *Azospirillum* was determined by 2,3,5-triphenyl-tetrazolium chloride reduction and by culturing root fragments in N-free semisolid malate medium. 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 *A. bhrasilense* constituted 42% and 45% of the isolates, respectively, in the coconut-based cropping systems. Isolates from guinea grass, sugarcane and jackfruit exhibited higher nitrogenase (C_2H_4 reduction) than those isolated from plantation crops, tuber crops and spices. The large variation in the extent of association and nitrogenase activity of isolates from different crops indicated the need for inoculation with efficient cultures in a number of crops in coconut-based cropping systems (Ghai and Thomas, 1989).

Changes in AM status and extent of root colonisation were reported in coconut based high density multi-species cropping system involving 18 component crops and three fertilizer regimes (namely, one-third, two-third and full doses of recommended fertilizers for each component crop) (Rohini Iyer *et al.* 1991).

10. Complementary and synergistic interactions in the cropping system

Scientific studies in different cropping systems indicated complementary and synergistic interactions between component crops in the systems. The beneficial effects include improvement in soil fertility status, enhanced microbial activity, better microclimate and reduced weed growth which helped to achieve higher productivity. The micro-climate inside the system was characterised by lower maximum temperature, less evaporative demand and higher nutrient and moisture status than pure crop stands. Improvement in soil available N,P, K and Ca status in soils of cropping system has been reported. Cocoa raised as a mixed crop adds significant quantity of organic matter to the soil and improvement in soil organic carbon status has been reported from the system. Mixed farming stystem with animal husbandry enterprises enable enrichement of soil with organic matter through cow dung slurry application and other residues from the system. All these factors contribute to improved microbial activity, nutrient mobilisation and mineralisation and higher crop productivity in the system.

11. Conclusion

Cropping and farming systems are considered as the keys to achieve sustainability in coconut farming due to the utilization of natural resources to the maximum extent. Intensive research conducted in several cropping systems revealed augmentation of plant beneficial micro-organisms, function specific micro-organisms, enzyme activities, mineralisation and availability of nutrients in the system, when compared to the monocrop of coconut. Microbial processes assume great significance to maintain and improve soil quality for sustaining crop productivity. Microbially mediated processes interact with soil resources to regulate nutrient supply in the ecosystems. The microbes support intrinsic ecosystem processes to improve nutrient use efficiency and nutrient balance at ecosystem scale, while maintaining productivity.

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Bio inputs in coconut based cropping system

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Introduction

In India, out of 329 million ha of its geographical area, more than 50% area is considered problematic or degraded where crop/forage production is very poor or negligible. Though the estimates of degraded and problematic lands significantly vary in different survey reports, it has been estimated that about 141 million ha suffer from acidity, 9 million ha are salt affected, 8.5 million ha water logged, about 4 million ha have been disturbed by ravines and gullies and 4.9 million ha under shifting cultivation (Indian Agriculture in Brief, 1992). In Kerala, the soils are mostly acidic because of high rainfall and coastal nature. Patches of acid sulphate soils with pH as low as 3.5 too occur in many areas in the State. Coconut (*Cocos nucifera*) is one of the major plantation crops that is grown throughout Kerala. It is generally grown as the main component of homestead garden. Irrigation is mainly through rainfed and minimum manurial applications are given. These situations have led to loss of soil fertility and productivity. Application of chemical fertilizers will improve the soil fertility. However, application of chemicals alone is resulting in severe degradation of soil health and pollution of ground water. It is in such situations that bioinputs can improve the soil productivity. The organic wastes (crop, animal and farm wastes, aquatic wastes) and other biological materials, mostly produced *in situ* —— along with beneficial microbes (biofertilizers) to release nutrients to crops, comprise bioinputs and are an essential component of organic agriculture or 'Javik Krishi'.

The usage of bioinputs was recognized from early times in countries like India, China and Egypt. The benefits credited to bioinputs include increase in available plant nutrients and organic matter content and improvements in the microbiological and physio-chemical properties of the soil. Bioinputs, when present in sufficient quantities, protect the soil from the different forms of degradation. Some of the important bioinputs are discussed in this chapter.

2. Vermicompost

Vermicompost is a loosely packed, granular aggregate of earthworms and associated microbes-mediated and enzymatically digested organic matter containing nutrients in easily available or mineralizable form. It is also rich in earthworm mucus containing energy sources. So, when vermicompost is added to soil, it will act as top soil and enhance soil microbial activity, thus making soil alive. Because of its granular nature, vermicompost improves soil aeration, water holding capacity and thus root growth.

Vermicomposts contain more counts of plant beneficial microbes such as nitrogen fixing bacteria, phosphate solubilizing bacteria, fungi, actinomycetes, plant growth promoting bacteria, and microbes capable of degrading a number of biopolymers such as cellulose and lignin. Vermicomposts also contain a number of bioactive compounds such as auxins, gibberellins, cytokinins, vitamins and aminoacids, which have the capacity to influence plant growth, development, reproduction and yield. It contains humic acid which has plant growth promoting activity. Application of vermicompost improves cation exchange capacity and soil physical conditions. Advantages of using vermicompost are that it contains less human and plant pathogens, is easy to handle, store, and incorporate into soil compared to the conventional composts.

2.1 Potential applications of vermicompost in horticulture

Vermicompost is a finely divided peat-like organic material with excellent structure, porosity, aeration, drainage and water holding capacity. It has appearance and many characteristics of peat. It can influence a number of soil physical, biological and chemical processes which have their bearing on plant growth, development and yield and is a better source of organic matter than other composts.

2.2 Process of vermicomposting

Now a days, earthworms are increasingly being employed for vermicomposting of biodegradable agricultural and urban wastes. It is generally known that epigeic species of earthworm have better potential as waste decomposers than anecics and endogeics. This is due to predominantly humus consuming surface dwelling nature of the epigeics. The commonly used epigeic species are *Eudrilus eugeniae, Eisenia foetida* and *Perionyx excavatus*. All these species are prolific feeders and can feed upon a wide variety of degradable organic wastes. They have very high growth rate too that helps in quicker decomposition of the wastes.

3. Organic wastes from coconut based farming systems

Nearly 6 to 8 tonnes of coconut wastes in the form of leaves, spathe, bunch waste, husk of nuts are available from one hectare of well managed coconut garden. In India, the total area under coconut cultivation is 1.81 million hectares from which nearly 14.36 million tones coconut waste biomass is available. Along with coconut wastes, wastes from other crops like banana, cocoa, etc. can also be used for vermicomposting. In the coconut gardens, a number of annuals and perennials are successfully grown as inter/ mixed crops for effective utilization of natural resources in the garden as well as to achieve economic viability in coconut farming. In coconut based farming systems, huge quantities of organic materials become available from intercrops grown in coconut garden. The

High density multispecies cropping systems (HDMSCS model at CPCRI, Kasaragod involving coconut, clove, banana and pineapple produces 17.00 to 22.58 t/ha/yr biomass under different fertilizer treatments. These wastes can be recycled into organic manures using vermicomposting technique. Mixed farming, in which animal enterprises are integrated with coconut cultivation, involving coconut, fodder grass, dairy unit, poultry and rabbitry, 15 tonnes of farm yard manure, 2 tonnes of poultry manure as well as 50,000 litres of cow urine and cowshed washings were obtained annually and if these are recycled as organic manures back into the system, savings of upto 125 kg N, 78 kg P_2O_5 and 115 kg K_2O in chemical fertilizer application can be achieved (Maheshwarappa *et al.,* 2001).

Recycling of these vast resources of crop residues containing appreciable quantity of nutrients, produced by coconut plantations into bioinputs/organic manures gives wide scope for nutrient management in plantation crops and cropping systems. These organic materials, which are generated on farm in coconut based farming system, can be converted into compost and used to meet a considerable part of nutrient requirement of coconut palm, as well as the component crops of coconut based farming system.

3.1 Process of vermicomposting of coconut wastes

The natural decomposition of organic by-products resulting from coconut cultivation and the nutrient release is very slow due to the presence of lignin and polyphenols in it. But earthworms, which survive only in organic matter, known as compost worms or manure worms can enhance the decomposition of such organic materials and mediate humus formation. At CPCRI, scientists have identified a local strain of earthworm related to African Night Crawler (*Eudrilus* sp.) which is quite efficient in converting coconut leaves into granular vermicompost (Prabhu *et al.,* 1998).

The technology of producing vermicompost from lignin rich and highly recalcitrant coconut leaf litter using an indigenous strain of African night crawler earthworm, *Eudrilus* sp, was developed by Central Plantation Crops Research Institute a decade back (Prabhu *et al.,* 1998). The indigenous earthworm strain capable of degrading the coconut leaves is large sized; dark violet in colour, vigorous and the cocoon case produced is spindle shaped, thick and dark in colour. It converts coconut leaves into vermicompost in less than three months period and compost has C: N ratio of 9.95, 1.8% N, 0.21% P and 0.16% K and organic carbon content of 17.84. As much as 4000 kg of good quality vermicompost can be produced from the wastes generated from 1 ha of healthy coconut garden every year by this earthworm that can meet a considerable percentage of nutrient need of the coconut palm. This technology has been considered as an important component of sustainable production technology for coconut. This vermicompost can also be used for improving the productivity of other annuals, vegetables, fruits, flowers as well as cash crops. The coconut leaf vermicomposting technology has two components : (1) production of nucleus culture of earthworm *Eudrilus* sp. and (2) large scale vermicompost production.

3.2 Nucleus earthworm culturing

Fallen and weathered coconut leaves are chopped into 15 cm pieces in chaff cutter, and mixed with cow dung slurry in 1:1 ratio. This substrate is pre-decomposed for 15-20 days with constant moisture. The pre-decomposed material is then filled into plastic basins, cement tanks or wooden boxes, or made into 10 cm bed on floor. The nucleus culture of Eudrilus sp. is then introduced into the above mixture at the rate of 50 worms per 10 kg of the substrate and properly mulched with dry grass, straw or wet gunny bag. The units are protected from direct sunlight, and watered regularly. Once in a week, fresh cow dung slurry can be added to the material. Within 1-2 months, the earthworms multiply to 300 times, which is used for large-scale vermicompost production from coconut leaves.

3.3 Large-scale vermicompost production

Large-scale coconut leaf vermicompost can be produced in pits, thatched sheds, open ground and cement tanks. However, the bed system of compost production carried out in cement tanks was found to be most efficient. The length and breadth of the tanks can be made as per convenience; but, the depth should be less than 1 metre. This is because more depth of the tank will increase the amount of substrate loading which will weigh upon the earthworms and hinder their movements and composting capacity.

Coconut leaves weathered for 2-3 months are to be used. After chopping off the thick base, the rest of the leaf can be put as such or in two pieces. They must be stacked with bottom side up in the tank, pit or shed upto 1 feet height. Above this, a layer of cow dung slurry is spread. Three such layers can be accommodated in 1 metre deep cement tank. The ratio of coconut leaves to cow dung slurry must be 10: 1 (e.g. 1000 kg leaves: 100 kg cow dung slurry). Sufficient moisture must be ensured by sprinkling water regularly and the whole substrate is allowed to pre-decompose for 2-3 weeks. At the end of this period, 1000 worms per tonnes of substrate are introduced into the tank. Mulching with available organic wastes, dry grass, straw or coconut leaves help to conserve moisture. Watering must be done once in a week during monsoon and twice in week in summers. The composting area should be provided with sufficient shade to protect from direct sunlight and rainwater. Covering the tanks/heaps/pits with nylon mesh prevents entry of predatory birds, rats and rhinoceros beetle. The rhinoceros beetle can also be managed by application of an entomopathogenic fungus *Metarhizium anisopliae* in the substrate (Murali Gopal *et al.,* 2006). Providing water channels around the tanks will prevent access to ants into the vermicomposting material.

Depending upon the extent of weathering and pre-decomposition, a maximum of 70% of the substrate would be converted to vermicompost within a period of 60-75 days, indicated by the fall in the level of substrate by more than ½ metre in the tank. At this stage, watering should be stopped and the composted material is heaped into a mound. This causes migration of the earthworms to the bottom of the mound. After another 2 weeks, the vermicompost free of earthworms can be collected from the top layer of the mound, sieved, shade dried and packed. Earthworms accumulated at the bottom of the mound can be sorted and picked by hand and can be used for next round of composting.

The indigenous earthworm *Eudrilus* sp. also has affinity for wastes other than coconut leaf wastes. A coconut garden, where other intercrops/ mixed crops are grown, generates leaf wastes from these intercrops also. All these mixture of wastes can be successfully composted using *Eudrilus* sp. earthworm. It has been found that coconut leaves can be mixed with pineapple waste, banana pseudo stem or gliricidia leaves in 3:1 ratio for effective utilization of other wastes commonly produced in coconut based cropping system.

Though the vermicompost production from coconut leaves can be carried out through out the year, however, it was found that efficient compost turnover and multiplication of worms takes place when the temperature was in the range of 28-32°C and relative humidity was above 90%, which normally coincides during June to Oct. months in the coastal tract of Kerala (Gopal *et al.,* 2004).

3.4 Supply of nucleus earthworm culture to farmers and other target groups

To disseminate and popularize the coconut leaf vermicomposting technology, CPCRI has been continuously producing and supplying nucleus earthworm culture to farmers, developmental agencies and other target groups within Kerala and to other states where coconut is commonly grown. Approximately 12 lakh earthworms have been supplied to

Table 1. Details of distribution of Eudrilus sp. earthworms among end users

Year	Number of nucleus earthworm culture supplied	Districts covered in Kerala	States and UT covered other than Kerala
2003-04	2,40,725	Kasaragod, Kannur, Kozhikode, Mallapuram, Palakkad, Thrissur, Kottayam, Alappuzha, Kollam, Ernakulam	Karnataka, Andhra Pradesh, Tamil Nadu, Pondicherry, Bihar, Orissa, West Bengal, Maharashtra, Assam, Chhattisgarh
2004-05	2,56,100		
2005-06	2,94,860		
2006-07	2,146,00		
2007-08	1,65,000		
2008-09	92,300		

(Gopal *et al.,* 2009)

end-users during the last 6-year period between 2003 and 2009. Farmers from almost all the panchayats of Kasaragod have taken the worms and have initiated vermicompost production. Next to Kasaragod, most number of panchayats covered was in Kannur District. In addition to Kerala, end-users from 10 other states and Union Territories (UT) have collected the nucleus earthworm culture from CPCRI (Table 1). The number of worms supplied was a clear indication of popularity and acceptance of the technology of producing vermicompost from coconut leaves using this indigenous strain of *Eudrilus* sp. However, most farmers in Kerala who had taken the earthworms informed that they were mixing other farm wastes along with coconut leaves for vermicompost production. It mostly included leaves from arecanut, jack fruit, mango and banana pseudostem.

4. Coconut leaf vermiwash

Vermiwash (vermin-wash) is the clear brown coloured liquid collected after the passage of water through a column of actively vermicomposting substrate with earthworms. It is actually a combination of the washings of the earthworms' body surface along with the leachate of the vermicomposting substrate. CPCRI had isolated a local strain of earthworm *Eudrilus* sp. capable of vermicomposting the highly lignin and phenol rich coconut leaves. The technology of vermicompost production from coconut leaves has spread rapidly in Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Orissa, Maharashtra and Assam confirmed by the supply of large numbers of earthworms in the last five years by the Institute. Vermiwash is a spin off technology from vermicompost production that helps in increasing the farm income.

Vermiwash can be produced by allowing water to percolate through the drilosphere (tunnels), made by *Eudrilus* sp in coconut leaf-cow dung substrate kept in a 200 litre plastic barrel. Water is allowed to fall drop by drop from a pot hung above the barrel into the actively vermicomposting system. The clear brown coloured liquid is collected out of the tap fixed at the bottom of the barrel. Alternatively, farmer can make an exit hole in the tanks built for large-scale vermicompost production and collect the vermiwash regularly from it.

Fresh coconut leaf vermiwash is alkaline and contains N, P, K, Ca, Mg, Zn, Mn in appreciable quantities. It also has sugars, amino acids, and phenols along with the plant growth promoting hormones viz. indole acetic acid, gibberellic acid and humic acid. Fresh vermiwash harbours a large number of fluorescent pseudomonad bacteria that help in plant growth promotion and protection (Gopal *et al.,* 2007). Laboratory studies have shown that coconut leaf vermiwash improves the germination percentage and seedling vigour of cowpea and paddy. In green house experiments with nutmeg, clove, pepper and vanilla, application of vermiwash has resulted in better shoot growth, more leaf production and particularly higher root biomass that too with large amount of fine root hairs that improve the water and mineral absorption capacity of plants.

Limited field studies carried out in the Institute has demonstrated that soil application of coconut leaf vermiwash once in 15 days has increased biomass production of cowpea (for green manure purpose) by 36%, with 30 % increase in nodule numbers. In maize, 5-10% increase in cob yield with 29-64% higher cob weight could be realized. Bhendi yield could be enhanced to the range 22 to 33%. Vermiwash application stimulated the numbers of microorganisms particularly the beneficial ones (free living nitrogen fixing bacteria, phosphate solubilizers, cellulose degraders, and antibiotic producing actinomyctes) in the root region of the above crops along with increasing the soil dehydrogenase, phosphatase and enzyme activities (Gopal *et al.,* 2005).

In the study with bhendi, the population and gall formation by the nematode *Meloidogyne incognita* was greatly checked on application of vermiwash. One important aspect to be noted is, vermiwash should not be applied without proper dilution, as it is phytotoxic at original concentrations. Coconut leaf vermiwash acts as a plant growth stimulator when diluted 5 to 10 times with water and then applied to crops. Adoption of this technology by farmers already carrying out vermicompost production involves very less investment. The vermiwash produced in addition to the vermicompost can be used for improving the yield of crops that give quick returns like vegetables, flowers and also export oriented crops like pepper, nutmeg, clove and vanilla.

5. Green Manures

Soil Science Society of America in 1971 described green manure as "plant material incorporated with the soil while green or soon after maturity for improving the soil". In practice, it includes *in situ* growing and incorporation of biomass or collection and ploughing of the biomass grown outside the main field. In India, green manuring is estimated to be practised on 6.3 million ha, which form only 4.4% of the net cultivated areas.

The best known and popular green manure crops are those, which fix nitrogen in association with *Rhizobium*. Biomass production of green manure crops and their nitrogen and phosphorous contents vary widely according to the species, their growth stage, environmental conditions, soil fertility and crop management practices. The details of some of the common green manure crops are given in Table 2.

Besides legumes, several other plants may be used as green manure. For example, water hyacinth (*Eichhornia crassipes*) which grows wildly in stagnant and backwaters in Kerala contains 2.0% N on dry weight basis and some sea-weeds containing 1-2% N, may be used for manuring crop in coastal areas like Kerala.

Table 2. Characteristics of some of the important green manure crops

Green manure crop	Green matter (t ha-1)	Moisture (%)	N content (% of dry matter)	P content (% of dry matter)	C:N ratio
Cultivated annual legumes					
Crotalaria juncea (Sunnhemp)	16.5-25.0	73	2.0-3.12 (2.86)	0.18-0.40 (0.34)	13.5-24.0 (16.1)
Melilotus alba (Zenji)	28.6	—	0.57	—	—
Phaseolus aureus (Mung, green gram)	7.7-8.0	82	2.21-2.96	—	16.1
P.trilobus (Pillipesara)	5.3-18.3	79	1.10-2.47	—	—
Vign unguiculata (Cowpea)	10.0-15.0	85	1.60-3.89 (2.69)	0.22-0.43 (0.28)	10.3-23.2 (17.1)
Sesbania aculeate / (Dhaincha) *bispinosa / cannabina*	14.8-25.0 (20.0)	78	1.79-4.16 (2.62)	0.21-0.40 (0.32)	8.6-28.8 (16.4)
S.speciosa, sesban (Sesbania)	7.8-60.0	78	2.43	—	—
Trifolium alexandrinum (Berseem)	15.5	80	0.43	—	—
Perennial legumes					
Desmodium gyroides	1.4	72	3.35	—	—
Gliricidia sepium	30-110	75	2.5-4.30 (3.49)	0.13-0.29 (0.22)	10.42
Indigofera tinctoria (Indigo)	10-12	—	—	—	—
Leucaena leucocephala	—	—	2.42-3.50	0.13-0.27	12.7
Sesbania punctata	3.7	73	2.42	—	—
S.rostrata	3-5	74	—	—	—
Wild annual legumes					
Calopogonium mucunoides (Calopa)	4.5-5.0	74	3.02-4.20	—	8.5
Cassia tora	5.2	71	2.13	—	—
Lathyrus sativus	—	82	4.67	—	—
Tephrosea purpurea (Wild Indigo)	3.5-6.0	70	3.46	—	—
Azolla pinnata	—	—	0.95-6.57 (4.46)	0.06-1.74 (0.38)	9.0-12.9

(Values in paranthesis are average)

The technique for utilization of leguminous cover crops as green manures to supply biologically fixed nitrogen and easily decomposable biomass to coconut was standardized at CPCRI. It involves cultivation of leguminous creepers such as *Pueraria phaseoloides, Mimosa invisa* and *Calopogonium mucunoides* in coconut basins during monsoon period from June to October and incorporation of legume biomass in respective basins. During a growth period of 140-150 days, the promising legumes can generate 15-28 kg of biomass and 102-197 g of nitrogen in the basin of a coconut palm. The method of cultivating the leguminous crops in coconut basins is simple and inexpensive and with the continuous cultivation of the legumes it is possible to augment soil organic matter resources for sustaining soil fertility and improving coconut yield.

In most coconut growing areas, the interspace between the palms is cultivated with tuber crops, cocoa, pepper and banana. The green manure/cover crops can be cultivated in the basins of coconut palms. The recommended radius for opening the basins in coconut cultivation is 1.8 m^2 and this space can be utilized for growing green manures without competing for the interspaces, which are utilized for raising other crops. For this purpose, nine green manure/cover crops, *Calopogonium mucunoides, Glycine wightii, Leucaena leucocephala, Macroptilium atropurpureum, Macrotyloma axillaire, Mimosa invisa, Pueraira phaseoloides, Sesbania aegiptica* and *Stylosanthes guianensis,* were tested for their suitability to establish under coconut. Most of these are tropical forage legume and some are known to establish well under coconut in the interspaces. Green manures are incorporated at the rate of 20 kg per basin.

Data on green matter production (tops) and native nodulation status of green manure legumes are presented in Table 3. *Pueraria phaseoloides, Mimosa invisa* and *Calopogonium mucunoides* established well under coconuts in the basins. The mean yield obtained being 19.43, 17.00 and 14.71 kg/basin respectively. From this study, *P. phaseoloides, M. invisa* and *C. mucunoides* were recognized as suitable crops for cultivation in coconut basins.

Table 3. Growth and nodulation of green manure crops in coconut basins

Legume species	**Growth**		**Nodulation**	
	Fresh weight (kg/basin)	**Total N added (g/basin)**	**Nodule number/ five plants**	**Nodule dry weight (g/five plants)**
Calopogonium mucunoides	14.71	102.61	145	0.485
Macrotyloma axillaire	0.95	6.67	58	0.132
Mimosa invisa	17.00	153.19	125	1.860
Pueraria phaseoloides	19.43	121.29	132	1.128
Leucaena leucocephala	2.95	16.55	0	0.0
Sesbania aegiptica	1.30	9.98	56	0.535
Macroptilium atropurpureum	9.10	66.64	60	0.108
Glycine wightii	2.35	19.20	95	0.205
Stylosanthes guianensis	3.50	12.70	350	0.055
CD at 5%	7.59	53.24	65	2.905

(Source : Thomas and Shantaram, 1984)

Green manure application was found to increase population of specific groups of microorganisms. However, with *M. invisa* a reduction in the populations of bacteria and the number of nitrogen fixing microorganisms was evident. Comparatively *Pueraria* green manure application resulted in the maximum increase in the population of the different groups of microorganisms. Significant increase in the enzymatic activities due to green manure application was also noticed. The response in terms of enzymatic activities was comparatively low with the incorporation of *M.invisa*. Maximum increase in dehydrogenase activity was evident with *Pueraria* treated coconut while with *Calopogonium,* phosphatase and urease activities increased considerably. The green manuring increased both the intensity of mycorrhizal infection in coconut roots and the number of extrametrical chlamydospores in the basin soil. The basins cropped with *Calopogonium* recorded the highest number of spores, whereas root infection was more in Pueraria treatment.

A field experiment conducted in a coconut plantation in an acidic laterite soil type revealed feasibility of substituting up to 50 % of fertilizer nitrogen with nitrogen contributed by leguminous green manures. Glyricidia, a fast growing leguminous tree crop, has been particularly found suitable for growing in littoral sandy soils which can contribute large quantities of nitrogen rich biomass. In recent years, the cultivation of cowpea in the basins of coconut has also shown to be a viable alternative crop for the green manures that can be easily cultivated. It has also been observed to increase the yield of the nuts besides decreasing the root (wilt) disease index of the palms (Maheswarappa *et al,* 2003).

6. Biofertilizers

Biofertilizers are carrier-based preparations containing beneficial microorganisms in a viable state intended for seed or soil application and designed to improve soil fertility and help plant growth by increasing the number and biological activity of desired microorganisms in the root environment. Function-specific microbial groups such as nitrogen-fixers, phosphate solubilizers, plant growth promoting rhizobacteria (PGPR) and mycorrhizae are used as biofertilizers and are one of the key components of bio inputs for organic farming. These groups of microorganisms are responsible for nitrogen fixation, phosphate solubilization/phosphorus mobilization and production of plant growth promoting substances.

The most widely used biofertilizer is *Rhizobium*, which colonizes the roots of specific legumes to form tumour like growth called root nodules. It is these nodules that act as factories of ammonia production. The *Rhizobium*-legume association can fix up to 100-300 kg N/ha. The range of nitrogen fixed per hectare per year by different legumes is 100-150 kg for clover, 80-85 kg for cowpea, 100-300 kg for alfalfa, 240-320 kg for faba bean, 90 - 100 kg for lentil, 150-200 kg for lupins, 50 - 60 kg for groundnut, 60 - 80 kg for soybean, 50 - 55 kg for mungbean and 100-400 kg for pasture legumes.

Though *Rhizobium* directly does not benefit coconut crop, enhancing the soil fertility employing *Rhizobium* sp. in conjunction with green manure crops like *Puereria phaseoloides, Mimosa invisa* and *Calapogonium mucunoides* supplementing 187 to 196 g N per coconut basin in laterite soils and 102 to 153 g N per coconut basin in sandy soils have also been reported.

Stem nodulating legumes such as *Sesbania rostrata, Aeschynomene* sp. and *Neptunia oleracea* have also become popular in improving the soil fertility. The N-fixing bacteria associated with such stem nodulating legumes belong to *Azorhizobium* and fast growing species of *Rhizobium*. The N-accumulating potential of stem nodulating legumes under flooded conditions ranges from 40 - 200 kg N ha^{-1}. The possibility of growing *Sesbania* as an alley crop in coconut gardens is worth exploring.

Azospirillum is also a diazotroph which colonize the root zones and fix nitrogen in loose association with plants. It is an associative microaerophilic organism living in association with diverse groups of plants including coconut. It consists of five species namely *A. brasilense, A. lipoferum, A. amazonense, A. halopreference* and *A. irkense,* out of which first three have been reported from coconut . The principal mechanism by which the bacterium enhances the crop productivity includes nitrogen fixation, production of plant growth promoting substances and antibacterial/antifungal substances. Inoculation with *Azospirillum* results in enhanced assimilation of mineral nutrients (N, P, K, Rb, Fe) and water and offers resistance to pathogens. The crops, which respond to *Azospirillum* inoculation, are coconut, maize, barley, oats, sorghum, pearl millet and forage crops. Inoculation of *Azospirillum brasilense* to coconut seedlings grown in polybags induce profuse growth of root biomass suggesting the use of biofertilizers as a viable option to take the advantage of microorganisms in producing healthy coconut seedlings.

The root regions of coconut palm are inhabited by a number of free living and associative symbiotic nitrogen-fixing bacteria having nitrogenase activity, such as, *Azospirillum lipoferum, Azospirillum brasilense, Bacillus* spp., *Burkholderia* spp., *Azoarcus* spp. and *Arthrobacter* spp. (Thomas *et al.,* 2001). A new bacterium *Herbaspirillum frisingense,* taxonomically closely related to *Azospirillum*, has also been isolated from coconut.

Some of these are capable of fixing nitrogen even in the presence of nitrogen fertilizer. These organisms may have additive or synergistic effects on plant growth and health if they function in concert in the rhizosphere of coconut palms.

The microbial inoculants are prepared by formulating living cells of beneficial microorganisms in suitable carriers. The carrier material prepared using the mixture of coir dust + soil + FYM (1:1:1 ratio) is highly suitable for production of biofertilizer of

Beijerinckia indica. For formulating nitrogen fixing *Azospirillum brasilense* and phosphate solubilizing *Bacillus* sp. into bio-inoculants/biofertilizers, sterilized vermicompost is used as carrier material. The cell count at the time of preparation is maintained at a minimum of $1x10^7$ for *Azospirillum brasilense* and $1x10^8$ for *Bacillus* sp. as per Bureau of Indian Standards (BIS) specifications. Utilization of vermicompost produced from coconut leaves results in the production of high quality biofertilizers with more than 10^8 cfu of bacteria per gram of the carrier material. The recommended dose of biofertilizers for coconut is 100g of carrier based inoculant per palm. The biofertilizer is to be applied in the coconut basin, twice in a year (pre-monsoon and post-monsoon), by mixing with top soil followed by application of organic amendments.

Organic amendments are added to soil and are vital to organic farming. They bring about changes in rhizosphere microflora, which favour the growth of specific microorganisms, thus leading to better plant growth and crop yield. Organic amendments like cow dung increase VA-mycorrhizal colonization as well as the population of phosphate solubilizing bacteria in the root zone of coconut palms. However, organic amendments along with microbial inoculation elicits a greater level of plant growth response. Organic amendments such as vermicompost, coir pith compost, farm yard manure, neem cake, green manures etc. can be combined with microbial inoculants. For additive effects, the compost prepared from coir-pith and other coconut wastes can be enriched with nitrogen-fixing bacteria like *Beijerinckia indica* and also phosphate-solubilizing bacteria, for application in coconut basins. While applying biofertilizers, organic amendments such as vermicompost are added @20 kg/coconut palm. Also, the activities and positive effects of these beneficial microorganisms become more tangible in mixed cropping/farming systems in which coconut and other component crops continually add plant residues to the soil which undergo organic recycling.

Biofertilizers/beneficial microbial inoculants improve crop stand by producing and secreting plant growth promoting substances (phytohormones) such as auxins, gibberellins, cytokinins; by stimulating root metabolic activities using bacterial surface components; by stimulation of phytoalexins in roots; by phosphate solubilization, by reducing the soil pH by production of organic acids or other acidic substances; and/or by supplying biologically fixed nitrogen. Consequently, germination, root development, mineral nutrition and water utilization are improved. PGPRs also influence plant growth by indirect mechanisms such as suppression of bacterial, fungal and nematode pathogens by the production of various metabolites, by induced systemic resistance and/or by competing with the pathogen for nutrients or for colonization space. The diazotrophs convert atmospheric nitrogen to plant usable form and can provide up to 200 kg N/ha/crop. *Azospirillum* can fix upto 40 kg N/ha/crop. Microbial combinations work well for plant growth enhancement. Additive growth benefits can be obtained by inoculating a plant growth-promoting bacterium in combination with phosphate-solubilizing bacterium and associative nitrogen-fixing bacterium.

The inoculation of associative diazotrophs such as *Azospirillum, Arthrobacter, Azoarcus, Herbaspirillum, Bacillus, Burkholderia* and *Pseudomonas* enhance growth and vigour of polybag raised coconut seedlings. These bioinoculants effectively enhance root biomass and branching of the secondary roots of the coconut seedlings. Inoculation of PGPRs *Brevibacillus brevis* and *Bacillus coagulans* result in production of coconut seedlings with high seedling quality index (Gupta *et al.,* 2006). Coconut seedlings grown in polybags respond well to inoculation of biofertilizers of *Azospirillum brasilense*. The response is most conspicuous in the root biomass of coconut seedlings which is reflected in the number of roots, branching of roots and root dry weight. While raising coconut seedlings in coir dust-soil mixture, *Beijerinckia indica* is a promising microbial inoculant which enhances the growth and performance of seedlings. Apart from production of quality coconut seedlings, biofertilizers also improve the economic traits of coconut such as yield. . A field experiment conducted for a period of five years on the role of biofertilizers in the integrated nutrient management of coconut palms revealed the effectiveness of biofertilizers of *Beijerinckia indica* and phosphate solubilizing bacteria (*Bacillus* sp.) to enhance the productivity of adult coconut palms. The application of *Bacillus* sp. and *Azoarcus* sp. as biofertilizer in the basins of adult coconut palms of Laccadive ordinary variety resulted in significant increase in nut as well as copra yield.

7. Coir pith

Coir pith is a lignocellulosic waste biomass which accumulates around coir processing factories as a waste material. Though coir pith has a number of beneficial properties, its direct utilization as manure is not advisable as it contains large amounts of lignin and phytotoxic polyphenols and less of nitrogen. Technologies are available for bioconversion of coir pith having a C:N ratio of 100:1 to acceptable manure with the help of biopolymer degrading microorganisms. Studies conducted at CPCRI resulted in the isolation of efficient strains of fungi with high lignocellulose degradation capabilities, from naturally decomposing coconut wastes. *Marasmiellus troyanus,* an efficient producer of ligninolytic and cellulolytic enzymes isolated from decomposing coconut waste, and *Trichoderma* inoculations were effective in production of quality compost from coir pith. Large scale composting is standardized with amendment of lime and rock phosphate at 0.5 % level each and Glyricidia leaves (10%) and fungal inoculation at 0.2 % level (Thomas *et al.*, 2001). The raw coir pith with a C:N ratio of 100 % is converted to an acceptable manure with a C:N ratio of 17:1 with a period of 40-45 days.

Coir pith can also be composted using white rot fungus, *Pleurotus sajor caju/ Pleurotus platypus*. For composting one tonne of coir pith, 5kg urea and 5 bottles of *Pleurotus* spawn are required. The technique involves spreading of a layer of 100 kg coir pith in shaded place, and followed by sprinkling of a bottle of spawn. The spawn is covered by a layer of 100 kg coir pith and one kg urea is spread over it. Similarly five layers are prepared and the heap should be kept moist by watering within 30-40 days, the waste would turn into organic manure. Coir pith compost can be enrichment with N_2 fixing bacteria and phosphate solubilisers for production of good quality compost with better manurial value.

Efforts have also been made to prepare vermicompost from coir pith using the local strain of *Eudrilus* sp. Coir pith alone is not able to support growth of earthworms. Coir pith treated with lime and rock phosphate @0.5 % each and incubated for 3 weeks has to be mixed with cow dung @ 10% and fresh vermicompost @ 10%. This mixture is layered with uncut coconut leaves @ 20% to facilitate aeration in the bed. The earthworm *Eudrilus* sp. is introduced at the rate of 1000/ tonne of organic materials and the bed is mulched and protected from direct sunlight. Moisture is maintained at 50 % by regular irrigation. Earthworms from burrows in bed and vermicastings appear as surface casts. A granular vermicompost with 1.2 % nitrogen and 16.7:1 C:N ratio can be obtained in 2 months (Thomas *et al.* 2001).

8. Coconut wastes as mulch in plantations

Coconut leaves, husk and coir pith could be utilized as mulches to reduce loss of soil moisture and create conditions for proper root growth and proliferation of soil flora and fauna. Decomposition of the mulches after a period of time result in enrichment of soil organic matter pool. Burial of husk in trenches in between rows of palms is highly effective for moisture conservation in coconut gardens. Husk burying is done at the beginning of monsoon in linear trenches of 1.5 to 2.0 m wide and about 0.3 to 0.5 m deep between rows of palms with concave side of husk facing upwards. Each layer is covered with soil. The husks are also used as surface mulch around base of the palms. Husks in a single layer are placed with convex side up around the palm upto a radius of 2 m from the base. Coconut husks are also important sources of potash which becomes available to palms over a period of time.

9. Conclusion

There is worldwide awareness for adopting organic agriculture due to the deterioration of soil health and increased environmental pollution caused by indiscriminate use of chemicals and off farm inputs. The basic concept of organic farming involves the use of bioinputs or on farm organic sources to meet the nutrient requirement of crops dispensing with the use of chemicals and off farm inputs. Enormous potential exist for organic farming in coconut due to the availability of large quantities of waste biomass in coconut plantation itself. Bio inputs generated via adoption of appropriate techniques for recycling of waste biomass, effective utilization of nitrogen fixing potential of legumes and biofertilizers can go a long way to achieve sustainable production in coconut in an eco-friendly manner. Integrated farming with diversity of crops and animal enterprises as well as on farm recycling in coconut holdings will provide generation of important bioinputs for managing soil fertility to obtain consistantly high production of coconut without the use of chemical inputs.

The effectiveness of organic manuring to enhance nutrient content of soil and soil physical conditions was demonstrated in littoral sandy soil with different organic bio inputs viz. Forest leaves, coconut & sheddings, cattle manure and coir pith. The incorporation of organics significantly enhanced the content of organic carbon available N, Fe, Mn and exchangeable Ca and Mg in littoral sandy soil. Organic amendment was also effective to increase water holding capacity and decrease the bulk density of soil. Organic manures also had profound influence on the establishment, growth, flowering of coconut seedlings as revealed in a 10 year study. Application of organic inputs like coconut pith, forest leaves and cattle manure enormously improved the growth and flowering in coconut. In the mixed farming system, there was a build up of organic carbon, N, P, K and Fe status in soil and foliar nutrient levels of palm as a result of application of bio inputs by way of recycling of wastes in the system.

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Ecological interaction of soil microorganisms and plant allelochemicals in coconut based cropping ecosystem

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Introduction

Soil is one of the major governing factors for cultivation of any crop. The formation of the soil is a long drawn dynamic process, which bestows the soil with its unique physical, chemical and biological properties. Naturally growing plants, as well as cultivated crops besides the soil microbes produce certain organic compounds, which influence the basic quality of the soil. This results in different kinds of interactions taking place in the soil milieu.

Allelopathy is one such kind of soil ecological interaction described by Molisch (1937) denoting "the beneficial and detrimental chemical interactions among plant organisms and microorganisms". The International Allelopathy Society in 1996 had redefined allelopathy as to "any process involving secondary metabolites produced by plants, bacteria, viruses and fungi that influence the growth and development of agricultural and biological systems". This interaction takes place due to the production of organic compounds termed *allelochemicals* by the plants and microorganisms. About 10,000 allelochemicals have been already identified and another 4,00,000 estimated to exist (Narwal and Tauro, 1994). Researchers recognize 14 classes of allelochemicals including phenolic acids, coumarins, flavanoids, tripenoids, alkaloids and sulphides (Rice, 1984).

A large number of studies have shown that there is some sort of allelopathic interactions taking place between plants, especially trees because of production of allelochemicals (Table 1). Though allelochemicals are reported to be present in practically all plant tissues, including leaves, flowers, fruits, stems, roots, rhizomes, and seeds; for allelopathy to be an ecologically relevant mechanism in influencing growth of plants in field situations, allelochemicals must accumulate and persist at phytotoxic levels and come in contact with the target plant. However, after entering soil, the allelochemicals undergo changes in concentrations and forms due to processes like retention (sorption), transport and transformation. The transformation of the allelochemicals is usually mediated by the soil microorganisms in addition to chemical and physical reactions. The type of allelochemical, microflora and substrate conditions each play an important role in determining the persistence of allelochemicals in soils (Inderjit, 2005).

2. How allelopathic interactions occur

Allelopathic interactions in any cropping system may result from allelochemicals generated from foliage leaching, root exudates, volatiles from the main and component crops. Soils microorganisms also play an important role in the alleopathic interactions.

Table 1. Examples of some of the tree/plantation crop species showing allelopathic properties (Rizvi *et al.,* 1999)

Tree species	Effect on
Tamarindus indica	Barnyard grass, white clover, lettuce and radish
Mangifera indicia	Wheat, radish, okra. mustard
Coconut	Mango, Jackfruit Black pepper, nutmeg soil microorganisms
Coffea Arabica	Spearmint, basil, sage and oregano
Camelia sinensis	*Tea (autotoxicity)*
Casuarina equisetifolia	Cowpea, sorghum, sunflower
Eucalyptus tereticornis	Cowpea, sorghum, sunflower, potato
Gliricida sepium	Maize/rice seedlings, tropical grasses
Grevillea robusta	*Grevillea* seedlings
Leucaena leucocephala	Maize/rice seedlings cowpea, sorghum, sunflower
Azadirachta indica	Soya bean, paddy, pea, wheat, maize and number of microorganisms
Tectona grandis	Ground nut, chick pea, gingelly, maize

Plant residues fallen from the crops undergo natural microbial decomposition and produces metabolites which may have allelopathic effects on the crops.

a) Leaching

Leaching is the removal of substances from plants by aqueous solutions such as rain, dew, mist and fog. Radioisotope labeling of plant tissue before leaching has shown that large quantities of both inorganic and many classes of organic natural products are leached from plant tissue. Both the quantity and quality of leachable natural products differ greatly with species, physiological age of tissue, stage of plant development, plant health, light, temperature, nutritional conditions, and the intensity and volume of the leaching solution. The secondary compounds released will be influenced by the type of crop being leached. To determine the presence of allelopathic activity, the protocol for leachate preparation should be similar as possible to that prevailing naturally during symptom development.

b) Root exudation

Root exudates represent one of the largest direct inputs of plant chemicals into the rhizosphere environment, and therefore root exudates also likely represent the largest source of allelochemical inputs into the soil environment. These include sugars and simple polysaccharides (such as arabinose, fructose, glucose, maltose, mannose, oligosaccharides), amino acids (such as arginine, asparagine, aspartic, cysteine, cystine, glutamine), organic acids (such as acetic, ascorbic, benzoic, ferulic, malic acids), and phenolic compounds. Some of these compounds, especially the phenolics, influence the growth and development of surrounding plants and soil microorganisms. In addition, higher-molecular-weight compounds such as flavonoids, enzymes, fatty acids, growth regulators, nucleotides, tannins, carbohydrates, steroids, terpenoids, alkaloids, polyacetylenes, and vitamins are released in large quantities as well.

Many factors can affect the quantity and quality of natural products obtained e.g. plant species, plant age or stage of development, temperature, light, nutritional conditions, soil micro-organisms, root supporting medium, soil moisture and root damage. Similarly, exudation in soils can be expected to vary with soil physical and chemical properties. Root exudation usually increases greatly during wilting and root damage. Soil microorganisms modify root-cell permeability and root metabolism and rhizosphere organisms may absorb or excrete qualitatively different natural products than plant roots.

c) Volatilization

Volatilization is the release of natural products into the atmosphere. A variety of plants either secretes or excretes metabolic products into special structures such as trichomes and glands, into intercellular spaces and canals, or onto leaf surfaces. In hot, dry weather, natural products with high vapour pressure are released into the atmosphere where they may be absorbed directly by plants or adsorbed onto soil surface.

d) Soil microorganisms

It is now well known that plant population dynamics may be linked with the development of the below-ground community. The biologically active soil zone where root-root and root-microbe communications occur is named “Rhizosphere” where root exudates play active roles in regulating rhizosphere interactions. Root exudation can regulate the soil microbial community, withstand herbivory, facilitate beneficial symbioses, modify the chemical and physical soil properties and inhibit the growth of competing plant species (Sanon *et al.,* 2009). Soil microorganisms interact with plants in a diversified manner ranging from mobilizing nutrients and enhancing their growth, to inducing diseases. They also produce allelochemicals directly or indirectly through conversion from other compounds. In order to hamper plant growth, allelochemicals must accumulate and persist at phytotoxic levels in the rhizosphere soil. However, after their entry into environment, persistence, availability and biological activities of allelochemicals are influenced by microorganisms. Transformation of allelochemicals by soil microbes may result into the compounds with modified biological properties. Such bio-transformations affect the overall allelopathic capability of the producer plant in a direct manner (Jilani *et al.*, 2008).

Plant residue mulches commonly used in multi-storey cropping systems to protect soil from erosion, conserve moisture and supply nutrients may be the source of allelochemicals that interfere with crop productivity. To improve nitrogen nutrition of crop plants, plant-residue mulches, particularly of nitrogen-fixing species, are commonly used, which in fact may result in allelopathic interference. Mulching and conservation tillage, which leave plant residues on the soil surface or incorporate them into the soil, result in the liberation of large quantities of water soluble and partially water soluble products during residues decomposition. Large quantity of crop residues left annually in the fields results in soil sickness by allelopathic means.

3. Allelopathy studies in coconut

Coconut (*Cocos nucifera* L.) is an important oil seed crop and majority of the farmers cultivating this crop possess land holding lesser than 0.5 ha area. As coconut is a widely spaced crop; therefore it is possible to adopt various farming/ cropping system (Nelliat *et al.,* 1974, Reddy and Biddappa, 2000). A number of annuals of vegetable crops, pulses, fruits and tuber crops perennials like spices and cash crops are being successfully grown in coconut gardens. It was estimated that around 7000 kg of dry leaves, sheaths, spadices/ inflorescences and coconut husk is generated from 1 ha area having 175 coconut palms. During monsoon, tannins, which are potential allelochemicals, ooze out of such crop residues possibly creating plant growth interference (Biddappa *et al.,* 1996). In addition to this, it has been reported that approximately 12 µg/g of phenol is released by root exudates of coconut (Bopaiah *et al.,* 1987) and it is also present in coconut leaf (Dey *et al.,* 2005). Phenolic compounds are secondary metabolites widespread in plants and are leached from green foliage by rainfall and decomposing litter and thus reach the soil underneath the canopy. As allelopathic agents, phenolics from the donor plant affect the performance of target plants, either by inhibiting seed germination, root elongation or plant growth. In forest ecosystems, allelopathic effects of dominant trees on the under-story species and also the under-story species on tree seedlings and other plants in the plant community have been studied. Availability of these allelochemicals in the soil provides an ideal situation for occurrence of allelopathic interactions in coconut based cropping system (John and Nair, 2001). In such conditions, a high density multiple species cropping system including spices, fruits, vegetables and cash crops like vanilla are suggested to be grown as intercrops in coconut garden to improve the economic returns. It is also well studied that rhizosphere of coconut and coconut based cropping systems harbour a variety of beneficial microorganisms (Thomas *et al.*, 1991) which may also be playing an important role in the allelopathic interactions.

3.1 Flow of allelochemicals from coconut canopy

Coconut palms are tall plantation crops with dense crown of leaves mostly grown in coastal, humid regions in India where the average annual rainfall ranges from 1000 to 3000 mm. These leaves intercept a substantial amount of rainfall during the monsoons. The rain water while traversing the leaf area collects different chemicals that are present on the leaf surface and transport them to the soil, particularly near the rhizosphere as throughput, stem flow and drops. Rainfall partitioning studies in coconut carried out at CPCRI has shown that 85-90% of rain passes as through fall from the coconut canopy and more than 50% as stem flow that carry the leachate to the soil.

Analysis of important allelochemicals like the total phenols and sugars were carried out in the coconut based high density multi-species cropping system. Among the crops, coconut leachate carried the maximum phenol concentration of 0.73 µg/ml, and banana the least of 0.07µg/ml. Though we had only the total phenols in our studies, it has already been reported that coconut leaves contain high concentrations of *p-hydroxybenzoic* (Dey *et al.,* 2005), which is one the important autotoxic phenols recorded in many plants. The other important ones are lactic, benzoic, *p-hydroxybenzoic,* vanillic, adipic and succinic (Asao *et al.,* 2004). In the immediate next leachate collection, the phenol concentrations decreased by 70% in the coconut, 50% in clove and 25% in nutmeg. However, the concentrations of total sugars content increased by more than 60% in all the samples. It was clear that, concentrations of both the phenols and sugars were highest in the coconut canopy leachate, followed by clove and then in nutmeg, and the concentration of sugars flowing down was always more compared to phenols. However, it was observed that phenol (Fig. 1) concentration peaked during the October collection while it was opposite in case of sugars (Fig.2).

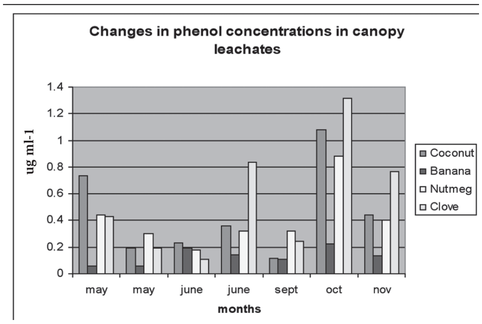


Fig. 1. The flow of total phenol from canopy leachates of coconut, clove and nutmeg during monsoon in coconut based high density multi species cropping system

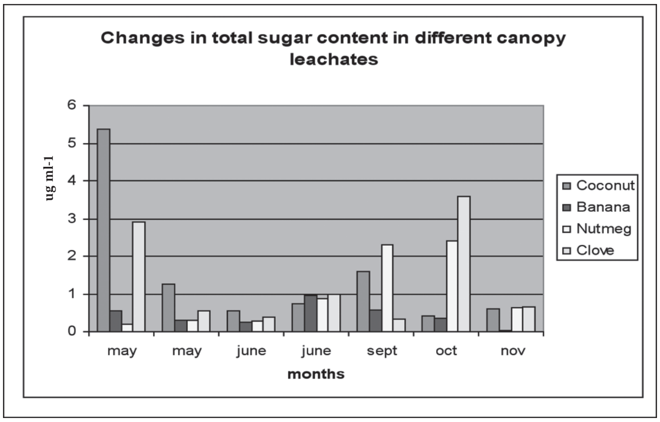


Fig. 2. The flow of total sugars from canopy leachates of coconut, clove and nutmeg during monsoon in coconut based high density multi species cropping system

The flow of these important chemicals depended upon the distribution and amount of precipitation received during the monsoon as well as the physiological status of the crops during that period.

The field collected leachates were characterized for their pH, biochemical and chemical characteristics. The pH of coconut and banana leachates was closer to neutral and others were in acidic region. It is also seen that coconut leachates had highest total sugars and potassium content when compared to others.

3.2 Root exudates from coconut palm

The roots of coconut palm spread laterally to large distance and a healthy and normal coconut palm has 4000 to 7000 roots which exude large volume of allelochemicals. The nature and the amount of these chemicals depend upon the age and stage of the pal, and the environmental conditions in which it is growing. The exudates play an important role in neutralizing the soil pH and altering the microclimate of the rhizosphere through the liberation of water and carbon dioxide. A method to of collection of root exudates of coconut has been developed at CPCRI (Ramadasan *et al.,* 1967). Later Bopaiah and co-workers (1987) studied the biochemical characters of root exudates from coconut. Intact coconut roots were sequentially surface sterilized in 80% ethanol (30 sec), 0.1% mercuric chloride (3 min) followed by washing with sterile water, 0.003% streptomycin sulphate (1min) and 0.2% copper oxychloride(1min). The roots are introduced aseptically into the sterilized test tubes (150x22mm) containing Whatman No 1 filter paper strip and plugged with cotton and the tubes were then buried in soil. After five days, the roots are cut at the top of the test tube. The filter paper strips are checked for microbial contamination and only those showing negative features can be used for the extraction of root exudates.

The filter paper strips are extracted with 80% ethanol and fractioned into sugars, amino acids and organic acids by ion exchange chromatography using Dowex 1 and 50H+. The results indictaed that coconut root exudates contained 993 ± 174 µg/g total sugars and 226 ± 43 µg/g reducing sugars. The sugars present in the root exudates were raffinose, lactose, glucose and fructose. The total amino acids content was 18.6 ± 3.9 µg/g, which included serine/glycine, glutamine, alanine, phenyl alanine and isoleucine/leucine. The exudate also contained 11.6 ± 3 µg/g phenols. Only succinic acid was found in the organic fraction of the root exudates.

3.3 *In vitro* studies

Preparation of leachates

The extraction procedure for the leachates from the root and leaf tissues of adult coconut palm (WCT variety) was standardized using washing method (Inderjit and Dakshini, 1998). To get the concentration of phenols and sugars equivalent to natural flow of these allelochemicals as in the field conditions, it required soaking the tissues in distilled (non-ionic water) for 72 hours. Leaves from young non bearing ; adult and yielding coconut palm of West Coast Tall var. were washed with deionized water and then air-dried for 48 hours at room temperature (30°C). About 200 g of these leaves were taken (70% green and 30% senescent) and soaked in 1000 ml of deionized water for 72 hours. Similarly, fresh growing roots from the same palms were collected, and their leachates prepared. This gave 1:5 concentrations of leaf and root leachates. The physical, chemical and biochemical characters of coconut leachates from adult coconut palm of WCT variety were also analysed and the results are given in Table 2.

Table 2. Some of the chemical and biochemical properties of leachates of coconut palm of WCT variety (in ppm)

Properties Leachates	pH	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn	Total sugars	Total phenols
Leaf	4.5-5.0	1.7	7.5	43.8	42.4	3.8	0.2	2.1	Trace	1.2	124.8	13.4
Root	5.0-5.5	1.7	11.2	27.0	17.0	3.5	0.3	0.1	0.1	0.1	413.5	56.1

(Gopal and Gupta, 2005)

Laboratory bioassay

Laboratory bioassay was performed in Petri dishes to compare the seedling vigour index of cowpea seeds (test crop for dicot plants) and paddy seeds (test crop for monocrop) at 1:5, 1:10, 1:15 and 1:20 concentrations of coconut leaf and root leachates. Bottom plates of Petri dish were layered with Whatman No. 1 filter paper and then were sterilized in an autoclave. Ten cowpea /paddy seeds (uniform size and weight) were washed once with deionized then with sterilized water and placed on the filter paper of sterilized dishes. Ten replications per treatment were maintained. Irrigation with 5 ml of leachates/ deionised water was given twice a day. Once the seeds germinated and started growing, the lids of the dishes were removed. This was followed by irrigation at three times a day. After 10 days, the length of the individual seedlings was measured and their fresh and dry weights were recorded. The vigour index of the seedlings was calculated by multiplying germination% with seedling length (Abdul Baki and Anderson, 1973). The results are given in Table 3.

Table 3. Effect of coconut leaf and root leachates at different concentration on vigour index of cow pea seedlings (Gopal and Gupta, 2005)

Leaf Leachate	Vigour Index	Root Leachate	Vigour Index
1:5	4.0	1:5	4.6
1:10	4.9	1:10	5.0
1:15	5.4	1:15	7.2
1:20	6.1	1:20	7.6
Control	7.8	Control	7.8

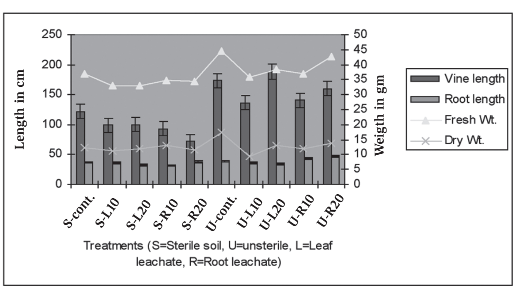
The results of laboratory bioassay showed that leaf leachate from young coconut palm increased the cowpea seedling vigour index (9.8 to 10.6) as compared to control (7.8). However, leaf and root leachates from adult coconut palm at 1:5 and 1:10 concentrations produced a significant suppressive effect on seedling vigour. On paddt seeds, the 1:5 concentration of the coconut leaf leachate significantly suppressed the seedling vigour index whereas, the 1:10, 1:15 and 1:20 concentrations were on par with that of water.

Based on these results soil microcosm studies in green house were conducted with 1:10 and 1:20 concentrations, as the possibility of 1:5 concentration reaching the soil was considered to be remote

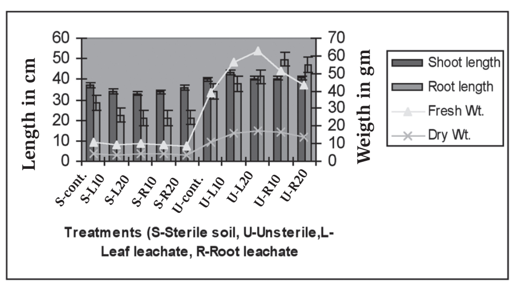
3.4 Soil microcosm studies

The effect of coconut leachates on black pepper and nutmeg was conducted in soil microcosm experiment in green house. Bulk soil was collected from coconut garden where coconut palms of WCT variety were growing. Ten kilo of sieved soil was packed in clean perforated black poly-bags of dimensions 22 x 12.5 inches. One lot of the bulk soil was sterilized by moist heat autoclaving (Wolf and Skipper, 1994) and filled in similar poly-bags after ensuring that the soil was totally free of microorganisms. Black pepper (*Piper nigrum*) variety Panniyur-1 cuttings of 3 months age and nutmeg (*Myristica fragrans*) grafts same age of Viswasree variety was then replanted into the above poly-bags. Before replanting, the plant roots were thoroughly washed with deionised water to remove the soil particles. Pepper cuttings were planted with the support of bamboo poles. Both pepper and nutmeg were allowed to establish in the bulk soils (non-sterile and sterilized) taken from coconut garden. Five treatments i.e. coconut leaf and root leachates at 1:10 and 1:20 concentrations and water were used for irrigating pepper and nutmeg in both categories of soil. The experiment was set up in Completely Randomized Design. Ten replications per treatment were maintained for each plant. Application of leachates (200-250ml/plant) extracted in plain as well as sterile water was carried out approximately equal to the number of rainy days received in a year in the locality. All other times plain/sterilized water was added. Plant growth parameters of both crops were recorded immediately after the pepper and nutmeg established properly in the bulk soil. At the end of the study, the vine/shoot and root length and the total fresh and dry weights were recorded. Soil microflora viz. bacteria, fungi, actinomycetes, free living N_2-fixers, phosphate solubilizers and cellulose degraders were analyzed from each treatment as and when the plant growth observations were recorded. Standard microbial media, serial dilution and spread plate methods were used for the enumeration

The effect of coconut leachates on growth parameters of pepper is given in Fig 1(a). In sterilized soil the coconut root leachates reduced the growth of vine, but the total fresh and dry weights remained on par in all the treatments. In non-sterile soil, the 1:20 concentration of leaf leachate resulted in maximum growth of pepper vine (188cm) whereas, the root leachates at both the concentrations significantly enhanced the root length of pepper (43 and 46 cm respectively). The initial rhizosphere population of different microbial communities in pepper was significantly less in the sterile soil when compared to non-sterile soil except in case of N_2-fixers which was on par in all the treatments in both the categories of soil (data not shown). The final adjusted data showed similar trends (Table 1). Coconut root leachate at 1:20 concentration significantly enhanced the population of most of rhizosphere microbial communities in non-sterile soil when compared to other treatments.



a



b

Fig.3. Effect of coconut leaf and root leachates on growth parameters of (a) black pepper and (b) nutmeg

Application of coconut leachates killed the nutmeg grafts after 6 to 7 months in sterilized soil; however the plants survived in control treatment (sterile water) and continued to grow at slower rate. In non-sterile soil, the leaf leachate at 1: 20 concentration appeared to improve the nutmeg growth parameters. The root leachates as in the case of pepper, significantly improved the root growth of the nutmeg. The initial microbial numbers in the rhizosphere was significantly higher in non-sterile soil as compared to the sterilized soil. The adjusted and transformed data shows that the bacterial population was on par in all the treatments in both the categories of soil. In sterilized soil the control treatment (sterile water) had significantly higher counts of actinomycetes, free living N_2 fixers, phosphate solubilizers and very low counts of fungi and cellulose degraders when compared to leachate treatments in same soil category. In the non-sterile soil, again the coconut root leachate at 1:20 concentration significantly boosted the rhizosphere microflora of nutmeg (Table 4).

The result suggests that rhizosphere microflora of pepper is able to overcome the inhibitory allelopathic effect of coconut leachates as evidenced by its growth in sterilized and unsterile bulk soil. The inability of nutmeg to grow in sterile bulk soil on application of leachates indicates the failure of its rhizosphere microflora to prevail over the inhibitory effect of coconut leachates, whereas growth in unsterile soil implies that bulk soil taken from coconut garden already contains microflora that can detoxify the suppressive nature of coconut leachates and support the growth of nutmeg (Gopal and Gupta, 2005).

Rainfall partitioning studies in coconut has shown that 85-90% of rain passes as through fall from the coconut canopy and more than 50% as stem flow that carry the leachates to

Table 4: Effect of coconut leachates on rhizosphere microflora of pepper and nutmeg (adjusted and transformed data)

	Pepper						Nutmeg					
Treatments	Bacteria ($nX10^3$)	Fungi ($nX10^2$)	Actino. ($nX10^2$)	N_2-fixer ($nX10^3$)	Phos.sol ($nX10^2$)	Cell. deg ($nX10^2$)	Bacteria ($nX10^3$)	Fungi ($nX10^2$)	Actino. ($nX10^2$)	N_2-fixer ($nX10^3$)	Phos.sol ($nX10^2$)	Cell. deg ($nX10^2$)
S-Cont	669.0	77.0	85.0	399.0	60.7	34.0	485.0	33.0	83.0	120.0	237.0	74.0
S-L 10	480.0	82.0	92.0	244.0	9.0	34.0	488.0	64.0	53.0	14.0	5.0	155.0
S-L 20	467.0	95.0	91.0	287.0	12.0	26.0	398.0	38.0	37.0	16.0	10.0	177.0
S-R 10	463.0	61.0	75.0	200.0	12.0	37.0	473.0	48.0	40.0	19.0	8.0	157.0
S-R 20	422.0	74.0	62.0	273.0	15.0	31.4	428.0	39.0	41.0	21.0	10.0	180.0
U-Cont	1010.0	62.0	54.0	248.0	40.0	59.0	335.0	139.0	236.0	308.0	246.0	280.0
U-L 10	1207.0	96.0	67.0	598.0	22.0	48.0	504.0	147.0	260.0	234.0	138.0	284.0
U-L 20	1570.0	107.0	76.0	585.0	22.0	55.0	396.0	187.0	262.0	313.0	164.0	307.0
U-R 10	1200.0	99.0	97.0	533.0	22.0	45.0	393.0	140.0	233.0	311.0	122.0	245.0
U-R 20	1542.0	113.0	109.0	691.0	28.0	64.0	490.0	237.0	228.0	318.0	204.0	311.0
CD (P = 0.05)	119.0	12.00	18.0	120.0	4.0	4.0	———	15.0	7.0	11.0	14.0	27.0

the soil. The radial spread of coconut roots to a distance of more than 2 to 3m aid the translocation of the root leachates to more ground area. Pepper is usually planted in basin area of coconut and is allowed to twirl around the trunk whereas nutmeg is grown in the interspaces. The studies showed that both pepper and nutmeg grow well in non-sterile bulk soil taken from coconut garden when irrigated with coconut leaf and root leachates. It could be deduced that the presence of nutrients, organic acids and proteins in leachates act as substrates, which is efficiently used by the microflora in non-sterile bulk soil than the rhizosphere microflora of pepper in sterile soil. Increase in numbers of N_2-fixers, phosphate solubilizers and cellulose degraders probably improve the soil nutrient pool and enhance the plant growth. Though the root exudates contain very high phenol which are attributed with allelochemical property, soil microbes capable of overcoming them must be resident in the bulk soil as well as native inhabitant in pepper rhizosphere. Ages of cultivation of pepper in the coconut basin would have resulted in almost similar microbial make up as that of coconut which has adapted well to the leachates. In nutmeg, death of plants in response to coconut and leaf leachates when grown in sterilized soil and significant suppression of rhizosphere microflora barring the bacteria suggests that, the native rhizosphere microbes of nutmeg are not up to the stress put by the leachates. It is seen that the nutmeg is able to grow in sterile soil on irrigation with sterile water, the rhizosphere microflora (N_2-fixers, phosphate solubilizers, etc) also showing better activity and supporting the growth of crop. The cellulose degraders are recorded in large numbers in the leachate applied sterile soil, possibly consuming the detritus added because of the death of the grafts. In the non-sterile soil we see that the growth of nutmeg is enhanced in presence of coconut leachates, implying that the bulk soil contains the microflora that are capable of utilizing the leachates, multiply and improve the growth of the plant.

3.5 *In vitro* agar cup assay

Agar media selected for the different groups of microorganisms were poured to the thickness of 2 cm in sterile petriplates and then seeded with microorganisms. The seeded plates were allowed to dry. Then using a sterilized 9 mm cork borer, four holes of 9 mm diameter were made in each plate. In the first, second and third wells, 150 µl of leachates of 5, 10 and 20% concentrations were added, respectively, Deionized water was added to the fourth well. One set of experiment was conducted with non-sterile and another set with filter sterilized leachates. All the treatments were replicated five times. The plates were incubated at 30°C for 5 days, thereafter, the hallow zone of inhibition (mm) around the cup was recorded.

The pH value of 20% root leachate was near to neutral pH than the 20% leaf leachate. Root leachate had more phenols (70%), reducing sugars (74%) and total sugars (70%), respectively, than leaf leachate.

3.6 Non-sterile leachates

The diazotrophs were found sensitive to both root and leaf leachates, with the latter being more allelopathic (Table 4). Increase in concentration of leachates proved to be more inhibitory to growth of microorganisms. Among the five diazotrophs tested, *Herbaspirillum frisingense* was suppressed most and the inhibition zone was greater at 20% concentration. However, *Burkholderia* sp. proved to be very resistant and was least inhibited by both leachates. The growth of *Azoarcus* sp., *Azospirillum amazonense* and *A. brasilense* with leachates was better than *Herbaspirillum* sp. The leachates were not harmful to phosphate solubilizer and PGPRs (*Pseudomonas fluorescens*, *Brevibacillus brevis* and *Pseudomonas* sp.), rather, there was accumulation of bacterial colonies around the leachate wells. At 5 and 10% concentration of both root and leaf leachates, the bump of the colonies (overgrowth) was more than that at 20% concentration well and control well. However amongst the PGPRs, *Bacillus coagulans* proved sensitive (as its growth was inhibited by both leachates).

3.7 Filter sterilized leachates

The sterilized root and leaf leachates were more suppressive than non-sterile. The response pattern of the diazotrophs was similar, i.e. greater inhibition. Among the diazotrophs tested, *Herbaspirillum frisingense* was most sensitive to sterilized root leachate as well as to leaf leachate at all test concentrations. The sterilized leaf leachate suppressed the growth more prominently than root leachate, the 20% concentrations of both leachates proved inhibitory. *Azospirillum amazonense* was least sensitive to sterilized root leachate and *Burkholderia* towards sterilized leaf leachate. The phosphate solubilizing *Bacillus* sp. grew in 5% sterilized root leachate and 5 and 10% sterilized leaf leachate, while got suppressed at 20% concentration of both leachates. Among the PGPRs, *Pseudomonas* sp., *P. fluorescens* and *Brevibacillus brevis* grew profusely in sterilized root and leaf leachates, particularly at 10% concentration; whereas *Bacillus coagulans* was suppressed by both leachates (Table 5).

The *in vitro* experiments showed that coconut root and leaf leachates had both positive and negative allelopathic effects on beneficial microorganisms isolated from coconut rhizosphere (Gopal *et al.*, 2006). The non-sterile leachates exhibited less suppression than sterilized leachate, because the resident microflora present on the phylloplane and rhizoplane adapted to the allelochemicals released by the leaf and root tissues may have already diminished the effective concentration of the allelochemicals by utilizing them for their growth. Sensitivity of diazotrophs to leaf leachates is more, probably due to presence of phenols and nitrogen in both leachates. Though the phenol content is high in roots, but

Table 5. Effect of leaf and root leachates on growth of beneficial microorganisms isolated from coconut rhizosphere

Microorganisms	Control	Non-sterile leachate (%)						Filter-sterilized leachate (%)					
		Leaf			Root			Leaf			Root		
		5	10	20	5	10	20	5	10	20	5	10	20
Diazotrophs													
Azoarcus sp.	+	1.5	1.5	2.8	0.5	1.1	1.8	2.1	3.6	4.1	0.9	1.9	2.1
Azospirillum amazonense	+	1.7	2.1	2.9	0.8	1.0	1.2	1.9	2.6	3.2	1.2	1.6	2.1
Azospirillum brasilense	+	1.2	1.7	2.1	0.3	0.9	1.1	1.8	2.2	3.2	0.5	1.2	1.7
Burkholderia sp.	+	1.1	1.2	1.8	0.5	0.8	1.1	1.7	2.3	2.8	1.1	1.7	2.3
Herbaspirillum frisingense	+	3.1	4.8	6.3	3.1	4.3	4.8	3.9	5.1	7.2	4.3	4.9	5.6
Phosphate solubilizer													
Bacillus sp.	+	+	+	+	+	+ +	+ +	+	+	0.2	+	0.5	1.1
Plant growth promoting rhizobacteria													
Bacillus coagulans	+	0.8	1.2	1.9	0.5	0.7	0.9	1.5	1.9	2.4	0.9	1.2	2.1
Brevibacillus brevis	+	+	+	+	+	+	+ +	+	+	+	+	+ +	+
Pseudomonas fluorescens	+	+	+ +	+	+	+	+ +	+	+	+	+	+ +	+
Pseudomonas sp.	+	+	+ +	+	+	+	+ +	+	+	+	+	+ +	0.3

+ and + + indicates the degree of enhanced growth of microbial colonies around the wells in agar cup containing the leachates as compared to growth around the well containing water. The other numerical data indicates the radial hallow zone area in mm around the wells where no growth of the microorganisms takes place due to the inhibitory effect of the leachates present in the wells in agar cup, when compared to growth around the well containing water.

(Gopal *el al.*, 2006)

its suppression effect was low, presumably owing to presence of high amount of sugars, which offset the effect of phenols by providing growth nutrients to the organisms. Though the leaves are rich in sugars than phenols, but, the presence of 62.9 µg of highly allelopathic 4-hydroxybenzoic acid per g dry coconut leaves, a known anti bacterial component supports our observation of suppressive nature of coconut leaf leachate. Kapusta and Rice (1976) reported that seven phenolic acids (identified as allelopathic agents), inhibited the growth of three free living nitrogen fixers viz., *Azotobacter, Enterobacter* and *Clostridium*. The effects of root extracts from coconut on certain bacterial species are known (Bopaiah, 1998). The phosphate solubilization and growth promoting abilities of *Bacillus* spp. and *Pseudomonas* spp. overcome the inhibitory effect of leachates by their catabolic property of using phenols for their growth (Blum, 2004). Moreover, native *Bacillus* spp. and *Pseudomonas* spp. are capable of utilizing the polyphenols from coconut (Uma *et al*, 1994). Our observation of positive influence of coconut leachates on phosphate solubilizers and PGPRs agrees with Rajappan *et al.* (1977). They had found *in vitro* studies that dried leaf extract of *Ipomoea* spp. inhibited the growth of rice sheath rot pathogen, while beneficial microbes (*Bacillus subtilis, Pseudomonas fluorescens* and *Trichoderma viride*) were not affected.

This preliminary *in vitro* study establishes the differential response of beneficial microorganisms to the allelochemicals present in coconut root and leaf leachates. Similar reports of differential response to the allelochemicals released from decomposition of leaves stimulating the growth of some soil fungi and bacteria and inhibiting the growth of other types of microorganisms had been reported. Identification of the allelochemical that stimulates the activity of the beneficial microorganisms is of great importance as it could be used to increase the microbial activity and improve the soil fertility (Mabood and Smith, 2005).

4. Future studies

The field of allelopathy is burgeoning science which is getting slowly recognized. Many studies are producing convincing evidence that allelopathic interactions between plants play a crucial role in both natural and manipulated ecosystems. The allelopathic studies in coconut ecosystem needs to be carried out more in field conditions to prove if it is really happening. Application of technologies with capabilities to analyze minute quantities of allelochemicals, determine the critical dose of allelochemicals along with use of appropriate bioassays are needed to be utilized in the plantation based cropping systems. As this phenomenon mostly occurs in soil milieu, understanding the soil microbial interactions with metagenomic approach could throw more light upon the tritrophic level plant-soil-microbial exchanges.

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Physiological investigations in coconut based cropping systems

K.V. Kasturi Bai

Introduction

The productivity of any crop is determined by its biological efficiency and is mainly dependent on dry matter production and partitioning towards the economically important part i.e., Harvest Index. The biological efficiency of any crop depends on the conversion efficiency of the solar radiation intercepted. In plantation crops wide gap in potential conversion efficiency and yield realization has been observed, thus showing the poor exploitation of production potential (Corley, 1983). In coconut wide gap in potential conversion efficiency and yield realization has been observed (Kasturi Bai *et al.*, 1996). Various physiological and biochemical processes at different stages of crop growth, starting from seed germination through early seedling growth, flowering and post fertilization stages culminating in the yield influence the production. These stages are influenced by agro climatic conditions, soil characteristics etc. Dry matter (DM) is the accumulated photosynthates by a plant during photosynthesis and plants utilize these energy rich compounds for its growth, development and production. Hence, DM production is a very important trait for evaluation of production potential of crop plants.

2. Factors affecting dry matter production

Source - sink relationship, light interception efficiency, leaf area index (LAI), photosynthetic efficiency, respiration rates, leaf longevity and harvest index influence the DM production. In addition to these, agro meteorological variables also affect the DM production. In tree crops like coconut, arecanut and cocoa, sink is not found to be a limiting factor for productivity. In perennial crops, where the growth habit is indeterminate, competition for assimilates between vegetative and reproductive parts even after flowering, results in source limitation. Maximum crop productivity depends on the light use efficiency, which is related to leaf area index.

3. High Density Multi Species Cropping System (HDMSC)

Productivity per unit area of land can be increased by adopting high density cropping system. The principle of multistoreyed cropping is to use the basic production inputs such as light, water and nutrients to the maximum extent with minimum soil deterioration. This is attained by growing suitable crops having different canopy patterns and root systems. Crops with deep and shallow penetrating root systems will utilize soil nutrients and moisture available in the zones of their penetration. High and low canopied crops will have minimum mutual competition for solar energy. Hence, maximum utilization of solar radiation can be realized by appropriate combination of crops. Multi-storied cropping, thus, is an effective method for increasing agricultural production per unit area.

4. Coconut based HDMSC system

One of the major factors deciding the performance of intercrops is the amount of light that filters through the coconut canopy. It has been observed that the percentage of light infiltrated through coconut plantations of various age groups ranged from 20 to 70% depending on the age of palms. But under natural conditions this may not hold good. It has been observed that light infiltration decreased with plant height up to 5-6 m and increased beyond it. The decrease in light infiltration with increase in height in the early years is explainable as there will be corresponding increase in canopy size and density with advancing age. The increase in light infiltration beyond this critical height may be due to decrease in effective canopy size and increase in its height. Recommendations on the choice of inter/mixed crops can be improved by incorporating additional observation on canopy volume and crown diameter. Since the shade cast by trees and transmitted light will be richer in non-PAR, it is essential that the intercrops species should be able to adapt to such an environment. To achieve this goal, suitable species of crop combinations have to be grown to convert maximum solar energy to chemical energy. Studies have revealed that a substantial share of solar energy reaching the land surface is wasted. It is estimated that a palm bearing 100 nuts per year will utilize only 6% of the light reaching the leaf canopy for its growth (Corley, 1983).

A variety of crops are grown in the interspaces of coconut ranging from short season annuals to perennial tree species. In an intercropping system even if all other conditions are favourable for the growth of the intercrops, light is the limiting factor since the light penetration of a plant stand is reduced through interception and absorption by the taller canopy. The capacity of crop plants to adapt to shade is a major physiological limitation to production. In an intercropping system competition for various factors may be involved but there are also adaptive mechanisms of crops in response to competition for light, space and nutrients. Biomass production of various crops in a cropping system gives a rough indication of their compatibility. Hence, in the physiological studies on the HDMSC emphasis needs to be given on the growth and dry matter production of component crops under the system in comparison with the mono cropping system (open system).

5. Solar radiation

The amount of light incident on the field is not the limiting factor for yield, but the amount of light intercepted by a crop is the major determinant factor (Watson, 1952). On a clear day, in the open condition for a 12 hr period starting from 7 AM to 7 PM, the incident light on coconut ranged from 10 to 15 μ $E.m^{-2}.s^{-1}$ with a peak at 12 noon where the light ranged from 1500 to 1800 μ $E.m^{-2}s^{-1}$ (Fig. 1).

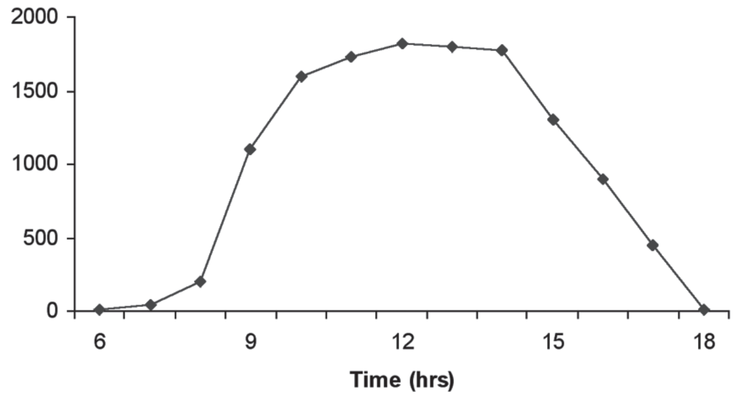

Fig.1. Day time fluctuations in the light levels (PAR) in the open condition

Below the coconut canopy, the incident PAR is 40 to 50% less than the open. In a plantation of 18 years old coconut palms at any time of the day, the incident PAR received by the crops at the ground level is 40 to 80 μ E.m-2s-1 which is only 3.8 to 4.5% of the open. Tall palms of arecanut and coconut allow light penetration through their fixed canopies to an extent of around 30%. The under story is interspersed with sun fleck areas and fully shaded areas which changed with the angle of sun. The PAR input of the sun fleck is as high as 80% of the total PAR in the open. The light interception pattern will change with the increase in the height of the palms. This will increase the amount of sunlight reaching the ground. Influence of light on the water relations as well as carbohydrate metabolism in coconut has been reported by (Kasturi Bai *et al.,* 1988 and Kasturi Bai and Ramadasan, 1990).

6. Light interception and growth of component crops

Relationship between the light interception patterns in a cropping system was found to have profound influence on the growth and productivity of the component crops. A number of factors viz; spacing of palms, height, crown diameter and canopy density influence this. The plant canopies will absorb, reflect and transmit the solar radiation and this will vary according to the thickness of leaf. Due to the thick leaf structure, the leaves of pineapple may show the highest reflection. At 550 nm the maximum reflectance is 16% and the minimum is 8% at blue and red regions. This is well in the range of the data reported for tropical tree crops. This high reflectance is due to the thick cuticle of the leaf. The major portion of radiation absorbed by the plants is in the wave length band 400-700 nm and reflects as much as 96% of light in the infrared range i.e., 800-1000. In a densely planted plantation, the interception of light per frond is less than in a less densely planted plantation. The transmittance of coconut leaf is low. At 550 nm the maximum is 3% and at minimum it is negligible at the blue and red regions. This may seriously affect the photosynthesis of intercrops. It is in this context, the importance of sun fleck is understood in coconut garden.

7. Light interception by large canopy tree crops and growth of under plants

The large canopy tree crops were found to influence the growth of the under plants by the greater absorption of light. Extreme extension growth of the stem with reduced branches and less partitioning of dry matter towards the storage parts were some of the features observed in the intercrops to combat the less favourable environment. Reduction in growth and yield of intercrops has been observed which can be attributed to the incident PAR on each crop. The impact of light interception on the productivity at different canopy levels was also well understood which indicated higher yield at the top of the canopy than the base (Ramadasan, 1983; un published). A study conducted in the pattern on interception of light in pepper canopy under two different systems viz., pepper on coconut with cocoa in double hedge (V1) and pepper on coconut with single row of cinnamon (V2) revealed that in general the top portion of pepper canopy received the highest percentage of light at all times of the day. The interception was the lowest at the base portion with slight increase in the mid region. The mean value was 40-45% at the top, 30-40% at the middle and less than 30% at the base. The productivity of vines at these distinct regions also varied accordingly. A good relationship on the yield of pepper and interception of light was observed (Fig. 2).

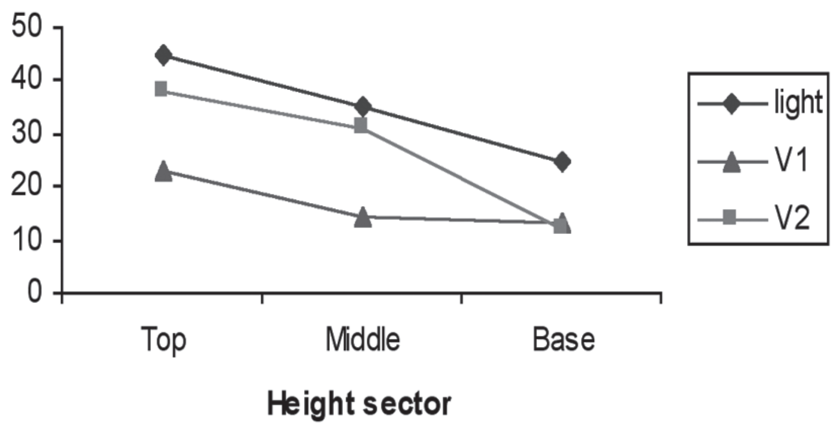

Fig.2. Relationship between light levels and yield of pepper vines

Earliness in the flowering was noticed in the case of papaya, banana, pineapple and sapota in the open condition than the shaded condition. This is corroborated by the data on light profile in the HDMSC system (Fig. 3, Kasturi Bai *et al.*, 1991). The reduction in growth under the system can be mainly attributed to the incident PAR on each crop (Trenbath, 1976). It was observed that the coconut canopy intercepts 50% of the light. The incident light on banana was 28.1% and pineapple receives only 3.5% of the total intercepted radiation.

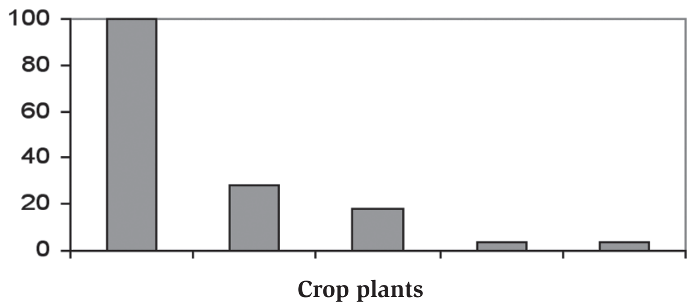

Fig.3. Day time fluctuations in the light levels (PAR) in the open condition

Since the adult gardens are characterized by large number of sun flecks, they offer another possibility to the growth of intercrops by alternating with shady and bright light during the movement of the coconut leaf. Observation revealed that the larger canopy tree crops influence the growth of under plants within one meter of its radius more than those at 2 meter radius and beyond. The incident PAR at 1 meter radius was lower (560 µ $Em^{-2} S^{-1}$) than at 2 metre radius (920 µ $Em^{-2} S^{-1}$). This may be because of the greater absorption of light by the taller canopy. Reduction in canopy area of component crops also has been noticed under the system as compared to the open system (Table 1).

8. Adaptive strategies under low light levels

The extreme extension growth of stems and reduced branches observed in subabul, guava and tapioca is another adaptive nature of these crops under shaded condition. It was noticed that when there was two to three branches for guava plant in the open system,

Table 1. Comparision of the canopy growth of the crops between HDMSC system and open system

Crop	Canopy area (m^2/plant)	
	HDMSCS	Open
Banana	6.42	8.84
Pineapple	0.07	0.29
Guava	4.80	68.70
Sapota	5.00	7.70

only a single branch was seen under HDMSCS. The thin spikeless leaves of pineapple with small fruits under HDMSCS as compared to the thick leaves with spikes and bigger fruits in the open condition show the modifications of plants to adapt in the less favourable environments (Kasturi Bai *et al.*,1991). More than 40% of the pineapple fruits in the open weighed above two kg (Table 2).

Table 2. Comparison of the harvested produce of the crops between HDMSC system and open condition

Crop	Fresh wt. (kg/plant)		Dry wt. (kg/plant)	
	HDMSCS	Open	HDMSCS	Open
Tapioca (tuber)	0.96	2.82	0.22	0.65
Pineapple (fruit)	1.40	1.90	0.18	0.24
Banana (bunch)	9.42	13.0	1.60	2.2

Although the yield potential could not be fully realized in tapioca, pineapple and banana under shaded conditions of HDMSCS as much as that under open system, the reduced yield showed their adaptability to low light profiles. The partitioning of dry matter in tapioca was found to be more towards the tuber growth (1.13 kg) than for shoot growth (0.94 kg) when grown as a monocrop while the reverse trend occurred under HDMSCS i.e., tuber growth (0.22 kg) lower than shoot growth (1.46 kg).

It has been well established that the capacity of crop plants to shade is a major physiological limitation to productivity. Trenbath (1976) reported, in an intercropping system competition for various factors may be involved but there are also adaptive mechanisms of crops in response to competition for light, space and nutrients. The energy output: input ratio calculated based on NPK as active ingredients (Pimental, 1980) revealed higher ratios in the open condition (Table 3). This may be because of the use of light to the fullest extent which is another form of energy whose input is less under HDMSCS. Bengali Baboo and Ramadasan (1986) reported that under rainfed conditions, a WCT palm produces annually about 2,83,710 K calories (output) with an annual input of about 11,471 K calories. This gives the energy output to input ratio of 24.73.

Table 3. Energy output: input ratio in the system

Crop	Energy output: input ratio	
	HDMSCS	Open
Tapioca	0.084	0.25
Pineapple	0.086	0.116
Banana	0.018	0.026

9. Conclusion

From the foregoing it is obvious that the amount of light incident is not the limiting factor for yield but the amount of light intercepted by crops is the major determinant factor. Therefore, identification of suitable shade adapted species which will give a better yield when grown as an intercrop, as compared to the open condition is highly desirable before going for cropping system models. Effective utilization of land, airspace and inputs with maximum returns are the advantages of HDMSCS. Even though the system gave an additional income from the increased coconut yield (Bavappa, *et al.*, 1986) as well as from the yield of inter crops, effective utilization of all the inputs was not seen as compared to open condition. This is mainly because of the lower light intensity reaching the canopy of their crops by interception by the coconut canopy. Initial research studies carried out clearly revealed the importance of the system for biomass production and carbon accumulation. Further extensive studies are needed to be carried out to understand carbon sequestration potential and stock in different cropping system models as viable carbon sequesters for carbon mitigation strategies.

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Integrated pest management for coconut based farming system

C.P.R. Nair and A. Josephrajkumar

Introduction

Cococut (*Cocos nucifera* Linn.) popularly known as "Tree of Life" is one of the most important tree species cultivated in humid tropics. The crop provides livelihood securities and employment opportunities to major segments of the rural mass of the region. India ranks first in the world in coconut production with a production of 15,840 million nuts from 1.94 million hectares (Mathew, 2008). The other major coconut producing countries are Indonesia, Philippines, Vietnam, Thailand and Sri Lanka. Coconut palm is considered to be the benevolent and benign tree which provides food, drinks and shelter to mankind. It provides livelihood securities to more than 10 million people in 18 states and 3 union territories of India. About 90% of area and 89% of production of coconut are emanated from the four southern states *viz*., Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. Coconut plays a pivotal role in the agrarian economy of Kerala. It is predominantly cultivated in marginal and small holdings and occupies about 40% of the total cultivated area in Kerala. It is a source of permanent income to 5 million farm families (Mathew, 2008). Coconut contributes more than Rs.8900 crores to the country's GDP apart from an export earning of Rs.695 crores (Mathew, 2008).

A farming system is a result of complex interactions among a number of inter-dependent components, where an individual farmer allocates certain quantities and qualities of four factor of production namely land, labour, capital and management to which he has access (Mahapatra, 1994). This is a multidisciplinary whole-farm approach and very effective in solving the problems of marginal and small farmers. The approach aims at increasing income and employment from small-holdings by integrating various farm enterprises and recycling crop residues and by-products within the farm itself (Singh *et al.*, 2006). The Indian economy is predominantly rural and agricultural, and the declining trend in size of land holding poses a serious challenge to the sustainability and profitability of farming. In view of the decline in per capita availability of land from 0.5 ha in 1950-51 to 0.15 ha by the turn of the century and a projected further decline to less than 0.1 ha by 2020, it is imperative to develop strategies and agricultural technologies that enable adequate employment and income generation especially for marginal and small farmers who constitute more than 80% of the farming community. In this changing scenario crop and cropping system based perspective of research made way for farming system based research conducted in a holistic manner for the sound management of available resources by marginal farmers (Jha, 2003). No single farm enterprise is likely to be able to sustain the marginal and small farmers without resorting to integrated farming systems (IFS) for the generation of adequate income and gainful employment year round (Mahapatra, 1994). Farming system approach, therefore, is a valuable approach to addressing the problems of sustainable economic growth for farming communities in India. IFS are less risky, if managed efficiently and they benefit from synergisms among enterprises, diversity in produce and environmental soundness (Lightfoot, 1990).

As coconut in India is essentially grown by small and marginal farmers and a monocrop of coconut does not provide adequate farm income and employment opportunities for the family it is feasible to adopt multiple cropping or mixed farming system to fetch more farm income. More over the crown shape, root pattern and growth habit of coconut gives ample opportunities for many compatible annual or perennial crops. The choice of the intercrops mainly depends on the necessity of the grower either for food crops for nutritional safety or for cash crops for economic safety. While perennial crops like black pepper, cocoa, tree spices etc. provide added stable income, annual crops like tubers, banana and vegetable meet the nutritional requirement of the farmer. In certain cases medicinal plants and fodder also are grown for specific needs. The multi tier cropping growing different crops of varying height, rooting pattern and duration based on coconut + black pepper + cocoa + pineapple is mostly prevalent and widely acceptable in plantation sector of northern Kerala. In this system, the leaf canopies of intercrop components occupy different vertical layers. The taller components have foliage tolerant to strong light and high evaporative demand and the shorter components with foliage requiring shade on relatively high humidity. It increases the cultivated land utilization index and crop intensity index thereby increasing the land use efficiency. Intercropping of compatible crops also encourages biodiversity, by providing a habitat for a variety of insects and soil organisms that would not be present in a single crop environment. This biodiversity can in turn help to limit outbreaks of crop pests (Altieri, 1994) by increasing the diversity and abundance of natural enemies such as spiders or parasitic wasps. Increasing the complexity of the crop environment through intercropping also limits the places where pests can find optimal foraging or reproductive conditions. Diversity of natural enemy complexes attacking various stages of the pests prevalent in poly crop and intercropping systems tends to prevent severe pest outbreaks, maintain biotic balance and reduces pest population below the economic injury level.

It is impractical to narrate individual pests of various crops grown under the coconut canopy. When an array of all the above crops are viewed as components under the coconut based cropping system and analyzed for occurrence of various pest complexes, the following groups of pests assume importance. These pest complexes have more or less similar habits, seasonal fluctuation and many are polyphagous in nature. Hence, their management strategies also are more or less mutually applicable due to their responses to certain basic concepts in plant protection. Pest management is a comprehensive approach to pest control that uses combined means to reduce the pest status to tolerable level while maintaining a quality environment. The main objective is to reduce pest status and prevent the loss. Although this may be achieved by killing pests, killing certainly is not the objective. It also proposes several techniques to be employed to alleviate problems, rather than relying on the single tactic. Pest management has to leave a pest residue for the natural enemies to thrive and sustain. Finally the capstone objective is the maintenance of quality environment which includes the quality of both cropping and nonagricultural environment (air, water, soil, wildlife and plant life). The following are the major species / groups of pests occurring under the coconut based production system affecting either the main crop coconut or the component crop or both.

2. Pests of Coconut

Coconut palm is affected by a large number of insect and non-insect pests. The perennial nature of the palm provides a continuous supply of food and shelter for build up of the pests. Among the insect pests, beetles and weevils belonging to Coleoptera, caterpillars belonging to Lepidoptera and sucking pests belonging to Hemiptera form potential pests of the palm. Besides, mites, rodents and nematodes also cause economic crop loss to the palm. The concept of IPM has been well taken care in the management of major pests of coconut and these methods have been recommended to manage the specific problems in the farming sector (Nair *et al.*, 1997).

2.1. **Rhinoceros beetle** : *Oryctes rhinoceros* L.

This is a ubiquitous pest on coconut inflicting severe damage by boring into the unopened fronds and inflorescences. Adult beetles chew the tender tissues and throw out the fibrous material as frass. The damaged fronds when fully opened show the characteristic 'V' shaped cut pattern. Damage on spathe causes drying resulting in yield loss up to 10 per cent. Rhinoceros beetle breeds in the decaying organic debri like cattle dung, compost, dead and decaying wood in which the adults lay eggs and the larvae and pupae completes their life stages. The adult emergence occurs mostly during June- September coinciding with the monsoon period.

The IPM method combining mechanical, chemical and biological methods has been found effective in the management of rhinoceros beetle. In the normal situation the pest can be well managed by biological control methods. However, if very high pest incidence is observed the IPM package shall be adopted. Mechanical method involves periodical examination of the seedlings and young palms for pest attack and extraction of the adult beetle using a metal road of 0.5 m length with a hook at one end. Pest monitoring shall be made especially during the peak adult emergence period in June-September. After beetle extraction, the bore hole is to be treated with a mixture of fungicide (3 g mancozeb) and river sand (200 g).

Prompt disposal/ treatment of breeding grounds and field sanitation are important in reducing the pest incidence. Incorporation of the weed plant, *Clerodendron infortunatum* Linn. @ 10 per cent w/w in the composting medium helps in regulating the pest in the field (Chandrika and Nair, 2000). As an alternative, treatment of breeding material with carbaryl 0.01% is also recommended to manage the pest in the breeding ground. As a prophylactic method leaf axil filling with a mixture of neem cake/marotti (*Hydnocarpus wightiana* Bl.) cake @250 g per palm mixed with equal volume of sand around 2-3 leaf axils surrounding spindle leaf during May-June, September-October and December-January has given significant reduction in pest incidence (Chandrika *et al.*, 2000). Placement of naphthalene balls @ 12g per palm in the leaf axils surrounding spindle leaves at 45-60 days interval during periods of peak pest incidence gives good control of the beetle (Sadakathulla and Ramachandran, 1990).

Biological pest suppression using two microbial agents viz., the green muscardine fungus, *Metarhizium anisopliae* M and the viral pathogen *Oryctes rhinoceros virus* (OrV) is the most important and effective tool in the IPM schedule (Pillai et al., 1993). Treatment of the breeding sites of the pest with *M. anisopliae* @ 5x 10^{11} spores/m^3 of breeding material gives significant control of the pest (Danger *et al.*, 1991). The viral pathogen is effective in reducing the longevity and fecundity of adult beetle. Field dissemination of the virus is done through release of virus inoculated adult beetles @ 12-15 per hectare during dusk. The infective beetles released in the field transmit the viral pathogen in the breeding sites through excreta and helps in spreading the infection to the pest population in the field.

2.2. Red palm weevil : *Rhynchophorus ferrugineus* Oliv.

Being a tissue borer, red palm weevil is the fatal enemy of coconut palm. Cuts and injuries on the palm due to mechanical injuries, infestation by rhinoceros beetle or fungal disease like bud rot or leaf rot are predisposing factors favouring invasion of the red weevil attack. Weevils lay eggs in the soft injured tissues and grubs tunnel into the crown/trunk. The life cycle of the pest is completed inside the palm. Though the pest population is persistent, incidence is more during monsoon and post-monsoon periods. Young palms below 20-25 years are relatively more prone to the pest infestation. The pest attack occurs through the crown, soft stem and bole region. Crown entry is more common and is highly fatal as it quickly damages the soft cabbage. It also results in drying of the young spindle leaf. Presence of holes on the affected crown or stem, exudation of a brown viscous fluid, yellowing of inner whorls of leaves close to the spindle leaf, presence of chewed up fibres in the leaf axils etc. are major symptoms of pest attack. Regular monitoring for the pest in the garden and adoption of timely curative treatment are essential steps in the IPM. An IPM package integrating sanitational, chemical and trapping of weevils is recommended for managing the pest (Nair *et al.*, 1997). The following are the IPM measures recommended.

Sanitation is important to prevent introduction of insects, pathogens, nematodes and weeds into pest free fields and to reduce losses in infested fields. Sanitation includes all measures aimed at eliminating or reducing the amount of inoculum present in a plant or field and at preventing the spread of pests to other healthy plants and plant products. Sanitation practices such as use of healthy seed material, burning and destruction of crop refuse, clean storage etc. reduce pest population, discourage breeding and hibernating sites and prevent carry over to the next crop season. These methods are economical, effective and easy to adopt.

Prevention of pest entry is possible by avoiding injuries on the palm and treatment of injuries if any, with coal tar + carbaryl. If petioles are to be cut, leave a length of 1.2 metre from the base of the petiole to prevent pest entry into the crown. Curative treatment with 1% carbaryl is effective. After plugging the holes on the lower portions of the affected palm, insecticide suspension is to be administered into the palm using a long tailed funnel. In case of pest entry through the spindle, the insecticide may be poured after removing the affected rotten portion. Root feeding with monocrotophos 10 ml mixed with equal volume of water is also effective. This is recommended to save juvenile palms. However, if it is adopted for an yielding palm, the harvest will have to be restricted by resorting to plucking of nuts after 45 days of insecticidal application to avoid insecticidal residue in the harvested nut.

Trapping of weevils using attractant traps employing fermented toddy treated coconut logs or bucket traps with the pheromone lure ferrrugineol (Abraham *et al.*, 1999) is effective in reducing the pest population. When pheromone lures are employed, the farmer will have to follow all the precautions recommended for pheromone trapping. Moreover, an area wise operation covering larger area is more effective. Effective management of red weevil is achieved only when all the above recommendations are integrated and adopted meticulously. However, it is pointed out that farmers may not be carried away with a feeling that by adoption of pheromone trapping alone, the pest can be managed.

2.3. Leaf eating caterpillar: *Opisina arenosella* Wlk.

The leaf eating caterpillar assumes severe proportion resulting in considerable damage on palms in many parts of coastal and Peninsular India. The caterpillars construct galleries of silken webs reinforced with plant debri and excreta. Living within the galleries, on the lower side of leaflets they feed on the chlorophyll containing leaf tissue. Pest infestation results in drying of outer and middle whorls of leaves. In the endemic areas by proper monitoring on the pest build up starting from post-monsoon period onwards and by periodic inoculative / innundative release of parasitoids in the field at regular intervals, the pest can be very well managed by restricting to biological method (Chandrika *et al.*, 2008). But during the period of epidemic out break an integrated method involving cutting and burning of badly infested outer 2- leaves and spraying of a low residual pesticide like diclorvos 0.02% or malathion 0.05% is to be adopted. The spraying has to be followed by release of recommended stage specific parasitoids after 21 days of pesticidal spraying (Nair *et al.*, 1997).

The recommended parasitoids viz., the larval parasitoid, *Goniozus nephantidis*_Mues (Bethylidae) / *Bracon brevicornis* (Braconidae), the pre-pupal parasitoid *Elasmus nephantidis* Roh (Elasmidae) and the pupal parasitoid *Brachymeria nosatoi* H (Chalcididae) are to be released at fixed norms at 20, 49 and 32% for every 100 larvae, pre-pupae and pupae respectively, at fortnightly intervals depending on the occurrence of the pest in the field for an effective biological suppression (Sathiamma *et al.*, 1996).

2.4. Coconut mite: *Aceria guerreronis* Keifer

The coconut mite is a potential pest of recent origin in India. In a short period, it has spread to all coconut growing states in India causing severe crop loss. The nymphs and adults colonise under the perianth of developing young buttons soon after pollination. They suck the sap from tender meristematic tissues which results in formation of white longitudinal patches just below perianth. These patches soon develop to triangular yellow halo. As the nut grows the affected nuts show longitudinal fissures and wartings and become undersized with considerable reduction in the copra and fibre content of the nut. The pest occurs persistently but peak period of incidence occurs during hot summer months.

The mite management is possible only through adoption of an integrated IPM-INM package. The plant protection schedule includes spraying of 2 per cent neem oil garlic soap mixture or azadirachtin 0.004 per cent. Root feeding of azadirachtin 5 percent at 7.5 ml mixed with equal volume of water is also recommended. Application of botanicals has to be done three times in an year during post-monsoon (October-November) and early summer (January-February) and peak summer months (April-May).

A comprehensive nutritional management of the affected palms with NPK at recommended dose of 500g N, 320g P_2O5 and 1200g K_2O along with application of 50 kg compost/recycling of bio-mass and *in situ* green manuring is also essential to manage the pest (Rajan *et al.*, 2009).

2.5. Root grub: *Leucopholis coneophora* Bierm

The root grub or white grub is a problem on palms grown in sandy and loamy soils. The grubs of this cockchafer beetle feed on the roots of coconut palm. Besides, they are also feeding on most of the tubers and vegetables grown as intercrops in coconut gardens. Pest infestation leads to yellowing of leaves, premature nut fall, tapering of crown, retarded growth and reduction in yield. The pest occurrence is high during monsoon and post-monsoon period. Adoption of an IPM schedule integrating physical, cultural and chemical methods provides good management of pest in the field (Abraham and Mohandas, 1988; Chandrika and Vidyasagar, 1993).

The steps in the IPM schedule are deep ploughing or digging during pre and post-monsoon periods to expose grubs for predation by birds, collection and destruction of adult beetles during peak adult emergence in May-June, setting up of light traps to attract and trap adult beetles and application and incorporation of phorate 10G @ 100 g per palm applied and incorporated in to the coconut basins during May-June and September-October.

2.6. Minor pests and emerging pests of coconut

Various species of insects belonging to order lepidoptera and hemiptera form important minor pests of coconut. Due to biotic and abiotic changes in the ecosystem, minor pests like coreid bug, slug caterpillars, mealy bugs scale insects occur sporadically on coconut and cause economic damage. Of late, the coreid bug, *Paradasynus rostratus* Dist. also has been observed as an emerging pest of coconut in parts of Kerala.

2.6.1. Coreid bug : *Paradasynus rostratus* Dist

This is a polyphagous insect affecting coconut palm, cocoa, tamarind and guava. The adults and nymphs feed on developing buttons and young nuts resulting in button shedding and malformation in mature nuts. The pest feeds below the perianth and the feeding points develop to necrotic lesions which later coalesce. The affected nuts either drop down or develop malformation resulting in barren nuts or nuts with partially filled kernel. Pest population is active in the field from May to December.

Management measures include crown cleaning, spraying of developing bunches with carbaryl 0.1% 2-3 times starting with the build up of the pest in May giving an interval of

2-3 months (Visalakshy *et al.*, 1987). Placement of phorate 10 G @ 5g in two perforated polythene sachets deep in the stalk of bunches/leaf axils provides ample protection from the pest attack (CPCRI, 1995).

2.6.2. Slug caterpillars

Slug caterpillars are sporadic in nature, especially during post monsoon and summer season. Three species of caterpillars *viz., Latoia lepida* Cram., *Contheyla rotunda* Harm and *Macroplectra nararia* M. are reported on coconut. They are found infesting other hosts like palmyrah palm and banana which are present in the coconut ecosystem. It has been observed that the slug caterpillar, *L. lepida* population is generally prevalent in banana plants especially during post-monsoon months. The caterpillars are voracious defoliators and they leave only the mid rib. In case of epidemic out break cutting and burning of severely affected lower fronds and spraying with carbaryl 0.1% are suggested as management measure. The pest can be fully checked, if control strategies are taken up in the initial days of pest out break. In nature the natural parasitism by *Apanteles parasae* Rohw. is observed. Since slug caterpillar out breaks are generally noticed on a periodic cyclic manner in nature proper monitoring of the pest on both main crop and intercrops are essential to control its outbreak.

2.6.3. Mealy bugs

Mealy bugs are persistent pests in coconut based cropping system. Their population is high during summer months. Drought situation promotes mealy bug multiplication in crop plants. The association of mealy bug with their attendant ants is a major factor to be considered in managing the pest. Ants play a vital role in disposal and spread of mealy bugs. The ant activity in the host plants is a clear indication of probable presence of mealy bug colonies. Spot application of recommended pesticides like fenthion, quinalphos, dimethoate at 0.05% is effective in managing mealy bugs along with their attendant ants (Nair and Nair, 1982). Natural enemies like *Pullus* sp. (Coccinellidae) and *Spalgis opius* Westw. (Lyceanidae) feed on crawlers and adult females in the field.

Important species of mealy bugs seen in coconut based cropping system are given in Table 1.

2.6.4. Scale insects

Scale insects occur sporadically on coconut during summer months. Scale insects form another group of potential pests in coconut based production system. Table 2 gives species composition of scale insects in coconut based cropping system. Like the mealy bug, though they are persistent in the ecosystem high temperature moisture stress and

Table 1. Important species of mealy bugs seen in coconut based cropping system.

Sl. no.	Species name	Host plants	Infested plant parts
1	*Palmicultor palmarum* Ehron	Coconut	Sphere leaf
2	*Pseudococcus longispinus* Targ.	Coconut	Sphere leaf
3	*Pseudococcus cocotis* Maskell	Coconut	Spathe, floral parts
4	*Rhizoecus* sp.	Coconut, Yam	Root, tuber
5	*Planococcus lilacinus* Ckll.	Cocoa	Pods, Shoots, cherelles, flower cushion
6	*Planococcus citri* Risso	Cocoa, Black pepper	Pods, Shoots, cherelles, flower cushion, berries
7	*Ferrisia virgata* Ckll.	Cocoa, Black pepper, Yam	Cherelles, flower cushion, Shoots, leaves
8	*Droshicha mangiferae* Gr.	Cocoa	Shoots
9	*Coccidohystrix insolitus* Gr.	Brinjal	Leaves and shoots

poor nutritional management of the crops favour colonization by this group of insects. The scale insects in some cases affect even the harvested produce as seen in case of tuber like yam or rhizome like turmeric or stem stored for planting purpose as in the case of cassava. Hence, when planting materials of such crops are selected care shall be taken to use scale insect free seed material. Natural enemies particularly the coccinellid predators *Chilocorus nigritus* present in the coconut ecosystem exerts a low level of biological control. When the pest level requires urgent chemical treatment, the insecticides recommended for field use is systemic insecticides like dimethoate or monocrotophos at 0.05%. Fish oil rosin at 2.5% is also effective in managing scale insect infestation. The pesticidal application may have to be repeated after an interval of 20 days for a satisfactory management of the pest.

Table 2. Major species of scale insects occurring in coconut based cropping system.

Sl. no.	Species name	Host plants	Infested plant parts
1	*Aspidiotus destructor* Sign.	Coconut, Banana, Black pepper	Leaves
2	*Lepidosaphes mcgregori* Banks	Coconut	Leaves, nuts
3	*Aonidomytilus albus* Ckll.	Cassava	Stem
4	*Parasaissetia nigra*	Cassava	Leaves
5	*Aspidiella hartii* Ckll.	Yam, Ginger, Turmeric	Tubers, Vines, rhizomes
6	*Lepidosaphes piperis* Gr.	Black pepper	Stem, leaves, berries
7	*Marsipococcus marsupiale* Gr.	Black pepper	Leaves

2.6.5. Nematodes

Though as many as 165 species of nematodes belonging to 77 genera have been reported from coconut rhizosphere (Kutty and Koshy, 1979; Koshy and Banu, 2002). The burrowing nematode *Radopholus similis* (Cobb, 1893), Thorne 1949 is the most important species affecting coconut in India. Besides coconut, the nematode is also reported to cause considerable damage on banana, black pepper, ginger and betel vine grown as intercrops in coconut. *R. similis* causes decline symptoms on crops. Foliar yellowing stunted growth, delayed flowering and general yield decline are major symptoms of the burrowing nematode infestation in coconut. Infestation leads to the formation of small, elongate orange coloured lesions on tender roots. Later these lesions coalesce causing extensive rotting of roots (Koshy and Sosamma, 1996).

The root knot nematode *Meloidogyne incognita* (Kofold and White, 1919) Chitwood, 1949 is an economically important plant parasitic nematode seen in many intercrops like black pepper, turmeric and vegetables. It has been observed that the establishment of pepper rooted cuttings in coconut gardens is poor due to infestation by burrowing nematodes and occasionally due to root knot nematode also. As a management measure application of phorate 10G at 3 g ai/vine during pre-monsoon and post-monsoon has been recommended. To manage *R. similis* infestation in coconut, application of phorate 10G at10 g ai/palm and 3 g a.i / seedling twice during pre and post-monsoon period is recommended (Koshy and Chandrika, 2006). Other measures to manage plant parasitic nematodes in coconut cropping system include application of 10kg farm yard manure/ green manuring with *Glyricidia maculata* @10 kg or neem cake @1 kg per palm. The biocontrol agents like *Paecilionyces lilacinus*, *Pasteuria penetrans, Trichoderma viride, T. harzianum* and AMF are effective in reducing nematode infestation. Natural occurrence of *Pastueria* sp. has been found in association with burrowing nematode in coconut gardens.

2.6.7. Rodents

Rodents constitute the major group of vertebrate pests of coconut ecosystem. Associated with coconut and its intercrops, 10 species of rodents are known to co-exist (Koshy and Chandrika, 2006). The arboreal black rat *Rattus rattus wroughtoni* Hinton is the most predominant species followed by the field mouse *Mus booduga*. The other species of rodents in coconut gardens are the tree mouse *Vandeleuria oleracea*, Western Ghats squirrel *Funambulus tristriatus*, the Indian gerbil, *Tatera indica*, tree rat *Rattus rattus rufescens*, the lesser *bandicoot Bandicota* bengalensis and the larger bandicoot, *Bandicota indica* (Bhat *et al.*,1991).

On coconut, the arboreal rats feed on coconuts during their early stages of development. They also damage unopened spathe, floral parts and leaf stalk. The burrowing rats damage the young seedlings by feeding away the cabbage portion. Among the various intercrops, cocoa experiences maximum rodent damage caused by the arboreal rat, *R. r. wroughtoni* and the squirrel, *F. tristriatus*. Rats usually damage the pods by making holes near the stalk region of the pod and the squirrels grow the pods feed on the mucilage covering on the mature beans leaving the bean on the ground. Tubers and fruit plants like banana under coconut are also damaged by the rodents.

3. Management

An integrated approach involving use of mechanical tree barriers, trapping, field sanitation and rodenticidal control is suitable for field adoption. When coconut plantations are raised giving wider spacing to avoid touching of leaves of adjacent palms, the mechanical barriers can be adopted to control rats. Banding the coconut trunk at a height of 2 metre above ground level with GI sheet of 30 cm width is recommended to ward off the rats. But this method is not practical in coconut gardens with intercrops. Trapping though labour extensive is an effective way of rodent control. Live traps and death traps of various models are in conventional use among the farmers for trapping arboreal rats .Burrowing rodents are trapped by employing bamboo traps or PVC tube traps. Orchard sanitation by clean cultivation practices reduce rodent damage to some extent. Regulation of harvest is a cultural way of managing rodents.

The most effective rodent control is obtained by resorting to poison baiting with rodenticides. The use of single dose anticoagulant rodenticide bromodialone (0.005%) applied twice at an interval of 12 days effectively managed rat damage on coconut (Bhat *et al.*, 1991). Placement of 10g of the rodenticide wax block on the crown of one palm out of every 5 palms in the plantation gives the best management of rats.

For management of terrestrial rats like bandicoots and gerbils, poison baiting with zinc phosphide is effective. Poison bait is prepared by mixing 95 parts of raw rice, 3 parts of vegetable oil and 2 parts of zinc phosphide. As poison baiting causes bait shyness in rodents due to acute poisoning by zinc phosphide, plain baiting may be practiced when frequent poison baiting is resorted in a garden. Change of baits to other food materials like coconut, cassava fruit, dry fish etc adds to efficacy of poison baiting.

4. Major pests specific to important intercrops in coconut based production system

As already indicated the crops grown as intercrops under coconut canopy include annuals or perennials having either food value or commercial value. Like the major crop coconut, these crops are also prone to infestation by certain specific pests causing economic loss and, hence require adequate plant protection measures.

4.1. Pepper pollu beetle: *Longitarsus nigripennis* Mots.

This is the most destructive pest of pepper causing many times crop loss to the extent of 30-40 percent. Adult beetles fixed on tender shoots, leaves and spikes and the grubs feed on the internal contents of berries and spikes.

Management for *pollu* beetle is obtained through judicious pesticidal spray and regulation of shade by lopping the shade plants (Devasahayam, 2002). Mild raking up of soil during pre-monsoon helps in exposure of grubs in soil for predation by birds. Insecticides like quinalphos 0.05% or cypermethrin at 0.01% is recommended twice during spike emergence in June-July and at berry formation in September-October. Neem based pesticides at 0.6 percent is also recommended as an alternative.

4.2. Leaf gall thrips: *Liothrips karnyi* Bagn.

It affects leaves of pepper plants causing marginal galls on the leaf. Severe infestation leads to stunted plant growth and low yield. If pest incidence is severe spraying of 0.05% dimethoate is recommended.

4.3. Ginger shoot borer: *Conogethes punctiferalis*

This is a serious pest of ginger and turmeric. The larvae bore into the pseudostem and feed on internal tissue. Infestation leads to yellowing and drying of affected pseudostems. Spraying of malathion 0.1% or monocrotophos 0.05% at monthly intervals from July to October is effective against the pest.

4.4. Tea mosquito bug: *Helopeltis antonii* Sign.

Though a major pest on cashew, the pest is also found on cocoa plants affecting cherelles, pods and young shoots. Feeding by the adults and nymphs results in production of necrotic lesions on the affected tissue and ultimate drying of the affected cherelles or shoots. Need based application with imidacloprid 200 SL at 0.006% is recommended to manage the pest.

4.5. Banana pseudostem weevil: *Odioporus longicollis* Olivier

This is a serious pest of banana causing significant crop loss. The grubs of this weevil bore into the pseudostem making extensive tunnels. Infested plants show yellowing and withering of leaves and severely affected plants break and topple.

An integrated management schedule combining field sanitation and pesticidal application is recommended (Nair, 1989; KAU, 2007). Removal and burying / burning the affected plant is helpful in reducing pest incidence. Application of carbaryl 0.2% or chlorpyrifos 0.03% so as to effect penetration of the pesticide into the pseudostem is effective to manage the pest infestation.

4.6. Banana rhizome weevil: *Cosmopolites sordidus* Germ.

The grubs of the weevil bore into the rhizome making irregular tunnels. Pest attack is indicated by the death of the roll of unopened leaves. Withering of outer leaves and young suckers are common symptoms of attack. Adoption of strict field sanitation, planting of pest free suckers and setting up of traps using banana pseudostem and collection and destruction of attracted weevils are recommended for managing the pest.

4.7. Sweet potato weevil: *Cylas formicarius* F.

The pest is specific on sweet potato causing crop loss extending up to 60 percent. The adult weevil feeds on leaves, tender buds, stem, roots and tubers. The grubs feed on the collar region and further feed on the roots and tubers.

An integrated pest management schedule involving crop rotation, deep ploughing, cultivation of short duration varieties, disinfesting planting materials and setting up of pheromone traps (one trap/ 100 m^2) to attract and destroy the weevil is recommended to manage the pest (Nair *et al.*, 2006).

Sustainable crop protection in coconut based farming system would involve an array of interactions among the herbivores, natural enemies and vegetation. An agroecosystem which is free from chemical pesticides harbours rich arthropod community, including different kinds of natural enemies and their abundance is sometimes greater than the pests. To achieve sustainability in agriculture through integrated farming system, biodiversity need to be maintained and conserved. Use of traditional knowledge based farmers practices like biopesticides and organic farming for sustainable agriculture need to be stressed.

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Integrated disease management in coconut based farming system

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Intensification of agriculture has contributed substantially to the increase in world food production. Coconut based farming system aims at maximizing and/or complementing the benefits that can be derived from land under coconut. It is also regarded as a simple but effective diversification strategy for small holders who are often dependent on few cash crops. Yields of intercrops are known to vary with species. But the profitability of the farming system depends not only on yield levels, but also on other economic factors, such as cost of production. Disease management needs in mixed cropping system differ from those in pure stands. A holistic approach is needed for economic and efficient disease management in a farming system with several crops. With the increase in crop diversity due to multi-species cultivation the incidence and intensity of diseases also increase. But the synchronization of plant protection measures to be adopted will reduce the cost involved. Adoption of appropriate and economically viable management practices compatible with the farming system will help in enhancing the profitability and sustainability. Extensive research is going on to integrate the different components of disease control in an effective manner to reduce losses due to diseases. Economically viable integrated disease management practices have been evolved for the control of diseases of coconut and its intercrops.

1. Root (wilt)

The occurrence of root (wilt) disease of coconut was first noticed in 1882 in Erattupetta area of Meenachil taluk in Kottayam district. Around 1907 the disease was reported from Kaviyoor and Kalloopara areas of Tiruvalla taluk in Pathanamthitta district and later from Kayangulam area of Karthikapally taluk in Alappuzha district (Butler, 1908; Pillai, 1911; Menon and Pandalai, 1958, Koshy, 1999). Since then, the disease has spread in all directions from the original focci of infection and according to a survey of 1984-85, the disease occurred in a contiguous manner in 0.41 million ha., in eight southern districts of Kerala state and sporadically in the remaining 6 northern districts of the state and bordering districts of Tamil Nadu, Goa and Karnataka (Solomon *et al.*, 1999, Koshy, 2000; Koshy *et al.*, 2002). Based on a sample survey conducted in 1996, the disease intensity in the contiguous diseased tract ranged between 2.1% in Thiruvananthapuram district to 48.0% in Alappuzha district (Solomon *et al.*, 1999).The annual loss due to the disease was estimated to be about 968 million nuts and the monetary loss assessed in terms of loss in husk, copra yield and leaf on the basis of 1984 price index of coconut was of the order of about Rs.3000 million. Mathew *et al*. (1993) reported a decline in yield to the tune of 45% in West Coast Tall variety and 60% in D x T hybrids and delayed bearing of seedlings that took up the infection. Root (wilt) disease is non-lethal but debilitating. If the palms are affected at the seedling stage, flowering is delayed and also yield is considerably reduced. The reduction in yield of nuts up to 80% has been reported in palms in the advanced stages of disease (Radha *et al*., 1962; Ramadasan *et al*., 1971).

1.1. Symptoms

Flaccidity, yellowing, and marginal necrosis of leaflets of the leaves of central and outer whorls were considered to be the typical foliar symptoms (Varghese, 1934; Menon and Nair, 1952; Menon and Pandalai, 1958). Radha and Lal (1972) recorded flaccidity, the characteristic bending or ribbing of leaf lets as the earliest consistent visual symptom. Symptom expression varies with the age, nutritional status/management practices, variety, and the time lag after disease incidence. In general, 67 to 97% palms show flaccidity, 38 to 67% develop yellowing and 28 to 48% show marginal necrosis. When palms below the age of 10 years are affected, 96.8% of them exhibit flaccidity while yellowing and marginal necrosis are virtually absent in them. In some palms, the distal ends of leaves at the fourth or fifth position from the spindle, curl (1-1.5 m below the leaf tip), break, hang down, become yellow, dry and drop off (Koshy, 2000).

Inflorescence necrosis, lack of ability to produce female flowers and pollen sterility render the palm unproductive (Varghese, 1934; Varkey and Davis, 1960). Shedding of immature nuts even before the appearance of other visual symptoms or after is another important symptom.

Butler (1908) observed that half the numbers of main roots were rotten in some disease-advanced palms and the smaller roots exhibited rotting in high proportion. Percentage of root decay varied from 12-94.4% depending upon the intensity of the disease (Michael, 1964; Anon., 1971). Michael (1964) reported reduction in the number of roots produced by diseased palms compared to healthy. Anatomy of the roots of diseased palms revealed degenerated phloem, disorganized tracheal elements and tyloses in metaxylem (Indira and Ramadasan, 1968; Govindankutty and Vellaichami, 1983).A number of physiological derangements were noticed in the root functioning, water relations, mineral nutrition, respiration, and photosynthesis and phenol metabolism. A single root of diseased palm absorbed 150 ml water per day compared to 250-500 ml by a root of a healthy palm (Davis, 1964). The uptake and transport of water through the trunk in diseased palms was reported to be 35% less than that of healthy palms (Ramadasan, 1964).

1.2. Etiology

Etiology of root (wilt) disease of coconut was established as phytoplasma by electron microscopy, transmission studies with vectors, transmission through dodder and light microscopic staining techniques (Solomon and Govindankutty, 1991). The phytoplasma was detected in sieve tubes of roots, tender stem, petiole and developing leaf bases of root (wilt) diseased palms (Solomon *et al.,* 1983). Lace bug, Stephanitis typica and the plant hopper, *Proutista moesta* are the proven vectors of the disease (Mathen *et al.*, 1990, Anon., 1997). Remission of symptoms observed in tetracycline treated palms added further evidence to the phytoplasmal etiology of the disease. The association of phytoplasma has been established beyond doubt by the molecular detection of 16Sr XI group phytoplasma by PCR using custom designed primers (Manimekalai *et al.,* 2010).

1.3. Disease Management

The perennial nature of the crop, persistence of the pathogen once it is acquired and the possible transmission in brief duration of feeding by the vectors rule out the effective prevention of the spread of the disease by control of vector. Since the phytoplasma is not amenable to culturing *in vitro*, screening of chemicals for adopting control measures is not at all feasible. Diseased palms treated with Tetracycline hydrochloride exhibited only temporary remission of symptoms and needs to be applied repeatedly. Prohibitive cost of the antibiotic and caution against its indiscriminate use for treating any plant disease are the other limitations of its use.

One of the significant features of this disease is that it is not lethal but a slow declining malady that responds to ideal management practice. The loss can be reduced to the minimum if palms could be attended immediately on appearance of symptoms and prophylactic and curative treatment for leaf rot is given to all palms in the disease prevalent areas twice a year (Koshy *et al.*, 2002). Two strategies, one for the heavily diseased contiguous area, and another for the mildly affected area have been formulated (Anon., 1986; Muralidharan *et al.*, 1991).

1.3.1. Strategy for heavily diseased tracts

In the heavily diseased area, the yield of palms can be sustained or even improved through adoption of integrated management practices:

- Removal of disease advanced and juvenile palms
- Management of leaf rot disease
- Balanced fertilizer application
- Addition of organic manures

- Raising green manure crops in the basins and incorporation. Increase in yield of palms as a result of legume treatment, fertilizer application and adoption of plant protection measures under farmer's condition was reported by Thomas *et al.* (1993).
- Irrigation during summer months
- Management of other diseases and pests
- Adopting inter and mixed cropping. Multiple cropping and mixed farming systems in root (wilt) disease prevalent gardens have indicated the possibility of increasing the income from unit area of land as well as the employment potential of farm. Menon and Nayar (1978) reported that intercropping with cassava, elephant foot yam and greater yam for five years gave an overall increase of nut yield of root (wilt) affected palms to the extent of 5, 15 and 8 per cent respectively and 5% reduction in disease intensity. Nair *et al*. (1975) reported 27 to 35 per cent increase in yield by mixed cropping.
- Mixed farming in the diseased gardens involving raising of fodder crops in the inter spaces, maintaining milch cows and recycling of organic waste.
- Management of leaf rot is very important in addition to irrigation and recommended dose of fertilizers and manures for the effective management of root (wilt) disease of coconut. Koshy *et al*. (2002) developed an integrated management practice for the control of leaf rot disease and insect pest attack

1.3.2. Strategy for mildly affected area

- ***Removing all the diseased palms:*** The spread of the disease can be arrested by systematic surveillance and rouging of diseased palms as and when identified. Eradication of disease affected palms to contain the disease within contiguously infected geographic limits can be successful if continuous monitoring for occurrence of the disease and uprooting of suspected and diseased palms are taken up simultaneously. But if the programme is not monitored uninterruptedly the desired goal will not be achieved. This is evident from the present status of disease incidence in Vallom village in Shencottai in Tamil Nadu (Anon., 1986) and in the areas in north of Karuvannur river in Thrissur district (Rethinam *et al*., 1982). Accurate and timely diagnosis of plant diseases is an essential component of integrated disease management. A number of tests were developed to detect infection sufficiently early before the visual manifestation of symptoms (Joseph and Shanta, 1963; Pillai and Shanta, 1965; Rajagopal *et al*., 1988). Agar Gel Double Diffusion Test (Solomon *et al*., 1983) could be used to detect the disease in palms irrespective of their age group. The disease status could be determined 6-24 months before the expression of foliar symptoms. Using the disease specific antiserum, direct antigen coated indirect Enzyme Linked Immunosorbent Assay

(DAC ELISA) has been standardized for the quick detection of root (wilt) disease (Sasikala *et al.*, 2001; Sasikala *et al.*, 2004). The advantage of this test is that it could be completed within 44 hours as against 96 hours taken in the case of intra gel double diffusion test and twenty samples with three replications could be screened using microlitre quantities of specific antibody.

- ***Replanting with disease free healthy seedlings*:** Sero-diagnostic test is being used extensively in the identification of healthy elite mother palms, screening of the progenies of elite palms, screening nursery seedlings and for confirmation of RWD in new areas of incidence. Replanting with quality seedlings has to be undertaken only in gardens with sufficient space.

2. Leaf rot

Leaf rot, a disease of fungal etiology, occurs superimposed on about 65 per cent of root (wilt) affected palms (Srinivasan, 1991). The affected palms show rapid decline in yield. Information on the loss due to leaf rot disease alone is not available, as the disease generally does not occur independent of the root (wilt) disease. However, Menon and Nair (1948) estimated the annual loss as Rs. 5.6 million and Joseph and Rawther (1991) as 461 million nuts. Normally farmers identify a palm as root (wilt) affected only when the leaf rot sets in. Flaccidity and marginal necrosis of leaflets are not easily recognized by the farmers especially in the early stages. Severity of leaf rot symptom is more during rainy season.

2.1. Symptoms

Tiny water soaked lesions appear on spindle leaves which gradually enlarge, coalesce freely leading to extensive rotting. The rotting may advance into the interior of the spindle. When the spindle grows, the rotten portions dry up, turn dark brown to black, break and are blown off in the wind. In many cases, the rotten distal portions of leaflet adhere to each other from top to bottom on both sides thereby giving a fish bone appearance. On drying these portions drop off. Hardening of the tissues and development of chlorophyll in the maturing leaflets generally slow down the progress of rotting towards the base of the leaflets so that the basal portions of the affected leaflets remain green and normal giving a fan like appearance. Normally the symptoms would appear on each successive spindle thereby showing symptoms on all leaves. Leaf rot causes reduction in photosynthetic area, disfiguration of the palms and reduction in yield apart from attracting a number of insects that feed, multiply and cause further damage. In the early stages of the disease some spindles escape rotting during summer months. Severity of leaf rot symptom is more during monsoons and trees of all ages are susceptible and during summer months the leaflets show more of dry rot. The disease causes drastic reduction in photosynthetic area, which in turn causes reduction in yield.

2.2. Etiology

McRae (1916) and Sundararaman (1925) isolated a *Penicillium* like fungus from diseased leaves. *Helminthosporium halodes (Bipolaris halodes)*, *Gleosporium* sp., *Curvularia* sp., *Gliocladium roseum, Pestalotia* sp. and *Fusarium* sp. were isolated from the diseased leaves (Menon and Nair 1948, Anon., 1985b). Though several fungi have been reported to be associated with leaf rot of coconut, *Colletotrichum gloeosporioides* (Penzig) Penzig and Sacc. and *Exserohilum rostratum* (Drechsler) Leonard and Suggs are the main (primary) pathogens. *C. gloeosporioides* is mainly associated with early stages of lesion throughout the year except January and July. *E. rostratum* is more frequent on early lesions in February and March, but differences are small in other months. Occurrence of *C. gloeosporioides* is low from January - April, increasing to more than 50% between May and July and thereafter remaining the most commonly detected species until December. *E. rostratum* is less frequent than *C. gloeosporioides* in the leaf rot lesions from April-December, with periodic fluctuation through the year (Srinivasan and Gunasekaran, 1996a).

2.3. Disease Management

Ideally an inflorescence is to be produced from every leaf axil in coconut. The number of female flowers, setting percentage, number and size of nuts, quantity of copra, oil content etc. are directly correlated with the health of the leaf that supports the inflorescence. The fact that the white, soft, leaflets of spindle alone are susceptible to fungal attack, suggests that the spindle alone needs to be protected. The rhinoceros beetle also attacks the spear leaf and entry of red weevil through the crown is also very common

Earlier field trials using contact and systemic fungicides had given excellent results. Four sequential spraying of Bordeaux mixture 1%, Dithane M 45 0.3% and Fytolan 0.5% on leaf rot affected palms in farmers' gardens resulted in the control of the disease (Anon., 1985b). Srinivasan and Gunasekaran (1996b) reported moderate impact for pouring of Calixin and spraying of Indofil M 45 in the control of leaf rot when applied thrice a year, for three years regularly.

Though the recommendations of sequential spraying of Bordeaux mixture 1%, Indofil M-45 0.3% and Fytolan 0.5% on leaf rot affected palms using rocker sprayer (6 labour) and separate application of Sevidol 8G for the control of rhinoceros beetle three times a year (3 labour) are effective, farmers had not adopted because of the very high requirement of skilled labour (6 + 3) and the cumbersome spraying involved. Therefore, the need for a much simpler, ecofriendly and less labour intensive method, which combines the application of fungicide and insecticide, without the aid of a sprayer, was keenly felt. A series of field trials conducted in this direction over a period of three years using various fungicides, bactericides and insecticides having contact and systemic properties led to the development of a very effective, economic, environment friendly and easy method to manage leaf rot disease and insect pest attack (Koshy, 2000a; Koshy *et al.*, 2002). The integration of leaf rot management with pest management and general cultivation practices is very effective in improving the health of the palms and thereby increasing the yield.

- ➢ Cut and remove rotten portions of the spindle and the adjacent two innermost fully opened leaves, if affected by leaf rot. White soft leaflets of the spindle alone are susceptible to fungal attack. Therefore, older leaves that had leaf rot disease earlier need not be removed.
- ➢ Mix Contaf 5 EC (Hexaconazole) 2 ml or Dithane M-45 (Mancozeb) 3 g in 300 ml water and pour into the well around the base of the spindle leaf.
- ➢ Apply 20g Phorate 10G or 30g Furadan 3G mixed with 200g sand around the base of the spindle leaf.
- ➢ Treat all palms in the garden (healthy and diseased) twice a year, i.e. in April-May and October-November. To make this operation more economical the treatment should be given along with harvest of nuts before and after south - west monsoon.

Residue analysis done for the chemicals, Contaf 5EC, Indofil M45 and Phorate 10 G in mature and tender nuts showed that the nut water, kernel, coconut oil and coconut cake are free from residues after 45 days of application at the rates suggested above(Koshy *et al.*, 2002). Palms in the early stages of disease will recover totally (100%) with two or three applications. Palms in the advanced stages (with an index of more than 50%) may take 3 years to recover fully. To prevent the recurrence of the disease the treatment needs to be continued. The same treatment may be given to all unaffected healthy palms also twice a year as a prophylactic measure. Koshy *et al.* (2000) also demonstrated that the above treatment twice a year could prevent the incidence of leaf rot in serologically positive palms.

The advantages of the management practices are:

1. Pouring of fungicides is more effective and target specific since it is applied directly on to the susceptible, white, non- chlorophyllous soft leaflets of spindle resulting in better protection.

2. The cumbersome spraying is avoided.
3. The quantity of spray fluid is reduced from 3000 ml to 300 ml.
4. By removing the rotten portions of spindle and the adjacent two leaves the fungal spore load that would become otherwise available to the next, very tender, susceptible, upcoming spindle gets reduced considerably.
5. All the available chlorophyll area is retained by not cutting and removing the older leaves that had leaf rot infection earlier.
6. The leaf rot affected spindle leaf is also colonized by mealy bugs, mites, nematodes etc. The leaf rot disease affected palms are more prone to red weevil infestation. Application of a systemic insecticide that has nematicidal property (Phorate 10G) along with fungicide was found to protect from infestation of rhinoceros beetle, red weevil, coreid bug, ash weevil, mealy bugs and nematodes.

The adoption of the integrated disease and pest management save up to 88 per cent labour cost. The cost of two applications will work out to Rs. 14.60 when Contaf 5EC is used and Rs. 13.60 when Indofil M 45 is used compared to separate quarterly applications of fungicides and insecticides costing Rs. 79 (Rs. 50 + Rs. 29) per palm per year. The combined application of insecticide and fungicide did not affect the effectiveness of each other (Koshy *et al.*, 2002). Palms that showed boron deficiency symptoms may be given 50 g Borax along with the application of fungicide till the symptoms disappear (Koshy, 2000).

3. *Colletotrichum* diseases of intercrops

The leaf rot pathogen, C. gloeosporioides incites disease in some of the intercrops also. This is most noticeable and severe when Colletotrichum directly attacks the harvested/ economic portion of the crop, often the fruit as seen in cocoa and black pepper

3.1. Cherelle rot of cocoa

The young developing fruit (pod) of cocoa is known as ‘cherelle’. Large number of young pods of 2-3 months age dry up and remain on the tree as mummified fruit and this type of drying of pods is commonly referred as ‘cherelle wilt’. Such ‘cherelle wilt’ where no pathogen is involved is considered as a physiological thinning mechanism. Detailed studies on the involvement of pathogen in cherelle rot revealed that a considerable percentage of drying and mummification of young pods, hitherto considered as cherelle wilt, is caused by *C. gloeosporioides* (ChandraMohanan *et al.*, 1987; ChandraMohanan and Kaveriappa, 1984a). The critical period for cherelle rot is February-May, when the susceptible stages of the pods are plenty (ChandraMohanan *et al.*, 1989b).

3.1.1. Symptoms

The symptom of cherelle rot mostly starts from the stalk end, particularly at the point of attachment of the stalk to the pod. The infection proceeds towards the tip of the pod as dark brown sunken lesion with a diffused yellow halo. The infection also extends to the stalk and reaches the cushion, but does not spread further in the cushion. The infected stalk becomes highly shrunken and can be easily distinguished from healthy stalk. As the infection progresses, the internal tissue of the pod also becomes discoloured. The infection may also start from anywhere on pod surface other than stalk region as dark brown sunken lesion. Such lesions coalesce and form bigger lesions. Microscopic examination of the pinkish slimy mass on the lesions reveals the presence of acervuli with setae and abundant conidia of *C. gloeosporioides*. Ultimately, the pod turns dark brown to black and remains on the tree as mummified fruit (ChandraMohanan and Kaveriappa, 1983a). At this stage, these pods can be easily confused for pods affected by cherelle wilt, which is a physiological phenomenon. The physiological wilt begins as general yellowing of the entire pod (cherelle) followed by browning and blackening of the entire pod. Thus, the physiological wilt of cherelle is distinguishable from cherelle rot. *Colletotrichum* pod rot is found only on cherelles and young pods with the maximum incidence on cherelles (ChandraMohanan, 1983; ChandraMohanan *et al.*, 1989a).

3.1.2. Management

Bavistin WP (carbendazim 0.05%) and Indofil M-45 (mancozeb) 0.2% are reported to be promising fungicides for the control of *Colletotrichum* infection on cocoa (ChandraMohanan and Kaveriappa, 1984b).

3.2. *Pollu disease (Anthracnose) of blackpepper*

This disease is caused by *C. gloeosporioides*. Unnikrishnan *et al.* (1987) reported up to 77% weight loss of berries due to early infection.

3.2.1. Symptoms

Fungal infection can be distinguished from pollu (hollow berry) caused by the beetle by the presence of characteristic cracks on the infected berries. The disease appears towards the end of the monsoon. The affected berries show brown sunken patches during early stages and their further development is affected. In later stages, the discolouration gradually increases and the berries show the characteristic cross splitting. Finally, the berries turn black and dry. Infection of stalks as dark spots results in spike shedding. On leaves, the fungus causes angular to irregular brownish lesions with a chlorotic halo on the leaves.

3.2.2. Management

The disease can be controlled by spraying Bordeaux mixture 1%.

4. Bud rot

Bud rot of coconut was first noticed in Grand Cayman (Tucker, 1926). The disease is now known to occur in Cuba, India, the Philippines, Jamaica, East Africa, Puerto Rico, Dominican Republic and Santo Domingo, Fiji, Papua New Guinea, Colombia, Sri Lanka, French Polynesia and Vanuatu (Butler, 1906; Menon and Pandalai, 1958; Child, 1974). The disease is sporadic in nature; however, outbreaks of epidemics are also common. The disease occurs commonly in West and East Coasts of India (Menon and Pandalai, 1958). Radha and Joseph (1974) reported an incidence of 0.1 to 6.5 per cent in Kerala (west coast of India) and 0.4 to 6.7 per cent in Tamil Nadu (east coast of India). Sporadic occurrence of the disease (between 0.9 and 10%) was observed in some gardens in Andhra Pradesh.

4.1.Symptoms

The symptom of the disease was first described by Briton-Jones (1940). The primary visible symptom is the withering of the spindle marked by pale colour. The spear leaf or spindle turns brown and bends over. Later younger leaves next to the spindle also exhibit such symptoms. On dissecting such affected trees, rotting of internal tissues could be observed. These tissues assume pale pink colour with a brown border. The affected spindle can easily be pulled out at this stage. The spindle droops down among the neighbouring leaves. One by one, the inner leaves also fall away leaving only fully matured leaves in the crown. The rotting tissue emits a foul smell. The palm ultimately succumbs to the disease with the death of the spindle (Briton-Jones, 1940; Menon and Pandalai, 1958; Lingaraj, 1972). It took a few weeks for the decay to involve the entire bud before destroying the meristem. The tender leaves and leaf sheaths sometimes show water soaked sunken lesions at their base in the early stages. These lesions turn brownish later (Radha and Joseph, 1974). The older nuts persist on the crown for some time, while the younger ones may fall off.

4.2. Etiology

Butler (1906), and Shaw and Sundararaman (1914) reported the causal organism as *Phytophthora palmivora* Butl. In the Philippines, *P. faberi Maubl*. has been reported as the causal agent of bud rot, while *P. heveae* in the Ivory Coast. These pathogens also cause lesions on nuts, quite independent of bud rot, and cause nut fall. Joseph and Radha (1975) observed bud rot symptoms in 2 to 5 year-old seedlings of coconut inoculated with sporangial suspension of *P. palmivora* both in the laboratory and in the field.

4.3. Integrated disease management

The methods of control have been described by Menon and Pandalai (1958), Peiris (1962), Radha and Joseph (1974) and Celino (1970). Ohler (1984) suggested that measures like improved drainage, wider spacing, weed control, etc., would help in reducing the relative humidity resulting in an indirect prevention of disease incidence. Bud rot disease can be effectively managed by adopting integrated management practices.

4.3.1. Cut and removal of severely disease affected palms (beyond recovery) or dead palms

Cut and removal of palms which are in the advanced stage of bud rot or palms dead due to the disease are very important operations to be carried out in all the affected gardens for better control of the disease. This will help to reduce the inoculum load in the garden and thereby checking the fast spread of the disease within the garden and to the neighbouring gardens. Rotten portion of the crown should be destroyed by burning.

4.3.2. Curative treatment

- To save the palm, curative measures have to be adopted when the disease is in early stages.
- The appropriate period would be the stage when the spindle has just started showing symptoms of withering.
- In the early stage of the disease, remove the spindle leaf by pulling it out and cut and remove the infected tissues completely.
- Two or three healthy leaves adjacent to the spindle may have to be removed if necessary for easy removal of all rotten portions and thorough cleaning.
- The wound should be treated with Bordeaux paste(10%).
- The treated wound should be covered with polythene cover to prevent entry of rain water and this protective covering should be retained till normal shoot emerges.
- In case of advanced stages of infection, the palm should be cut and removed.
- The diseased tissues should be burnt after their removal.
- All the healthy palms in the surroundings should be treated with 1% Bordeaux mixture/ mancozeb sachets.

4.3.3. Prophylactic treatment

It is important to give prophylactic treatment to all palms before the onset of monsoon, in gardens with a previous history of bud rot incidence. In certain dwarf palms, phytotoxic symptoms like brown sunken spots followed by nut shedding have been observed when Bordeaux mixture is sprayed (Nambiar, 1994). Therefore, in copper sensitive palms like Chowghat Orange Dwarf (COD) and Malayan Yellow Dwarf (MYD), keeping perforated sachets containing mancozeb in the innermost leaf axils during rainy season is found to be useful. Large scale field trials conducted recently revealed that pouring mancozeb solution (5g in 300 ml water /palm) into the well around the base of the spindle followed by placing perforated sachets containing mancozeb (2 sachets/palm; 5 gm mancozeb/ sachet) in the inner most leaf axils before the onset of south West monsoon is a very effective prophylactic treatment for bud rot management in disease endemic areas (unpublished).

4.3.4. Nutrient management

Besides integrated disease management techniques, nutrient management practices for the affected palms as well as healthy palms are also important for improving the health and vigour of the palms for higher yield.

4.3.5. Irrigation

The yield of the palms can be increased by summer irrigation

4.3.6. Replanting

In order to maintain optimum population of palms in the gardens from where the palms in the advanced stage of disease or dead palms are cut and removed it is necessary to fill up the gaps by planting good quality coconut seedlings, wherever sufficient space is available. So far, no cultivar has been found to be resistant to this disease under field conditions. Quillec *et al*. (1984) observed that hybrids were less sensitive to bud rot than West African Tall. Brahmana and Kelana (1988) reported that dwarf palms were more sensitive and tall varieties or tall x tall hybrids more resistant. Franqueville *et al*. (1989) found that among the progenies of Malayan Yellow Dwarf x West African Tall hybrid (PB 12), some were sensitive while others were highly tolerant.

5. *Phytophthora* diseases of intercrops

Phytophthora diseases are very important owing to the heavy economic loss they cause every year. In hilly tracts, *Phytophthora* is a major pathogen of coconut and its intercrops *viz*., black pepper and cocoa. It is a major menace in coconut based farming system during rainy season. In order to limit the incidence and severity of diseases caused by *Phytophthora*, effective management strategies are needed. Management of *Phytophthora* diseases is based on a number of principles such as field sanitation, limiting susceptibility through drainage and irrigation, improving soil health, use of disease-resistant germplasm, and biological and chemical control. The effectiveness of control strategies depends on the ability of an individual species of *Phytophthora* to survive, either as a saprophyte or as dormant spores. Since rainy season is conducive for the emergence of *Phytopthora* diseases, prophylactic treatment before monsoon with recommended fungicides limits the risks associated with the disease.

5.1. Cocoa

In cocoa, *P. palmivora* causes two major diseases viz., black pod and stem canker. Black pod disease initiates as one or more small, chocolate brown circular lesion(s) anywhere on the pod surface. Within four to seven days, the lesion enlarges assuming an elliptical shape. As the lesion advances, a whitish growth of the fungus consisting of mycelia and sporangia is produced over the dark brown pod surface. The lesion increases rapidly and covers the whole pod surface. After about 15 days of infection, the whole pod and beans are invaded by the fungus and the pod turns black in colour. By this time, several saprophytic microorganisms colonize the rotten pod. The beans in ripe pod may escape partly or wholly from infection as the beans get separated from the pod husk on ripening. Pods of all ages are susceptible to the disease (Gregory, 1974; Thorold, 1975).

Based on the studies on the symptoms of the stem canker disease occurring in West-Coast of India different kinds of external symptoms, have been reported. Dark brown, round to oval discolouration of the bark formed as a result of exudation of reddish brown liquid from the point of infection is the usual symptom. Sometimes the lesions are water soaked and greyish brown. In severe cases, canker lesions coalesce to form larger lesions. Cankers at the collar region are bigger and spread faster. The collar infection appears as dark brown irregular water soaked lesion with reddish brown liquid oozing out. The collar infection then spread to the tap root and main stem. Ultimately, the portions above the infected portion show wilting and finally leading to death. Cankers also develop without any external symptom mainly on seedlings of two or three years and on branches of trees. Such infected seedlings appear weak. Such cankers can be detected only by examining the internal tissue. When the outer bark of canker infected portion of the stem is removed, the tissues beneath always show a characteristic reddish brown discolouration. Lesions in the internal tissues coalesce leading to extensive rotting. The infection spreads from the cortical tissues to the vascular tissues and reaches the wood. Wood infection appears as greyish brown to black discolouration with black streaks. When canker girdles the stem, dieback occurs. Leaves wilt, turn yellow and fall off. Pods also show wilting. Finally the whole tree dies. Spread of infection in the internal bark is faster than the spread in the surface of bark (Rao and ChandraMohanan, 1993 and 1995).

In case of chupon blight and twig die back caused by *Phytophthora*, the infection usually initiates in the axils of leaves at the tip of twigs or chupons. It appears as water soaked lesions. Infection also starts anywhere on the leaf blade or petiole and extends backwards into the stem. In any case the chief characteristic symptom is the appearance of water soaked lesion, which soon turns dark brown to black. The lesions coalesce to form bigger lesions .The lesion on stem spreads longitudinally in all directions and turns dark brown to black and shrunken. When the lesions girdle the stem, the portion above the point of infection wilts showing twig dieback or chupon blight. Lesions on leaves generally start from the apex or margin of the leaves, more at the apical portion and usually enlarge and coalesce forming large blighted areas. It leads to much defoliation and dieback (ChandraMohanan *et al*., 1979).

5.1.1. Management

Phytosanitation, fungicidal application, host resistance, pruning and shade regulation are the major aspects in the management of phytopthora diseases of cocoa.

a. Phytosanitation

Since infected pods form the main source of secondary infection, all the diseased pods should be removed at weekly intervals or during each harvest and buried in the soil. Periodic removal and destruction of infected pods alone will help to reduce the black pod disease incidence to the extent of 50%. Removal and destruction of infected twigs and chupons are also very important in the effective management of all *Phytophthora* diseases of cocoa. High yielding cocoa trees and rare germplasm collections with advanced stages of stem canker disease can be rejuvenated by cutting the whole tree well below the canker lesion and allowing a fresh chupon to develop from the basal portion of the stem (Gregory, 1974; ChandraMohanan, 2002).

b. Fungicidal application

Spraying of Bordeaux mixture (1%) at 15 days interval starting from the onset of south- west monsoon along with periodic removal of infected pods is effective in controlling the black pod disease in severely affected gardens. Experiments conducted during last several years revealed that the black pod can be effectively controlled by the use of copper based fungicides (ChandraMohanan, 2002). Stem canker can be controlled in the initial stages by the excision of diseased bark followed by wound dressing with Bordeaux paste or any other copper funigicide. In cases of severe incidence of chupon blight, the plants may be sprayed with one per cent Bordeaux mixture or any other copper fungicide after removing the infected twigs and chupons (ChandraMohanan, 1994).

c. Host resistance

From the results of screening of 51 cultivars for P. palmivora resistance in Costa Rica, nine cultivars viz., EET 59, EET 376, UF 713, UF 715, SCA 6, SCA 12, Pound 7, Catongo and Diamantes 800 have been found to be exhibiting promising degree of resistance (Lawrence, 1978). Studies conducted in Java have indicated that the cocoa accessions DRC 16, SCA 6, SCA 12, and ICS 6 were resistant to Phytophthora pod rot. However, in India, the cocoa Accession C 78 has been found to be comparatively less susceptible to wound inoculation by *P. palmivora*. (ChandraMohanan, 1982).Later, based on the studies on inoculation of detached cocoa pods of 20 accessions with *P. palmivora, P. capsici* and *P. citrophthora*, Chowdappa and ChandraMohanan(1997) reported that the accessions C 44 and C 79 were highly tolerant to all the three species of *Phytophthora* whereas Landas 364 highly susceptible.

d. Pruning and shade regulation

Phytophthora diseases become severe under conditions of high humidity, improper pruning and heavy overhead shade. Proper spacing between plants and pruning are important to regulate the shade

Diseases caused by the genus *Phytophthora* have had a substantial impact on world agricultural production through their capacity to cause economic losses on a number of economically important crops. Quick wilt disease/ foot rot of pepper caused by *P. capsici* is the major cause of losses in black pepper cultivation and a study (1982-84) indicated that on average 188 900 vines are killed annually with a loss of 119 t black pepper/yr (Balakrishnan *et al.*, 1986). Though *P. capsici* has also been reported to be a pathogen of cocoa in India, it has not been so far reported as a pathogen of coconut.

6. Stem bleeding

Stem bleeding disease is known to occur in all coconut growing regions in the tropics. The disease was first reported from Sri Lanka (Petch, 1906). Later, the disease was reported from India (Sundararaman, 1922). This was followed by reports of the disease occurrence in other countries like the Philippines, Malaysia, Trinidad, Papua New Guinea, Fiji, Ghana and Indonesia (Briton-Jones, 1940; Menon and Pandalai, 1958; Renard *et al.*, 1984). In the early stages of the disease, there is not much yield loss. However, in late stages, there is a steady yield decline causing considerable loss and in advanced stages even death of affected palms occurs (Nambiar and Sastry, 1988). The disease has been found to occur in all soil types, but more in laterite soils and sandy soils on the seashore or backwater areas.

6.1. Symptoms

The disease is characterised by development of dark brown patches appearing at the basal portion of the trunk. In course of time, this progresses upwards. A dark reddish brown liquid exudes from the longitudinal growth cracks present on the stem bark and form irregular streaks of exudation. These streaks may coalesce and form larger lesions. No oozing is seen from old lesions. The exudates eventually dry up to form black encrustations with brownish orange margin. The tissues beneath the discoloured patch show decay. The internal decay can be observed even in areas beyond the margins of external lesions indicating that the internal decay is not confined to the area of external symptoms. As the decay progresses, the tissues become black and fibrous. This process is fast in young palms. As a result of this, cavities are formed from which liquid comes out, when the bark is pressed or punctured. Serious infection was found to lead to reducing yield and death of young palms (Ohler, 1984; Nambiar and Sastry, 1988). Radhakrishnan (1987) observed maximum symptoms of bleeding in July under red lateritic loam conditions at Pilicode (Kerala) and the least in summer months in irrigated trees growing on sandy loam soils at Nileswar (Kerala).

Symptoms appear in the crown also. The outer whorl of leaves becomes yellow rather prematurely, droops and finally dries up. Though nut fall is noticed in later stages of disease, it is more in palms exposed to drought conditions. The trunk gradually tapers towards the apex and the crown size is reduced. Crown symptoms are more pronounced during the summer season. During the rainy season, as well as in well managed and irrigated gardens, the crown symptoms are not conspicuous till very late. Based on the aerial symptoms, Mathew *et al*. (1989) worked out a method for indexing the disease severity.

6.2. Etiology

Thielaviopsis paradoxa (de Seynes) von Hohnel has been isolated from affected stem tissues. The perithecial stage (*Ceratocystis paradoxa* (Dade) Moreau has also been recorded from the affected palms. The fungus remained a suspected pathogen till recently (Menon and Pandalai, 1958; Ohler, 1984). Nambiar *et al*. (1986) reproduced the symptoms by artificially inoculating healthy trees with the fungus thus establishing its role as a pathogen. Splitting of husk and gummy exudation on nuts of all stages has been observed in one or two gardens. *T. paradoxa* was isolated from such affected nuts (Nambiar, 1994). In advanced stages of the disease, infestation with Diocalandra weevil can be seen which quickens the deterioration of the palms.

6.3. Management

The control measures adopted till recently mainly consisted of phytosanitation measures involving removal of affected bark tissues with a chisel and application of hot coal tar or Bordeaux paste to protect the wound. The chiselled tissues are destroyed by burning. Reddy *et al*. (1985) found that *C. paradoxa* developed tolerance to copper sulphate in *in vitro* tests. Nambiar and Sastry (1988), and Anon. (1990) obtained encouraging results in control when Bavistin or Calixin were applied through root feeding. Radhakrishnan (1990) reported that drenching Calixin (0.1%) @ 25 litre per tree once in every two months arrested the spread of the disease. The disease can be effectively managed if control measures are adopted in early stages of infection. The affected tissues should be completely removed using a chisel. Treat the wound with Calixin 5% followed by hot coal tar after 2 days. Apply 100 ml Calixin 5% through root feeding thrice a year during June, Sept.- Oct. and January. Soil application of 5 kg neem cake per palm per year during Sept.- Oct. is also found beneficial. Summer irrigation improves the health of the palm as well as yield. Since wounds on the trunks predispose the palms to infection, any type of wounding of palms is to be avoided. Care should be taken not to injure the stem base while ploughing the garden with tractor.

7. Ganoderma wilt /Basal stem rot

Ganoderma wilt also known as Thanjavur wilt is a very important destructive disease of coconut. In Tamil Nadu, this disease was first observed in Thanjavur district in 1952 and hence called Thanjavur wilt (Vijayan and Natarajan, 1972). In Karnataka it is known by the popular Kannada name 'Anabe roga' and in Andhra Pradesh, Ganoderma wilt. In India, Butler first recorded *G. lucidum* in coconut palm in Karnataka State in 1913. Till 1965-66, the disease was confined to the coastal areas of Tamil Nadu and the incidence ranged from 3.3 to 10.8 per cent with the highest incidence (10.8%) in Thanjavur district followed by Kanyakumari (6.3%), Tiruchirappalli (4.0%), Ramanathapuram (4.0%), South Arcot (3.5%) and Chengalpattu (3.3%) districts. In 1978, the disease was noticed in all the districts of Tamil Nadu and the incidence ranged from 0.6 to 4.9 per cent (Bhaskaran and Ramanathan, 1984). Wilson *et al*. (1987) reported a disease of coconut caused by *Ganoderma lucidum* (Leys) Karst. in Kerala state as basal stem rot.Disease with similar symptom was found also in Maharashtra and Gujarat states (Nambiar and Rethinam, 1986; Bhaskaran *et al*., 1989). Peries (1974) reported the occurrence of basal stem rot disease of coconut caused by *G. boninense* Pat. in Sri Lanka.

7.1. Symptoms

Five distinct stages can be recognized in the development of Tanjavur wilt (Bhaskaran *et al*., 1994). Wilting of leaflets (which sometimes may not be very prominent), yellowing of the leaves of lowest leaf whorl and decay and death of fine roots are the symptoms in the initial stage of disease development. In the second stage bleeding patches appear at the base of the stem near the ground level; the lesions gradually extend upwards; roots decay extensively and there is no new bunch production. Bleeding patches extend in the stem, leaves droop in the outer whorl followed by heavy button shedding and barren nuts. As stem decay traverses upwards; outer leaf whorl dries and drops off; other leaves also droop except the spindle leaf and surrounding two or three young leaves which remain erect and healthy. Ultimately all the leaves droop and fall off leaving the decapitated stem. Stem shrivels and dries up.

The time taken from the initial appearance of bleeding patches in the stem to the death of the palms is from 6 to 54 months, the average being 24 months. In the middle or late stages of disease sometimes the scolytid beetle, *Xyleborus perforans* and the weevil, *Diocalandra stigmaticollis* are found infesting the stem in large numbers at the bleeding patches from which powdery mass is thrown out. The insects accelerate the death of the palm (Anon., 1976; Rethinam 1984; Bhaskaran, 1986; Bhaskaran *et al.*, 1989).

7.2. Etiology

From diseased palms, *Ganoderma applanatum* (Pers.) Pat., *G. lucidum, Ceratostomella* sp., *Fusarium solani*, *Rhizoctonia* sp., *Schizophyllum commune* and *Trichoderma* sp. were isolated. But none of these fungi could produce symptoms of the disease on artificial inoculation.

Isolation of the causal organism(s) from different tissues of the affected palms with profuse or less bleeding symptoms and with or without *Ganoderma* fruiting bodies was carried out. *G. applanatum* and *G. lucidum* were isolated only from roots irrespective of the extent of bleeding symptom and not from above ground parts of the palm (Anon., 1987). Six months after inoculation with *G. lucidum*, root rotting up to 21 per cent was noticed. However, in the roots inoculated with *G. applanatum*, there was no root rotting, but the fungus colonized the surface of the roots to a distance of 8-10 cm on either side from the point of inoculation. From inoculated roots, *G. lucidum* was re-isolated both from cortical tissues and bark of the roots, while *G. applanatum* was re-isolated only from the bark of the roots (Anon., 1989a, 1990). Venkatarayan (1936) had reported the pathogenicity of *G. lucidum* in coconut by inoculating the fungus in the trunk region.

7.3. Integrated Management

The disease is generally observed in sandy or sandy loam soils in coastal areas in the east coast where coconut is grown under rainfed conditions and also in neglected plantations. Soil moisture stress experienced during summer months, water stagnation during rainy seasons, presence of old infected stumps in the garden and non-adoption of recommended cultural practices were found to favour the spread of the disease. Presence of hard pan formation in the sub-soil impedes root penetration, which in turn predisposes the coconut palms to infection (Anon., 1976; Ramasami *et al.*, 1977). In Andhra Pradesh, the disease incidence was low in heavy soils than in lighter soils (Rao and Rao, 1966; Satyanarayana *et al.*, 1985). This was attributed to retention of more moisture by heavy soils, besides the presence of high population of antagonistic microflora. Coconut trees in the age group of 10 to 30 years are generally more susceptible to the disease (43%) than younger trees (17%) (Vijayan and Natarajan, 1972). The hybrid VHC 1 was found to be affected up to 5 per cent at the age of 5 to 6 years in endemic areas.

Ganoderma wilt disease of coconut can be contained by adopting integrated management practices, if the disease is detected in the early stages. The indicator plants, Subabul (*Leucaena leucocephala*) and *Glyricidia maculata* show natural infection under field conditions at least six months earlier to infection on coconut palms (Anon., 1989b). The EDTA test also helps in the early detection of the disease (Natarajan *et al.*, 1986; Vijayaraghavan *et al.*, 1987).

8. Immature nut fall

Immature nut fall in coconut has been attributed to several factors. The characteristic feature of mother palm is one of the prime reasons for button shedding in coconut. Hence the selection of good yielding mother palm is very important for collection of seed nuts for raising coconut seedlings. Very high soil acidity or alkalinity also leads to high percentage of button shedding and immature nut fall (Karunanidhi *et al.*, 2002). Drought condition or water shortage for a longer period, water logging and sudden changes in soil moisture also cause heavy button shedding (Anunciado, 1974; Ohler, 1984; PrasadaRao, 1988). Imbalance or deficiency of nutrients leads to nut fall (Smith, 1969). Poor pollination is also one of the major factors responsible for button shedding in coconut. It has been reported that in some coconut palms the production of plant growth regulators was below optimal and in such palms, the nut fall was high when compared to other palms.

Shedding of buttons is also caused by insect attack. Eriophyid mite (*Aceria guerreronis* Keifer) attack also leads to immature nut fall to some extent. It has been observed that mite injury provides entry points for pathogenic fungi causing rotting and nut fall (ChandraMohanan and Baby, 2004). In certain cases, eventhough the mite infestation or injury is negligible, the infection caused by fungal pathogen causes severe rotting and immature nut fall. Severe incidence of immature nut fall due to rotting of mite infested nuts has been observed in several locations in Kerala leading to heavy economic loss. Venugopal and ChandMohanan(2010) reported significant positive correlation between immature nut fall disease and relative humidity and minimum temperature.

8.1. Symptoms

Rotting starts from the point of mite infestation on the nut surface near the perianth as dark brown to black discoloration and gradually extends to the entire surface area. The lesion also spreads deep into the internal tissues. As the lesions spread to about 30% surface area near the perianth region or when the lesion encircles the perianth region, the nut gets detached from the bunch and shed or remains on the bunch in between other nuts.

Mite attack followed by rotting of nuts is noticed in different varieties. Though mite infestation in COD nuts is comparatively low, incidence of rotting and immature nut fall due to fungal infestation is frequently observed in COD. Even slight injury caused by mite paves way for the pathogen to enter and cause severe rotting. Intensity of rotting and immature nut fall varied from locality to locality as well as from garden to garden. In certain cases when the fungal infection starts in nearly mature nuts, it continues even after harvest and storage. The infection goes deep into the husk and spreads to the kernel through the softy eye. The kernel rots assuming a grayish black discoloration and becomes soft (Venugopal and ChandraMohanan, 2006; Venugopal, 2008).

8.2. Etiology

Nut fall or mahali or koleroga caused by *Phytophthora palmivora* is common in high rainfall areas during monsoon season. Though, *P. palmivora* and *Thielaviopsis paradoxa* are also found associated with mite infested nuts, *Lansiodiploida theobromae* is the main causal organism of rotting and immature nut fall of mite infested nuts (Venugopal, 2008).

8.3. Disease management

This disease can be controlled by spraying carbendazim (Bavistin 0.1%) to bunches of the affected palms. If coconut is cultivated under the organic farming system, spraying of garlic bulb extract (10%) can be recommended for the management of the disease.

9. *Lassiodiplodia* diseases in intercrops

9.1. Charcoal pod rot of cocoa

It is found throughout the year with severity during summer months. Pods of all ages are susceptible. The infection takes place through wounds generally caused by rodents, other pests and insects. The infection appears as dark brown to black spot anywhere on the pod surface and spread rapidly, as a result of which, the pods turn black and remain on the tree as mummified fruits. The infection spreads to the internal tissue and the affected beans turn black in colour. On the surface of the affected pods, spores appear as black powdery mass resembling soot.

9.1.1. Etiology

The disease is caused by *Lasiodiplodia theobromae* (Pat.) Griffon and Maubl. (*Botryodiplodia theobromae* Pat.).

9.1.2. Disease management

Spraying one per cent Bordeaux mixture to the pods, especially during summer months is recommended for the management of this disease. Since *B. theobromae* causes infection through wounds, measures to control insects and rodent pests will also help to reduce the incidence.

10. Conclusion

Farmers consider intercropping as a technique that reduces risks in crop production. Planting intercrops are more cost effective than pure stands. Planning crop disease management in mixed cropping system is challenging, as the full needs of all crops must be met. Hence it requires advanced planning and keen management. Planting crop mixtures, which increase farmscape biodiversity, can make crop ecosystems more stable, and thereby reduce disease problems. But, mixed cropping alters microclimates within the crop and could effect disease development positively or negatively. Any disease that prospers in shady conditions could increase in a mixed cropping system. Then the farmer has to formulate /tailor the recommended disease management strategy to suit the needs of crops grown. Multi-disciplinary and agro-ecologically oriented long term research based on diseases in well established coconut based farming systems is necessary to formulate sustainable and effective integrated management practices.

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Status and development of coconut based homesteads in Kerala

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Introduction

The unique feature of the agricultural scene of Kerala is the existence of a dispersed pattern of settlement with homestead system of cultivation. Cultivation of crops in small and fragmented land holdings makes the agricultural scenario of Kerala State altogether different from other states. More than 80% of the cultivated area comes under homestead farming (HF). There are about 5.4 million small operational holdings (mostly less than 0.5 ha in area) covering a total area of 1.8 M ha in Kerala, and about 80% of them are homestead farms (HSFs) (Government of Kerala, 2008) and therefore the state is estimated to have around 4.32 million HSFs covering 1.4 M ha of land.

HSFs surround the farmer's home and are cultivated by an array of annual / perennial crops and managed often with a component of livestock to meet the requirements of farm family. However, a closer look into the functioning of such farms reveals that scientific agro management practices are not being followed and hence, farmers are not able to realize the optimum production potential. HSFs of Kerala are low external input systems, which often give only a proportionately low output, and hence, a low income, which in the context of an ever escalating cost of living, becomes increasingly inadequate. At present, the farmers concentrate mainly on crop production, which is subjected to a high degree of uncertainty in income and employment opportunity to the farmers. Most of the HSFs are predominantly coconut or arecanut based.

With the advent of market economy, and consequent emphasis on maximization of production and use of external inputs in crop production, the HSF have lost some of their relevance. There has been a resurgence of interest, however, in traditional land use practices in the wake of mounting environmental deterioration and/or failures of single-species agricultural enterprises; consequently HSF are receiving some attention although they may not address environmental deterioration at a large scale because they exist in scattered small plots.

The recent trends in agrarian structure and the high market orientation exert pressures on the HSFs and hence, its sustainability is in question. In spite of rich resource endowments and high intensity of cropping, the productivity of most of the crops grown in HSFs is much lower as it could be noticed that no serious attempts are being made by the farmers to adopt scientific management practices in cultivation of various crops (Thamban and Venugopalan, 2002 and Krishnakumar *et al.*, 2007a). Most often high intensity of shade does not allow the different crops to yield to their maximum potential. Krishnakumar *et al.* (2007a) found that only a piece meal approach is followed in the management of homestead farms, which is neither sustainable nor scientific.

Intensification of cropping and diversification of enterprises are very much essential for realizing sustainable income and livelihood security to farmers. But this requires proper planning and restructuring of HSFs for effective utilization of on farm and off farm resources to their fullest extent. Swaminathan(1998) has highlighted the fact that intensive crop and animal husbandry techniques practiced on an ecologically sustainable basis are essential for the rehabilitation of degraded lands and to conserve our rich genetic heritage. Farm diversification helps to conserve the natural resources and protect the environment. Restructuring of HSF and diversification of farm income sources could be a viable option for farmers in improving the livelihood choices and total income from unit area of farm land.

2. Characteristics of HSFs

The HSFs of Kerala constitute the predominant farming systems of the state. They are small in size (more or less 0.5 ha) and traditionally coconut-based. HSFs are typically multi-strata systems characterized by a high density and diversity of various crop components. The floristic composition and density may vary significantly at plot level according to site conditions and farmers' needs and strategies. The highest densities and indices of diversity are found in the smaller HSFs. The medium and large HSFs, which have been predominantly cropped with rubber trees for considerably long time, at the expense of crop diversity, have clearly been making inroads into the sustenance of various other food and cash crops. Conversely, small HSFs correspond to the farmers' strategy to reduce risk and achieve food security.

One of the common factors influencing the diversity is the indigenous knowledge of the farmers about different species, their uses, compatibility, complimentary benefits of the species and various constraints encountered while growing them in the limited area available. Often farmers deliberately retain and managed numerous crops in their HSFs.

Homestead farming systems also record greater total canopy coverage (130 to 150% as a total of lower, medium and upper strata). The other main characteristics of the HSFs are their higher productivity and diversity of production to satisfy the primary needs of the farm family viz., food, fuel, timber and cash.

Basic data of 208 HSFs in a contiguous area of 25 ha near CPCRI, RS, Kayamkulam, Alappuzha district, Kerala indicated that the average number of coconut palms per ha was 247 as against the recommended 175. The palm population was found to be similar irrespective of holding size. This indicates that the farmers are adopting an average spacing of 6.3 m only. Anithakumari and Manoj (2004) opined that this closer spacing may lead to competition and also be a factor in reducing the optimum productivity of holdings particularly cropping systems in the HSFs. They opined that, however, this situation could not be altered all on a sudden in a given field condition.

From a detailed survey of 90 coconut-based HSFs from six wards of Thamarassery grama panchayat in Kozhikode district, Thamban *et al*. (2006) observed that coconut is being predominantly cultivated in small and marginal holdings. The average density per ha varied from 100 coconut palms in the case of medium and large farms to 170 in the case of small farms. It was seen that in the higher and middle reaches, optimum spacing has been maintained for coconut palms facilitating accommodation of various inter/mixed crops in the coconut based homestead farming models. However, in the lower reaches where size of land holdings is comparatively small, optimum palm density was not maintained. The closer spacing adopted reduced the opportunity for effective adoption of inter/mixed cropping practices. They also noticed that the degree of crop intensification varied widely across the farms and ranged from 19.8 in the case of nut meg to 65.8 in the case of arecanut and elephant foot yam (Table 1).

Table1. Distribution of crops/enterprise in the coconut based HSF models observed in farmers' field

Farming system	Crops/Enterprise	No. of farmers	Percentage	Average planting density per unit area in percentage
I. Intercropping	1.Banana	43	47.8	34.5
	2.Tapioca	3	3.3	52.7
	3.Elephant foot yam	7	7.8	65.8
	4.Colocasia	8	8.9	26.4
	5.Bittergourd	2	2.2	42.9
	6.Cowpea	2	2.2	33.8
	7.Ginger	2	2.2	62.8
	8.Turmeric	6	6.7	55.8
	9.Fodder grass	3	3.3	49.2
II .Mixed cropping	1.Pepper	55	61.1	45.4
	2. Cocoa	11	12.2	38.3
	3.Arecanut	66	73.3	65.8
	4.Nutmeg	2	2.2	19.8
	5.Vanilla	1	1.1	43.8
III. Mixed farming	1.Dairy	31	34.4	NA
	2.Piggery	1	1.1	NA

A variety of inter/mixed crops are being cultivated by the farmers and arecanut, pepper and banana are the most frequently observed component crops in the coconut based homestead farming models in farmers' field, appearing in 73, 61 and 48 per cent of holdings, respectively. It was noticed that arecanut, which is having similar growth pattern as that of coconut and not usually a recommended mixed crop in coconut gardens, was adopted in a substantial number of farms. This field situation warrants intervening in the management of HSFs through suitable restructuring in the long run.

From another detailed survey of 815 HSFs from 83 panchayats of four northern districts (Kasaargod, Kannur, Kozhikkode and Malappuram) of Kerala conducted during 2002, it was found that the average size of HSFs varied from 0.2 to 1.0 ha. The total number of cultivated and other species of plants in the farms varied mainly depending up on the holding size and the intensity of management adopted. Coconut based farming system was the most common cultivation system occupying more than 95% of the HSFs surveyed (Krishnakumar *et al.*, 2007a). Arecanut and spice based homesteads were also prevalent, but only in a few of the areas surveyed.

The species-wise analysis (Table 2) indicated that the maximum was in the case of ornamental plants, followed by timber and miscellaneous trees, wherein farmers grow them to realise economic return at the time of financial requirement or construction purposes.

Table 2. Crop diversity noticed in HSFs of Northern Kerala

Category of plants/crops	**No. of species recoded under each category**
Medicinal plants	29
Fruit crops	28
Ornamental plants	34
Timber and other miscellaneous trees	31
Vegetables	19
Spices and condiments	10
Plantation Crops	6
Tuber crops	7
Fodder plants	3
Common weeds	24

The spatial arrangement of crops was found to be irregular and appeared very haphazard with trees/shrubs and food crops intimately mixed. Though vertically many relatively distinct zones could be distinguished, high amount of shade was noticed affecting the growth and yield of most of the crops.

All the HSFs in various studies followed a multilayered canopy arrangement. The first layer consisted of plants under 2 m height, such as vegetables, tuber crops, grasses, medicinal plants and ornamentals, some of which were planted in pots. The second layer consisted of herbaceous crops such as banana, shrubs such as papaya and trees such as short varieties of arecanut palms, mango and cacao between 2 and 10 m in height. The uppermost layer constituted trees over 10 m in height, such as coconut palms, jackfruit, breadfruit and rubber. The tree layer usually had two levels as well, with the lower tree level consisting of medium-sized trees (10 to 20 m high) and fully-grown timber and fruit trees occupying the uppermost layer (more than 25 m high). Fruit trees, some of which could continue vertical development, could occupy an intermediate layer (3 to 10 m high).

In some of the HSFs, a decrease in the tree/shrub diversity, a gradual concentration of cash crop species, an increase in ornamental plants and an increase in use of external inputs were also could be observed. Traditional HSFs combining multispecies composition and intensive management practices could, however, offer alternative development strategies to adapt to the changing socioeconomic conditions of the state.

3. Approaches for restructuring

Due to government policy and various socio-economic factors, HSFs, which has a long tradition in Kerala, and which are capable of providing multifaceted opportunities for income and employment, are gradually being replaced by monocropping system with predominance for perennial crops (e.g. cultivation of rubber is being taken up in some of the traditionally coconut growing areas due to uneconomic situation).The consequent disappearance of the widely diverse cropping pattern, which existed in the HSFs, pave way for loss of self reliance and increased dependence on external sources for food, increased risk to farmers, loss of genetic and biological diversity as well as unfavorable ecological and environmental consequences. It has also been noticed that in many of the HSFs no proper scientific management practices are followed resulting in improper utilization of farm resources and lower total productivity. In order to make most use of the resources available at the disposal of famers and to maximise income from the unit area as well as to increase the employment opportunities, it is necessary that proper restructuring of HSFs, suitable planning and adoption of package of practices of crop production are necessary. The following are some of the approaches suitable for restructuring HSFs to attain self reliance and sustainability.

1. Utilize the available land to its maximum productivity by adopting various suitable measures according to the land capability and without any resource degradation

2. Correcting defects in the traditional farming practices with respect to resource utilization, nutrient management and plant protection methods etc.
3. Maximizing productivity per unit area through increasing cropping intensity by reorienting existing cropping system and by introducing suitable intercrops wherever possible.
4. Integrated production approach by enterprise diversification for subsidiary source of income, employment generation, nutritional security to the farm family and effective utilization of available resources within the farm.
5. Recycling of farm wastes through vermicomposting, which is otherwise being wasted without proper utilization.
6. Soil and water conservation through agronomic measures.
7. Maximizing the combined income from the inter-related and dynamic crop-livestock-tree-labour complex over years.

4. Impact of restructuring HSFs

4.1. Increase in cropping intensity

When various tree species available in the HSFs are properly spaced, it could be possible to introduce different kinds of intercrops to meet various family needs. Introduction of new interventions in technology and scientific management by adoption of package of practices will increase cropping intensity per unit area by virtue of intensification of crops and other enterprises including dairy, poultry and fishery. The cropping intensity was found to be around 96 per cent in Kasaragod to 149 per cent in Kannur during the pre project period (Krishnakumar *et al.*, 2007b). The former presented a situation of gross under utilization of space and solar energy resources whereas, in the latter it was because of overcrowding. This ultimately resulted in low productivity of all the components and the system as a whole. However, in both the types of HSFs, it was noticed that the farm resource use efficiency could be enhanced through proper scientific planning, planting and crop management. In the identified HSFs, regulation of excess shade by removal of unwanted trees, pruning branches of other trees and planting inter/mixed crops as well as introduction of new interventions in technology and scientific management by adoption of package of practices were carried out. These operations resulted in increasing cropping intensity per unit area. The details on the net cropped area, total area cultivated, and cropping intensity of all homestead farms before and after the implementation of the project are presented in Table 3.

Table 3. Change in net cropped area, total area cultivated and cropping intensity of HSF in four northern districts of Kerala

Districts	Net cropped area (ha)	Total area cultivated /yr (ha)		Cropping intensity (%)	
		Before	After	Before	After
Kasaragod	0.34	0.47	0.77	136.30	222.70
Kannur	0.29	0.45	0.71	148.80	231.60
Kozhikkode	0.33	0.48	0.78	144.50	234.40
Malappuram	0.33	0.47	0.87	139.90	260.15

The average net cropped area under the selected homestead farms ranged from 0.29 ha in Kannur to 0.34 ha in Kasaragod district. The average total area cultivated during the pre- project period varied from 0.45 ha in Kannur to 0.48 ha in Kozhikkode district. Restructuring of HSF through incorporation of various interventions resulted in an increase in total cropped area and the highest percentage was recorded in Malappuram district (85) followed by Kasaragod/Kannur (62). The increase in cropping intensity was to the extent of 56 per cent in Kannur, 62 per cent in Kozhikkode, 63 per cent in Kasaragod and 86 per cent in Malappuram district.

4.2. Increase in productivity and profitability

Although interest in HSFs has been primarily focused on producing subsistence items, its role in generating additional cash income cannot be overlooked. In spite of the fact that various cropping/farming systems can increase income generation, due to non-scientific farming, the resource use efficiency as well as income generation per unit area is far below the potential level (Sairam *et al.*, 2004). Anithakumari (2007) observed that integration of enterprises and mutual utilization of inputs in farming could be increased by imparting proper training to farmers facilitating planning of different enterprises in the farm. In the case of intercrops, almost two to four fold increases in the area under cultivation was observed due to restructuring and implementation of interventions in the project area at Karunagappaly panchayat of Kollam district, Kerala. The economic analysis indicated the scope for improving the income from coconut based HSFs by adopting intercrops/enterprises despite the holding size. It was observed that maximum income could be realized for livelihood by those farmers having landholdings of more than 0.4 ha size. Earning a livelihood through proper combination of diversification/ intensification could be achieved by farmers with 0.4 ha or above, whereas, those below 0.4 ha could earn additional income and meet the family consumption/nutritional needs as evident from the Table 4.

Table 4. Improvement in income (Rs.) through intercrops/allied enterprises

Sl.no.	Category of farmers	Average income from intercrops/allied enterprises(before interventions)	Average income from intercrops/allied enterprises(after interventions)	Improvement (%)
1	Below 0.1ha	334	2451	633
2	0.1 to 0.2 ha	3005	4698	5707
3	0.2 to 0.4 ha	12785	20421	5604

Adoption of ideal cropping system and enterprise diversification will result in higher income than pre intervention. Krishnakumar *et al.* (2007b) found that through scientific restructuring of HSFs, the productivity of the main crop (coconut) and other short duration intercrops could be improved when compared to the base year yield. Adoption of integrated nutrient management practices including use of more organic manure viz., vermicompost and growing green manure crops in the base of coconut are also expected to increase the yield of various crops. An analysis of the productivity of restructured HSFs by converting different components integrated in each farm into coconut nut equivalent to form total productivity based on the prevailing unit cost of the produce of each component indicated that they will become profitable in the long run. The restructured system as a whole also provided opportunity to make use of the waste materials of one component as input for another enterprise and thus helped for cost reduction and to realize higher profitability. The increase in base crop yield i.e. coconut ranged from 35 to 60% in Kasaragod; 23 to 55% in Kannur; 25 to 65% in Kozhikkode and 11 to 49% in Malappuram districts by restructuring. The change in total productivity, gross income, net income and Benefit Cost ratio of HSFs are presented in Table 5.

Table 5. Change in productivity and profitability of restructured HSFs in four northern districts of Kerala

Homestead farm	Total productivity of coconut (nut basis)		Gross income (Rs./ha)		Net income (Rs./ha)		BC ratio	
	A*	B**	A	B	A	B	A	B
Kasaragod	5,097	8,637	20,388	51,822	8,681	32,667	1.75	2.74
Kannur	3,827	6,537	15,308	39,218	6,152	22,084	1.68	2.43
Kozhikkode	5,348	7,497	21,394	55,074	10,108	36,549	1.90	2.94
Malappuram	8,079	12214	32317	73289	14043	47810	1.83	2.82

*A = Before restructuring ** B = After restructuring

C.D (P = 0.05) for total productivity: 2455.61, for gross income: 12368.01, for net income: 13050.26

The results indicate that there is significant overall increase in total productivity, gross and net incomes of participating farmers due to restructuring of HSFs. The diversification of farming with new interventions like poultry and fish rearing and growing short duration crops as intercrops broadened the income base of farmers and reduced the risk of complete failure of any particular crop and resulted in sustainable income. Due to the difference in maturity periods of various crop combinations, income could be generated at regular and shorter intervals. Multiplicity of crops by way of incorporation of vegetables, tuber crops and fruit crops as well as integration of other enterprises (livestock, poultry, pisciculture etc., already existing in certain farms) in the restructured HSFs also resulted in production of different sources of nutrition for farm families.

Under the IFAD/COGENT/BIOVERSITY International Project on "Overcoming poverty in coconut growing communities: Coconut genetic resources for sustainable livelihood in India", a Coconut-Based Homestead Farming System (CBHFS) models were introduced in three project sites viz., Pathiyoor and Devikulangara (Alappuzha District) and Thodiyoor (Kollam District) in Kerala to increase income from coconut based farming and to improve food security. Various interventions including intercropping were implemented in the homestead farms from 2005 to 2008. The overall result (Kalavathi *et al.*, 2009) indicated that there was substantial change in economic indicators through restructuring of homestead farms as given in Table 6.

Table 6. Overall change in economic indicators in the IFAD project area between 2005 and 2008

Indicators	Pre- Project (2005)	Post- Project (2008)	Change
Average yield of coconut (nuts/ palm/ year)	30	37	7 (23%)
Average income from coconut (Rs./ holding)	67	100	33 (50%)
Average area under intercrops (cents)	3.25	7.00	3.75 (> Double)
Average income from intercrops (Rs./ holding)	19	102	83 (5.4 folds)

Significant changes in the yield of coconut and income generated could be brought out through various interventions including intercropping. The area under intercrops also increased to double than that of the pre- project period.

4.3. Organic recycling and environmental protection

Coconut based HSFs offer considerable scope for recycling organic biomass produced within the system. Integration of vermicompost production helps to effectively recycle the farm wastes from different enterprises like coconut leaves, banana stems, vegetable waste, weeds and household wastes into the system as organic manure. This approach will not only reduce the dependence on organic manure from outside source, which ultimately reduce the cost of production of system, but also prevent environmental pollution and provide a clean environment in the HSFs. The frequency of composting varies with availability of waste materials and size of the farm. In addition to compost, vermiwash could also collected at the rate of around 10-15 litres/week in each homestead, which is very ideal for use both as biopesticides spray and bio- growth regulator for vegetables and other crops. Krishnakumar *et al.* (2007b) reported that the average quantity of vermicompost produced/year in HSFs varied from 2.16 t in Kannur to 3.95 t in Malappuram, which could contribute about 35 to 60 kg N, 3.5 to 6.0 kg P and 6.5 to 12.0 kg K apart from the long range beneficial effect of application of organic manures in the HSFs.

4.4. Employment generation

Quite apart from providing cash income and subsistence products to the growers, HSFs have a tremendous potential for rural employment generation. Labour requirements will vary among regions depending on the size of farms and the farming intensity. Family labour is mainly utilized for management of HSFs. Both male and female members of the household participate in farm activities and in economic decision making processes. Hired labourers are employed according to need. Labour is hired mainly for skilled tasks such as harvesting of coconut, milking of cows, etc.

Use of family labour, especially women labour in the production process not only ensures lowering of production costs but also satisfies a wide range of domestic needs more economically and effortlessly. The great diversity of products from HSFs can also provide opportunities for development of small-scale rural industries and creates off-farm employment and marketing opportunities.

The results of the survey by Krishnakumar *et al.* (2007b) revealed that the percentage of family labour used in HSFs franged from 26 in Kozhikkode and Kannur to 32 in Kasaragod and Malappuram districts. The percentage of farmers exclusively hiring outside labour for farm operations ranged from 14 in Kasaragod to 26 in Kozhikkode district. The percentage of HSFs using both family and hired labour varied from 36 in Malappuram to 62 in Kasaragod district. In conventional farming, employment opportunity is seasonal and mostly required only during the pre and post monsoon season. Farming in restructured homestead involved more labour and generated additional employment especially for family labour because of inclusion of more crops per unit area, integration of allied enterprises and land management practices for soil and water conservation as well as vermicomposting. Due to new interventions, on an average an additional 51 man-days/year was generated not only for the farm family (especially for cultivation of vegetables and tuber crops, production of vermicompost etc.), but also for hired labour (which varied, based on activities included like land preparation, soil and water conservation measures; cropping intensity and size of the homestead farm). The details of labour utilization are presented in Table 7.

Table 7. Labour utilization (man-days) /year in selected HSFs of Northern Kerala (M = Male, F = Female)

Districts	Before restructuring HSFs				After restructuring HSFs				Additional man-days generated
	Family		Hired	Total	Family		Hired	Total	
	M	F			M	F			
Kasaragod	75	30	48	153	103	41	55	199	46
Kannur	57	27	45	129	81	35	62	178	49
Kozhikkode	91	39	40	170	118	55	49	222	52
Malappuram	97	23	60	180	126	30	81	237	57
Overall mean	80	30	48	158	107	40	62	209	51

4.5. HSFs and nutritional security

Food production either directly (producing edible fruits, nuts, grain, rhizomes and tubers, leaves, flowers etc.) or indirectly (facilitating enhanced and/or sustained production) is a basic function of tropical HSF. In many cases, if the HSF is the only land available to the household, food crops (such as tubers- cassava (tapioca), elephant foot yam, colocasia etc.) will dominate the species composition of the farm. HSFs are also significant sources of minerals and nutrients. In addition, the diverse products available year-round in HSFs contribute to food security especially during lean seasons. Consequently, there is now a growing awareness that restructuring HSFs with incorporation of crops with high nutritive value and combining with nutrition education can be a viable strategy for improving household nutritional security of farm family members especially children and women.

Multiplicity of crops by way of incorporation of vegetables, tuber crops and fruit crops as well as inclusion of other enterprises (livestock, poultry, pisciculture etc.) in the restructured homesteads will result in production of different sources of nutrient viz., proteins, carbohydrates, fats and minerals from the same farm unit and this will enhance the availability of balanced nutrition for farm family and help to a certain extent to solve the malnutrition problem that exists in the diet of the average Indian.

Another key dimension of HSFs is the equitable distribution of the produce within the community. While a large proportion of the production is consumed mostly within the farm family itself, many products such as fruits, vegetables and medicinal/ornamental plants are also often shared within the neighbourhood.

4.6. Increased resource use efficiency and improvement in standard of living

Integration of various enterprises in the restructured HSFs result in internal generation of inputs especially organic manure for farm and various quality foods for family and higher productivity of enterprises leading to more effective utilization of various resources including land and water available within the farm. Regulation of shade by selective pruning of tree species and removal of unwanted plants allow infiltration of light in to the restructured HSFs and help to accommodate more inter/ mixed crops and increase land use pattern and cropping intensity.

When once provisions are made at the farm level to generate quality food for the family use apart from commercial purposes through restructured homestead, it can create a feeling of security among the farmers. Need based integration of various enterprises in a single unit will result in cost reduction, higher production, larger profits, more employment generation and availability of better food. All these ultimately help to improve the standard of living of the farm family.

5. Future Research and Extension needs

- Lack of awareness and knowledge about technologies for effective maintenance of CBFS are some of the major constraints in the adoption of various recommended practices in HSFs. More farmer participatory technology transfer programmes related to the recommended practices for management of HSF appropriate to a particular locality are to be organized.
- Soil and water conservation measures such as drip irrigation system, use of bio-engineering methods for moisture and soil conservation etc. are needed to be adopted on a larger scale for proper management of most of the HSFs of Kerala. Long-term, vision oriented strategic plans are to be formulated and effectively implemented involving the research, development, extension and cooperative marketing agencies. Restructuring of HSFs through intensive production rather than area expansion should be the aim.
- In order to ensure better farm productivity and cluster area productivity through restructuring of HSFs, various approaches such as shifting of focus from individual or scattered farmer to contiguous area, raising market demand oriented crops with multiple utility, value addition of crop produces through product diversification are need of the hour.
- Potential clusters of HSFs for agricultural production and market oriented development are to be identified and all the required forward and backward linkages established. Various programmes envisaging productivity improvement, increasing cropping intensity, growing of high value inter crops, adoption of soil and water conservation measures including vegetative methods, organic recycling etc. are to be planned and implemented in a time bound manner.

- Properly restructured HSFs offer considerable scope for carbon sequestration. The biophysical aspects of HSFs such as soil conservation effects and potential for carbon sequestration for ecological benefits etc. are also needed to be studied in detail.

6. Conclusion

Diversification of activities by restructuring HSFs enables the farmers to acquire more knowledge and skills in farming system production. When once provisions are made at the farm level to generate quality food for the family use, apart from commercial purposes through restructuring HSFs, it can create a feeling of security among the farmers. Need based integration of various enterprises in a single unit will result in cost reduction, higher production, larger profits, more employment generation and availability of better food. All these will ultimately help in improving the standard of living of the farm family. Restructuring will also help to derive maximum benefit from more than one source of enterprise so as to ensure balanced productive system and effective utilization of available resources within the homestead. It is essential that farmers should include various enterprises that yield regular and evenly distributed income throughout the year in their production programme with a view to mitigate the risks and uncertainties of income from crop enterprises.

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Economics of coconut based cropping/farming systems

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Introduction

Adoption of any cropping system by the farming community will ultimately be decided by its economic advantage. The interest for palm based farming systems has stemmed from both technical and economic grounds. When we consider the monocropping of the trees from the labour utilization point of view we find that barring the establishment stage, the labour absorption is low and seasonal, for the remaining life span. For the regions with surplus labour, this type of systems may not be desirable. Another economic disadvantage of monocropping is that the investment in establishing the crop till its bearing age becomes sizable, which a small holder may not be able to afford. It is estimated that the average size of the operational holdings in Kerala is about 0.27 hectare against the all India average of 1.41 hectares. Such small units obviously do not provide adequate income and employment to the dependent families, when coconuts are monocropped. In order to find out a solution to this important problem, increased attention has been given to coconut-based cropping system research at the Central Plantation Crops Research Institute (CPCRI), Kasaragod.

A large number of annual and perennial crops have been introduced for feasibility studies and to evolve different crop combinations with coconut. Perennials such as cocoa, cinnamon, pepper etc. require meticulous care during the early stages of their establishment, whereas annuals could be grown as rainfed crops with relatively lesser ease of management. Such systems have income through the sale of additional products. Furthermore, coconut based mixed farming provides considerable safeguard to the smallholder's returns, against the failure of coconut crop as well as the crash in prices of nuts and copra. Besides these, the farmer obtains a higher productivity of nuts from his palms when they are grown in the mixed farming systems as compared to monoculture. It is because the palms are benefited from the application of fertilizers and irrigation to the associated crops and the cultural operations given to them which are generally not available to the pure stand of coconuts. Even though the smallholders have been practicing coconut based mixed farming with the consideration that the systems provide with a higher return per unit area, input and time than monoculture; yet the opportunities to maximise the economic gains are lost in most cases because of unscientific selection and arrangement of component crops. The choice and arrangement of intercrops under the palms are, however, influenced by the technical factors such as the age of the palms, climatic conditions, irrigation facilities and soil types, and economic factors like availability of labour, financial resources and other inputs.

2. Coconut based farming systems

For many years now the CPCRI has been conducting a number of scientifically designed experiments on various aspects of cultivation of plantation crops. Apart from conventional experiments which are primarily designed to estimate the optimal combinations of the inputs required for coconut cultivation, these include experiments to explore the economics of mixed cropping. The experiments involving trials of different crop combinations are intended to study both the prospects of increasing productivity per hectare and the agronomic desirability of the crop combinations. It was perhaps assumed that the magnitude of economic viability of a model is closely associated with its degree of success based on technical feasibility. This assumption stems from some of the following basic considerations: Firstly, the coconut lands in India, by and large are conducive to produce a variety of annuals, biennials and perennials. Secondly, since coconut is planted at a wider spacing due to its characteristic morphological features, the inter-and intra-row spaces in coconut gardens are adequate to provide the best forms of cropping system without adversely affecting the productivity of the palms. Thirdly, several inter/mixed crops yield reasonably well because of their ability to tolerate coconut shade. On these accounts, the returns from the system offset the costs and ensure profits (Das, 1989 b).

A sole crop of coconut at the recommended spacing does not fully utilise the available soil and air space and incident solar radiation. Crops identified as compatible ones with coconut include many tuber crops (cassava, elephant foot yam, yams, colocasia), rhizomatous spices (ginger, turmeric), pulses (cowpea), oilseeds (groundnut, soybean), upland rice, fruit crops (banana, pineapple) and vegetables among the annuals and cocoa, black pepper, clove and nutmeg among the perennials. Many intensive crop combinations which involve different annuals and perennials over a period of time such as multistoreyed cropping system and High Density Multi Species Crop models (HDMSCs) have also been developed. Mixed farming systems, which integrate other enterprises like dairying and sericulture provide higher employment generation and enhanced net income. Research on cropping systems in coconut was initiated during 1930s, which was intensified in the seventies at CPCRI, Kasaragod. It received further impetus with the launch of All India Co-ordinated Research Project (AICRP) on palms. Cropping systems involving annuals, perennials and combination of both has been developed to suit the availability of resources like labour, rainfall, irrigation, fertilizers, finances, soil characteristics, farmers needs and market demands.

This chapter is an attempt to review the studies related to economic aspects of coconut based farming systems conducted for the last fifty years at CPCRI, Kasaragod and its Regional Stations and Centers. For the purpose of this review, the performance of the component crops and their impact on the yield of coconut have been considered as the shadow values of the economic returns for the systems, wherever the economics has not been worked out. However, in some cases though economics is shown, the estimates were made taking the market rates for the inputs and outputs prevailing during those periods, and it is not possible to re-estimate the economic potentials of those earlier studies as the physical units of the inputs used in the model are not indicated in many cases. It was, therefore, considered to show the estimated returns at the then prevailing market rates and wherever possible, the revised estimates have been shown at the current prices.

3. Intercropping

At Kasaragod, raising of finger millet as an intercrop was not profitable during 1930-31 and 1931-32 as it yielded only 292 kg and 236 kg of grain per hectare (Anonymous, 1932). At Pilicode during 1939-40 to 1941-42 various millets like finger millet, Kodo millet, hog millet, Japanese barnyard millet and bajra gave equal or better yields under coconut compared to their yields in the open. However, though Kodo millet performed better than other millets with 1,311 kg grain/hectare, the economic prospect was extremely limited due to lack of demand from local population (Anonymous, 1941 and 1942). Sahasranaman (1964) reported that groundnut variety TMV-2 when grown as an intercrop in coconut garden at CPCRI, Regional Station, Kayangulam yielded 600 kg/hectare and gave an additional net profit of Rs.183/hectare (at 1964 prices). Besides it helped to suppress the weed growth and kept the soil in good tilth for a major part of the year. Kannan and Nambiar (1976) and Leela and Bhaskaran (1978) also studied various aspects of intercropping with groundnut and showed that growing groundnut as an intercrop in coconut stand was not only remunerative but also had beneficial effects on the productivity of coconut as well as fertility of the soil.

Intercropping with annuals like elephant foot yam, tapioca, sweet potato, ginger, turmeric, coleus and yam can bring handsome profits to the coconut grower, according to the experiments carried out at CPCRI, Kasaragod. (Nair *et al.*, 1974).The maximum favorable cost: benefit ratio was observed in the case of ginger and the minimum for turmeric (net returns Rs. 2.46 and 0.29, respectively per rupee invested). This lower return for turmeric was mainly due to the lower market rate of the commodity. The cost: benefit analysis of food crops like tubers cannot be compared with that of cash crops like ginger. A net return of more than a rupee per rupee invested is a very encouraging economic consideration in the case of food crops, especially when they are grown as intercrops.

Varghese *et al.* (1979) conducted a feasibility study of growing tubers like greater yam, lesser yam, chinese potato colocasia, ginger and turmeric as intercrops in coconut garden.

It was found that even under rainfed conditions, a net income of Rs.7,000 to 8,000 per hectare could be obtained by growing tuber crops in coconut gardens. Elephant foot yam followed by ginger gave the highest total net return per hectare. Crops like elephant foot yam and ginger are more labour intensive than tapioca and sweet potato. Elephant foot yam doubles the employment potential per unit area of land compared to sole crop of coconut. Intercropping in coconut revealed that raising tuber crops has no adverse effect on the main crop of coconut, provided, the same intercrop was not grown on the same plot every year and that both the intercrop and the main crop were manured adequately and separately. A five per cent increased yield of coconut over pre-experimental yield was obtained when tapioca, elephant foot yam, sweet potato, ginger and turmeric were grown in rotation as intercrops and 15% increase when greater yam, lesser yam, colocasia, and chinese potato were rotated. Tapioca, cultivar M-4 yielded 4.5 tons/hectare when grown continuously in the same plot as against 6.3 tons/hectare when it was alternated with elephant foot yam. Similarly, yield of elephant foot yam increased from 6.4 tons/hectare (continuous crop) to 11.8 tons/hectare (in rotation with tapioca). Further improvement in the yield of these crops was noticed in five year rotations. Among the intercrops, elephant foot yam and ginger were the most profitable. Besides giving higher net returns per unit area, intercrops genera*ted additional employment to the tune of about 130 mandays/hectare/year.

Gopalasundaram and Nelliat (1979) undertook a trial at Kasaragod during 1976 -78 to study the performance of upland rice in the rainy season as an intercrop in mature coconut stands. The variety 'Rohini' with a three year mean yield of 1,646 kg/hectare was found to be the most remunerative one among the three varieties tried.

Das (1989a) analysed the economic potentials of elephant foot yam and ginger as intercrops in coconut stands and found that under the 1988 factor-product price situation that prevailed in Kerala, coconut + elephant foot yam combination gave a net profit of Rs. 18,550/hectare/year and coconut + ginger system resulted in a net return of Rs. 14,350/hectare/year, while coconut sole crop under similar situation yielded a net return of Rs. 5,150/ hectare/year. Das and Vijayakumar (1990) have reported that under rainfed system, the Land Equivalent Ratio (LER) for coconut + ginger and coconut + turmeric were 1.56 and 1.41.

At Kasaragod, pineapple variety Kew was tried as an intercrop in coconut stands both under rainfed and irrigated conditions. The report indicated that both the number of fruits/hectare and the fruit weight were significantly higher in the irrigated plot compared to the rainfed one (KAU, 1979). Hegde *et al*. (1990) have reported a net return of Rs. 17,450/hectare/year for the coconut + pineapple cropping system under irrigation in

Kasaragod condition.

Economic evaluation of some of the promising coconut based farming system models was carried out at CPCRI with the 1988-89 factor-product costs to show the potential for resource maximization and enhancing net return from lands planted to coconut by adoption of farming systems approach (Das, 1990) Feasibility studies under rainfed coconut gardens involving different crop species and varieties as intercrops revealed that the tubers and rhizomatous crops were relatively more remunerative components in the systems than that of cereals, pulses and oilseeds. The economic potential in terms of net profit in the case of coconut + amorphophallus system was worked out as US $ 1160 /hectare/year and in the case of coconut + ginger system it was US $ 896 /hectare/year, while coconut monocrop under similar situation gave a net return of US $ 319. Another evaluation of the impact of coconut intercropping with cassava revealed greater returns to the resource management. Contrary to the general belief, the cassava intercrop was even beneficial to coconut, as plots with this intercrops resulted in marginally higher yields than the plots with coconut alone (Das, 1991a). Based on the economic situation of 1990-91, an additional net income of Rs. 8,168/hectare/year was realized from cassava intercrop alone. The advantage of cassava intercrop is that it yields a fairly good return for very few inputs. In other words, the income from cassava even under the coconut shade is sufficient to offset its cost of production. The combined income from the coconut + cassava cropping system was, therefore, found to be significantly higher than those realized from coconut monoculture.

Feasibility studies under rainfed situation involving different species and varieties of cereals, pulses, oilseeds, tubers and rhizomes revealed that under Kerala conditions the tubers and rhizomes are relatively more compatible and remunerative intercrops than that of other groups in coconut gardens (Das, 1991b). The economic potential in terms of net profit in the case of coconut + elephant foot yam system was estimated at Rs. 18,550/hectare/year, while it was Rs. 14,350 in the case of coconut + ginger system and Rs. 5,150 in coconut sole crop system. Among several feasible combinations under irrigation, one of the most promising systems is the integration of coconut + black pepper + cocoa + pineapple in an adult garden of above 20 years. The economic analysis suggests that this combination could generate a net return of Rs. 33,550/hectare/year, while the net return realization from an irrigated middle aged coconut monocrop is estimated at Rs. 23,200/hectare/year. The Benefit Cost Ratio (BCR) in this system comes to 1.76, the Internal Rate of Returns (IRR) is higher than 20% and the annual Net Present Worth (NPW) is Rs. 32,700.

The profitability of growing vegetables as intercrops in coconut gardens has been reported. at CPCRI, Kasaragod. The vegetable crops compatible with coconut were snake gourd, amaranthus, coccinia, brinjal, and bitter gourd (Hegde *et al*. 1990). The most remunerative combination was snake gourd-ridge gourd-amaranthus system (Rs. 22,217/ hectare/year). The introduction of the system resulted in generation of additional employment to the tune of 215 to 365 man days / hectare / year.

In a case study conducted on farmers' field by CPCRI (IPRI/COGENT project) it was observed that a farmer owning 0.88 hectare of farm with coconut as main crop where out of 110 coconut palms, 75 are in bearing stage, he has planted tapioca as intercrop in 0.5 acre, earning a profit of Rs 3,000. He has cultivated banana in 0.25 acre as another intercrop, accommodating 75 plants, which fetched him a profit of Rs 6,400. He had also cultivated okra and cowpea, earning a profit of Rs 1,000. On an average his additional income generated from intercropping was Rs. 10,000 to12,000/year. Besides he had also maintained 8-10 poultry birds for additional income. The intensive intercropping practices adopted by him are an indication of exploiting the opportunities available for enhancing income from coconut farming (Thamban and Arulraj, 2007).

4. Mixed cropping

Mixing cropping with perennials such as cocoa, pepper, nutmeg, cinnamon, coffee, betel vine, 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 at Kasaragod. Experiments conducted at CPCRI showed that it is possible to raise the yield of garden land through the introduction of mixed and intercropping. A hectare of land under coconut cultivation can generate a net income of the order of Rs. 5,000 even on plantations where the proportion of bearing trees in total is two thirds, provided optimal farming practices, including the use of fertilizers, are followed (Krishnaji *et al*. 1976).

Cocoa was introduced for commercial cultivation in India after experiencing success in field experiments as a mixed crop with coconut and arecanut at CPCRI during the early seventies. The analysis revealed that the net return from cocoa grown in the interspaces of coconuts amounts to Rs. 2,900/hectare/year. The coconut-cocoa system as a whole promises a net return of Rs. 16,500 hectare/ year as against Rs. 7,300/hectare/year in the case of rainfed coconut monoculture. In view of this, the interplanting of cocoa with coconuts was found to be a very attractive proposition (Das, 1987).

The cash flow analysis of the coconut based system was done for the period 1983 to 1997 involving banana, clove and pineapple (Sairam and Gopalasundram, 1999). The variable capital requirement for adoption of system ranged between Rs. 82,000/hectare during 1984-85 to Rs. 40,570/hectare during 1996-97.

A study of the cropping system model, initiated in 1983, in 1.2 hectares of coconut garden aged 18 years, to identify a suitable crop combination for maximizing the productivity per unit area of land, was modified in 1993 and continued to study the response of main and component crops to six different levels of fertilizers viz., control, one-fifth, one-forth, one-third, two-third and full dose of recommended fertilizers of main and component crops. The economic analysis of model under full dose of recommended fertilizers during 1998-99 revealed that the annual cost of cultivation was Rs. 52,000 per hectare and annual net profit was recorded at Rs. 89,086 (CPCRI, 2000).

Dhanapal *et al*. (2001) studied the advantages in coconut and arecanut based mixed cropping systems, using Land Equivalent Ratio (LER), Monetary Advantage (MA), Aggressivity Index (A) and Competition Ratio (CR). Coconut and cacao combination recorded a monetary advantage of Rs. 14,920 per hectare per year with an LER of 1.46. Under rainfed system, coconut and ginger gave a monetary advantage of Rs. 29,683 per hectare per year with a corresponding LER of 1.56. Coconut and turmeric recorded a monetary advantage of Rs. 16,483 per hectare per year with an LER of 1.41.

A field experiment was conducted at CPCRI, Regional Station, Kayangulam to study the impact of high density multi species cropping system in root (wilt) affected garden on productivity and economic viability. It is evident from the result that the system productivity was higher and there was increase in the yield of coconut from 30 nuts per palm per year (pre-experimental) to 75.8 nuts per palm per year during 2000-2001. The intercrops/mixed crops like banana, pineapple, pepper, nutmeg and tuber crops performed very well and provided additional yield and income. The higher Benefit: Cost ratio of 2.28 indicated higher additional return for the investment and higher positive Net Present Worth (Rs. 1,80,106/ hectare) indicated that high density multi species cropping system is economically viable in root (wilt) affected area. By adopting the system, there was stabilized income for coconut farmers even during lower price prevailing for the coconut (Maheswarappa *et al*. 2003).

Another field survey was conducted at Kannur district in 100 coconut holdings located in seven panchayats selected through simple random sampling for studying the coconut based farming system (CBFS). The selected respondents were post stratified according to land holding size as marginal, small, medium and large. Coconut monocrop, coconut + arecanut, coconut + pepper, coconut + banana with or without animal husbandry were the predominantly existing coconut based farming/cropping systems. The average realized net returns from different CBFS models under rain fed conditions varied from Rs. 20,000 to Rs. 40,000/hectare under rainfed conditions. The same in the case of irrigated conditions ranged from Rs.40, 000 to Rs.60, 000/hectare., (CPCRI, 2003).

5. Mixed Farming

In a study conducted by Jacob Mathew and Mohamed Shaffee (1979) on the mixed farming in coconut gardens, they put forth one of the main objectives to find out the economic viability of the system. Three milch animals of Jersey cross breed (first lactation) were handed over to a family which consisted of a man, his wife and children in September 1972. The family was staying in a semipucca house, within the experimental plot. Analysis of farm data showed that the returns to the farmer family for their labour and management were over Rs. 12,000 per annum, during the six year period, from a net area tof little over one hectare. The minimum returns received in any year were Rs. 8,500. A comparative analysis with a sole crop of coconut garden of 233 palms, under good management in rainfed condition, was made on the assumption that the yield from such a garden could be 60 nuts/palm/year. During the first four years, only 191 palms were assumed to be bearing and later all the 233. Cost of cultivation for monocrop of coconut garden was obtained from the research project on cost of production. Incremental costs incurred and benefits received by superimposing a mixed farming system in coconut garden were worked out. Overall cost-benefit ratio (incremental), for the six year period was 1: 1.28 and it was above unity, in all the years, showing thereby that this type of investment is sound.

A mixed farming programme consisting of cultivation of fodder grasses and legumes in the interspaces of coconut, maintaining milch cows and recycling of cattle wastes was studied at the institute at Kasaragod and Kayangulam (Sahasranaman *et al*. 1983). An evaluation of the economics of the system taking into accounts all the inputs and income from coconut and milk showed that mixed farming could increase per hectare income considerably. Employment potential also increased several folds due to the introduction of this system in coconut gardens. The cost accounting of the project show that by maintaining eight milch cows in 1.3 hectare under mixed farming practices, a profit of Rs. 6,693 was obtained in five years from dairy alone with a cost: benefit ratio of 1:1.06. But when the income from coconuts was also taken into account the profit went up to Rs. 18,064 with a cost: benefit ratio of 1:1.15. If the dairy work is done by the owner family the imputed cost: benefit ratio would be 1:1.37, providing the farmer family with employment worth Rs. 424 per month. The study at Kasaragod had the specific objective of finding out the economics of raising fodder grasses and legumes in coconut gardens along with milch cows by a farmer family having a small holding. The farmer maintained five Jersey cows in 1.04 ha coconut garden. Hybrid Napier was grown as fodder crop. The beneficial nature of the mixed farming was quite evident as yield of coconut increased by 18 per cent. The farmer who managed the operations of the project earned Rs. 43,944 in a four years period. The cost: benefit ratio in this case worked out to 1:1.50. Taking into account all the labour inputs for the project as compared to a pure culture of coconut, it was estimated that the annual employment potential increased from 150 man days/hectare to 1,000 man days by the introduction to mixed farming in coconut gardens.

In a study on economics of mixed farming in coconut gardens which include fodders (Hybrid Napier and Guinea Grass), training of pepper on coconut palm, growing vegetables and banana around farm house, rearing 5 units of milch cows and 30 units of rabbits recorded a net return of Rs. 14,500/hectare/year (Table 1). Since this system is highly labour intensive the total return to the family labour earning is estimated at Rs 35,000/ hectare/year. This system could be an ideal model for the self reliant small holder because of its high turn over and resource use efficiency (CPCRI, 1987).

Table 1. Economics of mixed farming in coconut gardens

Particulars	Rupees/hectare/year
Fixed cost	13,170
Variable cost	43,330
Total cost	56,500
Total return	71,000
Net return	14,500
Earnings by family labor	20,500
Total return to the family	35,000

(CPCRI, 1987)

An experiment was initiated in one root (wilt) affected coconut garden at CPCRI, Regional Station Kayangulam during the year 1983-84. Seventy percent of palms in the plot were affected by root (wilt) disease. All the disease advanced palms were removed and replanted with COD x WCT hybrid seedlings. Hybrid Napier grass was raised in the interspaces and pepper trained on all adult coconut palms. Five Jersey cows were also maintained in the system. The economic analysis (Table 2) of the system revealed that a gross return of Rs 51,352 could be raised with net profit of around Rs 12,000 per hectare (CPCRI, 1991).

In an experiment started during 1989 to study the economic viability of integrating fodder grass, cattle, poultry, rabbitry and pisciculture with coconut revealed that the total cost for maintaining the system was Rs.1,35,567 and the total return was Rs.1,66,712. The net return Rs 21,066 includes income realised from the sales of eggs, poultry, quails and rabbits (CPCRI, 1994).

Table 2. Input output analysis

Input		Output		
Item	**Cost (Rs)**	**Item**	**Yield**	**Value (Rs)**
Labour (758 mandays)	26,277	Coconut	9,684 nuts	25,858
Fertilizers	1,899	Milk	52,95 litres	23,726
Cattle feed	9,445	Pepper	50 kg	750
Electricity	625	Others		1,018
Others	2,622			
Total	**40,868**			**51,352**

(CPCRI, 1987)

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 (Maheswarappa *et al.*, 2000). 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.1,77,800 to Rs. 2,67,640 (Table 3). The cash flow analysis performed using a discount rate of 14 percent realized 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 (IRR) was 25.44 percent 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.

Table 3. Cash flow analysis of coconut based farming system

Year	Total cost (Rs.)	Total return (Rs.)	Discounted		
			Cost(Rs)	**Returns(Rs.)**	**Margin(Rs.)**
1989-90	130000	177800	114035	155965	41930
1990-91	127800	177480	98338	136565	38227
1991-92	149200	157890	100706	106571	5866
1992-93	153400	169140	90825	100144	9318
1993-94	169700	208270	88137	108169	20032
1994-95	171000	230230	77905	104890	26984
1995-96	189300	259830	75651	103838	28186
1996-97	195300	263850	68464	92495	24031
1997-98	160500	267640	49335	82301	32946
Total			763417	990939	
BCR				1.29	
NPW				227522	
IRR				25.44%	

(Maheswarappa *et al.*, 2000)

An experiment was initiated during July 1999 to study the sustainability and profitability of coconut based farming system comprising coconut, grass, dairy, poultry, sericulture and pisciculture. The output obtained from the system was 22050 coconuts, 12365 litres of milk, 546 kg of broiler birds, 90 kg fish, 1385 quail eggs, 500 kg of banana and an estimated biogas production of 500m^3 (CPCRI, 2004). Thus, the total revenue obtained from the system was Rs 2, 78,988. Coconut, milk and broiler's sale accounted for 95% of the revenue from the system. The total cost involved in maintaining the system was Rs. 1,75,015/-. The feed cost (poultry feed, cattle feed and fish feed) comprised 76% of the variable cost. The net return obtained from the system was Rs. 1,03,973/- (Table 5).

Table 4. Output and receipt from the coconut based farming system

Component	Output	Rs/annum
1. Coconut (@Rs 4 per nut)	22050	88,200
2. Milk (in litres)	12365	1,54,563
3. Broiler birds (in kg)	546	21,840
4. Quail eggs (no.)	1385	1,385
5. Fish (kg)	90	4,500
6. Banana (kg)	500	2,500
7. Biogas (m^3)	500	6,000
Total		**2,78,988**

(CPCRI, 1987)

In the case of coconut-based irrigated mixed farming system involving the production of fodder grass in the interspaces of palms, training pepper on coconut, maintaining cross-bred cows and rabbits and raising of subsidiary crops, it was observed that the net return from one hectare coconut block of 60-70 year age group could be as high as Rs. 29,500 per annum (Das, 1991). While the annual employment generations in one hectare rainfed coconut monocrop and irrigated coconut monocrop are assessed at 120 and 144 mandays, the same was estimated at 620 mandays in the case of rainfed coconut + ginger system, 335 mandays on coconut + pepper + coconut + pineapple mixed cropping system and 850 mandays in coconut based mixed farming system. In the traditional homestead farming in Kerala, the technical feasibility of coconut-based farming system is grossly misused, thus, the opportunities to maximise the economic gains per unit area, input and time are lost.

6. Conclusions and future research needs

In the evolving trade liberalization regime, sustaining coconut cultivation as a profitable enterprise is extremely challenging. Hence, the policies should focus more on competitiveness through higher productivity. One way to achieve this goal is through reduction in cost of production or in other words increases the net returns. There are possibilities of increasing the productivity and net returns from coconut gardens by raising compatible subsidiary crops and/or integrating with live stocks. The farming system models of CPCRI have conclusively proved that the scientifically designed coconut-based farming system is not only capable of generating higher income, but also employment potentials of smallholders. In a scientifically laid out coconut based farming, unlike the traditional ones, the resource use efficiency gets considerably enhanced from crop interactions in the system.

Since a large majority of the plantations are less than one hectare in extent, in developing the inter/mixed cropping system, the feasibility and economics including employment opportunities that may be generated and credit requirements for such intensive cropping systems and the size of the holdings should be carefully taken into account. Of the out lay in the initial establishment period, the investment on the intercrops alone becomes recoverable during the course of the year, as the response to inputs in coconut accrues only from the fifth year. This would mean that credit facilities are necessary for successful adoption of this intensive cropping programmes and realization of enhanced agricultural production.

Future research and development efforts should be initiated to understand and improve the existing status of the coconut based farming systems under different agro-climatic and socio- economic environments of all the coconut growing states. Since a vast majority of the smallholders pin their hope to homestead farming, research in this area needs better attention than what is given to it now, at least from the socio-economic considerations. Further strengthening of on-farm-research should also be the correct approach for the transfer of technology on farming system as the component technologies could be evaluated in the field and recommended for adoption by the coconut growers. It is however; often felt that much could be achieved by improving institutional credit supply position and guaranteeing remunerative prices for the agricultural commodities including coconut products.

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Effective transfer of technology for enhancing adoption of coconut based cropping/farming systems

C. Thamban

Introduction

Coconut plays a pivotal role in the agrarian economy of many states in India. It is predominantly cultivated in small and marginal holdings. Majority of these holdings do not generate sufficient income to meet the family requirement. In the present era of globalised economy and free trade agreements coconut growers are more exposed to economic risks and uncertainties owing to the high degree of price fluctuations. The prevailing price fluctuations in coconut and coconut products have been in progress for the last three decades and the monoculture systems of coconut ranks very low in productivity and economic returns compared to other croplands. In this context, it is needless to emphasize the importance of crop diversification in coconut gardens. The main concept behind the coconut based farming system is the resource use intensification in order to attain a socio economic stability (Nair, 1976).

The agronomic feasibility and economic viability of adoption of coconut based farming systems have been amply demonstrated in research stations and farmers' fields. The rationale for adoption of coconut based farming systems is that the same land can simultaneously and profitably be used to produce other compatible crops and live stock enterprises such that productivity of land is increased. It is also regarded as a simple but effective diversification strategy that can minimize the risks associated with over dependence on one type of commodity.

2. Extent of adoption of coconut based farming systems

In spite of the obvious benefits of CBFS over the traditional monoculture, the extent of adoption of the recommended cropping systems is not at a satisfactory level. It was observed that only 24 per cent of the coconut growers adopted inter/mixed cropping practices (Sud *et al.*, 2004). The degree of crop intensification varied widely across the farms. A study conducted in farmers' field in Kozhikode District of Kerala State revealed that pepper and banana were the most frequently observed component crops in the CBFS models. About one third of the CBFS holdings were integrated with dairy enterprise (Thamban *et al.*, 2006). Local varieties are mostly cultivated in crops like ginger, turmeric, colocasia, elephant foot yam and other intercrops in the CBFS. Farmers used different types of organic manure to coconut palms and component crops in the CBFS. Most of the farmers applied them annually. The study also revealed that the level of adoption of recommended dose of chemical fertilizers was very low in the CBFS. Vermicomposting of the biomass available in the CBFS was adopted by only four per cent of the farmers in the study area. The extent of adoption of crop protection measures was quite low. Similarly, the level of adoption of post harvest processing technologies available for coconut and component crops for value addition was also very poor.

3. Constraints in the adoption of CBFS

The above study also revealed that low price of agricultural produce is the most important constraint experienced by farmers in the adoption of CBFS, followed by pest and disease problems and lack of labour and high wage rate. Lack of availability of organic manures and their high cost is another problem adversely affecting the sustainability of CBFS. Farmers also perceived great difficulty to procure good quality planting materials, especially of various inter/mixed crops for the CBFS. Hence, it is imperative that efforts are to be made to formulate and implement schemes to promote adoption of farming systems rather than crop specific schemes. Intensive participatory technology transfer programmes are to be implemented for enhancing the adoption of various crop/enterprise management technologies to increase the techno-economic efficiency of the existing CBFS models in farmers' field.

4. Role of transfer of technology

Lack of adoption of scientific cultivation practices has been stated to be one of the important reasons for low productivity of coconut. Despite all the sincere efforts, the extent of adoption of the available technologies at the cultivator's level is not that satisfactory. Studies conducted at CPCRI show that even in a state like Kerala in India which boasts of 100 per cent literacy, there still exists a situation where many farmers do not possess sufficient knowledge about the available technologies for enhancing the production and productivity of coconut. A comparison between the best managed gardens and national average of productivity of coconut will reveal the fact that there still exists a wide gap between the technologies generated and their utilization by the growers, especially in small holdings (Rajagopal *et al.*, 2004).

The low level of technology utilisation at farmers' fields calls for formulating effective extension strategies suitable to the heterogeneous farming situations in coconut cultivation. Various programmes are implemented by research and development agencies on a regular basis as part of the efforts to disseminate the research results among the cultivators. The important transfer of technology activities for coconut development implemented by CPCRI include training programmes, Front Line Demonstrations (FLD), Research-Extension-Farmer

Interface facilitated through Cyber Extension Programmes, information communication through mass media like radio, television, newspapers and farm magazines, extension pamphlets, CD ROMs, video cassettes etc., arranging exhibitions, seminars, Kisan Melas and group meetings, providing consultancy through field visits and replying postal queries etc.

5. Training programmes

A substantial number of appropriate technologies relating to production, protection and processing of coconut have been evolved at various coconut research institutes. To be meaningful, the technologies generated at the research stations should reach the ultimate users, the farmers. On campus/off-campus training programmes for farmers and extension personnel on specific topics related to coconut based farming systems form an important component of Transfer of Technology (TOT) programmes to enhance their knowledge and skill for better technology utilisation. A study on the effectiveness of training programmes revealed that the efforts by CPCRI for organising the training programmes on coconut based farming systems for the extension personnel were highly successful in achieving the objectives as indicated by the high training effectiveness index (TEI) values obtained for these training programmes (CPCRI, 2000).

6. Front Line Demonstrations

Demonstration is a very effective method of TOT in a community. It is a group method of extension usually conducted to educate and motivate groups of farmers. Demonstration may stimulate farmers to try out innovations themselves, or may even replace a test of the innovation by the farmer. A great advantage of demonstration is seeing how an innovation works in practice. Demonstrations to be effective should be integrated with the total extension programme. Result demonstration attempts to motivate the people for adoption of a new practice by showing its distinctly superior result. FLD of various improved coconut production technologies with the active participation of farmers has been proved to be an effective method of TOT for improving the yield and income from coconut farming. CPCRI has been organizing FLD in farmers' field on different coconut cultivation technologies. Such demonstration programmes have proved to be effective in convincing the farmers about the technical feasibility and economic viability of the technologies. Further, these demonstration programmes have multiplier effects in the dissemination of recommended technologies among cultivators at large. In the FLD at CPCRI Kasaragod, the observations on yield of coconut revealed an increase in productivity of palms from a pre-demonstration yield of 95 nuts per palm per year under mono crop situation to 122 nuts per palm per year in coconut based High Density Multi Species Cropping System

(CPCRI, 1998). In the FLD on High Density Multi Species Cropping System in the root (wilt) affected coconut garden at CPCRI Kayangulam, on an average the coconut palms recorded an increase in yield of 23 to 65 per cent (CPCRI, 2000).

7. Group management approach for enhancing income from coconut farming

One of the major causes for low production and productivity of coconut in regions like Kerala in India is the fragmentation of holdings with little or no resource with the owner farmers for the efficient utilization of these holdings. The fragmented holdings don't render themselves viable for the optimum utilization of resources and the adoption of improved technologies by the cultivators. To augment the income from such small and marginal holdings it was suggested to have group management of resources that helps to overcome the inherent weaknesses of the fragmented holdings. Group approach helps to overcome the limitation of small size of holding in utilizing resources and improved technologies and also provides opportunities for better social integration among farmers. In Kerala, the State Department of Agriculture initiated programmes for organising coconut growers to form groups at grass root level through the formation of Kera Vikasana Samithies (coconut development committees) since 1989. Under the Comprehensive Coconut Development Programme (CCDP) group approach was promoted to implement coconut based interventions in farmers' field. Apart from the group management of resources these farmers group can be effectively utilized for organising educational programmes for the benefit of the member cultivators. Moreover these groups can act as an effective link between various systems engaged in the technology generation and dissemination (Thamban, 1999).

8. Community Based Organisations (CBOs) for income generation in poor rural communities

Livelihood of a substantial number of families in rural poor communities in countries like India depend on coconut farming. Many a times, the income generated from coconut farming in small and marginal holdings does not provide enough for meeting the requirements of such families. Technology options for enhancing income from coconut farming in such poor rural communities do exist, but not fully realised in field situation. A project sponsored by IPGRI for developing sustainable coconut based income generating technologies in poor rural communities was implemented during the period 2002-04 by CPCRI in two selected coconut communities at Pallikkara in West Coast region and Ariyankuppam in East Coast region. One of the important strategies for implementing the project was growing suitable inter/mixed crops in coconut gardens and integrating animal husbandry and other subsidiary enterprises with coconut farming to enhance the yield and income.

The implementation of the strategies envisaged in the project was routed through Community Based Organization of coconut growers in the selected communities. Micro-credit facility was extended to farmers for introducing various interventions. Participatory analysis of the coconut farming scenario in the community was undertaken by the team of scientists and farmers under the CBO to design the technological interventions to be implemented. A close linkage was developed between the CBO and scientists from CPCRI for the effective implementation of interventions. Arrangements for procuring planting materials, inputs and organizing training programmes on CBO management and relevant technologies were done through the CBO with close collaboration with CPCRI and other agencies. Monitoring and evaluation of the interventions implemented in farmers' field were done through CBO. The net income from the coconut farming could be substantially increased through the technology interventions related to CBFS introduced in the communities (CPCRI, 2004).

Under the IFAD Project on "Overcoming Poverty in Coconut-Growing Communities: Coconut Genetic Resources for Sustainable Livelihoods in India", implemented during 2006-08 by CPCRI in three coconut communities in Kerala viz., Pathiyoor, Thodiyoor and Devikulangara also the approach involving CBOs of coconut growers was successfully adopted. Intercropping in coconut-based homesteads was one of the major interventions under the project. Apart from the household level income enhancement, the other benefits of the project were the conserved genetic resources, enhanced food security and nutrition, improved social status and self esteem of the farmwomen (CPCRI, 2008).

This innovative extension methodology is being adopted for the implementation of other similar projects also. Under the project on 'Cluster approach among coconut farming community for improving productivity and income from small and marginal coconut based homesteads' in the root (wilt) affected coconut area the farm family members of 25 hectare area clustered together for deciding the farm strategies; both individual and group ventures for improving productivity and income. The average yield of coconut was doubled after technology package implementation for three years. The cluster approach has been scaled up by other agencies like Coconut Development Board (CDB) among coconut farming communities through their development schemes. The scheme on "Integrated Farming for Productivity Improvement on cluster basis" is being implemented by the Board on cluster basis in a contiguous area of appropriate size of 25-50 ha irrespective of the individual size of the holdings. The selection of the cluster is based on criteria such as demonstration value, easy accessibility, availability of minimum infrastructure facilities for the adoption of average management practices, cohesiveness of the group and most importantly the readiness of the farmers in the cluster to assume responsibility and implement the programme in a farmer participatory mode as per the Board's guidelines.

The National Agricultural Innovation Project (NAIP) on ‘Value chain in coconut’ being implemented by CPCRI since 2008 also employs a similar strategy for the implementation of the technological interventions related to CBFS for coconut in ten coconut clusters of 25 ha each in Kasaragod District in Kerala State through the formation of CBOs of coconut farmers.

9. Farmers’ participation in coconut research and extension

The extent of adoption of available technologies in coconut is not at a satisfactory level, as has been discussed earlier. And it is generally assumed that the main factor hindering adoption of technology is the farmers’ lack of information regarding appropriate techniques for improving his farming. This may indeed be a case in some situation but in most of the situations the fact behind the low acceptance of technologies may be that the technologies are not economically viable, not technically feasible, not matching with the farmers needs and not compatible with the farmers’ overall farming system. In the farmer participating technology generation efforts, conducting on farm trials are to be envisaged wherein trials are conducted in the fields of participating farmers who will be allowed to manage the trials by themselves in collaboration with researchers and extension agencies. Farmer participation in agriculture technology development and dissemination should begin from diagnosis to planning and designing technological solutions, to implementation, to evaluation and feedback into dissemination. On the above lines, ICAR implemented a project for Technology Assessment and Refinement under National Agricultural Technology Project.

Institution Village Linkage Programme (IVLP) was a novel farmer participatory programme for technology assessment and refinement to enhance technology utilisation at farm level. CPCRI, Kasaragod implemented IVLP in selected areas with coconut as one of the important crops in the production systems of the villages. Using various PRA and RRA tools and techniques, activities like a detailed agro-ecosystem analysis of the selected village, diagnosing the problems of coconut based production systems and prioritizing these; identification of technological interventions based on problem-cause relationship; the development of action plans and their implementation and detailed socio-economic evaluation including farmers reaction and perception about the interventions were carried out under the project. Implementation of the project revealed the effectiveness of participatory approach in the performance assessment of various coconut production technologies including inter/mixed cropping in coconut garden (Thamban *et al.*, 2004).

10. Decentralised planning and participatory approach

In Kerala State, agriculture sector has been given due importance under the decentralized planning programme implemented since the ninth plan period onwards. Under the people's plan programme, 40% of the grant-in-aid allotted to the local bodies was set apart for implementing projects in production sector. Accordingly, various interventions in farming sector were taken up by local bodies with the active participation of farmers to solve location specific problems. Taking into account the scope for implementing interventions to enhance income from coconut cultivation through the adoption of various CBFS, some grama panchayats have implemented schemes under the decentralised planning programme to encourage intensifying CBFS activities.

The case study conducted by CPCRI on experiences of implementing the scheme on intercropping in coconut garden under decentralised planning programme in Peralassery grama panchayat indicated that the implementation of the scheme was successful in creating awareness about the importance of taking up intercropping in coconut gardens for enhancing the income. There is inherent limitation due to the high palm density in the fragmented holdings rendering the coconut gardens unsuitable for crop intensification. Hence, farmers suggested formulating programmes for restructuring the homesteads for optimum palm density for higher productivity from CBFS (Thamban and Muralidharan, 2006). Farmer participatory approach for planning and implementation of location specific schemes to popularize inter/mixed cropping in coconut gardens has to be strengthened under the decentralized planning programme to enhance income from coconut farming especially among small and marginal farmers.

11. Research-Extension-Farmer Interface facilitated through Cyber Extension Programmes

Cyber extension include effective use of information and communication technology (ICT), national and international information networks, internet expert systems, multimedia learning systems and computer based training systems to improve information access to the farmers, extension workers, research scientists and extension managers. CPCRI has been implementing various cyber extension activities as part of strengthening the technology transfer programmes of the Institute especially on CBFS.

11.1. Group video conferencing system: As part of the cyber extension activities, a group video conferencing system through ISDN was installed at the ATIC, CPCRI, Kasaragod to facilitate interaction between various stakeholders for enhancing technology utilization in coconut, arecanut and cocoa. The video conferencing facility can be effectively utilized for scheduling and implementing interface programmes at regular intervals involving various stakeholders including researchers, extension personnel, farmers and entrepreneurs. Coconut Development Board (CDB) also has installed video conferencing systems in different centers in Assam, West Bengal, Andhra Pradesh, Tamil Nadu, Orissa and Karnataka. Collaborative programmes are being implemented with CDB for facilitating technology transfer utilizing the facilities located in different coconut growing tracts of the country. Collaborative programmes are also being conducted with other ICAR Institutes and agencies such as State Agricultural Universities, State Agri/Horti Departments, NGOs like MSSRF and farmer organizations to implement IT enabled technology transfer programmes in coconut, arecanut and cocoa under the cyber extension project. Of late, CPCRI has also initiated field-based videoconferencing utilizing Wi-max connectivity provided by BSNL for strengthening the Research-Extension-Farmer interface. The formal launching of this facility was done during the International Conference on Coconut Biodiversity for Prosperity (ICCBP) held at CPCRI, Kasaragod. CPCRI web site (www.cpcri.gov.in) and other services provided by CPCRI for the benefit of farmers also form a part of the cyber extension activities of the Institute. Arrangements have been made for answering querries from farmers, extension personnel and entrepreneurs on different aspects of production, protection and processing of palms and cocoa through e-mail. CD ROMs as interactive software packages on different technologies of production, protection and processing of palms and cocoa are also being produced and distributed as part of the cyber extension project. Besides the above, an IT enabled kiosk has also been installed at CPCRI Kasaragod to provide information in English, Hindi and regional languages about various technologies evolved at the Institute and also various services offered to farmers and entrepreneurs.

12. Strengthening research-extension-farmer linkage in coconut sector

As has been already described, there are various agencies both from research and extension systems striving for the development of coconut. Invariably some overlaps do occur in their functioning. But taking into account the enormous number of farm families with small holdings, the duplication will only have a multiplier effect in dissemination of technologies for enhancing coconut production. For better impact, the extension activities of the research and extension/ development agencies are to be co-ordinated at different levels. Technology dissemination process will be accelerated if concerted efforts are made by the different agencies having proper co-ordination among them. The experiences of CPCRI in implementing the interface programme to strengthen the research-extension -farmer linkage in coconut sector indicate the relevance of strengthening this important aspect in the coconut sector.

Interface programme for coconut is an approach for strengthening the transfer of technology efforts for the development of coconut sector in Kerala state. In this approach, the research and extension personnel and farmers are brought in a common platform to streamline activities for the sustainable development of coconut. The programme was implemented during the year 2001-02 and 2002-03. Thematic sessions relating to crop improvement, crop production, crop protection and post harvest processing technologies were included in these interface programmes, in which scientists from CPCRI and KAU, extension personnel from Department of Agriculture and Commodity Boards, people's representatives and selected farmers participated. CBFS was one of the important subject matter areas covered in the interface programme. The results of impact analysis indicated the effectiveness of the interface programmes in enhancing the awareness and knowledge about the technologies for improving coconut productivity and income of farmers (Rajagopal *et al.*, 2004).

13. Conclusion

The agronomic feasibility and economic viability of adoption of coconut based farming systems have been amply demonstrated in research stations and farmers' fields. In spite of the obvious benefits of coconut based farming system over the traditional monoculture, the extent of adoption of the recommended cropping/farming systems is not at a satisfactory level. Hence, intensive participatory technology transfer programmes are to be implemented for enhancing the adoption of various crop/enterprise management technologies to increase the techno-economic efficiency of the existing Coconut Based Farming System models in farmers' field.

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