Arecanut Based Cropping/Farming Systems

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FOREWORD

Arecanut (*Areca catechu* L.), a plantation crop, grown for betel nuts in Asia, is a source of livelihood of nearly 16 million people in India, and a crop of small and marginal farmers. Efficient utilization of resources assumes much significance. Sustainability of perennial crop like arecanut can be achieved through adoption of cropping system approach. The system not only provides better profitability but also hedges the farmers against volatile price behaviour of nuts. The plantation provides 30% of area, 16% of air space, and permits 40% of PAR to penetrate, thus gives scope for accommodating several component crops. The Central Plantation Crops Research Institute has successfully evolved many remunerative arecanut based cropping system models suitable for different agroclimatic conditions. Experimental results indicated that cocoa, black pepper, banana, vanilla, medicinal and aromatic plants, vegetables and flower crops are ideal mixed / inter crops in arecanut plantation and such inter/mixed crops have improved soil fertility status apart from increased productivity and income per unit area.

The book **"Arecanut based cropping/farming systems"** is a comprehensive review of the work done on all aspects of arecanut based cropping/farming system. I am sure the book will be of much use to all the stakeholders. I compliment the authors for their efforts in compiling the information together and packing it for the use to benefit the farmers and researchers.

(H.P. SINGH)

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Arecanut palm : crop scenario and relevance of cropping systems

George V. Thomas and D. Balasimha

The arecanut palm, *Areca catechu* L., belonging to family Palmae is a traditionally important plantation crop of India and is the source of arecanut commonly referred to as betelnut or *supari*. It is used in Indian and other South East Asian countries as a masticatory and forms one of the ingredients of betel quid. Arecanut industry forms the economic backbone of nearly ten million people in India and for many of them it is a sole means of livelihood. It is a crop of small and marginal farmers in the major arecanut growing states of Karnataka, Kerala and Assam.

1. Importance

Being grown in the hot and humid regions of the world, the palm has commercial, economic, religious, cultural and medicinal importance. It contributes substantially to the Gross National Product as the palm is cultivated in India in 3,96,800 ha with a production of 5,59,200 tonnes during 2006-07 (Anon., 2008). The nut is chewed either alone or in combination with betel leaves (*Piper betle* L.) or 'pan', lime, tobacco, camphor, which is locally called 'Tambula' or betel quid. Chewing increases production of saliva, gastric juices and strengthens gums. Traditionally betel nut and betel leaves are offered in religious functions.

In addition to this, other parts of the palm are also used for various purposes. The leaf sheath is used to make throw away cups and plates and it is also used to grow mushrooms. The other uses include use of leaf sheath in manufacturing ply wood, tannin extracted from the immature and mature nuts in leather industries for colouring and the trunk in construction works.

2. Area and Production

The world arecanut area was 3.0 million ha in 1960-61 which increased to 5.97 million ha in 2000-01 and to 7.03 million ha in 2005-06. The major arecanut growing countries are: India, Sri Lanka, Bangladesh, Malaysia, Indonesia and Philippines (Table 1). India leads the world in production with a share of 55%, followed by Sri Lanka and Bangladesh. Production trend showed sharp increase from 2.14 mt in 1960-61 to 7.08 mt in 2000-01 and 8.54 mt in 2005-06 (Table 1). The productivity trend (kg/ha) shows that other countries like China (2885), Sri Lanka (2056) and Myanmar (1583) have higher productivity than India (1268).

Table 1. Area and production of arecanut in countries

Country	Area ('000 ha)			Production (MT)			Yield (kg/ha)		
	1960-61	2000-01	2005-06	1960-61	2000-01	2005-06	1960-61	2000-01	2005-06
Bangladesh	82.60	77.80	78.0	62.99	47.0	55.0	762	604	705
China	0.62	51.03	52.0	3.71	165.1	150.0	5984	3235	2885
India	135.0	315.2	381.1	120.00	373.1	483.1	889	1184	1268
Indonesia	65.00	102.02	124.9	13.00	45.6	51.9	200	447	415
Malayasia	6.00	1.5	0.8	6.50	2.5	1.3	1083	667	1625
Maldives	0.003	0.05	0.04	0.001	0.04	0.33	333	740	8325
Myanmar	11.33	34.98	36.0	8.00	51.5	57.0	706	1471	1583
Thailand	-	14.0	16.0	-	23.0	27.0	-	1643	1668
Sri Lanka	-	-	11.97	-	-	24.6	-	-	2056
Nepal	-	-	2.02	-	-	3.9	-	-	1909
World	300.55	596.6	702.9	214.21	707.9	854.2	713	1187	1215

(Source: FAO, 2007)

During the last 45 years (1961-2006), the area under arecanut cultivation increased by four times while production increased by eight times in India. The productivity increase was not substantial. The increase in production was mainly due to increase in area (Table 2). Major share of area under arecanut cultivation is by three states Karnataka, Kerala and Assam (89%) in 2002 and 86% in 2006. The area is increasing in other states also in recent years. The major share of production was from Karnataka, Kerala and Assam (84%) in 2002 which was reduced to 71% in 2006. This may be due to the area increase in other states (Table 3). More than 16 million people in different parts of the country, particularly those in Karnataka, Kerala and Assam are dependent on arecanut industry for their living.

Table 2. Trends in area, production and productivity of arecanut in India (at five yearly intervals since 1956-57 to 2006-2007)

Year	Area (ha)	Production (tones)	Productivity (kg/ha)
1956-57	94,800	74,700	789
1961-62	1,16,830	95,170	816
1966-67	1,42,100	1,30,100	916
1971-72	1,73,800	1,47,100	846
1976-77	1,70,700	1,65,100	967
1981-82	1,82,600	1,93,100	1061
1986-87	1,76,300	2,09,400	1188
1991-92	2,20,400	2,43,200	1103
1996-97	2,61,200	3,07,700	1178
2001-02	3,40,900	4,03,100	1182
2006-07	3,96,800	5,59,200	1409

(Anon., 2008)

Table 3. State wise area, production and yield of arecanut (Area - '000 ha; Production - '000 tonnes; Yield - kg/ha)

State	2002-03			2006-07		
	Area	Production	Yield	Area	Production	Yield
Andhra Pradesh	0.3	0.2	667	–	–	–
Assam	73.7	51.6	700	71.0	65.0	915
Goa	1.6	2.5	1563	1.7	2.6	1529
Karnataka	144.1	192.8	1338	168.0	224.0	1333
Kerala	97.5	107.3	1101	102.0	110.0	1077
Maharashtra	2.0	4.0	2000	2.3	3.6	1565
Meghalaya	11.2	14.2	1268	12.0	16.6	1383
Mizoram	1.7	5.7	3353	2.0	5.3	2650
Nagaland	0.2	1.3	6500	0.2	1.3	6500
Tamil Nadu	5.0	5.3	1065	5.5	11.9	2164
Tripura	3.4	6.9	2029	3.4	6.9	2029
West Bengal	9.1	16.6	1824	24.4	106.1	4348
Andaman & Nicobar Islands	4.4	7.4	1682	4.1	5.8	1415
Pondicherry	0.1	0.1	1000	0.3	0.1	1000
All India	354.3	415.9	1174	396.8	559.2	1409

3. Growing conditions

The cultivation of arecanut is mostly confined to 28° north and south of the equator. It grows well within the temperature range of 14°C and 36°C and is adversely affected by temperatures below 10°C and above 40°C. Due to its susceptibility to low temperature, the palms also do not come up at an altitude of more than 1000 m MSL. Even though major area under arecanut is in gravelly laterite soil of red clay type, it can also be grown in fertile clay loam soils. Sticky clay, sandy, brackish and calcareous soils are not suitable for areca cultivation.

4. Production constraints

In arecanut cultivation, long pre-bearing period, poor adaptability to waterlogging and water limiting situations are important. Arecanut is predominantly grown in acidic laterite soils characterized by heavy rainfall leading to deficiency of N, Ca and K, rapid depletion of organic matter, low CEC, presence of kaolinite clay mineral, P fixation, newly emerging nutrient disorders, low productivity and less income. Arecanut farmers adopt closer planting which when coupled with interplanting with improper input management leads to reduced productivity. In view of these constraints, cropping/farming system approach is indispensable to tackle these problems.

5. Relevance for cropping systems

Cropping/Farming system would be highly effective in providing balanced food, regular employment, sustaining soil health, mitigating aberrant weather situation and in increasing the farm productivity and income. Farming systems research is an approach to agricultural research that attempts to deal more effectively with problems of complex, marginal, diverse and risk prone agriculture. As the price fluctuations in arecanut is very wide, often the income derived from the small holdings are not adequate to meet the livelihood requirement of farm families. Limitation of the land for agriculture is another factor pointing to the need for utilization of interspaces for growing other crops. The palm has a long pre-bearing period and the farmer do not get any income from his garden during this period. Utilization of natural resources such as land, sunlight and air space is at a low level in arecanut mono crop plantation. In an adult arecanut garden planted under recommended spacing of 2.7 x 2.7 m, the total area covered by roots is only 2.27 m^2 and 68.9% of area is not effectively utilized (Sham Bhat and Leela, 1969). Hence, arecanut garden offers excellent opportunities for growing wide range of crops including annuals, biennials and perennials in interspaces to enhance the productivity per unit area, time and inputs by more efficient utilization of resources like sunlight, soil, water and labour.

In cropping systems all the management practices and component of production systems should be selected in such a way to achieve high productivity, profitability and sustainability of the existing plantations by maximizing the economic yield of the farm. Sustainability is achieved in cropping system by optimization of production process through efficient utilization of the inputs and improving soil fertility parameters and safeguarding the environment.

6. Development of viable cropping systems

Research efforts taken up by CPCRI over the several decades resulted in the development of viable cropping system models to enhance the productivity and profitability. The selection of crops is very important to achieve success in the development of cropping systems. Crops should be selected according to soil type, rainfall pattern, irrigation facilities, age of the main crop and the availability of solar radiation. The root stem of the crops should exploit different horizons of soil and crops should not be more susceptible than main crop to diseases they have in common. The availability of marketing and processing facilities for intercrops and labour availability are the other criteria for crop selection and development of successful farming systems.

Intercropping refers to the cultivation of annuals and biennials in the cropping system. The annuals evaluated in different location include paddy, sorghum, cowpea, vegetables, yams, corn, ginger, turmeric, banana and pineapple. Mixed cropping refers to the cultivation of perennials in the interspaces. The important perennial crops evaluated include cocoa, spices, medicinal and aromatic crops. High density multi species cropping system refers to growing a large number of crop species at high densities to achieve maximum resources efficiency and to meet diverse needs of the farmers (Bavappa *et al.*, 1986).

Crops and cropping system for the different agro-ecological regions of the country have been developed by conducting field experiments at CPCRI Regional Station, Vittal and Research Centres at Hirehalli (Karnataka), Palode and Kannara (Kerala), Kahikuchi (Assam) and Mohitnagar (West Bengal). Intensive research has been undertaken in a multidisciplinary mode in different cropping systems.

7. Benefits of cropping systems

Cropping system approach enables to address the food and nutritional security through inclusion of crops such as cereals, root crops, legumes, fruit crops, vegetables and spices. Employment generation is considerably improved due to crop diversification and intensification. Cropping systems contribute to improvement in ecosystem services provided through increased carbon sequestration, water infiltration and moisture retention and prevention of soil loss by run off. Synergistic and complimentary interactions are also reflected in augmented plant beneficial microbial communities, function specific minerals and nutrient transformations. The productivity and profitability increase contribute to the benefit of the farming community to enhance the returns from unit area of plantations.

8. Opportunities

The work done by CPCRI at its research centres has given choice of crops to be grown with arecanut in a cropping system mode. However, the crops should be selected based on the regional requirements. New crops are being added to this list every year to increase the choice for arecanut farmers. This will enhance the productivity and income per unit area per unit time and farmers will be benefitted through this. Adoption of cropping system has improved the soil fertility status and helped farmers to move towards organic farming through organic matter recycling from the system.

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Arecanut based inter and mixed cropping systems

S. Sujatha, Ravi Bhat, D. Balasimha and S. Elain Apshara

Introduction

Arecanut (*Areca catechu* L.) is essentially a crop of small and marginal holders with low productivity and insufficient income to sustain dependent families. Production and profitability of arecanut is undergoing significant changes during the last decade due to recurrent problems like erratic rainfall, pests, diseases and price fluctuations. The practice of well planned and executed inter/mixed cropping is fundamental for increasing the productivity and income per unit area under these conditions. The research work towards the same was being done at Central Arecanut Research Station and is being done at Central Plantation Crops Research Institute since 1950s. However, upgradation of existing technologies to develop highly productive, remunerative and farmer friendly cropping system is of prime importance. It becomes necessary to grow value added and export oriented inter/mixed crops in this era of WTO as arecanut has limited alternative uses and export potential.

The sustainability of soil health is most important in plantation belt as these crops occupy land for decades. Arecanut plantations are mostly concentrated in laterite soil belt, which have inherent soil constraints such as water logging, water stress, leaching of nutrients due to heavy rainfall and low CEC. Inter/mixed cropping in arecanut gives ample scope to overcome the soil, weather and crop constraints by improving resource use efficiency. The beneficial effects of crop combinations, agrometeorology, fertility management, rhizosphere microorganisms, light use efficiency etc., should be considered to develop suitable crop combinations with arecanut. Shama Bhat (1974) stressed the importance of intercropping as a source of additional income during off-season and also as a safeguard against the uncertainties of returns from monoculture gardens. According to Muralidharan (1980), initial period of 5-6 years is ideal for growing annual and biennial crops. In later years, mixed cropping with other shade tolerant crop species is advocated by several workers (Abdul Khader, 1982; Nair, 1982; Nayar *et al.*, 1985; Shama Bhat, 1988; Balasimha, 2004; Sujatha *et al.*, 2006; CPCRI, 2009). The review on inter/mixed cropping in arecanut showed ample evidence for maximum resource use efficiency and generation of supplemental income from the plantations (Muralidharan, 1990; Balasimha, 2004; Balasimha *et al.*, 2006). In this chapter, comprehensive and updated review of research work done on inter/mixed cropping in arecanut at CPCRI for last five decades is attempted.

2. Scope for inter/mixed cropping in arecanut plantation

There is ample evidence to show that arecanut as a sole crop does not utilize the natural resources such as soil, space and light fully (Shama Bhat and Leela, 1969; Muralidharan, 1980; Balasimha, 1989). The microclimate existing in the arecanut garden is expected to be congenial for intercrops. First studies on the climatic variables in pure arecanut gardens were made by Abdul Khader (1983). The evaporation during January to May was lower in arecanut garden than in the open. This is expected because of lower evaporative demand in the arecanut garden. Arecanut plantation maintains high humidity which, in turn, favours excellent growth of shade loving crops. Lower radiation reaching ground in cropping systems lowers air temperatures leading to increased humidity in the garden.

Rooting pattern revealed that arecanut palms planted at a spacing of 2.7 x 2.7 m could use only 30% of the land area and cultural operations are also confined to 75 cm radius from the base of the palm (Shama Bhat and Leela, 1968). About 61% of all the roots and 51% of fine roots are concentrated within a radius of 50 cm from the trunk of the palm (Table 1, Shama Bhat and Leela, 1969). Thus, the arecanut palm exploits only 2.27 m^2 of area out of 7.29 m^2 land area available to each palm. Recent studies with adoption of better management practices indicated that arecanut roots are concentrated within 50 cm distance and depth from the base of the palm and utilize only 40% of the land space (Table 2, Bhat and Sujtha, 2008).

Table 1. Distribution of arecanut roots planted at a spacing of 2.7 x 2.7m

Distance from the trunk (cm)	% total roots	% fine roots
26-50	61.3	51.3
51-75	19.2	23.2
76-100	8.4	9.9
101-125	6.1	8.4
126-150	5.0	7.2

(Source: Shama Bhat and Leela, 1969)

Table 2. Root distribution of arecanut palms as influenced by drip fertigation, basin and sprinkler irrigation methods

Parameter	100% NPK fertigation	75% NPK fertigation	50% NPK fertigation	100%NPK soil appli– cation + drip	Basin irrigation	Sprinkler irrigation
Maximum rooting length (cm)	135	144.5	128	115	121	127
Maximum rooting depth(cm)	136	116	101	117	78	77
Total root weight (kg/palm)	8.23	7.99	4.84	5.28	3.25	3.94
% of fine roots	34	37	43	33	22	21
% of total roots within 50 cm distance and depth	87	87	83	83	100	97

(Source: Bhat and Sujatha, 2008)

The orientation and structure of arecanut canopy permits 32.7- 47.8% of incident radiation to penetrate down to the ground depending on spacing of arecanut. It was further reported that light interception varied between 57 to 64% in arecanut planted at 2.7 x 2.7 m, while it went up to 97.2% with the presence of intercrops (Muralidharan, 1980). The review by Balasimha (2004) indicated that only 43% of light is intercepted by arecanut monocrop, while it can be increased to 95% with mixed crops. About 30 to 50% of PAR is transmitted through the arecanut canopy (Balasimha and Subramonian, 1984; Balasimha, 1989). The interception of the remaining radiation depends on the nature of intercrop canopy and leaf area index. Balasimha (2006) observed that cocoa intercepted 98% of the light once the canopy fully develops compared to 76.5% at the initial years. For example, cocoa with compact canopy and more leaf area intercepts nearly 90% of available light. Black pepper which is trained on arecanut palms receives differential light, which is dependent on directional and diurnal effects. The above review implies that 40% of land and 43% of light are utilized in sole arecanut and there is an excellent opportunity for temporal and spatial distribution of crop species in arecanut gardens.

In perennial based cropping systems, competition develops between component crops for below ground resources like water and nutrients. The inter/mixed cropping systems should be both biologically suitable and economically viable. For example, the survey revealed that coconut -arecanut mixed system is not ideal due to common pest, disease and morphological features resulting in competition for resources (Dhanapal *et al.*, 2000). Though this system is economical and preferred by farmers, it is biologically unsuitable in the long run. For getting synergistic/complimentary interaction between the component crops, adequate availability of moisture and nutrients is essential. The potential for multiple cropping in arecanut is greater because it is raised mainly as an irrigated crop. It is assumed that the introduction of intercrops, however, will increase the demand for water. Besides, it should be ensured that both arecanut and mixed crops should have common irrigation system requirement. If these critical aspects are taken care of, adoption of cropping system approach in arecanut plantation would be highly productive and remunerative.

3. Beneficial effects of inter/mixed cropping

Modern agricultural production requires implementation of efficient, sustainable and sound management practices for improving yield, income and soil quality indicators. The beneficial effects of inter/mixed cropping are discussed here.

3.1. Inter/mixed cropping and protection from weather vagaries

Detailed investigations on microclimate of arecanut-cocoa mixed cropping indicated that evaporation, air and soil temperatures are lower in mixed cropping than in sole arecanut and open conditions (Shama Bhat, 1983). The author also stressed that least diurnal variation in microclimate within the mixed cropping is an important feature besides lower evaporative demand, reduced wind velocity and higher soil moisture content. This is very important as the synergistic effects of wind and solar radiation can cause mechanical injury. The arecanut palms provide excellent protection to the intercrops against wind and vice versa. Wind does cause sporadic damage to adult palms by breaking the stem. This is found to be more severe in sun scorched arecanut palms where the stems have been already damaged. This damage can be controlled with the presence of mixed crops. Crops like cocoa and banana limit the damage of sun scorching effect in initial years (Shama Bhat, 1983; Nayar *et al.*, 1985).

3.2. Soil quality indicators

Increased root proliferation in arecanut due to intercropping was noticed by Muralidharan (1980), which in turn would increase organic matter content in soil. Bopaiah (1982) observed that intercropping legumes increased the content of available nitrogen and other nutrients in arecanut plantation. Several advantages like fixation of N, recycling of nutrients in the soil profile, prevention of soil erosion and improved soil fertility are reported due to intercropping with leguminous green manure crops or cover crops in arecanut (Mohapatra *et al.*, 1982). It was further noticed that intercropping with *Pueraria javanica* and *Mimosa invisa* in arecanut gardens could add on an average 10 kg green manure per palm which could meet 69 to 89 per cent of N requirement, 28 to 43 per cent P and 29-38 per cent of K. Fungal and bacterial population was relatively more under intercropping situations than in sole crop of arecanut (CPCRI, 1984). The potential of cocoa to recycle considerable biomass in terms of litter fall and pruned biomass was stressed by Abdul Haris *et al.* (1999) and Balasimha (2007) and the better nutrient quality of vermicompost made from arecanut and cocoa wastes was highlighted by Chowdappa *et al.*(1999). The positive impact of arecanut based cropping system on soil quality indicators is well documented (Muralidharan, 1980; Manikandan *et al.*, 1987). Increase in soil pH was noticed due to inter/mixed cropping by them. Thus, cropping system approach is important for soil acidity management of laterite soils in arecanut belt. These findings are worthwhile and indicate that inter/mixed cropping influences nutrient cycling, soil fertility and carbon cycling.

3.3. Efficient land use

Some of the studies focused on the economic advantages of arecanut based multiple cropping. Table 3 presents the estimated Land Equivalent Ratio (LER) and other advantages of different experimental works on arecanut based mixed cropping systems (Das and Vijaya Kumar, 1991). The LER computed for arecanut + cocoa system was very high (2.18) compared to arecanut + banana (1.45) and arecanut + black pepper (1.5). This indicates that arecanut + cocoa system is more beneficial. However, cocoa and black pepper were found 1.7 and 2 times more competitive than arecanut. This necessitates the importance of providing recommended nutrition and irrigation to both the base and mixed crops. Under irrigated conditions, arecanut-cocoa and arecanut-black pepper mixed cropping gave a monetary advantage of Rs.19,163 and Rs.18,402 per hectare per year (Das and Vijaya Kumar, 1991).

Table 3. LER and other advantages in arecanut based mixed cropping systems

Cropping system	Yield (t ha^{-1})	LER	Aggressivity	Competition ratio
Arecanut + Cocoa	1573 1284	2.18	-1.138 + 1.138	0.59 1.70
Arecanut + banana	2432 6000	1.45	+ 2.094 -2.094	6.23 0.16
Arecanut + black pepper	1950 600	1.50	-1.250 + 1.250	0.50 2.00

(Source: Das and Vijaya Kumar, 1991)

The studies conducted on arecanut + cocoa mixed cropping revealed that Land Equivalent Ratio (LER) can be increased to 1.74, thus giving 74% yield advantage over monocropping of arecanut (Table 4, Balasimha, 2001). The average LER for different treatments ranged from 0.82 to 1.74 which showed the advantage of mixed cropping of areca and cocoa. Similar results have been reported from spacing and fertilizer experiment (Shama Bhat, 1988). Considering the LER and combined yields, it is advantageous to grow cocoa at 2.7 x 5.4 m spacing with arecanut.

Table 4. Land Equivalent Ratio (LER) in areca-cocoa system

Spacing (m) (Cocoa)	Canopy size			Mean
	Low	Medium	Large	
2.7 x 2.7	1.13	1.34	1.68	1.38
2.7 x 5.4	1.34	1.38	1.74	1.48
5.4 x 5.4	0.82	1.53	1.67	1.34
Mean	1.09	1.42	1.70	1.40

(Balasimha, 2001)

4. Different arecanut based inter/mixed cropping systems

4.1. Intercropping of annuals/biennials/short statured perennials

Successful cultivation of crops such as turmeric, black pepper and cardamom in arecanut gardens is well documented (Abraham, 1956). The findings of earlier studies on intercropping of annual and biennial crops enabled to identify the level of productivity of each crop under intercropping situation (Table 5). Abraham (1974) reported that the tuber crops such as elephant foot yam and dioscorea performed better than sweet potato (Table 5). The poor performance of sweet potato was attributed to shade conditions and gravelly nature of soil. Shama Bhat (1974) stressed that intercrops like banana, elephant foot yam, pine apple and arrow root can increase the productivity per unit area. Crops like banana, ginger, chilli, colocasia, upland paddy, turmeric, elephant foot yam and dioscorea are more adapted for intercropping in arecanut gardens (Muralidharan, 1980).

Table 5. Productivity of different intercrops in arecanut based cropping systems

Location	Intercrop	Yield(kg/ha)	Reference
Vittal	Pepper	555	Abraham (1974)
	Tapioca	4836	
	Elephant foot yam	6496	
	Dioscorea	6744	
	Sweet potato	712	
	Pine apple	3942	
Vittal	Banana	4000	Shama Bhat (1974)
	Pineapple	8000	
	Elephant foot yam	12000	
	Arrow root	4000	
	Cacao	750	
Hirehalli	Ginger	1744	Sannamarappa and Muralidharan (1982)
	Turmeric	7274	
	Greater yam	8943	
	Elephant foot yam	8306	
	Sweet potato	7012	
	Chicory	1690	
	Turmeric	5228	
	Sweet potato - cowpea	4549 - 828	
Kannara	Ginger	2650	Balasimha (2004)
Palode	Greater yam	6744	
	Elephant foot yam	6496	
	Tapioca	10246	
	Sweet potato	712	
	Pineapple	3942	

The results of a four year trial at Hirehalli revealed that dioscorea and elephant foot yam performed better, while yield of ginger and turmeric declined under continuous cropping (Sannamarappa and Muralidharan, 1982). These results suggest the need for crop rotation when exhaustive tuber and rhizome crops are intercropped. Sannamarappa and Shivshankar (1988) reported that turmeric and sweet potato responded better to 60% population intensity as intercrops in arecanut plantation with yield of 5,228 kg ha^{-1} and 4,549 ha^{-1} compared to 3,764 and 3,743 kg ha^{-1} at 40% intensity, respectively. They also noticed that intercrops did not bring any significant change in yield of arecanut. In most of the studies at different regions, no deleterious effect on main crop due to intercropping was noticed (Abraham, 1974; Sadanandan, 1974; Muralidharan and Nayar, 1979; CPCRI, 1984). At CPCRI, Research Centre, Hirehalli, the yield of arecanut increased by 37% over a period of three years due to intercropping with cinnamon (Sannamarappa and Muralidharan, 1982). They also reported that intercropping of four varieties of coffee viz., arabica S-6, arabica S-1936, San Ramon and robusta also showed similar effects on yield of arecanut.

4.2. Arecanut + cocoa mixed cropping system

Systematic research on cocoa was initiated at CPCRI Regional Station, Vittal under ICAR in the late 1960's with the introduction of cocoa as mixed crop in arecanut gardens with the main objective of crop diversification. Small scale introductions have been made from Sri Lanka and Malaysia. Thus, feasibility studies with respect to growth and yield performance of cocoa under arecanut and its impact on yield of main crop became necessary.

4.2.1. Impact of weather

Cocoa was introduced into Indian continent in areas where agro climatic conditions were suitable for the crop. The altitude, latitude, temperature, rainfall and distance from sea were considered and the first introductions were done in South India. Conditions were favourable for cocoa at these stations with fertile soil and rainfall, supplemented by irrigation.

The investigations at CPCRI showed that the mixed cropping had profound influence on evaporation, wind velocity, soil and air temperature and relative humidity (Table 6, Shama Bhat, 1983; Bavappa, 1990). They further reported maximum possible utilization of solar energy in the system. In arecanut + cocoa system, the mean wind velocity was only 9% of that in open area. Initial studies on cocoa outlined how cocoa can effectively be grown in arecanut plantation to increase returns per unit area (Shama Bhat and Bavappa, 1972; Bhagavan and Shama Bhat, 1989). Weather plays an important role on growth and yield of cocoa. Impact of weather parameters on cocoa was evident from the studies by Vijayakumar *et al.* (1991). They noted that cocoa yield was significantly correlated with the number of rainy days in the previous year, and sunshine hours and maximum and minimum temperatures of the current year. The season of harvest and density of plants

Table 6. Micro climate existing in areca + cocoa mixed cropping system

System	Evaporation (mm)	Wind velocity (km h^{-1})	Soil temperature (^oC)		Relative humidity (%)		Air temperature (^oC)	
			0730h	1430h	0730h	1430h	0730h	1430h
Arecanut + Cocoa	1.15	0.20	26.4	27.4	90	50	23.5	33.3
Arecanut	3.07	0.72	28.7	31.1	90	47	23.4	34.5
Cocoa	1.33	-	27.8	29.7	91	49	20.4	33.6
Open area	6.6	2.16	31.1	40.8	91	45	22.8	34.1

(Source: Bavappa, 1990)

(Shama Bhat, 1988) and genotypes (Subramonian and Balasimha, 1981) influenced the pod and bean characters. Significant decrease in pod-value factors for the latter half of harvesting season (May-June) was noticed. The environmental factors especially photosynthetically active radiation have a profound influence on leaf function. Since the light intensity transmission varies with spacing, it can be expected that changes in leaf physiology exists. It was found that specific leaf weight and nitrate reductase activity were higher at wider spacing coinciding with maximum photosynthetically active radiation (Balasimha and Subramonian, 1984).

4.2.2. Performance of cocoa clones in arecanut based mixed cropping system

Crop genotypes may differ in their performance in mixed cropping system with arecanut as growth and yield vary from variety to variety. Evaluation of cocoa collections/varieties in arecanut based mixed cropping system is essential as requirement of shade and canopy volumes differ among collections as they are introduced from different agroclimatic conditions of different countries. The majority of the initial germplasm introductions were from Malaysian and Nigerian estates. The collections were further enhanced to 230 with clones of Ghana, Trinidad, Ecuador, England, Peru, Brazil, Mexico, Costa Rica and some local collections from Wynad. In collaboration with Cadbury (Bournville, England), hybrid seeds involving six crosses of Criollo variety of cocoa were planted in mixed cropping experiments in 1964 at Kahikuchi, Vittal, Peechi and Palode. Experimental results showed that arecanut + cocoa at 50: 50 ratio registered higher yield (pods per tree per year) of 81.7 than cocoa as border crop with 30.9 pods during 4th year of planting. This implies that cocoa performs better under arecanut than as border crop due to partial shade requirement of cocoa.

An experiment with intra racial hybrids obtained from Malaysia was planted during 1969 mixed with arecanut at Peechi under irrigated condition and at Palode under rain fed condition to compare two methods of alignment, two levels of manuring and six cross combinations (CPCRI, 1974, 1977, 1978). Significant differences between the hybrids were observed for number of pods, weight of pods and wet weight of beans. At Peechi, the hybrid V3 (I-I95x ICS-60) and at Palode, the hybrid V1 (I-195xICS-45) were identified as high yielders under quincunx system of planting and it was closely followed by V6 (ICS-45x ICS-60). From different progeny trials (Table 7), it was noticed that Nigerian collections are superior yielders with better quality (Bhat *et al.*, 2001) and drought tolerance (Balasimha, 1999) with a moderate canopy indicating their feasibility in the cropping design of arecanut. Comparative study of 21 elite hybrids under denser planting system under arecanut showed that the hybrids SCA-6 x ICS-6, NA-33 x ICS-89, ICS-6 x SCA-6, NA-31 x ICS-89 and IMC-67 x ICS-6 are good with optimum canopy volume (Elain Apshara *et al.*, 2008). These hybrids performed well both as seedlings and grafted plants. With regard to suitability of planting material, both seedlings and grafts performed uniformly as mixed crops in arecanut plantation (Balasimha, 2007 and 2009).

Table 7. Better performing collections of cocoa under arecanut

Variety	Single bean weight (g)	Shelling (%)	Dry bean yield (kg/ tree/ year)	Dry bean yield(kg/ ha)	Special features
NC 45/53	1.05	12.0	1.149	781	Early, heavy bearer, self and cross compatible
I-56 x II-67	1.00	13.0	1.481	1007	Early, high yielder
ICS-6 x SCA-6	0.95	10.9	1.145	779	High yielder with medium canopy
II-67 x NC-29/66	1.06	13.7	1.478	1006	High yielder & drought tolerant
II-67 x NC-42/94	0.99	12.1	1.245	847	High yielder & drought tolerant

(Source: Bhat *et al.*, 2001)

4.2.3. Spacing and pruning of cocoa

For optimum productivity of both arecanut and cocoa in mixed cropping system, ideal spacing and pruning regime are important to avoid competition. Studies have been conducted to standardize the spacing for cocoa under arecanut. Initially, the effect of spacing on growth parameters was studied by Shama Bhat (1988). Significant differences were observed from fifth year onwards between closer spacing giving compact canopy and wider spacing giving maximum canopy area. Only the closest spacing showed significantly lower values in most of the growth and biomass parameters, canopy photosynthesis (Pn) and harvest index. Thus, the spacing does influence the growth and subsequent yields. Hence, optimum spacing for cocoa-arecanut mixed cropping has to be evolved keeping in view the agronomic advantages and economic returns expected. Shama Bhat (1988) advocated that combination of 2.7 m x 2.7 m for arecanut and 2.7 m x 5.4 m for cocoa is preferable over 2.7 m x 2.7 m for both the crops in view of the operational advantages and as the yield difference between these two is not appreciable (Table 8). Experimental results at Kannara indicated that there were no significant differences between quincunx and square methods of alignment and arecanut yield was not affected by these cropping systems (Balasimha, 2004).

In earlier studies on canopy architecture in cocoa, it was found that big canopy with spreading nature seemed to be ideal for cocoa mixed cropped in arecanut plantation (Thomas and Balasimha, 1992). Subsequent studies on the canopy management in seedling progeny of cocoa for optimum productivity (Balasimha, 2001 and 2007) also indicated that large canopy is essential for higher net photosynthesis, LER and yield (Table 9). It was concluded from a long term study at Vittal that a spacing of 2.7 x 5.4 m and pruning regime of 16-20 m^3 canopy is recommended for grafts both from the yield point of view and agronomic advantage (Balasimha, 2009). This can be attributed to higher net photosynthesis and increased light interception upto 90%. From the above results, it is clear that spacing and pruning are important determinants of yield in cocoa.

Table 8. Average yield of inter planted cocoa and arecanut (7^{th} to 11^{th} year)

Spacing (m)		Cocoa pod yield (t/ha)	Arecanut yield (t/ha)
Arecanut	Cocoa		
2.7 x 2.7	2.7 x 2.7	17.7	6.6
2.7 x 2.7	2.7 x 5.4	15.0	7.8
2.7 x 2.7	5.4 x 5.4	9.2	9.6
3.9 x 3.9	3.9 x 3.9	13.6	4.5
3.3 x 3.3	3.3 x 3.3	19.2	5.9
1.8 x 5.4	3.6 x 5.4	13.0	6.2
CD(P=0.05)		3.14	1.89

(Source: Shama Bhat, 1988)

Table 9. Dry bean yield of mixed cropped cocoa (kg/ ha)

Spacing in m (S)	Pruning regime (P)							
	Seedlings				Grafts			
	P_1	P_2	P_3	Mean	P_1	P_2	P_3	Mean
S1 (2.7 x 2.7)	165	746	881	597	489	727	975	730
S2 (2.7 x 5.4)	354	661	729	581	530	705	828	688
S3 (5.4 x 5.4)	490	428	516	478	-	-	-	-
Mean	336	612	709	-	509	716	902	-
CD (P=0.05)								
S	92.8						NS	
P	71.0						97	
S x P							257	

Note: P1: $10m^3$; P2: $10\text{-}15m^3$; P3: $16\text{-}20m^3$ (Source : Balasimha, 2007 and 2009)

4.2.4. Nutrition and water requirement

The importance of nutrient balance in crop production is well recognized. The highest yields are obtained where nutrients and other growth factors are in a favorable state of balance. The nature of competition between component crops for water and nutrients in arecanut based inter/mixed cropping systems is not studied comprehensively. When more crops are inter/mixed cropped, there is an accumulation of litter enhancing the organic matter content of the soil. Another possibility is that the component species may occupy different soil profiles avoiding competition for nutrients. Cocoa is an exhaustive crop and removes large quantities of nutrients especially K (Manikandan *et al.*, 1987). The nutrient mining by arecanut is 79 kg N, 28 kg P_2O_5 and 79 kg K_2O per ha (Rethinam, 1990) and by cocoa is 43.8 kg N, 8 kg P and 64.3 kg K per ha (Bhat, 2002). Thus, it is clear that both arecanut and cocoa are heavy feeders and place great demand for nutrient on soil + fertilizer system. These nutrients must not only be replenished, but fertilizer and manurial additions must also compensate for nutrient losses, quantities locked up in perennial growth and removal through pruning. The fertilizer recommendation for cocoa under average management is 100:40:140 g of N, P_2O_5 and K_2O per plant for a year, which tallies with the crop removal figures (Shama Bhat, 1988). Systematic study for 10 years on drip irrigation and fertilizer requirement of cocoa mix cropped in arecanut revealed that drip irrigation at E_0 of unity and a fertilizer dose of 100: 40: 140 g of N P_2O_5 and K_2O per tree per year would be optimum for cocoa (Abdul Haris *et al.*, 1999, Fig. 1).

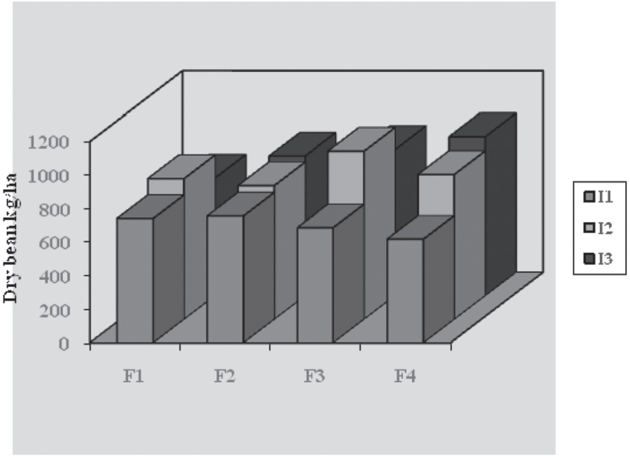

Fig. 1. Dry bean yield in response to drip irrigation and fertilizers
(Irrigation levels: 0.5Eo P(II), 1.0Eo P(12), 1.5Eo P(13); Fertilizer levels 0/0/0(F1), 50/20/70(F2), 100/40/140(F3), 150/60/210(F4)g N,P_2O_5 & K_2O)

The failure of cocoa under rainfed conditions at Palode and better performance of cocoa under irrigated and high fertility conditions at Kannara stressed the necessity for adequate availability of moisture and nutrition for successful cultivation of cocoa (Shama Bhat, 1979). In mixed cropping system, the lateral root distribution was upto 50 cm in arecanut and 125 cm in cocoa. Most of the roots were distributed within 100 cm depth in arecanut, while in cocoa it was found upto 160 cm (Shama Bhat, 1983). There was better exploitation of the root regions of 51-100 cm depth in mixed cropping.

4.2.5. Soil fertility

Cultivation of exhaustive crops like arecanut and cocoa continuously on the same land results in soil fertility depletion. Thus, it is essential to replenish nutrients regularly through both organic and inorganic sources. The wastes available from arecanut and cocoa gardens contain reasonable quantities of N, P and K (Biddappa *et al.*, 1996). The arecanut and cocoa leaves from the system can be converted into compost using earthworms with a recovery percentage of 74 to 87 (Chowdappa *et al.*, 1999). The composted leaves were found rich in nutrients, including micronutrients, which was more than the normal compost (Table 10). Maximum biomass recycling in the form of pruned biomass and litter fall is possible in arecanut + cocoa mixed cropping system (Abdul Haris *et al.*, 1999; Balasimha, 2001).

Table 10. Nutrient composition of dried leaves, normal compost (NC) and vermicompost (VC)

Nutrients	Arecanut			Cocoa		
	Leaves	NC	VC	Leaves	NC	VC
Organic carbon (%)	44.20	33.7	33.1	47.1	28.0	24.4
N (%)	0.71	1.01	1.38	1.27	1.29	1.65
P (%)	0.08	0.08	0.35	0.17	0.19	0.19
K (%)	0.94	0.96	0.98	0.27	0.27	0.32
C:N ratio	62	33	23	37	22	15
Cu (ppm)	101	120	120	32.7	70.5	83.6
Fe (ppm)	1746	2397	2561	1157	2580	2593
Zn (ppm)	307	346	396	228	355	368
Mn (ppm)	82	173	242	363	546	680
Moisture (%)	-	31	32	-	29	30
pH		8.1	7.3		8.0	7.5

(Source: Chowdappa *et al.*, 1999)

The studies pertaining to soil nutrient status revealed positive aspects of arecanut + cocoa mixed cropping system (Shama Bhat, 1983). Soil pH, Soil Organic Carbon, available P and K increased profoundly in both arecanut and cocoa basins compared to interspaces and fallow land. The nutrient profile within an arecanut-cocoa system on a laterite soil 13 years after planting as influenced by spacing, supply and exhaustion of nutrients was examined (Manikandan *et al.*, 1987). They noted that 100 g N and 40 g P_2O_5 per tree per year were adequate for cocoa and a negative balance in available K in the system suggesting the higher requirement of K by both crops. Manikandan *et al.* (1987) noticed reduced soil pH and improved organic carbon status in arecanut + cocoa system. This might be due to cocoa leaf fall, *in situ* root decay and fertilizer application. The available P in the arecanut basins of arecanut + cocoa mixed cropping system showed higher concentration than sole arecanut (Manikandan *et al.*, 1987). They suggested the need for inclusion of Zn in the fertilizer schedule of arecanut + cocoa system due to loss of Zn in the system especially in the case of closer planting of component crops (Table 11).

Table 11. Nutrient profile in arecanut + cocoa system

Cropping system and treatment		pH	OC (kg /m^3)	Available nutrients (g/ m^3)		
				P	K	Zn
Arecanut monocrop	Arecanut basin	6.3	8.4	22.2	352	11.2
	Interspace	5.7	6.5	1.5	157	1.6
Arecanut (2.7 x 2.7 m) Cocoa (2.7 x 5.4 m)	Arecanut basin	6.1	9.1	47.6	200	5.3
(100:40:140 g N, P_2O_5 and K_2O for both crops)	Cocoa basin	5.5	6.2	9.3	155	6.6
	Interspace	5.7	5.9	5.5	170	0.8
Arecanut (2.7 x 2.7 m) Cocoa (2.7 x 5.4 m)	Arecanut basin	5.5	11.0	72.5	152	2.8
(100:40:140 and 200:80:280 g N, P_2O_5 and K_2O for arecanut and cocoa respectively)	Cocoa basin	4.9	8.9	97.9	293	2.9
	Interspace	5.5	7.7	3.3	132	1.0
Arecanut (3.3 x 3.3 m) and cocoa (3.3 x 3.3 m)	Arecanut basin	5.9	8.4	23.4	130	14.5
(100:40:140 g N, P_2O_5 and K_2O for both crops)	Cocoa basin	5.4	7.3	17.2	89	8.5
	Interspace	5.5	6.1	1.6	98	1.8
Arecanut (3.3 x 3.3 m) Cocoa (3.3 x 3.3 m)	Arecanut basin	5.9	15.3	81.3	259	30.9
(100:40:140 and 200:80:280 g N, P_2O_5 and K_2O for arecanut and cocoa respectively)	Cocoa basin	5.2	8.9	55.0	180	9.8
	Interspace	5.7	7.8	5.5	120	3.5
LSD ($P = 0.05$)	Arecanut basin	0.11	2.99	NS	58	12.3
	Cocoa basin	0.17	1.29	24.9	79	4.7
	Interspace	0.09	1.08	2.2	39	1.1

(Source: Manikandan *et al.*, 1987)

4.3. Arecanut + banana intercropping system

Banana is usually grown as nurse or shade crop in arecanut plantations and its advantages were reported earlier (Shama Bhat and Khader, 1970; Bhandary, 1974). The yield of main crop was not affected by growing banana (Bhandary, 1974; Nagaraj, 1974). Similarly, the effects of intercropping banana in different durations and intensities in arecanut were studied (Shama Bhat, 1974). From a field study at Kannara on suitability of banana cultivars for intercropping (Table 12), Robusta, Mysore poovan, Red banana and Karpuravally were found suitable for intercropping (Nayar *et al.*, 1985). They also noticed that the variety Red banana gave maximum net returns without any adverse effect on yield of arecanut. Banana fetches interim revenue in the initial years, which will help the farmers in cash flows.

Table 12. Productivity of arecanut + banana intercropping system

Varieties	Yield of banana bunches (kg ha^{-1})	Yield of arecanut (kg ripe nuts per palm)
Arecanut sole crop	-	11.2
Arecanut + banana		
Robusta	7200	11.2
Karpuravally	6660	12.7
Dwarf Cavendish	5340	11.3
Red banana	6060	11.7
Mysore Poovan	7380	9.1
Poovan	3660	9.6
Nendran	3096	11.1
CD (P = 0.05)		NS

(Source : Nayar *et al.*, 1985)

4.4. Arecanut + Black pepper intercropping system

Black pepper is raised exclusively as mixed crop in homestead gardens in Kerala and Karnataka and over 90% black pepper is trained on coconut and arecanut palms. Studies carried out at CPCRI have revealed that black pepper is the most compatible perennial spice crop with arecanut and can be profitably grown as mixed crop. Black pepper is an excellent crop for mixed cropping with arecanut and high economic returns can be expected (Abraham, 1974; Nair, 1982; Nayar, 1982). The advantages of black pepper mixed cropping in arecanut plantations are not fully exploited by most of the farmers due to the fear that growing black pepper on arecanut may depress the yield of arecanut. Nair (1982) and Abdul Khader (1982) found black pepper as a profitable cash crop, suitable for mixed cropping in arecanut gardens. Experimental data from mixed cropping of arecanut and black pepper for a duration of 10 years showed that there was no detrimental effect on the yield of arecanut palms due to training black pepper on them (Table 13). Further, it helped to augment the income of the farmer by mixed cropping of black pepper (Nayar, 1982).

Table 13. Yield of arecanut as influenced by areca-black pepper mixed cropping

	Ripe nut yield (kg per palm)	
Year	Arecanut sole crop	Arecanut + pepper
1976-77	13.6	13.0
1977-78	12.8	12.1
1978-79	12.4	12.7

(Source: Nayar, 1982)

The performance of black pepper cultivars, Panniyur-1 and Karimunda, were better compared to others in all the spacing treatments at Vittal (Nair, 1982). A study was conducted to investigate the performance of four varieties of black pepper as a mixed crop in a 19-year-old arecanut garden with six planting densities (Table 14). The results revealed that, in arecanut garden with recommended spacing of 2.7 x 2.7 m, 43% of sunlight is available to other crops. Black pepper as a mixed crop did not influence the yield of arecanut. As regards the yield of black pepper, 1.8 x 2.7 m spacing had given more yield per ha (8.60 kg) followed by 1.8 x 3.6 m spacing. Among the cultivars of black pepper, Karimunda gave the highest yield (1068 kg/ha) followed by Panniyur-1 (768 kg/ha). The cultivars Uddakare and Malligesara had resulted in poor yield (Abdul Khader *et al*. 1993). Reduction in economic yield of black pepper due to *Phytophthora* diseases was reported. This necessitates the need for testing new varieties of black pepper as mixed crop for tolerance to shade and diseases in arecanut plantation.

Table 14. Arecanut and Black pepper yield at different plant densities

Spacing (m) for arecanut	Arecanut yield (kernel kg / ha)	Dry black pepper yield (kg/ha)				
		Panniyur-1	Karimunda	Uddakare	Malligesara	Mean
1.8 x 1.8	2500	665	736	194	142	434
1.8 x 2.7	1985	928	1973	285	253	860
1.8 x 3.6	1952	1264	1331	354	418	842
2.7 x 2.7	1983	789	826	458	302	594
2.7 x 3.6	1121	544	523	131	230	357
3.6 x 3.6	1133	417	1020	217	426	520
Mean	1779	768	1068	273	285	601

4.5. Intercropping of medicinal and aromatic plants (MAP)

Experimental results of four year trial at Vittal by Sujatha *et al*., (2010) revealed that medicinal and aromatic plants like Shatavari *(Asparagus racemosus)*, Vetiver *(Vetiver zizanoides)*, Long pepper *(Piper longum)*, Brahmi *(Bacopa monnieri), Nilagirianthus ciliatus,* Periwinkle *(Catharanthus roseus),* Aloe *(Aloe vera or barbadensis)*, Lemon grass *(Cymbopogon flexuous)*, Palmarosa *(Cymbopogon martinii)*, Basil *(Ocimum basilicum)*, Davana *(Artemisia pallens)* and Patchouli *(Pogostemon cablin)* performed better as intercrops in arecanut. However, Senna *(Cassia anguistifolia)*, Safed musli *(Chlorophytum borivillianum)*, aswagandha *(Withania somnifera)* and geranium *(Pelargonium* sp*)* did not come up well as intercrops in arecanut. Shatavari produced fresh root yield of 14.3 t/ha of arecanut garden and contributed maximum kernel equivalent yield (2045 kg/ ha). The net return accrued by intercropping of shatavari per ha of arecanut plantation was the highest (Rs. 80,000) followed by *Nilagirianthus ciliatus* (Rs. 42,000), brahmi (Rs. 39,380) and vetiver (Rs. 31,000). Aromatic plants like lemon grass, patchouli, davana, palmarosa and basil performed better with chali equivalent varying between 406 kg/ ha in the case of basil to 1,286 kg/ ha in lemon grass. All the medicinal and aromatic crops contributed to productivity increase varying between 10.7% in basil to 53% in shatavari in terms of chali equivalent per hectare of arecanut garden. Aromatic plants like lemon grass, patchouli, davana and palmarosa were found highly profitable with net returns of Rs. 22,700 to 58,387 per hectare of arecanut plantation. In terms of net profit per rupee investment, all the medicinal and aromatic plants were found superior and system productivity can be considerably enhanced with intercropping (Table 15, Sujatha *et al.*, 2009). Based on all advantages and disadvantages noticed in cultivation of MAPs in arecanut plantation, farmers are advised to grow aromatic plants in large areas on a community basis to meet the industrial demand and a variety of medicinal crops in small areas based on local demand (CPCRI, 2008).

Table 15. Production and productivity of medicinal and aromatic plants in arecanut garden (Pooled data of 2004-05 to 2006-07)

Crop	Production components (kg ha^{-1})				Net return per rupee investment (Rs./rupee)	Production efficiency (kg/ha/ day)
	Yield of intercrop*	Kernel equivalent of intercrop	Arecanut kernel	System productivity		
Vetiveria zizanoides	1006	706	2515	3231	*2.42*	3.7
Asparagus racemosus	10666	1524	3343	4359	2.59	6.0
Piper longum	231	272	2718	2990	2.22	4.1
Bacopa monnieri	2070	739	3586	4325	3.64	5.9
Nilagirianthus ciliatus	7087(leaf) 1017(root)	1429	1884	3313	2.88	4.0
Catharanthus roseus	2194(leaf) 115(root)	704	3440	4144	2.54	7.6
Aloe vera	15490	471	3081	3552	1.99	4.9
Cymbopogon flexuous	8460	1218	3121	4338	4.25	5.9
Cymbopogon martini	3249	485	2678	3164	1.95	4.3
Ocimum basilicum	8130	398	3311	3708	3.46	8.2
Pogostemon cablin	9082	863	3362	4225	2.18	5.8
Artemisia pallens	5248	629	3595	4224	3.12	7.8
LSD (P = 0.05)	-	162.5	756	553	-	-

Note: * For crops like *Asparagus racemosus* and *Cymbopogon martini,* two years data was available. *Asparagus racemosus* and *Aloe vera* yields are expressed on fresh weight basis.

4.6. Arecanut + vanilla intercropping system

Cultivation of vanilla as an intercrop of arecanut and coconut plantations in India is one of the most attractive propositions as it fetches remunerative prices (Madhusoodanan and Radhakrishnan, 2001). Usually, the plants are grown on supports. Some of the common living standards are Casuarina, Glyricidia, Mulberry and Erythrina trees. It can be successfully grown in arecanut gardens. The results of five year study on irrigation and organic nutrition of vanilla in arecanut plantation indicated that mist irrigation at 1.0 Ep registered significantly higher pod yield over 0.5 and 0.75 Ep (Sujatha and Bhat, 2010). Organic manure application in the form of vermicompost, FYM and recommended NPK produced fresh bean yield at par with recycling of *glyricidia* prunings. Irrigation at 1.0 Ep proved superior by registering maximum B: C ratio of 2.25 compared to 0.75 Ep (1.62). The highest benefit:cost ratio was obtained with recommended NPK (2.27) followed by recycling of *glyricidia* prunings (2.10), vermicompost (1.87), vermicompost + arecanut husk mulching (1.80) and FYM (1.64).

5. Conclusions and future research need

Recurrent problems like erratic rainfall, pests and diseases and price fluctuations are affecting the production and profitability of arecanut. It is imperative to adopt cropping system approach for increasing the productivity and income per unit area as arecanut has limited alternative uses and export potential. From the above review, it can be concluded that inter/ mixed cropping is an ideal option for arecanut farmers. Crops like cocoa, black pepper, banana, vanilla and medicinal and aromatic plants can be successfully inter/ mixed cropped in arecanut plantation. The review suggests that inter/mixed cropping in arecanut increases resource use efficiency and gives stability in terms of productivity and income. The benefits accrued are mainly congenial microclimate, improved soil fertility status, increased productivity and income. In this era of WTO, value added crops like vanilla and medicinal and aromatic plants would prove to be highly remunerative intercrops. Thus, diversified crop options with good agricultural practices are the need of the hour for arecanut farmers.

Most of the studies conducted so far on inter/mixed cropping in arecanut are of short term nature of less than five years. Arecanut, being a perennial crop with economic life span of over 40 years, there is necessity for long term field experimentation to identify how long suitable intercrops can be grown in the plantation. The focus of any crop model should be on practicability and socio-economic viability. Studies are required to quantify whether the input requirement in terms of water and pesticides can be lowered in inter/ mixed cropping systems.

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Arecanut based high density multispecies cropping/ farming systems

Ravi Bhat and S. Sujatha

Introduction

Arecanut (*Areca catechu* L.) is a commercially important plantation crop predominantly grown in humid tropics of West coast and North East regions of India. Small and marginal holdings of less than one hectare dominate in arecanut tract. The income generated from these holdings is insufficient to sustain the needs of farmers. Besides, arecanut farmers face recurrent problems due to price fluctuations, pests and diseases, water logging and drought resulting in considerable yield losses. The yield loss due to drought was 15% in 2002 in Karnataka (Jose *et al.*, 2004) while fruit rot inflicted a yield loss of 29-49% in 2007 (Jose *et al.*, 2008). Thus, it is necessary to increase the productivity per unit area in arecanut plantation through combination of several production activities. In the recent past, systems approach has gained importance in agriculture as cropping/farming system approach seeks to increase the benefit derived from different enterprises. The logic behind multispecies cropping system is that the spatial and temporal differences in growth habits of crops utilize resources more efficiently than monocropping. The primary objective of multispecies cropping system is to minimize the risk of total crop failure and to maximize the productivity per unit area.

Arecanut with its compact crown, raised well above the ground (10 to 15 m), allows more sunlight to transmit to ground and maintains high humidity which, in turn, favours excellent growth of shade loving inter/mixed crops. Studies have revealed that arecanut utilizes only 30% of the land area and 16% of air space and permits 40% of PAR for utilization by mixed crops (Bavappa *et al.*, 1986). Studies indicated only 43% light interception by arecanut monocrop, which can be increased to 95% with mixed crops in arecanut (Balasimha, 2004). Arecanut roots are concentrated within 50 cm radius from the base of the palm and utilize only 40% of the available land space (Bhat and Sujatha 2008b). Earlier studies indicated that 60% of land and 57% of light are unutilized in arecanut monocrop indicating low resource use efficiency in arecanut, which gives scope for accommodating several component crops in arecanut garden. Several studies reported that cocoa, black pepper, clove, lemon and banana are ideal mixed crops in arecanut plantation (Bavappa *et al.*, 1986; Sannamarappa, 1993; Reddy and Bhat, 1994; Bhat *et al.*, 1999).

2. Principles and benefits of HDMSCS in arecanut

Shrinking land, low or stagnant productivity of sole crops and the fluctuating prices of commodities in the market has made one to rethink about the present way of crop production. The challenge is to increase yield and income per unit area rather than production from a single crop. Thus, growing more crops in unit area takes centre stage in the present day agriculture. Adoption of cropping system approach is indispensable to increase the productivity per unit area and to avoid risks due to pests, diseases and price fluctuations. This is more so in arecanut, which has long pre-bearing period leading to high investment and low returns in the initial period. The success of involving multispecies cropping system depends on the relative shade tolerance of component crops. The crop occupying higher air space under arecanut should have lower interception efficiency and higher photosynthesis. More shade tolerant species are desired at still lower vertical heights.

Adoption of HDMSCS/Mixed farming, apart from increasing resourse use efficiency, increases employment opportunity and income (Bhat *et al.*, 1999) and makes the system more sustainable. Other tangible benefits noticed from the system are improvement in microclimate (Bavappa *et al.*, 1986), reduction in leaching losses of water and nutrients due to runoff (Mohapatra and Bhat, 1990) and improvement in soil fertility due to increased recycling of biomass (Abdul Khader *et al.*, 1992; Bhat and Sujatha, 2007). Several studies have proved that inter/mixed crops are not detrimental to the main crop of arecanut (Bavappa *et al.*, 1986; Sannamarappa, 1993; Bhat *et al.*, 1999 and 2001).

Arecanut alone may not give sufficient economic stability for the large number of small farmers. To ensure yield stability and economic sustainability of small farm units, it is necessary to develop scientific multiple cropping systems. The economic viability of HDMSCS was stressed by several workers (Bavappa *et al.*, 1986; Sannamarappa, 1993; Bhat *et al.*, 1999). The farming systems will have to be developed keeping in view the social needs and food habits of a particular region. The research studies carried out at CPCRI in the field of arecanut based HDMSCS and mixed farming are reviewed in this chapter.

3. Different HDMSCS models

3.1. Coastal regions in West Coast of India

At Vittal, arecanut based HDMSCS model was laid out in 1983 with six crop species in a 17 year old arecanut garden (Bavappa *et al.*, 1986; Abdul Khader *et al.*, 1992). Fig. 1 illustrates the schematic representation of the system. This system can accommodate 1300 arecanut palms with 1300 black pepper vines trailed on them, 210 cocoa, 180 clove, 390 banana and 2400 pineapple plants in one hectare area (Bhat *et al.*, 1999). It was

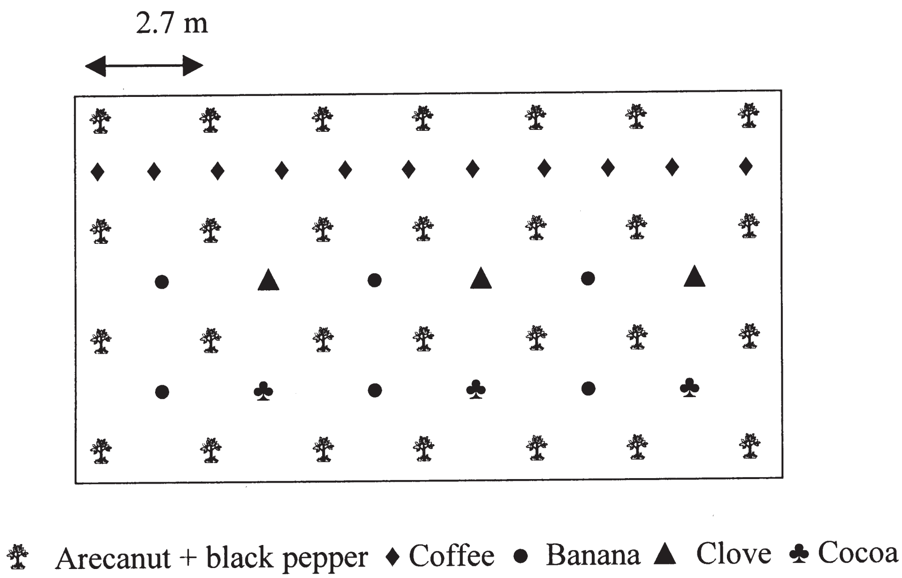

Fig.1. Schematic representation of component crops in arecanut based HDMSCS

reported that there is no reduction in yield of arecanut in HDMSCS and the year to year variation in arecanut yield was attributed to climatic variations. In fact, there was steady increase in the yield of arecanut after establishing component crops in the system (Table 1). The intercrops started yielding after third year of planting and the economic yield of intercrops accounted for approximately 27% of total economic yield. Further studies indicated that arecanut yields were not adversely affected by growing cocoa and clove as mixed crops (Table 2) (Bhat *et al.*, 2001).

Table 1. Yield of different crops (kg/ha) in arecanut based HDMSCS at Vittal

Crops	Year									
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Arecanut	2773	2800	4256	3943	3107	4400	2588	1819	1819	2718
Pepper	-	-	37	268	1191	194	174	65	92	132
Cocoa	-	-	71	918	980	1798	3951	3221	4324	4026
Banana	-	3183	2364	1421	390	217	-	-	-	-
Pineapple	-	771	423	244	427	17	-	-	-	-
Coffee	-	-	9	24	137	62	-	-		-
Clove	-	-	-	-	-	-	2	10	16	24

(Source: Bhat *et al.*, 1999)

Table 2. Yield of arecanut (kg chali/ palm) as influenced by different mixed crop combinations

Treatments	Pre-treatment	Post-treatment	SE
Control	1.6	1.4	0.23
Cocoa	1.9	1.8	0.14
Clove	1.8	1.9	0.13
Cocoa + Clove	1.9	1.9	0.14

(Source: Bhat *et al*., 2001)

The comprehensive study on arecanut based HDMSCS for over 10 years from 1983 to 1993 at Vittal has led to following conclusions (Bavappa *et al*., 1986; Abdul Khader *et al*., 1992). Among the six crops studied, cocoa, banana and black pepper are found suitable for multi-storeyed cropping system. The possibility of getting additional yields due to cropping systems was evident from these long term trials. However, crops like clove, coffee and pineapple gave negative returns due to late and low yielding behaviour in the system (Bhat *et al*., 1999). Due to higher shade levels in arecanut, clove has grown tall with a yield level of 1.0 kg per tree making harvesting difficult and uneconomical. The study clearly indicates the higher light requirement for both clove and pine apple. The component crops were complimentary in temporal and spatial sense exploiting soil depths and airspace. The temporal arrangement of the short duration crops (banana, pineapple, papaya) give scope for enhanced biomass production during early years. The crop species with leaf areas at higher strata is at an advantage to harness light energy. Black pepper can be grown profitably for the first 5 to 6 years. Cocoa gives consistently high returns over the years and banana can be profitable for the first three years. In the event of a crash in arecanut prices or failure of arecanut, mixed crops would be playing a vital role in maintaining or improving the returns.

3.2. Plains of Karnataka

Two arecanut based HDMSCS models consisting of black pepper, cocoa, coffee, mulberry and elephant foot yam (Model-I) and banana, betel vine, lemon, coffee and tapioca (Model - II) were tried at Hirehalli, Karnataka (Sannamarappa, 1993). Cocoa and black pepper or banana, betelvine and lemon crops are found to be profitable mixed crops for Maidan parts of Karnataka (Table 3). Mixed cropping with coffee was also found to be profitable. It was observed that arecanut yield has increased by 7 to 20% in the arecanut based cropping systems, besides progressive increase in yield of intercrops.

Table 3. Yield of component crops in arecanut based high density multispecies cropping system at Hirehalli

Crop	Yield (kg/ha)			
	1984-85	1985-86	1986-87	1989-90
Model I				
Elephant foot yam	3850	5166	-	-
Mulberry	8744	6574	3351	-
Cocoa	-	-	-	4755 (pods)
Black pepper	-	-	-	986 (dry)
Model II				
	1991-92			
Betel leaf (Nos.)	685800			
Banana	2761			
Lemon	890			

Note: Model I - Arecanut + Elephat foot yalm + Mulberry + Cocoa + Black pepper + Coffee
Model II - Arecanu + Betel lef + Banana + Lemon + Tapioca + coffee
Tapioca and Coffee were not economical; hence yield is not given in table.

4. Resource utilization in HDMSCS

4.1. Airspace utilization

In the arecanut based model, the air space occupied by component crops was higher than that occupied by arecanut (Table 4). The airspace utilization was 17.5% and 23.3% by arecanut and component crops, respectively in the first year of establishment of HDMSCS (Bavappa *et al.*, 1986). The air space utilization by mixed crops increased substantially to 46% in the third year, while that of arecanut remained more or less the same in different years. It is obvious that the arecanut based system is more efficient in air space utilization due to better growth of all component crops. These studies highlight the importance of including mixed crops in arecanut for higher resource use efficiency.

Table 4. Airspace utilization in arecanut based cropping model

Particulars	1984	1985	1986
Total airspace (‘000m^3/ha)	120	127	135
Percentage occupied by arecanut	17.5	17.3	16.3
Percentage occupied by other crops	23.3	29.9	46.7

(Source: Bavappa *et al.*, 1986).

4.2. Light utilization

In HDMSCS, arecanut canopy intercepted 55 to 90% of photosynthetically active radiation (PAR) depending on the season and time of the day (Abdul Khader *et al.*, 1992, Fig. 2). The stratified sampling gave a precise distribution of the LAI at different heights and the levels of transmitted lights (Fig. 3). The LAI and light profiles at different heights clearly indicate the relative competition for light among the component species. Most of the intercrops except pineapple showed shade tolerant characteristics. The net photosynthetic rates of the intercrops ranged from 3.56 to 6.30 µ moles CO_2 m^{-1} s^{-1} as compared to 7.87 in arecanut (Balasimha, 1989).

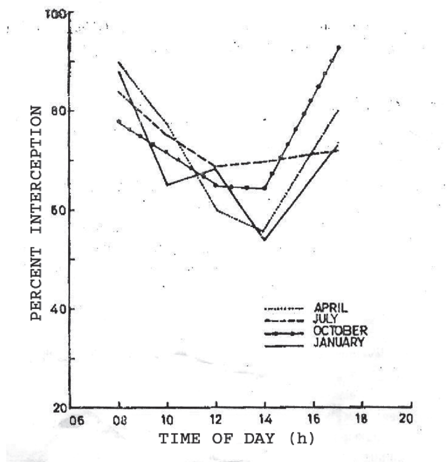

Fig. 2. Interception of light by arecanut canopy (mean of 1984-85) (Source: Abdul Khader *et al.*, 1992)

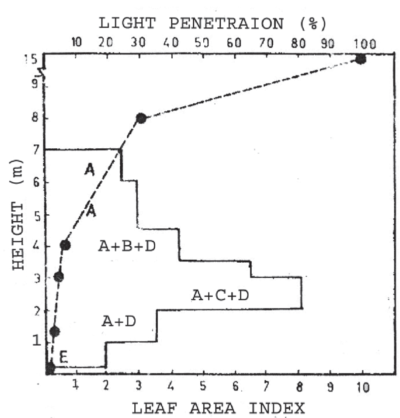

Fig. 3. Leaf area index and light penetration in arecanut HDMSCS in 1988. A-Black pepper, B-Banana, C-Cocoa, D-Clove, E-Coffee (Source: Abdul Khader *et al.*, 1992)

4.3. Land utilization

From Table 5, it is clear that the land utilization is very high in HDMS as population per hectare was 4160 with higher standing biomass and LAI (Abdul Khader *et al*., 1992). The LAI of Black pepper and cocoa were higher than arecanut and these along with other component crops improved the land use efficiency by covering more land area. The data clearly shows that the component species of a HDMSCS are complimentary in temporal and spatial terms by exploiting different soil depths.

Table 5. Leaf area and leaf area index of arecanut and intercrops

Crop	Plant population (no./ha)	Total standing biomass (t/ha)	Leaf area per plant (m^2)	LAI per plant	LAI per ha
Arecanut	1300	24.44	17.91	1.97	2.33
Black pepper	1300	3.49	24.05	21.86	3.13
Banana	390	2.68	8.71	0.68	0.34
Cocoa	210	3.1	109.93	6.86	2.30
Clove	180	0.61	7.82	1.94	0.14
Coffee	780	0.6	3.93	1.99	0.31

(Source : Abdul Khader *et al*., 1992)

4.4. Energy budgeting

The concept of energy budgeting is important in evaluating the cropping system and is the yardstick for measuring resource utilization efficiency. The study on energy budgeting indicated that there was gradual increase in output/input ratios in arecanut based cropping system as compared to arecanut alone (CPCRI, 1989; Table 6). The output to input ratio was less than unity in sole crop of arecanut indicating underutilization of applied resources. The ratio higher than unity in HDMSCS indicates that the use efficiency of resources can be improved by adopting cropping system approach.

4.5. Soil fertility management

High rates of outputs from the cropping system imply that they in long run will deplete the soil of its nutrient store and make the system ecologically unsustainable (Nair, 1999). It was also indicated that nutrient removal rates in harvested products from these systems are so high that N deficiency would eventually limit system's productivity. ABCS involving component crops like cocoa, banana and clove have high nutrient requirement, and thus, places a great demand for nutrients on the soil + fertilizer system. The nutrient removal by arecanut is estimated at 79 kg N, 28 kg P_2O_5 and 79 kg K_2O per ha (Rethinam, 1990)

Table 6. Energy budget (M cal/ ha) in arecanut based high density multispecies cropping system at Vittal

Input/Output	Years				
	1	2	3	4	5
Input					
Fertilizers	3241	3857	4422	10048	7789
Pesticides	1493	1496	505	904	1912
Diesel for irrigation	5873	6150	4756	5172	4202
Lime	57	57	19	108	196
Economic output					
Arecanut	6645	10458	17346	21214	16094
Banana	-	2230	1802	1194	328
Pineapple	-	530	176	328	179
Cocoa	-	-	60	191	911
Black pepper	-	-	189	785	5956
Coffee	-	-	39	48	134
Total	6645	13218	19612	23760	23602
Output/input ratio	0.62*	1.14	2.02	1.46	1.67

* Arecanut alone (Source: CPCRI, 1989)

and by cocoa is 43.8 kg N, 8 kg P and 64.3 kg K per ha (Bhat, 2002). Banana removes large quantities of N (320 kg), P (23 kg) and K (925 kg) to produce a yield level of 50 tonnes per hectare.

Fertilizer recommendations for HDMSCS have so far been generally based on the schedules recommended for the sole component crop. The studies on nutrient requirement of the HDMSCS as a whole were lacking. HDMSCS should be considered as closed system for nutrients and organic matter for saving in input and reducing cost of cultivation. The soil fertility status before initiation of HDMSCS (Table 7) and after six years of establishing the system (Table 8) indicated improvement in soil fertility status with the adoption of HDMSCS. Further, the nutrient status of the soils at Vittal under monocrop and HDMSCS indicated improved soil fertility under HDMSCS as compared to monocrop. Further studies on HDMSCS in old plantations showed improvement in soil fertility status in terms of soil pH, soil organic carbon and available P (Bhat and Sujatha, 2007).

There is greater scope for internal recycling of organic matter and nutrients due to higher production of crop residues. The study conducted at Vittal for four years highlighted the possibility of organic matter recycling in the system (Bhat and Sujatha, 2006). The

Table 7. Pre-experimental nutrient levels in the arecanut garden (1983)

Soil depth (cm)	pH	Organic C%	P_2O_5 (ppm)	K_2O (ppm)
Arecanut basin				
0-25	6.7	1.05	60	190
25-50	6.5	0.60	38	158
50-75	6.3	0.45	15	132
Interspace				
0-25	5.7	0.93	20	154
25-50	5.7	0.47	16	126
50-75	5.6	0.42	4	117

(Source: Abdul Khader *et al.*, 1992)

Table 8. Soil characteristics in HDMSCS and monocrop of arecanut at Vittal in 1988

Crop	Soil depth(cm)	Soil characters				
		pH	OC (%)	P_2O_5(ppm)	K_2O (ppm)	Ca (ppm)
Arecanut + Black pepper	0-25	4.6	1.20	1852	421	191
	25-50	4.3	0.66	152	260	125
	50-75	4.7	0.42	48	221	148
Clove	0-25	4.9	1.02	1700	425	193
	25-50	4.7	0.74	339	289	180
	50-75	4.6	0.34	56	226	174
Coffee	0-25	5.1	1.09	532	108	156
	25-50	5.2	0.73	93	131	178
	50-75	5.5	0.54	24	147	162
Cocoa	0-25	4.5	0.90	498	382	98
	25-50	4.2	0.66	57	241	83
	50-75	5.2	0.37	19	189	131
Interspace of arecanut in HDMSCS	0-25	5.3	0.80	127	101	152
	25-50	5.3	0.56	14	189	133
	50-75	5.3	0.34	9	166	305
Interspace of arecanut in monocrop	0-25	5.7	0.92	11	46	176
	25-50	5.7	0.67	8	55	192
	50-75	5.9	0.37	6	45	174

(Source : Abdul Khader *et al.*, 1992)

recyclable biomass produced from the system varied between 8.72 to 10.35 t / ha/ year. The nutrient content in vermicompost made out of recyclable biomass was 1.71% N, 0.21% P and 0.43% K. Organic matter recycling (OMR) maintained sufficient mineral N and available P levels in soil at par with integrated nutrient management treatments. Non-significant correlation between yield and soil NP and leaf NP indicated the beneficial effects of organic matter recycling in the form of vermicompost in sustaining crop yields and N and P supply to soil with minimum or no inorganic fertilizer input levels. The availability of K increased significantly with integrated use of inorganic fertilizer and OMR compared to only OMR at both soil depths. Significant depletion of available K in all crop rhizospheres at both soil depths during experimental period revealed the necessity of including K in the fertilizer schedule of the system due to heavy K feeding nature of all the component crops.

The nutrient balance studies done in arecanut based model in third (Table 9) and sixth year of establishing HDMSCS (Table 10) indicated better scope for internal recycling of nutrients (Bavappa *et al.*, 1986; Abdul Khader *et al.*, 1992). In 1985, there is a net gain of all the three nutrients in the system. The amount of N, P and K recycled through various processes annually was substantial, almost one-half in the case of N and equal in the case K. After 6th year, N content improved considerably, P remained same and K content reduced compared to initial levels. This is because the individual plants were fertilized at recommended doses resulting in gradual nutrient accumulation. This may also help in better root feeding of the nutrients. So, a reduction in the supply of these fertilizer inputs is indicated. The studies on nutrient requirement of ABCS (arecanut + Black pepper + cocoa + banana) indicated that 2/3rd of recommended fertilizer dose for each component crop is sufficient for optimum yield levels (Table 11) (CPCRI, 1996).

Table 9. N, P, K budget and balance in arecanut based model during 1985-86

Budget components	Nutrient (kg/ha)		
	N	P	K
Nutrients added through fertilizers	437	104	589
Nutrients added through organic recycling	220	17	480
Total budget for 1985-86	657	121	1069
Nutrients harvested through crop produce	57	3	31
Nutrients lost by other means	459	-	118
Nutrient balance at the end of 1985-86	141	118	920

(Source: Bavappa *et al.*, 1986)

Table 10. Nutrient budget in HDMSC system in 1988 (kg/ha)

Budget components	N	P	K
Nutrients added by fertilizers	234	104	330
Nutrients added by organic recycling	101	20	105
Nutrients added by microbial biomass	135	16	-
Total nutrients added	470	140	435
Total nutrients removed	120	20	134
Nutrient balance at the end of 1988	350	120	301

(Source : Abdul Khader *et al.*, 1992)

Table 11. Yields of component crops as influenced by fertilizer levels in HDMSCS at Vittal

Treatments	1989	1990	1991	1992	1993	1994
Arecanut (kg chali/ha)						
Control	3513	2766	1277	1437	1644	1138
1/3rd NPK	3595	3296	1485	2087	1641	1008
2/3rd NPK	4430	3224	1778	2194	2051	1723
100% NPK	4154	3785	2395	2288	2485	1690
Cocoa (kg dry beans/ha)						
Control	-	-	37	75	270	456
1/3rd NPK	-	-	103	190	540	658
2/3rd NPK	-	-	159	323	502	790
100% NPK	-	-	190	385	652	868
Black pepper dry (kg/ha)						
Control	-	-	68	269	546	-
1/3rd NPK	-	-	163	775	1396	-
2/3rd NPK	-	-	146	469	1325	-
100% NPK	-	-	104	380	1243	-
Banana (kg bunch/ha)						
Control	4307	5565	-	-	-	-
1/3rd NPK	4168	6103	-	-	-	-
2/3rd NPK	5224	6665	-	-	-	-
100% NPK	5729	9002	-	-	-	-

Testing regression co-efficients of different levels of fertilizers

Treatments	Difference of co-efficients	SD	't' value
Control & 1/3rd NPK	0.36	0.37	0.97 NS
1/3rd NPK & 2/3rd NPK	1.06	0.41	2.609 * *
1/3rd NPK & 100% NPK	1.50	0.38	3.970 * *
2/3rd NPK & 100% NPK	0.44	0.41	1.075 NS

(Source: CPCRI, 1996)

4.5.1. Leaching losses of soil and nutrients in HDMSCS

The potential of HDMSCS in reducing leaching losses was studied at Vittal (Mohapatra and Bhat, 1990). The nutrients present in the leachate from HDMSCS plot was 10 kg N as NH_4N, 138 kg N as NO_3-, 0.25 kg P, 225 kg K, 281 kg Ca and 80 kg Mg per ha and in unfertilized arecanut monocrop it was 5 kg N as NH_4N, 93 kg K, 15 kg Ca and 9 kg Mg per ha. This reveals that the leaching of nutrients from the soil is a serious problem in high rainfall areas.

Leaching losses of water soluble nutrients in HDMSCS plot were 0.1 kg P, 116 kg K, 81 kg Ca and 37 kg Mg per ha. Similarly the leaching losses in arecanut monocrop with fertilizer application through combination of organic and inorganic sources was 6.78 kg P, 190 kg K, 185 kg Ca and 34 kg Mg per ha. This indicates that the leaching losses can be reduced by adopting HDMSCS.

4.5.2. Rainfall partitioning

The partitioning of rain water into throughfall, stem flow and interception loss when passing through plant canopies depends on properties of the respective plant species, such as leaf area and branch angles. In high density cropping system, the presence of different plant species may consequently result in a mosaic of situations with respect to quantity and quality of water inputs into the soil. As these processes influence not only the water availability for the plants, but also water infiltration and nutrient leaching, understanding the effects of plants on the repartitioning of rain water may help in the optimization of land use systems and management practices. The rains during June added 3 kg N as NH_4, 4 kg N as NO_3, 37 kg Ca and 11 kg Mg per ha. The washings from arecanut canopy supplied 4.5 kg K, 6.0 kg Ca per ha (Mohapatra and Bhat, 1990). The studies to quantify throughfall, stem flow and nutrient recycling to the soil through these components of rainfall partitioning in ABCS indicated that arecanut intercepts less rainfall than cocoa and clove (Table 12) (Bhat and Sujatha, 2008a). Throughfall and stem flow added considerable quantity of N, P and K to soil. The addition of nutrients was more in cocoa and among nutrients K leaching through stem flow and throughfall was higher (Table 13). Significant correlation existed among rainfall partitioning components in all the crops. These results indicate that the advantages are substantial in multiple cropping due to the prevention of soil erosion and nutrient loss compared to mono crop system.

Table 12. Throughfall, stem flow and interception loss in arecanut based cropping system

Rainfall (mm) - 2001					
	August	**September**	**October**	**November**	**Total**
Rainfall	330.9	75.8	211.2	124.2	742.1
Arecanut					
Throughfall	173.9(52.5)	40.0 (53)	96.2(45)	56.9(45.8)	366.8(49)
Stem flow	139 (42)	30.3 (40)	95 (45)	54.6 (44)	319 (43)
Interception loss (%)	5.5	7.0	10.0	10.2	8.0
Cocoa					
Throughfall	228.3(69)	49.3(65)	154.2(73)	86.9(70)	518.7(69.9)
Stem flow	39.7(12)	10.6(14)	33.8(16)	16.1(13)	100.2(13.5)
Interception loss(%)	19.0	20.9	11.0	17.0	16.6
Clove					
Throughfall	251.5(76)	45.5(60)	147.8(70)	93.2(75)	538.0(72.5)
Stem flow	39.7(12)	8.34(11)	27.5(13)	19.9(16)	95.4(12.8)
Interception loss(%)	12.0	29.0	17.0	9.0	14.7
Rainfall (mm)- 2002					
	May	**June**	**July**	**August**	**Total**
Rainfall	60.4	722.5	487.9	573.0	1843.8
Arecanut					
Throughfall	39.8(66)	461.3(64)	190.0(39)	273.7(48)	964.8(52)
Stem flow	15.9(26)	230.2(31)	100.0(20.5)	118.6(21)	464.7(25)
Interception loss (%)	8.0	5.0	40.5	31.0	23.0
Cocoa					
Throughfall	40.3(66.7)	471.6(65)	333.6(68)	383.7(67)	1229.2(66.7)
Stem flow	10.5(17.4)	142.6(19.7)	79.6(16.3)	102.6(17.8)	335.6(18.2)
Interception loss(%)	15.9	15.3	15.7	15.2	15.0
Clove					
Throughfall	49.5(82)	477(66)	328.5(67.3)	378.3(66)	1233.3(66.9)
Stem flow	7.7(12.7)	114.2(15.8)	82.7(16.9)	108.6(18.9)	313.2(17.0)
Interception loss(%)	5.3	18.2	15.8	15.0	16.1

Note: Figures in parenthesis indicate percentage of rainfall

(Source: Bhat and Sujatha, 2008a)

Table 13. Nutrient concentrations (ppm) in throughfall and stem flow from different component crops and rain water in ABCS

	2001				2002			
	pH	**N**	**P**	**K**	**pH**	**N**	**P**	**K**
Arecanut								
Throughfall	5.96	0.55	0.22	1.69	5.93	0.30	0.19	1.52
Stem flow		0.48	0.10	7.32		0.40	0.20	4.77
Cocoa								
Throughfall	6.21	0.40	0.66	8.11	6.19	0.90	0.46	7.61
Stem flow		0.57	0.89	20.82		0.90	0.58	9.03
Clove								
Throughfall	6.13	0.58	0.36	4.05	6.13	0.60	0.25	4.0
Stem flow		0.74	0.05	5.20		0.70	0.16	2.91
Rain water	5.65	0.38	NA	0.27	5.67	0.43	NA	0.32

(Source: Bhat and Sujatha, 2008a)

4.6. Soil microflora

The soil microflora and fauna vary according to the soil conditions, agronomic practices and cropping pattern. The microorganisms associated with the perennial tree crops are most likely to be constant in their quantitative nature and abundance. The rhizosphere microorganisms in high density multiple cropping and arecanut monocrop have been recorded (Bopaiah and Bhat, 1981; Bopaiah and Reddy, 1982; Bopaiah, 1991) and presented in Table 14. The population of bacteria, fungi, actinomycetes, N_2-fixers and P-solubilizers were more in rhizophere of arecanut, cocoa and pinapple as compared to arecanut monocrop. The spore count, vesicular-arbuscular mycorhizae root infection and colonization were least in banana. The microbial biomass was also higher in multiple cropping system. The asymbiotic N_2 fixers isolated from arecanut based high density multiple cropping system had the N_2 fixing capacity in the range of 2.8 to 11.8 mg N/100 ml of medium (CPCRI, 1988).

Table 14. Microbial population and soil biomass in 0-25 cm soil layer at Vittal

Cropping system	Location of sampling	Total microbial population/g soil (10^3)	Soil microbial biomass (µg g/g soil)
Arecanut monocrop	Arecanut basin	768	763
Arecanut monocrop	Arecanut interspace	126	616
Arecanut HDMS	Arecanut basin	819	788
Arecanut HDMS	Arecanut interspace	530	676

(Source : Bavappa *et al.*, 1986)

Microbial studies in arecanut based cropping system showed marginal increase in total microbial population and soil microbial biomass both in arecanut basin and interspaces due to mixed crops compared to arecanut monocropping (Table 14). Further studies indicated that the population of bacteria, fungi and actinomycetes was considerably higher in rhizosphere of various crops like arecanut, cocoa, clove, banana and coffee than in interspaces and microbial biomass C was 10 times greater in various crop rhizospheres than in interspaces at 0-30 cm soil depth. (Bhat *et al.*, 2008). Significant variability ($P < 0.01$) in microbial quotient (the ratio of soil microbial biomass C to organic C ratio), which is a good indicator of changes in microbial performance caused by environmental conditions was noticed in rhizosphere of different crops with cocoa registering higher value of 3.90. The study by Bhat *et al.* (2008) revealed that arecanut based HDMSCS resulted in proliferation of microorganisms and increased enzymatic activities.

5. Socio-economic considerations

In the tropical countries the farm holdings are small, being less than two hectares with three-quarters of farmers. This applies to arecanut gardens as well. In perennial crops the land is committed for several years. This has led to a widespread practice of multiple cropping among farmers who have evolved various systems by experience, tradition and socio-economic needs. Only in recent years that researchers and policy-makers have begun to realise the potential for maximizing productivity. More scientific approach and methods are being developed now. Two other issues that are relevant here are the risk factors and employment generation. A small farmer cannot afford to loose the crop due to any of the climatic disasters or pest and disease attack as he is wholly dependent on it. The multiple cropping systems may protect the farmer from any eventual risks caused by non marketability or crop loss in any of the crop species. Different indices are used to evaluate cropping/farming systems. The profitability of arecanut based HDMSCS in terms of benefit-cost ratio and yield advantage was highlighted by several workers (Sannamarappa and Muralidhran, 1982; Bhat *et al.*, 1999). The creation of employment opportunities is of significant importance in developing countries. Farming in most of the plantation crops is labour intensive. The introduction of multiple cropping increases the labour inputs. The labour requirement for arecanut alone was 377.8 man days/ ha/ year. The labour requirement increased by 70% when cocoa, black pepper and clove were grown and by 103% when cocoa, black pepper, clove, banana, pineapple and coffee were grown along with arecanut (Bhat *et al.*, 1999). Since majority of arecanut cultivation is done as homestead, the additional employment generated through mixed cropping would provide employment to the farm family throughout the year.

6. Arecanut Based Mixed Farming system

Mixed farming system plays a major role in organic agriculture as the intermediary between the utilization of crop residues or fodder produced at the farm and the return of manure as nutrients. Dairy in particular helps small and marginal farmers to improve their income. Research work on arecanut based mixed farming system was initiated at Vittal in 2007. The two year trial on arecanut based mixed farming system generated around Rs. 3000/- net income per month from milk and cattle manure. Recycling of cattle manure has potential to meet the N requirement of 3 ha of arecanut garden. Hybrid napier (Co-3) was found to be a suitable fodder crop for inter cropping in arecanut plantation. About 62.5 t of green fodder per year was obtained from one ha of arecanut garden (CPCRI, 2009). The grass needs to be replanted after two years as yield reduction was noticed after second year.

7. Conclusions and future line of work

The review shows that arecanut based HDMSCS offers efficient utilization of resources like light, air space, soil, land etc. at different horizontal and vertical strata. The HDMSCS apart from increasing the productivity per unit area, improves the soil fertility and productivity as well. The suitable systems vary from region to region as per the local need and the climate. In coastal region the successful system involves arecanut, black pepper, cocoa and banana. In plain region the system includes arecanut, black pepper/betel vine, banana, lemon and tapioca. A judicious mix of cropping systems with associated enterprises like dairy would bring prosperity to the arecanut farmer.

Continuous monoculture of arecanut for several decades might lead to ecological imbalance. Adoption of cropping/farming system approach is indispensable to increase the productivity per unit area and to avoid risks due to pests, diseases and price fluctuations. Thus, arecanut based bio-diverse farming system model for different arecanut growing regions is the need of the hour. The integration of crops and / or livestock in arecanut garden requires careful studies with respect to its socio-economic benefit and its impact on productivity of arecanut. Nutrient budgeting studies in the cropping/farming system has to be done for better resource use efficiency.

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Arecanut based cropping systems in North East Region of India

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Introduction

Arecanut is mainly grown in the states of Kerala, Karnataka, Tamil Nadu, Assam, West Bengal, Meghalaya, Maharashtra, and Andaman & Nicobar group of Islands. The economic produce is the fruit called betelnut or 'supari' which is used mainly for masticatory purpose. India is the largest producer and consumer of arecanut and it continues to dominate world in area, production and productivity.

In Assam, arecanut is cultivated in an area of 71,000 ha producing 65,000 tonnes of chali with a productivity of 915 kg dry kernel/ha (2006-07)(Anon. 2008). However, the productivity is much less when compared to the other arecanut growing states like Karnataka, West Bengal and Kerala, where the corresponding figures are 1,333, 4,348 and 1,077 kg dry kernel/ha. Among NE states, arecanut is mainly cultivated in Assam, Tripura (3,400ha), Meghalaya (12,000 ha) and Mizoram (2,000 ha). In most parts of the NE region including Assam, arecanut finds place in all most every house holds, literally called as *Bari System of Planting*.

The characteristic features of the plantation crops such as their perennial nature, long gestation period, multiplicity of reproductive phase, continuous labour requirement, irrevocable nature of fixed resources like land etc., necessitate a separate approach of diversification. The state agriculture, which, is predominated by small and marginal farms is expected to adopt higher degree of farm diversification or intensification for protection against natural and economic risks. This means that these farmers can make use of the production complimentarities to reap the benefits of synergism through appropriate choice of crop combinations or other economic activities. This would help them to achieve maximum resource use efficiency through intensive use of land, optimum use of time, benefits from additional crop/ enterprise, reuse of farm waste and byproducts, rational use of farm family labour and integration of farm and non-farm activities. Besides, arecanut plantations as mono crops provide employment only for a part of year and farm families have to remain unemployed or have to go elsewhere searching for employment. Practicing mixed cropping in arecanut plantation offers 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.

2. Scope for mixed/ inter cropping

Arecanut as a sole crop does not utilize the natural resources like soil, space and light fully. The compact nature of arecanut crown, raised well above the ground (10 to 15 m), allows more sunlight to pass down to ground and maintain high humidity which, in turn, favour excellent growth of shade loving crops. Studies at CPCRI have revealed that orientation and structure of arecanut canopy permits 32.7-47.8% of incident radiation to penetrate down depending on the time of the day (Muralidharan, 1980). Normally in an arecanut garden spaced at 2.7 m x 2.7 m, the light energy reaches the ground and is wasted. Rooting pattern revealed that arecanut palms planted at 2.7 m x 2.7 m spacing could use effectively only 30% of the land area (Shama Bhat and Leela, 1969). The normal cultural operations are also confined within about 75-80 cm radius from the base. Thus, the areca palm exploits only 2.27 m^2 of land area (r = 0.85 m) out of 7.29 m^2 (2.7 m x 2.7 m) land available to each palm. So, growing only one crop as a mixed crop in an arecanut garden would not maximize the resources use and this has led to the concept of high-density multispecies cropping system, where more than one crop is grown as mixed crops (Bavappa *et al.*, 1986). Thus, the arecanut plantations are more ideal for inter/ mixed cropping. It is also desirable that the crop selected for mixed cropping should be preferably shade tolerant, since the maximum solar energy received below the canopy of the crops does not exceed 50 per cent at any period of growth.

3. Arecanut based cropping system

3.1. Intercropping of horticultural crops in pre-bearing arecanut garden

Various vegetables and flower crops were tried under the interspaces of a pre-bearing arecanut garden (variety Mohitnagar). The intercrops were planted in between two rows of arecanut palms with 1.5 m width, which constitutes 44.5% area for intercrops in an arecanut plantation (Ray *et al.*, 2007a). The yield of seven vegetable crops tried under the interspaces of arecanut was estimated taking into consideration of the yield obtained from the cropped area available in one ha of arecanut plantation and the data is presented in Table 1. The cost of production was the highest in potato (Rs.12,765/ha) followed by tomato (Rs.12,713/ha).

Among the vegetables tried, the maximum gross return (Rs.42,750/ha) was obtained with cabbage followed by brinjal (Rs 40,600/ha). Among the flower crops, the maximum cost of production was observed for gladiolus (Rs.68,850/ha), the maximum gross return of Rs.1,23,089/ha was obtained from gladiolus. The B:C ratio was the highest (5.05) in arecanut + brinjal followed by 4.68 in arecanut + cabbage cropping systems. Maximum B:C ratio was accrueded by growing chrysanthemum (2.43) and marigold (2.05) under arecanut.

The return per rupee invested on labour and per day return was estimated and presented in Table 2 for different vegetable and flower crops. It was observed that among the

Table 1. Yield and economics (Rs./ ha of arecanut garden)of vegetable and flowering crops grown under young areca plantation (average of two years)

Crop	Yield (t/ ha of Areca garden)	Cost of production	Gross return	Net return	B:C ratio
Radish	9.2	6850	27675	20825	4.05
Knolkhol	4.2	7350	14735	7385	2.00
Cabbage	21.4	9150	42750	33600	4.68
Cauliflower	9.5	8950	38000	29050	4.24
Tomato	6.6	12713	32750	20037	2.57
Potato	5.9	12765	28925	16160	2.26
Brinjal	10.2	8045	40600	32555	5.05
Gladiolus	17938* 34638**	68850	123089	54239	1.78
Chrysanthemum	6.0	12300	29850	17550	2.43
Marigold	4.5	10950	22425	11475	2.05

* Number of spikes ** Number of corms (Ray *et al.*, 2007a)

vegetables, the value for return per rupee invested was maximum (15.77) for brinjal followed by cabbage and radish. The pooled data revealed higher value for brinjal followed by cabbage and cauliflower suggesting better utilization of labour in these vegetable crops. Among the flower crops, it did not vary much and ranged from 4.61 to 6.25 for the pooled data of two years. The pooled data indicated that economic efficiency (per day return basis) was the highest (395.28) in cabbage followed by cauliflower and radish. Among the flower crops, the economic efficiency was found to be the highest (417.21) for gladiolus followed by chrysanthemum. From the trial it was clear that all the vegetable and flower crops evaluated can be grown suitably and profitably under arecanut plantation. Better labour utilization and economic efficiency could be possible by growing brinjal, cabbage, cauliflower and radish under young areca plantation. Therefore, vegetables like radish, cabbage, cauliflower and brinjal are suitable as intercrops. Flower crops like marigold and chrysanthemum are more suitable in view of the market demand and higher B:C ratio. However, it was also observed that some medicinal and aromatic crops like patchouli, long pepper and vanilla were coming up well in the interspaces of arecanut garden in this region.

3.2. High density multispecies cropping system

Arecanut based high density multispecies cropping system (HDMSCS) model was studied under three levels of fertilizer management, i.e., full, two-third and one-third dose of recommended fertilizers. The component crops included in the system were black pepper (cv. Panniyur-1) trained on arecanut palms, banana (cv. Cheni Champa) in a triangular system (5.4 m x 2.7 m), turmeric (cv. Kasturi) spaced 30 cm x 30 cm, and pineapple (cv. Queen) in two rows spaced 60 cm x 30 cm between two arecanut palms. Nine years of mean economic yield (1987-1996) revealed that the full dose of recommended fertilizer application resulted in higher production with arecanut chali yield of 2,405 kg ha^{-1}, black pepper yield of 1,252 kg ha^{-1}, pineapple fruit yield of 988 kg ha^{-1} and turmeric yield of 2,127 kg ha^{-1} (Table 3). However, the banana yield did not vary much between the full and two-third dose of fertilizers (6,331 kg to 6,313 kg ha^{-1}). Under one-third dose of fertilizers, all the crops realized the lowest yields. Application of full dose of fertilizers resulted in higher net returns of Rs 3,24,548 ha^{-1} yr^{-1}. The average data of 9 years revealed that maximum gross return was obtained from arecanut followed by black pepper, banana, turmeric and pineapple (Table. 4). It was also been observed that the realized B:C ratio under full, two-third and one-third dose of fertilizers was 3.28, 3.43 and 3.31, respectively, indicating the treatment with two-third level of fertilizers was economically more viable in the system as a whole. The major share was derived from the main crop of arecanut (48%) followed by the component crop of black pepper (43%). Other crops contributed the remaining 9%. Pineapple cultivation was found to be uneconomical as a component crop in the arecanut based HDMSCS model (Ray and Reddy, 2001).

Table 2. Return per rupee invested and per day return of different intercrops

Sl. No.	Vegetable / Flower crop	Return per rupee invested on labour (Rs.)			Per day return (Rs.)		
		2003-04	2004-05	Mean	2003-04	2004-05	Mean
1	Radish	13.41	9.61	11.48	373.8	266.92	320.35
2	Knolkhol	4.50	4.42	4.46	91.56	93.06	93.31
3	Cabbage	14.66	11.86	13.13	434.1	356.47	395.28
4	Cauliflower	11.30	12.31	11.80	32.22	343.33	322.77
5	Tomato	6.20	6.65	6.43	222.94	248.52	235.73
6	Potato	5.37	5.35	5.36	145.45	148.36	146.90
8	Brinjal	15.77	14.17	14.97	281.04	261.54	271.29
9	Gladiolus	6.29	6.20	6.25	417.88	416.55	417.21
10	Chrysanthemum	6.05	5.79	5.92	148.33	144.16	146.24
11	Marigold	5.11	4.12	4.61	107.5	83.75	95.62

(Ray *et al.*, 2007a).

The above arecanut based HDMSCS models were redesigned keeping in consideration of the non-profitability of pineapple and the systems was modified to:

1. Model I consisting of arecanut (Kahikuchi), black pepper (Karimunda), banana (Chenichampa), citrus (Assam lemon) and clove

Table 3. Yield response of different crops under different levels of fertilizers in HDMSCS (1987-88 to 1995-96)

Crop	Treat.	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	Mean
Arecanut	Full dose	3038	2379	2053	2560	2263	2643	2078	2253	2381	2405
(kg chali	2/3 dose	3022	2864	2042	2066	2089	2443	2138	2485	2339	2388
ha^{-1})	1/3 dose	2653	2211	1453	1664	1895	2317	1663	1969	1954	1975
Black pepper	Full dose	-	-	-	410	1627	1669	1074	1411	1320	1252
(dry kg	2/3 dose-	-	-	-	432	1463	1622	1032	1032	1188	1128
ha^{-1})	1/3 dose	-	-	-	410	2000	1374	853	800	867	1051
Banana	Full dose	7139	5812	6222	6339	7423	-	5328	6476	5766	6313
(kg bunch	2/3 dose	7623	5222	5559	8845	7092	-	4659	5592	6053	6331
ha^{-1})	1/3 dose	5296	3769	4674	7897	6044	-	4443	4380	4820	5165
Pineapple	Full dose	-	948	947	421	422	-	-	2348	839	988
(kg ha^{-1})	2/3 dose	-	284	758	368	316	-	-	2011	662	733
	1/3 dose	-	294	589	316	210	-	-	1358	492	543
Turmeric	Full dose	2511	2253	2516	2074	-	-	-	1663	1744	2127
(kg ha^{-1})	2/3 dose	2590	1884	2284	2010	-	-	-	1432	1640	1973
	1/3 dose	2948	1853	1816	1263	-	-	-	1243	1685	1801

(Ray and Reddy, 2001)

2. Model II comprising of arecanut (Kahikuchi), black pepper (Panniyur-1), banana (Chenichampa), citrus (Gandharaj lemon) and nutmeg (grafts)

Details of population and treatments are given in Table 5. The treatments such as full recommended dose of fertilizer, 2/3rd of the recommended dose and 1/3rd of the recommended dose of fertilizer were imposed for the main and component crops in the system. The biomass generated from the above models was also estimated from different treatments.

3.3. Yield of crops

The average yield of arecanut as influenced by different treatments is presented in Table 6. In general, the arecanut yield was higher in Model I compared to Model II and over the years there was increase in the yield of arecanut. Among the treatments, application of 2/3rd level of recommended fertilizer recorded higher yield in both the models followed by full dose of recommended fertilizer. The arecanut yield was the lowest in the 1/3rd of recommended fertilizer level in both the models. Higher yield under 2/3rd level of recommended fertilizer application along with recycling available biomass in the form of compost might have improved the soil physico-chemical properties, which had positive effect on growth and yield.

Table 4. Average economics (Rs/ha) of arecanut based HDMSCS model (1985-1996)

Crop		Cost of cultivation	Gross returns	Net returns
Arecanut	Full	8898	42797	33899
	2/3rd	7362	41880	34518
	1/3rd	7349	34955	27606
Black pepper	Full	6062	37521	31459
	2/3rd	5818	33017	27199
	1/3rd	4652	29171	24519
Banana	Full	8777	21217	12440
	2/3rd	8068	21101	13033
	1/3rd	7009	17383	10374
Pineapple	Full	5062	6045	983
	2/3rd	4173	4562	389
	1/3rd	3612	3353	-
Turmeric	Full	7573	20980	13407
	2/3rd	7185	18977	11792
	1/3rd	6499	17624	11125
Total	Full	36372	128560	92188
	2/3rd	32606	119537	86931
	1/3rd	29121	102486	73365

Table 5. Crops with varieties, population and treatment details

Model	Crop and variety	Population (No. of plants)	Treatment	Plot size (ha)
M1	Arecanut (Kahikuchi selection)	432	Full level of recommended dose (M1T1)	0.105
	Black pepper: Karimunda Banana: Chenichampa	432 135	2/3rd level of recommended dose (M1T2)	0.105
	Clove: Local Citrus: Assam lemon	72 138	1/3rd level of recommended dose (M1T3)	0.105
M2	Arecanut (Kahikuchi selection)	432	Full level of recommended dose (M2T1)	0.105
	Pepper: Panniyur 1 Banana: Chenichampa	432 135	2/3rd level of recommended dose (M2T2)	0.105
	Nutmeg grafts (Local) Citrus: Gandhraj lemon	72 138	1/3rd level of recommended dose (M2T3)	0.105

Yield of banana was higher under full dose in both the models followed by 2/3rd and it was the lowest in 1/3rd of recommended fertilizer treatments. This indicates that banana crop is an exhaustive crop and responds well to applied nutrients. The per plant yield ranged from 22 to 23 kg; 20 to 21 kg and 15 to 17 kg fruit, respectively under various fertilizer levels. Citrus fruit yield was higher at 2/3rd level followed by full dose and 1/3rd level of recommended fertilizer doses. Among the varieties, Assam lemon has performed well yielding 20 to 24 fruits per plant compared to Gandhraj lemon (15 to 20 fruits per plant). Black pepper yield was higher under 2/3rd level followed by full dose and the yield was very low under 1/3rd level of fertilizer treatments. Among the varieties, Karimunda performed better than Panniyur-1. Clove and nutmeg plants were planted during 1998 and only 33.3% of the clove and only 10% of nutmeg plants started yielding.

Table 6. Yield of component crops under HDMSCS (Average of 2001-04)

Model & Treatment	Yield (per ha)of component crops under HDMSCS			
	Arecanut (chali,kg)	Banana fruits (kg)	Citrus fruit (nos.)	Pepper (dry,kg)
M1T1	2125.5	8022.7	8927.7	1034.7
M1T2	2446.5	7836.2	10135.2	1333.7
M1T3	1996.5	7583.5	8416.7	596.7
M2T1	2001.2	8107.7	7464.0	958.0
M2T2	2189.7	7191.2	8731.7	1125.0
M2T3	1810.0	5885.2	6856.0	620.7

(Hussain *et al.*, 2008)

The cost of production varied from Rs 69,638/ ha under 1/3rd dose of fertilizer to Rs.93,660/ha under full recommended dose of fertilizer in the case of Model-I (Table 7). Same trend was noticed in the case of Model-II, where the corresponding figures were Rs. 65,568 and Rs 89,590/ha. The gross return calculated was the highest under 2/3rd dose of fertilizer in both the models i.e., Rs.2,93,652/ha and Rs. 2,49,471/ha in Model-I and II, respectively. Net return was also the highest under 2/3rd dose of fertilizer in both the models. In model I, the net return per hectare under 2/3rd dose of fertilizer was Rs.2,12,003, whereas, the lowest net return (Rs. 1,14,875/ha) was obtained under 1/3rd dose of fertilizer. In the case of Model-II, under 2/3rd dose of fertilizer, a net return of Rs.1,71,892/ha was obtained as against Rs 1,07,241/ha under 1/3rd dose of fertilizer. Similarly, the highest benefit cost ratio was calculated as 3.60 and 3.22 in Model-I and Model-II, respectively, under 2/3rd dose of fertilizer. Minimum B:C ratio was obtained under full dose of fertilizer in both the models. While studying the cropping system interventions in and around Guwahati, it has been reported that crops like turmeric, black pepper, ginger, cowpea, banana ands citrus are found to grow well in arecanut gardens and provide additional income to farmers (Ray *et al.*, 2007b).

Table 7. Economics of arecanut based HDMSCS (average of two years)

Model	Treatment	Cost of production (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	B:C ratio
M I	Full dose	93,660	2,29,425	1,35,765	2.45
	2/3rd dose	81,649	2,93,652	2,12,003	3.60
	1/3rd dose	69,638	1,84,513	1,14,875	2.65
M II	Full dose	89,590	2,21,191	1,31,601	2.47
	2/3rd dose	77,579	2,49,471	1,71,892	3.22
	1/3rd dose	65,568	1,72,809	1,07,241	2.64

3.4. Composting of available biomass

Investigations were carried out during 2001 to 2004 to quantify the available biomass for recycling from the arecanut based HDMSCS models (arecanut, black pepper, banana, clove, nutmeg, and citrus) under graded (full, 2/3rd,1/3rd of the recommended) level of fertilizers for all the crops (Hussain *et al.*, 2008). Results revealed that the total amount of available biomass from the system ranged from 8.76 to 10.58 t/ha/year (Table 8). The highest amount of biomass for recycling was recorded from 2/3rd level of fertilizer dose (10.58 t/ha/year) under model I and the compost produced ranged from 5.4 t to 8.4 t/ha/year and the highest was under 2/3rd level of fertilizer dose. The amount of nutrient contribution by recycling the compost in the garden ranged from 41.36 to 54.94 kg N, 32.69 to 42.55 kg P_2O_5 and 66.25 to 85.38 kg K_2O per ha per year (Table 9). The results also indicated that there was increase in the yield of main and component crops over the years. Yield of arecanut, citrus and pepper were higher under 2/3rd recommended level of

Table 8. Available biomass (t/ha) from 1.0 ha of arecanut based HDMSCS (Average of 4 years)

Model & Treatment	Available biomass(t/ha) of different crops						Total
	Arecanut	Black pepper	Banana	Clove	Nutmeg	Citrus	
M1T1	5.75	0.89	2.48	0.56	-	0.67	10.35
M1T2	6.28	0.93	2.08	0.58	-	0.71	10.58
M1T3	5.38	0.86	1.50	0.53	-	0.64	8.91
M2T1	5.58	0.88	2.30	-	0.74	0.65	10.15
M2T2	6.13	0.90	1.83	-	0.78	0.69	10.33
M2T3	5.08	0.85	1.50	-	0.70	0.63	8.76

(Hussain *et al.*, 2008).

fertilizer coupled with organic biomass recycling in the form of compost. However, banana yield was higher under full dose of recommended fertilizer (Hussain *et al.*, 2008).

Table 9. Chemical properties and nutrient content of compost (Average of 4 years)

Model & Treatment	pH	O.C. (%)	Av.N (%)	Av.P_2O_5 (%)	Av.K_2O (%)	C:N ratio	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
M1T1	6.53	7.06	0.69	0.54	1.09	10.3:1	49.78	39.13	78.74
M1T2	6.78	7.58	0.73	0.57	1.14	10.4:1	54.94	42.55	85.38
M1T3	6.35	6.78	0.67	0.53	1.07	10.1:1	42.00	33.26	67.23
M2T1	6.48	6.95	0.69	0.54	1.08	10.1:1	48.82	38.13	77.17
M2T2	6.75	7.46	0.71	0.55	1.12	10.5:1	52.10	40.42	81.88
M2T3	6.30	6.77	0.67	0.53	1.07	10.1:1	41.36	32.69	66.25

(Hussain *et al.*, 2008)

The quantity of compost produced from various treatments during different years is presented in Fig.1. It ranged from 5.4 t to 8.4 t/ha/year and it was the highest under 2/3rd level of fertilizer dose (8.4 t/ha/year) during 2004. The recovery of the compost ranged from 66.51 to 74.52% and it was higher during later years of the experiment i.e. 2003 and 2004 (72.36 to 74.52%) compared to the initial two years, which might be due to build up of microbial population in subsequent years in the compost pit (Hussain *et al.*, 2008).

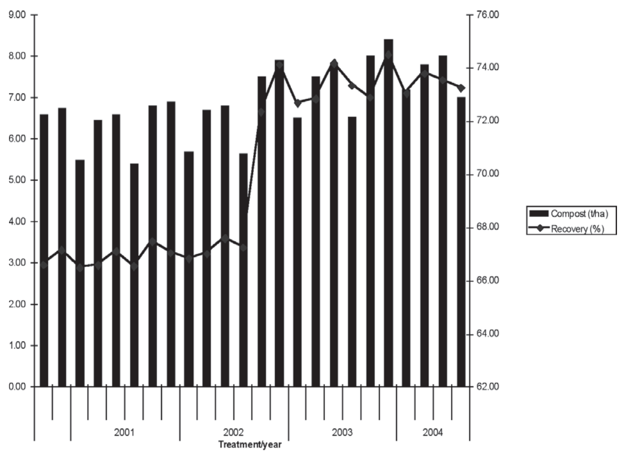

Fig 1. Production and recovery of compost

A survey was undertaken to ascertain the feasibility of vermicompost technology in the farmers homestead garden in two villages under Rani Development Block of Kamrup dist., Assam, during Feb-March, 2004. It was observed that on an average 60 kg of vermicompost could be produced from 100 kg of arecanut based biomass under farmers' field condition (Barman *et al.*, 2006).

4. Conclusion

In a state like Assam, where each and every household credits to growing arecanut in the backyards, it is rather essential that suitable mixed cropping systems should be followed in order to increase the net profit and the socio-economic status of the family. Apart from that, by adopting the mixed cropping system, there is always enough scope for generation of farm employment. The scientist/ researchers should make efforts to disseminate the proven technologies among the farmers to make it more successful.

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Arecanut based cropping systems in Sub Himalayan Terai Region of West Bengal

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Introduction

Arecanut is an important plantation crop grown in tropical and subtropical climate of the World. It is used as a masticatory for mouth freshening as raw as well as value added products. It is also used as gutkha and in religious, social and cultural functions as well as in Ayurvedic and veterinary medicines. A considerable quantity of natural resources (sun light of about 32.7 to 47% and land 70%) remain unutilized in the plantation garden as reported by Shama Bhat and Leela (1968) and Abdul Khader *et al*. (1993) which facilitate to grow suitable intercrops or mixed crops under the system. Intercropping in arecanut garden not only increases the return per unit area but also minimizes the risk of cultivation of arecanut as a mono-crop. Considering the long pre bearing stage and availability of natural resources (land and sun light), various experiments were conducted at different research stations of CPCRI to find out the best possible combination of different horticultural crops in arecanut plantation for proper utilization of land, sunlight and maximization of profit per unit area.

2. Intercropping/Mixed Cropping systems

2.1. Arecanut based high density cropping system models

High Density Multispecies Cropping System (HDMSCS) facilitates utilization of solar energy and soil resources wherein crops of different stature and root pattern are selected to form a compatible and profitable combination. The component crops utilize the radiant energy from different stages of the airspace under the canopy of the main crop, whereas, the root system of the component crops draw the nutrients from different columns of soil depth without competing the main crop. Intercrops with different annuals and perennials had no deleterious effect on yield of arecanut. Black pepper and betel vine are usually planted about 60 cm away from the arecanut palm at North Eastern sides and trailed with arecanut. Other crops are grown in between two rows of arecanut at the centre of four arecanut palms.

At CPCRI Research Centre, Mohitnagar, models of different crop combinations (Table 1) were studied during early nineties. Average data of nine years (1990-91 to 1998-99) showed that more returns can be obtained from different crop combinations than the arecanut monocrop from per unit area. Maximum return was obtained from Model V (arecanut, betel vine, banana and cinnamon) which was about 117.87% over control followed by Model-II (Arecanut + Black pepper + Banana + acid lime) (Chenchaiah *et al*. 2002a). Maximum net return (Rs. 82074/ha) was obtained from the model II followed by model V (Rs. 81299/ha). In case of return per rupee investment, it was maximum (8.33) in arecanut monocrop followed by Model V (5.54), Model III (3.85). Maximum value of net return/ rupee investment in arecanut as monocrop may be due to less input cost. The yield of arecanut was also influenced by different crop combinations. Low yield of arecanut was obtained in monocrop plot than the other model. Maximum yield of arecanut (1,934.9 kg chali/ha) was obtained from Model V followed by Model II (1,865.67 kg chali/ha).

Though the Models V and I performed better in sub Himalayan terai region of West Bengal, due to problems in marketing of cinnamon and cocoa, farmers were suggested to adopt Model II with a crop combination of arecanut, black pepper, banana and acid lime. Demonstration gardens of Model II are being maintained by this Centre at two locations of Jalpaiguri District since 1999. Maximum contribution to the total returns was from arecanut. On an average, 2.5 kg chali/palm, 1.0 kg dry pepper/vine, 16 kg banana/plant and 75 lime fruits/ tree was harvested per year from one hectare of plantation. Elephant foot yam was taken in other open available space of the system. On an average Rs.1,05,550/- was earned by the farmers in both the conditions.

Table 1. Net return of different arecanut based cropping models per hectare (9 years average)

Model	Crop combinations	Yield of different crops	Net return (Rs.)	Net return/rupee investment	% Increase over control
I	Arecanut (kg chali) Dry black pepper (kg) Banana (kg) Cocoa pod (nos.)	1641 334.95 701.3 9,055	74167	3.44	94.92
II	Arecanut (kg chali) Dry back pepper (kg) Banana (kg) Acid lime (nos.)	1865.67 290.33 1095.97 7116	82074	3.66	94.93
III	Arecanut (kg chali) Betel vine (nos. leaf) Banana (kg) Turmeric (kg)	1853.39 180244 1938.4 1980.3	65753	3.85	73.63
IV	Arecanut (kg chali) Dry black pepper (kg) Banana (kg) Dry Coffee (kg)	1740.90 61.12 2128.50 99.98	61383	3.17	53.45
V	Arecanut (kg chali) Betel vine (nos.leaf) Banana (kg) Dry Cinnamon (kg)	1934.90 213849 1925.4 65.54	81299	5.54	117.87
Control	Arecanut (kg chali)	1353.44	46265	8.33	

Input, output and economics of different annuals and perennials grown in arecanut plantation under irrigated and un-irrigated conditions were calculated separately by Chenchaiah *et al*. (2002b) and presented in Table 2. More return was obtained from all the crops under irrigated condition. The net returns for all the crops varied between Rs. 6262 (pineapple) to Rs. 26764 (black pepper) under irrigated condition and Rs. 2784 (pineapple) to Rs. 22560 (cocoa) under un-irrigated condition. Maximum net return/rupee investment (5.46) was obtained from black pepper followed by cocoa (4.60) and banana (Malbhog) (1.96) under irrigated condition. Among the four types, the performance of Malbhog banana was better than the other due to its more yield, demand and price.

Table 2. Economics of different inter/mixed crops under arecanut garden (average of 3 years under irrigated and un irrigated conditions

Crops	Conditions	Input (Rs.)	Output (Rs.)	Net return/ rupee investment
Dry black pepper (kg)	Irrigated	4900	31664	5.46
	Un-irrigated	4085	21450	4.65
Betel vine (no. of leaves)	Irrigated	3906	5125	0.31
	Un-irrigated	3742	3665	-0.02
Lemon (no. of fruits)	Irrigated	11700	28180	1.40
	Un-irrigated	11300	23871	1.10
Banana-Malbhog (kg)	Irrigated	8320	24636	1.96
	Un-irrigated	7928	22704	1.86
Banana-Champa (kg)	Irrigated	8284	22620	1.73
	Un-irrigated	8040	13284	0.65
Banana-D Cavendish (kg)	Irrigated	9412	13196	0.40
	Un-irrigated	9044	9594	0.60
Banana-Plantain (kg)	Irrigated	7424	5372	-0.28
	Un-irrigated	7180	4520	-0.37
Cocoa (no. of pods)	Irrigated	4450	25010	4.60
	Un-irrigated	4334	22560	4.20
Dry Coffee (kg)	Irrigated	5136	14296	1.90
	Un-irrigated	4788	9500	0.98
Pine apple (kg)	Irrigated	7624	13892	0.82
	Un-irrigated	6928	9712	0.40
Arrowroot (kg)	Irrigated	9740	2034	-0.79
	Un-irrigated	9168	1826	-0.80
Elephant foot yam (kg)	Irrigated	16567	12422	-0.25
	Un-irrigated	16192	11542	-0.29
Turmeric (kg)	Irrigated	12640	19160	0.52
	Un-irrigated	11868	16456	0.39

Source: Chenchaiah *et al*.(2002b)

2.1.1. Arecanut with Black pepper/betel vine

Black pepper, being a vine crop, is an excellent crop for mixed cropping system with arecanut as standard. Performance of different black pepper varieties like Panniyur-1 and Karimunda was better. Cultivation of black pepper (var. Panniyur-1) in arecanut garden was carried out in Mohitnagar condition during early 80's. Black pepper was planted at 60 cm away from the trunk of the arecanut at north eastern side and was allowed to climb on arecanut trunk. Dry black pepper yield ranged between 0.75 to 9.25 kg/vine with an average of 1.00 kg/vine (Sit *et al.*, 2002). Betel vine also can be profitably trailed with arecanut palm like black pepper at sub Himalayan Terai region of West Bengal (Chenchaiah *et al.*, 2002b).

2.1.2. Arecanut and Banana

Banana is an important crop grown as an inter crop with arecanut from the early growth stage of arecanut. It is mainly used for shade for arecanut at early stage and simultaneously it provides some income at initial stage (pre bearing) from arecanut garden. It is also one of the important component crops in arecanut based HDMSCS. The crop is planted at the centre of four arecanut palms in alternate rows. Recommended agronomic practices are followed. A total of three suckers are allowed to maintain the canopy spread. One is bigger one, second one is middle one and third one is smaller one. In an experiment at CPCRI Research Centre, Mohitnagar, four types of banana viz., Malbhog, Champa, Dwarf Cavindish and Kanchkela (Plantain) were planted in arecanut garden. The net return/rupee investment was maximum (1.96) in the case of Malbhog banana followed by Champa banana (1.76) and Dwarf Cavindish (0.40) (Chenchaiah *et al.*, 2002b) and yield of arecanut was not affected by this crop.

2.1.3. Coffee and cocoa as mixed crops

Coffee and cocoa are being grown as mixed crops in arecanut garden since long back. Coffee is grown at the centre of four arecanut palms at a spacing of 2.7 m x 2.7 m whereas, cocoa is also planted at the centre of four arecanut palms with a spacing of 2.7 m x 5.4 m. The crops are trained properly to adjust the available space in arecanut garden. Cocoa planting at a spacing of 2.7 m x 5.4 m was the best in terms of operational advantages and optimum yield in arecanut garden as a mixed crop.

At CPCRI, Research Centre, Mohitnagar, coffee and cocoa were included in arecanut based HDMSCS at a spacing of 2.7 m x 5.4 m. On an average, a total of 71 cocoa pods were harvested from a single plant under arecanut garden during the year 1991-92, whereas,on an average one kg dry coffee beans was harvested from a single plant under the sub Himalayan terai region of West Bengal (Chenchaiah *et al.*, 2002a). Maximum net return/ rupee investment (4.6) was achieved from cocoa whereas, in the case of coffee, it was 1.90 (Chenchaiah *et al.*, 2002b).

2.2. Inter cropping with annuals/biennials

2.2.1. Turmeric in arecanut garden

Different annuals and biennials are grown as inter crops in between two rows of arecanut leaving the root zone ie. 0.75 m radius. Cultivation of pine apple and turmeric in the inter space of arecanut was profitable whereas, cultivation of arrowroot was not profitable in irrigated and un-irrigated conditions at Mohitnagar condition (Chenchaiah *et al.*, 2002b).

Different turmeric varieties were planted in arecanut garden at Mohitnagar during 2001-03. The performance of all the varieties varied significantly for almost all the characters including yield (Table 3). The maximum yield was recorded in Suguna (29.04 t/ha) followed by CLS-2A (27.41 t/ha). The performance of Suguna was about 25% more in terms of yield than the Local variety. The same varieties were also grown in open condition to compare the yield performance in open as well as in arecanut plantation where the yield of Suguna variety was only 32% more than the yield under arecanut garden. Cultivation of turmeric varieties like Suguna, Sudarsana, CLS 2A and Kasturi in the interspace of arecanut garden was suggested by Sit *et al*, (2004) for sub Himalayan Terai region of West Bengal.

Table 3. Yield of different turmeric cultivars in open and under arecanut garden

Cultivar	Yield /plant (g)		Mother rhizome wt./plant (g)		Yield (t/ha)	
	Open	Arecanut Garden	Open	Arecanut Garden	Open	Arecanut Garden
Sudarsana	432.08	323.83	87.90	79.00	44.53	26.09
Prabha	239.13	276.50	62.93	61.50	24.25	21.40
Prathibha	255.40	224.67	92.53	87.00	30.15	25.84
Suvarna	229.60	213.33	57.10	62.67	26.50	22.28
Alleppey	293.75	231.77	86.68	87.33	34.43	22.77
Kasturi	312.00	308.50	117.08	113.00	38.05	26.22
Cl-24	310.83	272.67	112.93	84.67	35.10	26.09
CLS-2A	293.33	332.33	124.68	93.33	33.03	27.41
CLS-3D	302.50	278.33	110.85	94.67	28.90	25.95
Suguna	382.90	240.50	141.63	83.33	38.53	29.04
Local	312.50	224.33	135.00	81.67	33.45	23.32

2.2.2. Vegetables as inter crop in arecanut garden

Cultivation of perennial crops in arecanut garden is a common practice in almost all arecanut plantations in India. If perennial crops are grown in plantation, farmers can get return only once in a year. A study was conducted at this Centre to find out the suitable summer and winter vegetables during the year 2001. Vegetables of vine nature were planted at the centre of four palms and bower was made using the arecanut as pole and vines were allowed to grow on bawar. Recommended agronomic practices were followed for all the crops studied.

Table 4 shows the data on crop duration, yield per ha, output, input and benefit cost ratio of different vegetables crops. Among the three winter leafy vegetables (palak, amaranthus and rai sak (mustard)), maximum yield was obtained from Palak (200 q/ha) with a benefit

Table 4. Input and output cost of different vegetables grown in arecanut garden

Crop	Duration (Days)	Yield (q/ha)	Input (Rs./ha)	Output (Rs./ha)	Net return (Rs./ha)	B:C ratio
Winter Season						
Palak	107	200.00	33500	80000	46500	1.39
Amaranth	135	119.10	30126	47640	17514	0.58
Rai sak	76	175.00	31250	52500	21250	0.68
Sprouting broccoli	70	97.40	32500	68180	35680	1.10
Knolkhol	80	205.67	32590	82268	49678	1.52
Cauliflower	79	187.00	35400	74800	39400	1.11
Cabbage	111	437.50	29580	131250	101670	3.44
Radish	101	650.50	19550	65050	45500	2.33
Carrot	92	148.50	22500	59400	36900	1.64
Turnip	130	207.50	20150	62250	42100	2.09
Tomato	104	182.50	32500	82125	49625	1.53
Chilli	175	180.50	31400	108300	76900	2.45
Brinjal	170	270.50	31050	81150	50100	1.61
Capsicum	120	53.90	35250	80850	45600	1.29
Lab lab bean	190	101.50	21200	50750	29550	1.39
French bean	118	134.20	38800	80520	41720	1.08
Summer Season						
Cowpea	120	42.20	22100	25320	3220	0.15
Basella	80	192.30	21000	76800	55800	2.66
Bhindi	134	150.00	31000	90000	59000	1.90
Bottle gourd	142	96.20	22150	48112	25962	1.17
Ash gourd	145	74.00	17175	44400	27225	1.59
Snake gourd	137	51.37	16250	41100	24850	1.53
Pumpkin	155	232.20	27400	92880	65480	2.39

(Sit *et al.*, 2006)

cost ratio of 1.39. The benefit cost ratio of other two leafy vegetables was 0.58 and 0.68, respectively. Spinach crop was also taken as ratoon crops. A total of 4-5 cuts were taken within the same season 30-40 days after first cut. The leaf production was more in this crop which may be due to its shade loving nature. Among the root crops (radish, carrot and turnip), maximum yield (650.5q/ha) was recorded in radish followed by turnip and carrot. Among these three crops, maximum crop duration was recorded in turnip, followed by radish and carrot. The benefit cost ratio of radish, turnip and carrot was 2.33, 2.09 and 1.64, respectively. Cabbage, cauliflower, sprouting broccoli and knolkhol were also tested. Among the four cole crops, longer crop duration (111 days) was recorded in cabbage whereas, in other cole crops it was only 70-80 days. The maximum yield was recorded in cabbage (437.5 q/ha) with a benefit cost ratio of 3.44. It may be concluded that these crops can be taken as inter crops in arecanut garden. Among the solanaceous vegetables (tomato, brinjal, chilli and capsicum), the benefit cost ratio was also more than one. Though they are profitable, they require more attention. Due to shade, the internode of these crops gets elongated and hence they require proper staking in time to keep the plants erect. Among the pulse crops grown for vegetable, maximum benefit cost ratio was calculated in dolichos bean (1.39) followed by French bean (1.08) and cow pea (0.15). In case of French bean and cowpea powdery mildew problems were observed.

2.2.4. Summer Vegetables

During the summer season, various vegetables like bhendi, basella and different gourds were planted. Gourds require bower system to get higher yields. Arecanut palms were used as poles. Among the crops, the maximum out put was recorded from pumpkin (Rs. 65480 per ha) followed by ash gourd (Rs 27225 per ha), bottle gourd (25962 per ha) and snake gourd (Rs. 24850 per ha) with benefit cost ratios of 2.39, 1.59, 1.17 and 1.53, respectively.

Besides this, a comparative yield trial was also conducted to see the differences of growth and yield of different summer and winter vegetables between open and arecanut plantation. The yield/unit area of spinach, rai sag (mustard leaf) and snake gourd was more in arecanut garden than in the open condition. The yield/unit area of some vegetables like, basella, cauliflower, knolkhol was almost at par at both the conditions. Benefit cost ratio and return per rupee investment per ha were also more for all the crops when they are grown as intercrop than as mono crop.

Different seasonal flowers like Gladiolus, Aster, Halychrysum, Calendula, Anthurium, French and African Marigold, Sunflower and Salvia were also grown in interspace of arecanut garden. Benefit cost ratio varied from 0.91 (gladiolus) to 2.92 (salvia). Though the performance of all the flower crops was not as good as in open condition, the positive BCR of all the crops indicated that cultivation of these crops is profitable in arecanut garden.

3. Conclusion

Cultivation of different inter and mixed crops in arecanut garden not only intensifies the crop population per unit area, but also gives additional income to the farmers. Growing of various vegetables in arecanut garden helps to provide income round the year. Inter/ mixed cropping also helps the effective utilization of natural resources and generates additional employment opportunities to the farm families.

4. Future research needs

Though arecanut based cropping system was initiated long back, still the technology has not reached all the arecanut farming communities. Efforts have to be made to disseminate the technology to the end users so that they can take the benefits out of it. Besides, further detailed studies are required to understand the nutrient and microbial dynamics of the system and nutrient requirement of component crops in the system. In the case of vegetables, as difference in varietal performance is expected to vary when cultivated as intercrop in arecanut gardens, varietal evaluation also becomes necessary to identify the best suitable types for the system.

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Organic matter recycling in arecanut based high density multispecies cropping systems

Ravi Bhat and S. Sujatha

Introduction

In the present day agriculture, supplementary and complementary role of organics is being increasingly felt for sustaining productivity and soil health. Inorganic fertilizers alone will not be able to supply the total nutrient needs of crops and maintain the productivity and soil fertility. The ability of organic manures to neutralize the rapid yield reduction with continuous use of chemical fertilizers and to sustain the productivity has been emphasized. Arecanut (*Areca catechu* L.) is predominantly grown in laterite soils with acidic nature in humid tropics of West coast of India. Arecanut growing regions are characterized by heavy rainfall during monsoon season resulting in nutrient losses through run off, leaching etc. The laterite soils are poor in nutrient retention capacity due to low CEC of 3-15 c mol (p^+) kg^{-1}. The productivity of arecanut in India is stagnated at around 1268 kg dry kernel ha^{-1} (2005-06). Thus, there is a need to increase productivity and income per unit area to sustain the needs of arecanut farmers. Cropping system approach with economical mixed crops is essential to avoid risks due to climatic, crop and market constraints. Successful cultivation of mixed crops like cocoa, black pepper, clove and banana in arecanut based High density multispecies cropping system (HDMSCS) is well documented (Bhat, 1978; Bavappa *et al.*, 1986; Abdul Khader *et al.*, 1992).

Arecanut based cropping system (ABCS) with cocoa (*Theobroma cacao* L.), banana (*Musa* spp), clove (*Syzygium aromaticum*), black pepper (*Piper nigrum* L.) and coffee (*Coffea arabica*) as component crops has high nutrient requirement. The nutrient removal is estimated at 79 kg N, 28 kg P_2O_5 and 79 kg K_2O per ha by arecanut (Rethinam, 1990) and 43.8 kg N, 8 kg P and 64.3 kg K per ha by cocoa (Bhat, 2002). Banana removes large quantities of N (320 kg), P (23 kg) and K (925 kg) to produce a yield level of 50 t ha^{-1}. ABCS generates considerable organic wastes, which otherwise find no use. An integrated approach with on-farm waste recycling is essential to meet the crop nutrient demand and to make the system self-sustainable. Recycling of plantation wastes directly would not meet the crop nutrient demand immediately due to high C:N ratio. It is also important to avoid nitrogen immobilization which occurs when plantation wastes with a high C:N ratio (37-62), lignin and polyphenol contents are directly added to the soil. The low cost vermicomposting technology enhances the decomposition process and provides ecofriendly organic manure having less C: N ratio with higher nutrient content (Biddappa *et al.*, 1996; Khan *et al.*, 2000). Abdul Khader *et al.* (1992) opined that there is better scope to increase nutrient recycling in arecanut based high density multispecies cropping system (HDMSCS).

The potential of organic waste recycling in ABCS has been emphasized from long term studies at Vittal (Bavappa *et al.*, 1986; Bhat *et al.*, 2002a, 2002b and 2002c; Balasimha, 2004 and Bhat and Sujatha, 2006).

2. Need for organic matter recycling

The aim of cropping system is not only to obtain additional yield and income but also to improve the soil fertility status in the long run. High rates of outputs from the cropping system imply that they in long run will deplete the soil of its nutrient store and make the system ecologically unsustainable. The depletion of soil fertility over the years is of great concern especially in perennial crop based agriculture. The lack of availability of organic matter, which has a major role in maintaining the soil fertility, has led to decline in soil fertility status of such cropping system. The availability of organics is scarce due to their use for other purpose like fuel, fodder etc. So it becomes necessary to find out the organic sources, which otherwise find no use. Till now organic wastes from arecanut plantations were utilized for fuel and construction purposes. The problems of nutritional disorders, reduced nut recovery and lesser productivity due to imbalanced nutrient application are becoming major constraints in arecanut production. The depletion of fossil fuel source will lead to increased cost of fertilizers in coming years and so it is time to think about the possibility of recycling locally available organic wastes. Perennial crops like arecanut, cocoa and other crops have potential to produce large quantity of organic matter every year (Bavappa *et al.*, 1986; Bhat and Sujatha, 2007) that can be effectively utilized as a source of plant nutrients and soil conditioner. The dependence on on-farm resources will help in reducing the cost of production. Several studies have indicated the presence of considerable quantity of nutrients in organic wastes from ABCS (Bhat and Mohapatra, 1989; Abdul Khader *et al.*, 1992; Biddappa *et al.*, 1996; Chowdappa *et al.*, 1999). The waste availability and nutrient content from arecanut garden are given in Table 1. It was reported that arecanut wastes recycled in the form of vermicompost have a potential to meet 50% N, 32.5% P and 26% K requirement besides supplying considerable quantity of micronutrients (Table 2, Chowdappa *et al.*, 1999). Using arecanut wastes for vermicompost production is highly profitable (Table 3). Thus, recycling of such wastes is essential for improving yield of crops, soil fertility and avoiding environmental problems.

Table 1. Nutrient content and quantity of nutrients added by non-marketable produces in arecanut garden (per palm per year)

Byproduct	Mean dry biomass (kg per palm per year)	Nutrient content (%)			Nutrient added per palm per year (g)		
		N	P	K	N	P	K
Arecanut shed leaves	4.0	1.59	0.16	1.01	63.6	6.4	40.4
Leaf sheath	1.7	0.66	0.08	1.51	11.2	1.4	25.6
Arecanut husk	1.7	1.0	0.12	2.40	17	2.0	40.0
Arecanut bunch	0.3	1.04	0.07	1.10	3.1	0.2	3.63
Total nutrients added	-	-	-	-	94.9	10.0	109.63

(Source: Bhat and Mohapatra, 1989)

Table 2. Nutrient content of vermicompost produced from arecanut and cocoa wastes

Nutrients	Arecanut			Cocoa		
	Leaves	NC	VC	Leaves	NC	VC
Organic carbon (%)	44.20	33.7	33.1	47.1	28.0	24.4
N (%)	0.71	1.01	1.38	1.27	1.29	1.65
P (%)	0.08	0.08	0.35	0.17	0.19	0.19
K (%)	0.94	0.96	0.98	0.27	0.27	0.32
C:N ratio	62	33	23	37	22	15
Cu (ppm)	101	120	120	32.7	70.5	83.6
Fe (ppm)	1,746	2,397	2,561	1,157	2,580	2,593
Zn (ppm)	307	346	396	228	355	368
Mn (ppm)	82	173	242	363	546	680
Moisture (%)	-	31	32	-	29	30
pH		8.1	7.3		8.0	7.5

NC = Normal compost **VC = Vermicompost** (Source: Chowdappa *et al.*, 1999)

Table 3. Net returns from vermicompost production from one ha of arecanut garden

Number of shed leaves per palm per year	7
Weight of dried whole leaf per palm per year	600 g
Leaf waste available (per palm per year)	4.2 kg
Total leaf waste available (per ha per year)	5,460 kg
Labour cost (536.4 man hrs) for collection of wastes, cutting, watering and drying	Rs.4,694
Cost of earthworms (5.46 kg)	Rs.2,730
A. Total cost	Rs.7,424
Recovery of vermicompost	4,791 kg
Vermicompost Rs.5.00 /kg	Rs.23,955
Earthworms biomass multiplied (13.1 kg) @Rs 500/ kg.	Rs.6,552
B. Total Income	Rs.30,507
Net profit (B-A)	Rs.23,083

3. Biomass production from Arecanut Based Cropping System (ABCS)

3.1. Recyclable biomass from green manure crops intercropped in arecanut

Trials conducted at Vittal, Hirehalli and Mohitnagar to screen suitable green manure crops for arecanut garden showed that *Pueraria javanica and Mimosa invisa* have higher green manure yields and nutrient addition capacity (Table 4; Mohapatra *et al.*, 1970). Bopaiah (1981) stressed the need for intercropping of legumes in arecanut gardens to enrich the soil and to reduce cost of cultivation. Besides producing large quantity of organic matter, green manure crops act as cover crops also. *Sesbania* was found to be a good crop which can withstand water logging and drought. It can be grown in valleys of Assam, Karnataka and Kerala receiving high rainfall. *Calopogonium* and *Pueraria* can be used as cover crops in hilly slopes to prevent soil erosion. A study was also conducted in plains of Karnataka to screen suitable green manure crop for arecanut garden (Sannamarappa, 1987). The results indicated that *Mimosa invisa* and *Centrosema pubescens* produced significantly higher green matter than *Pueraria javanica (P. phaseoloides), Calopogonium mucunoides, Crotalaria anagyroides* and *Sesbania speciosa*. However, *M. invisa* and *C. mucunoides* gave the best improvement in soil organic C status.

Table 4. Green matter yield, nutrient content and amount of nutrients added by green manure crops in ABCS

Name of the crop	Yield of green matter (t ha^{-1})	Soil type	Nutrient composition (%)			Nutrient addition (kg/ha)		
			N	P	K	N	P_2O_5	K_2O
Calopogonium muconoides	7.1	Upland	2.63	0.23	2.80	40.5	7.9	51.9
Pueraria javanica	14.3	Heavy soil	3.30	0.24	1.63	99.3	16.5	59.1
Stylosanthes gracilis	12.8	Upland	2.42	0.23	1.63	63.6	13.5	51.6
Mimosa invisa	12.6	Upland	3.96	0.34	2.00	111.7	21.6	67.9
Sesbania speciosa	5.2	-	2.70	0.17	1.12	31.3	4.5	15.6
Centrosema pubescens	6.9	Upland	2.54	0.24	1.75	43.4	9.2	36.0
Crotalaria anagyroides	3.4	Upland	2.81	0.27	2.12	20.5	4.5	18.6
Gliricidia maculata	12 kg/tree	Upland	2.90	0.22	2.32	87.0*	7*	67*
Sesbania aculeate	25.5	Any soil	3.50	0.26	0.99	232	17.2	65.6
Tephreasia purpuria	7.7	Upland	3.20	0.13	1.08	69.0	2.8	23.3

(Source: Mohapatra *et al.*, 1970)

3.2. Recyclable biomass from weeds

Weed infestation is very high in arecanut growing areas with heavy rainfall. Weed biomass has potential to recycle nutrients apart from conserving the soil. Bhat and Mohapatra (1989) highlighted the nutrient contribution of weeds growing in arecanut plantation and stated that 14 kg fresh weeds supplied 32 g N, 7 g P_2O_5 and 52 g K_2O (Table 5).

Table 5. Nutrient composition of weed biomass and nutrient added per year

Nutrient	Nutrient composition (%)	Nutrient added (g) per palm per year in 14 kg fresh weight
Nitrogen (N)	1.83	32
Phosphorus (P_2O_5)	0.39	7
Potash (K_2O)	3.00	52

(Bhat and Mohapatra(1989)

3.3. Recyclable biomass from arecanut based cropping system

The recyclable biomass production from sole arecanut was estimated at 8.7 t ha^{-1} and it can be considerably increased to 14.3 t ha^{-1} with adoption of HDMSCS (Bavappa *et al.*, 1986). Though the quantity of recyclable biomass is reduced after 15 years of adoption of ABCS, still there is scope for efficient and economical recycling (Bhat and Sujatha, 2007). They reported that recyclable biomass produced from different component crops in arecanut based cropping system varied between 8,724 to 10,354 kg/ ha/ year (Table 6). The arecanut crop accounted for maximum biomass production of 42% from the cropping model followed by cocoa (24%). Weeds contributed 15% of the total biomass. The recyclable biomass can be converted in to vermicompost with 82 to 87% recovery. The estimated nutrient content in vermicompost was 1.71% N, 0.21% P and 0.43% K.

Table 6. Biomass production (kg/ ha) from the component crops in arecanut based cropping system

Treatments	Arecanut	Cocoa	Clove	Banana	Weeds	Total
1999-2000						
Pre-experimental	5270	3915	763	-	-	9948
Mean of 2001 and 2002						
Control + OMR	3656	2293	542	962	1271	8724
1/3rd NPK + OMR	3634	2499	596	1221	1648	9599
2/3rd NPK + OMR	4318	2481	462	1269	1699	10229
Full NPK + OMR	4641	2077	472	1939	1225	10354
CD (P = 0.05)	485.5	NS	NS	378.0	NS	869.4

OMR = Organic matter recycling; NS = Not significant (Source: Bhat and Sujatha, 2007)

4. Nutrient addition through organic matter recycling

Total nutrients supplied from organic and inorganic sources in ABCS are given in Table 7. Recycling of organics in ABCS in the form of vermicompost can supplement more than 1/3rd of the nitrogen requirement of the system. However, the supply of P and K were negligible through vermicompost. Organic matter recycling + application of 2/3rd of recommended NPK supplied 95% N, 73% P and 72% K requirement of the crops.

Table 7. Nutrients added to the system through organic and inorganic sources in different treatments

Treatments	Inorganic (kg/ha)			Organic (kg/ha)			Total (kg/ha)		
	N	P	K	N	P	K	N	P	K
Control + OMR	-	-	-	110.8	13.6	27.9	110.8	13.6	27.9
1/3rd of fertilizer dose + OMR	146.9	84.1	239.6	147.7	18.1	37.2	294.6	102.2	276.8
2/3rd of fertilizer dose + OMR	293.7	168.2	479.2	147.7	18.1	37.2	414.4	186.3	516.4
100% of fertilizer dose + OMR	440.6	252.4	718.8	184.7	22.7	46.4	625.3	275.1	765.2

5. Benefits accrued due to organic matter recycling (OMR)

5.1. Yield of the system

The positive impact of OMR on kernel equivalent yield of ABCS was noticed, though each component crop differed in its response to OMR, NPK and their combination (Table 8). Experimental results of four year studies clearly indicated that adoption of integrated nutrient management(INM) approach with organic matter recycling has resulted in sustaining yield levels of old plantation besides improving the yield marginally (Bhat and Sujatha, 2007). The equivalent yield from the ABCS increased significantly from 1,777 kg /ha in 1999 to 2,769 kg/ ha in 2002. Beneficial effects of OMR in terms of sustained yield of the crops and N and P supply to soil with minimum or no inorganic fertilizer input levels was highlighted (Bhat and Sujatha, 2006). OMR was sufficient for cocoa in ABCS as cocoa did not respond to fertilizer application in the system. It can be ascribed to highly shaded conditions existing in the system due to presence of several component crops. Banana responded significantly to integrated use of recommended NPK + OMR indicating its heavy feeding nature. As component crops occupy full land area and air space in ABCS, there is a need to develop manurial schedule for the system as a whole rather than different schedules for different crops.

5.2. Soil fertility status

The soil fertility status monitored after four years of imposition of INM with OMR in ABCS showed positive impact on soil pH (Table 9). The soil pH was significantly influenced due to different crops, while it was at par with all the nutrient levels. Cocoa crop rhizospheres registered reduction in soil pH (5.00) compared to initial soil pH (5.25). Overall, positive impact of ABCS was noticed with increase in soil pH to 5.18 and 4.95 at 0-30 and 30-60 cm soil depth, respectively in 2002 (Bhat and Sujatha, 2007) compared to

Table 8. Yield of component crops (kg/ ha) as influenced by nutrient management in arecanut based cropping system

Year	Treatment	Arecanut (dry kernel)	Cocoa (dry bean)	Clove (dry flower bud)	Banana bunch weight	Arecanut ** equivalent	Coffee (dry berry)
1999*	Control + OMR	1460	206.4	29.0	-	1722	-
	1/3rd NPK + OMR	1420	238.6	28.8	-	1717	-
	2/3rd NPK + OMR	1530	270.9	23.9	-	1854	-
	Full NPK + OMR	1490	266.6	27.5	-	1815	-
						1777	
	CD (P = 0.05)	NS	NS	NS			
2000	Control + OMR	1460	436.4	29.8	1436	2069	-
	1/3rd NPK + OMR	1400	421.0	67.3	2809	2149	-
	2/3rd NPK + OMR	1480	499.0	31.7	2150	2216	-
	Full NPK + OMR	1600	410.6	35.8	4461	2412	-
						2212	
	CD (P = 0.05)	NS	NS	26.57	836.2		
2001	Control + OMR	1460	539.6	32.4	3185	2312	81.8
	1/3rd NPK + OMR	1428	421.4	44.0	2877	2147	86.5
	2/3rd NPK + OMR	1444	498.8	23.1	2843	2216	40.4
	Full NPK + OMR	1509	462.2	27.0	5182	2413	101.5
						2272	-
	CD (P = 0.05)	NS	NS	NS	1543.4		
2002	Control + OMR	1564	713.0	38.8	2660	2572	5.4
	1/3rd NPK + OMR	1709	570.5	95.8	2899	2664	18.7
	2/3rd NPK + OMR	1497	639.0	155.0	4392	2717	12.6
	Full NPK + OMR	1614	690.0	100.8	6511	2963	20.5
						2769	-
	CD (P = 0.05)	NS	NS	NS	2569.4		
Mean (2000-02)	Control + OMR	1495	563	33.7	2427	2318	
	1/3rd NPK + OMR	1512	471	69.0	2862	2320	
	2/3rd NPK + OMR	1474	546	69.9	3129	2383	
	Full NPK + OMR	1574	521	54.5	5385	2596	

Note: * - Pre-experimental ** - CD (P = 0.05) for years - 249.5; for treatments - Not Significant

Table 9. Influence of nutrient management on pH at different soil depths in ABCS in 2003

Crop/Treatment	0-30 cm					30-60 cm				
	Control + OMR	1/3rd NPK + OMR	2/3rd NPK + OMR	Full NPK + OMR	Mean	Control + OMR	1/3rd NPK + OMR	2/3rd NPK + OMR	Full NPK + OMR	Mean
Arecanut + Pepper	5.14	5.06	5.24	5.12	**5.17**	4.92	4.82	4.85	4.74	**4.89**
Cocoa	5.07	5.27	4.82	4.85	**5.25**	4.60	5.02	4.86	4.67	**4.98**
Clove	4.93	5.53	5.33	5.87	**5.30**	4.83	4.94	4.67	4.71	**4.95**
Banana	5.47	5.27	5.47	5.30	**5.16**	5.34	5.24	5.30	5.14	**4.96**
Coffee	5.28	5.08	5.11	5.17	**5.21**	5.10	4.97	5.04	5.15	**4.94**
Mean	**5.18**	**5.24**	**5.19**	**5.26**	**5.22**	**4.96**	**5.00**	**4.94**	**4.88**	**4.95**
Crop (C)	CD (P = 0.05)	0.127	0.096							
Treat (T)	CD (P = 0.05)	NS	NS							
C x T	CD (P = 0.05)	0.254		0.192						

NS = Not significant (Source: Bhat and Sujatha, 2007)

Soil pH values in ABCS during 1988

Soil depth (cm)	Arecanut + pepper	Cocoa	Clove	Coffee
0-25	4.6	4.5	4.9	5.1
25-50	4.3	4.5	4.7	5.2
50-75	4.7	5.2	4.6	5.5

(Source: Abdul Khader *et al.*, 1992)

the reported value of 4.70 and 4.45 in 1988 (Abdul Khader *et al.*, 1992). The organic carbon content before establishment of the system in 1983 varied between 0.60 to 1.05 % at different soil depth as reported by Abdul Khader *et al.* (1992). The system resulted in enrichment of organic carbon with 58 to 105% increase in 2002. *In situ* addition of organic matter through recycling of organic wastes and dead and decayed roots would have been resulted in organic carbon enrichment in the system. Organic carbon content was significantly higher in arecanut + black pepper rhizospheres (1.87%) than in cocoa (1.62%) and clove (1.66%).

Mineral N was optimum in crop basins of all component crops in ABCS. This indicates that ABCS is self sustainable with respect to the availability of mineral N. Generally, P availability in acid soils is low. With recycling of organic residues, organic P availability will be more, as organic phosphates are less readily fixed than inorganic P. This was evident from INM approach with OMR in ABCS resulting in higher availability of P and similar nutrient status in all treatments and crop basins (Bhat and Sujatha, 2007). In general, the P content was higher at surface level (0-30 cm) and drastically reduced at 30-60 cm. This denotes the less mobility of P in soil. It might be due to strong P adsorption in acid laterite soils. The increase in phosphatase activity in different crop basins due to INM (Bhat *et al.*, 2008) indicates the potential of crops for greater efficiency in obtaining P. This might be the reason for significant increase in available P in ABCS (Bhat and Sujatha, 2007). Low phosphatase activity with OMR and high activity with inorganic fertilizer applications was noticed in this study.

In general, available K content in soil reduced in cocoa and clove rhizospheres over the years (Table 10). Manikandan *et al.* (1987) noticed a negative balance in available K in arecanut-cacao system indicating the higher requirement of K. The reduction in availability of K indicates the heavy K feeding nature of cocoa (Nelliat, 1978) and probable luxury consumption. The study indicated that application of N and P through inorganic fertilizers could be reduced or skipped, while the system proved exhaustive with regard to the availability of K. The exhaustion of K probably indicates the necessity of including K in the fertilizer schedule of the system, as organic matter cannot supplement K requirement of crops as all the component crops are heavy feeders of this major nutrient. Comparatively similar yield levels and soil nutrient status noticed with OMR and integrated use of chemical fertilizers and OMR emphasizes the point that the system can be self-sustainable over a long term period.

5.3. Soil microflora and enzyme activities

Studies on soil microflora and enzyme activities are important as they indicate the potential of the soil to support biochemical processes, which are essential for the maintenance of soil fertility. The nature and activity of microflora in a given environment depends upon the crops grown and management practices. The distribution of microflora

Table 10. Influence of nutrient management on available K content (ppm) in ABCS over the years

Treatment	Arecanut + pepper				Cocoa				Clove			
	2000	2001	2002	Mean	2000	2001	2002	Mean	2000	2001	2002	Mean
0-30 cm												
OMR	43.9	41.0	62.6	49.2	82.1	94.5	59.6	78.7	65.4	33.9	67.3	55.5
1/3rd NPK + OMR	53.9	73.4	61.1	62.8	129.9	102.8	81.4	104.7	70.9	66.6	79.1	72.2
2/3rd NPK + OMR	62.8	59.4	73.1	65.1	143.1	102.8	70.8	105.6	82.3	73.5	90.3	82.0
Full NPK + OMR	61.0	72.0	77.6	70.2	146.0	112.3	80.8	113.0	82.5	142.5	91.4	105.5
Mean	55.4	61.5	68.6	61.8	125.3	103.1	73.2	100.5	75.3	79.1	82.0	78.8
30-60 cm												
OMR	30.2	42.0	48.4	40.2	64.4	78.0	55.5	66.0	70.8	33.3	60.9	55.0
1/3rd NPK + OMR	47.4	57.3	62.4	55.7	90.0	64.3	63.7	72.7	172.5	70.1	72.0	104.9
2/3rd NPK + OMR	49.6	42.3	74.5	55.5	94.8	75.2	53.1	74.4	241.7	109.7	91.1	147.5
Full NPK + OMR	44.7	58.1	80.3	61.0	94.8	90.0	72.2	85.7	237.7	167.6	88.3	164.5
Mean	43.0	49.9	51.4	53.1	86.0	76.9	61.1	74.7	180.7	95.2	78.1	118.0

	0-30 cm CD P = 0.05)	30-60 cm CD (P = 0.05)
Year (Y)	7.64	7.41
Crop rhizosphere (C)	9.18	7.70
Treatment (T)	10.60	8.89
C x T	NS	NS
Y x C x T	26.46	25.66

NS = Not significant

in soil profile and the nature of rhizosphere microorganisms of arecanut monocropping system have been studied (Bopaiah and Bhat 1981; Bopaiah and Koti Reddy 1982). The intensive cropping system involving arecanut, cocoa, pepper, clove and banana is a successful crop combination and it generates considerable quantity of organic wastes. Chowdappa *et al.* (1999) observed that vermicompost produced from plantation wastes had maximum microbial load compared to normal compost (Table 11). Thus, OMR in the form of vermicompost would be helpful in proliferation of the microbial activity in these soils as vermicompost prepared from plantation wastes was rich in nutrient content and microbial population.

Table 11. Microbial population in vermicompost and normal compost (Mean of 1994 and 1995)

Organic source	Microbial population/ g sample			
	Bacteria (10^6)	Fungi (10^4)	Actinomycetes (10^6)	P-solubilizers (10^4)
Arecanut				
Normal compost	24.10 ± 5.4	23.07 ± 5.4	5.64 ± 3.8	13.84 ± 4.8
Vermicompost	30.76 ± 4.8	30.76 ± 4.8	6.28 ± 2.76	16.25 ± 3.2
Cocoa				
Normal compost	16.82 ± 3.2	6.15 ± 2.70	3.58 ± 1.8	12.81 ± 3.8
Vermicompost	17.43 ± 1.2	6.28 ± 1.73	6.15 ± 2.6	15.89 ± 4.0

(Source: Chowdappa *et al.*, 1999)

In a four year study on ABCS at Vittal, soil microbiological response to graded levels of chemical fertilizers and the impact of nutrient management through OMR in the form of vermicompost in various crop basins of ABCS was monitored after three years of treatment imposition (Bhat *et al.*, 2008). It was concluded that adoption of OMR with graded nutrient levels in ABCS helps in improving soil health in terms of soil microflora and enzymatic activities. Application of inorganic fertilizers up to 2/3rd of recommended dose for each component crops is congenial for better microbial activity. It is realized that in order to make chemical fertilization programmes successful according to the emerging value-system in agriculture, a critical balance must be maintained between optimizing nutrient availability in the basin, while minimizing potential for deleterious effects on soil biological activity. These results could serve as a basis for increasing both biological and enzymatic soil activities and in turn crop yields in laterite soils.

In general crop basins registered 11 times higher microbial biomass C as compared to interspaces. The greater microbial biomass C in various crop basins than in interspaces at 0-30 cm soils depth might be due to surface cultivation of soil in different crop basins leading to better aeration at 0-30 cm depth. It is stated that the ratio of soil microbial biomass C to organic C is a good indicator of changes in microbial performance caused by environmental conditions. The data in Table 12 reflect significant variability in microbial quotient due to different crop basins and nutrient management. This could be due to higher carbon inputs in these crops. None of the component crops in ABCS reduced C_{mic}/ C_{org}, and there was a higher positive correlation of C_{mic} with C_{org} ($y = -72.601x^2 + 65.297x + 1.8463$, $r^2 = 0.735$), which supports the concepts that C usually is the limiting factor for microorganisms in agricultural soils.

Table 12. Microbial quotient (C_{mic}/C_{org}) in percentage as influenced by nutrient management in ABCS in 2002 after three years of treatment application

Nutrient treatment (T)	Crop basin (C) 0-30 cm soil depth					
	Arecanut + pepper	Cocoa	Clove	Coffee	Banana	Mean
OMR	1.94	3.31	2.24	2.55	1.93	2.39
1/3rd NPK + OMR	2.30	4.54	2.79	2.56	2.20	2.88
2/3rd NPK + OMR	2.44	4.14	3.00	2.95	2.22	2.95
100% NPK + OMR	2.62	3.63	2.82	2.89	2.19	2.83
Mean	2.33	3.90	2.71	2.74	2.14	
CD (P = 0.01)	C	0.504	T	0.42	C x T	NS
30-60 cm soil depth						
OMR	2.03	2.06	1.79	1.84	1.09	1.76
1/3rd NPK + OMR	1.79	2.22	1.88	1.92	1.23	1.81
2/3rd NPK + OMR	2.02	2.32	2.11	2.19	1.63	2.04
100% NPK + OMR	1.58	2.10	2.09	1.74	1.56	1.81
Mean	1.86	2.18	1.96	1.92	1.38	
CD (P = 0.01)	C	0.319	T	NS	C x T	NS

NS = Not significant

Variations in microbes among different plant species may be related to plant specific differences in physico-chemical conditions induced in the basin, root exudate patterns and heterogeneity and quantity of carbon resource entering through root exudates and litter fall and nutrient acquisition patterns. Higher bacterial abundance was noticed with application NPK + OMR in crop basins. The overall increase in microbial population in ABCS could be due the microbes added through vermicompost. Chowdappa *et al*. (1999) reported higher microbial counts in vermicompost prepared from organic wastes of arecanut and cocoa. Overall in the system, bacterial abundance remained greater in 1/3rd of recommended NPK + OMR. Multi-year application of inorganic fertilizers and OMR in a cropping system slightly increased the soil pH to 5.22 (Bhat and Sujatha, 2007) compared to the initial reported value of 4.88 in 1988 (Abdul Khader *et al*. 1992). This could have contributed to increased bacterial population (Bopaiah and Bhat, 1981).

6. Conclusions and future line of work

The overall results of adoption of ABCS with nutrient management approach revealed that the system can be self-sustainable over the years as similar yield levels and soil nutrient status were noticed with OMR and integrated use of chemical fertilizers and OMR. Further, the studies indicated that application of N and P through inorganic fertilizers could be reduced or skipped, while the system proved exhaustive with regard to the availability of K. The exhaustion of K probably indicates the necessity of including K in the fertilizer schedule of the system, as organic matter cannot supplement K requirement of crops as all the component crops are heavy feeders of this major nutrient. Comprehensive work is needed to utilize locally available organic wastes to sustain ABCS/FS. Feasibility of OMR under varied soil and weather conditions for sustainable cropping/farming system is to be ascertained. Studies are required on K dynamics in ABCS, since the system is heavy feeder of K and the OMR was not able to meet the K nutrient demand of the system. There is a need to study the quality of economic products from the system with adoption of OMR approach.

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Physiological investigations in arecanut based cropping systems

D. Balasimha

Introduction

Arecanut is a crop of subhumid tropics and thrives well in regions of 28°N and 28°S of equator. Climatic conditions in agroclimatic regions of India are variable ranging from plains of South India and hilly regions of North East India. The microclimate under arecanut canopy is suitable for growing various intercrops and mixed crops. Physiology of some of these crops have been investigated.

2. Arecanut based HDMSC system

The biological efficiency is increased considerably in multiple cropping systems. The utilization of resources viz., light, water and nutrients is enhanced through a distribution of crop species in time and space. The long pre-bearing age of arecanut has prompted farmers to grow different annual or biennial crops for economic sustainability. This initial period of 5-6 years is ideal for growing short duration crops. In later years, as the arecanut canopy increases in height, mixed cropping with other shade tolerant perennial crop species can be adopted. Thus, there is an excellent opportunity for a temporal and potential distribution of crop species in arecanut gardens.

2.1. Microclimate in arecanut garden

As in coconut model, the microclimate existing in the arecanut is milder as compared to the open condition because of the shade cast by the trees. Abdul Khader (1983) observed the climatic variables in pure arecanut gardens. The evaporation during January to May from the soil surface of the arecanut garden is lower than in the open surface. This is expected because of the lower evaporative demand in the arecanut garden. Lower radiation in cropping systems especially of poly culture nature reduces the evapo-transpiration, lowering of air temperatures resulting in increased humidity in the garden.

Detailed investigation on microclimate of arecanut-cocoa mixed cropping has been made (Shama Bhat, 1988). The variables used include evaporation rate, wind velocity, soil temperature, relative humidity, vapour pressure and air temperature. The evapo-transpiration, air and soil temperature have been observed to be lower in mixed cropping as compared to the sole crops with minimum variation between morning and afternoon values in these factors within the system. In general, the micro climate shows lower evaporative demand, higher soil moisture content and least diurnal variations in temperature in standing cocoa plantations. The mean wind velocity inside the sole crop of arecanut was observed to be 33% while inside the mixed crop only 9% of the open wind velocity was observed. Thus, the arecanut palms provide excellent protection to the intercrops against wind.

2.2. Light profile in arecanut garden

On an average 8-9 leaves are borne in adult arecanut palm. The canopy area and leaf area are about 11.2 m^2 and 22.0 m^2, respectively. The arecanut canopy covers a ground area of 9.1 m^2 and the LAI is found to be 2.44. The photosynthesis in arecanut leaves ranges from 2.4 to 8.2 µmol CO_2 m^2s^{-1} depending on the cultivar and leaf position. The first fully open and third leaves showed the highest photosynthesis.

Approximately 30-50% of PAR is transmitted through the arecanut canopy (Balasimha and Subramonian, 1984 and Balasimha, 1989). This varies with season and time of the day. Under the arecanut canopy, the light environment is highly dynamic due to variations in shade cover, solar angle and canopy. The pattern of light transmission varies with the spacing of arecanut palms also. The mid-day light profile revealed that spacings of 3.3 x 3.3 m and 1.8 x 5.4 m allowed maximum transmission. However, in the afternoon, 3.9 x 3.9 m spacing showed maximum transmission (Table 1). The arecanut canopy on an average intercepts 70% of incoming radiation. The light interception varied due to seasonal and diurnal changes in areca gardens (Fig. 1). The interception of the remaining radiation depends on the nature of intercrop canopy and LAI. For example cocoa with compact canopy and LAI of 3-5 intercepts nearly 90% of available light. Pepper, which is trained on arecanut palms, receives differential light that is dependent on directional and diurnal

Table 1. Light profiles under arecanut canopy at different spacings

Spacing	PAR µE/ m^2/s		
	9.00 h	12.00 h	13.30 h
2.7x2.7 m	73	470	135
3.3.x3.3 m	80	1410	307
3.9x3.9 m	43	950	600
1.8x5.4 m	650	1710	810

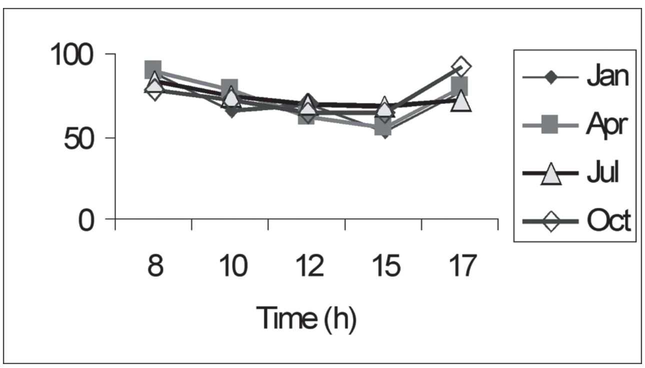

Fig.1. Seasonal and diurnal changes in light interception under areca

effects. The light penetration from an arecanut canopy and yield were optimum in 1:1 ratio of arecanut and cocoa combination at 3.3 x 3.3 m spacing. However, in the existing arecanut gardens with 2.7 x 2.7 m spacing, a planting of 2.7 x 5.4 m for cocoa is good due to least self-shading. The leaf morphology and photosynthetic rates attain optimum levels under these conditions (Balasimha, 1987 and 2006).

HDMSCS in arecanut typically comprises of black pepper, cocoa, clove, pineapple, coffee and banana occupying different vertical airspaces. Growing these crops did not affect the main arecanut crop (Bavappa *et al.*, 1986 and Abdul Khader *et al.*, 1992). The crop occupying higher airspace should have lower interception efficiency and higher photosynthesis. More shade tolerant species are desirable at lower vertical heights. The comparative dry matter partitioning and harvest index in pineapple and banana revealed higher values in the latter. The leaf area duration was maximum in cocoa and chlorophyll was the highest in cocoa and black pepper. The seasonal changes in specific leaf weight, chlorophylls and nitrate reductase activity were measured in these crops and compared with open conditions (Balasimha, 1989). There were significant differences with seasons and growth conditions. The photosynthetic characteristics in these crops also revealed their shade tolerance (Table 2). Plants adapt to shade by modifications in leaf thickness and higher chlorophyll contents. These under storey plants recorded higher chlorophyll and leaf thickness.

Table 5. PAR and photosynthetic characteristics in intercrops of areca

Crop	PAR (μE/ m2/s)	Leaf temp. (°C)	E (mmol/m^2/s)	Pn (μmol/ m^2/s)	Internal Internal CO2(ppm)	gs (cm/s)
Banana	508	32.3	3.01	6.38	236	0.63
Clove	613	31.7	1.72	4.01	237	0.24
Coffee	438	31.6	2.23	3.68	240	0.56
Cocoa	980	34.9	3.52	4.33	271	0.56
Pepper	352	31.9	2.02	4.98	253	0.34

Light interception by different canopies of intercrops at different heights and measurements of canopy structure in relation to light were reported in multistoried high density cropping (Abdul Khader *et al.*, 1992). The stratified sampling gave a precise distribution of LAI at different heights and the levels of transmitted light. This also demonstrated the relative competition for light by component species. The crop species with leaf areas at higher strata is always at an advantage to larger radiation. When such canopies become large enough and intercept most of the light, the component species at lower strata are at a disadvantage and are to be subsequently removed.

3. Root exudates

Root exudates from the component crop species may influence the soil composition microorganisms. The root exudates have been analysed for their biochemical constitution (Nagaraja *et al.*, 1986) and found that the optimum period for collection of root exudates was five days. Further, the root exudates contained sugars, amino acids and organic acids. Exudation of sugars was not significantly affected in the component crops grown under different cropping systems; arecanut, 2.1 - 4.4; banana, 3.4 - 10.5; cocoa, 0.36 - 0.58 and pepper 2.0 - 3.0 mg /g root dry weight. However, mixed and high density cropping system significantly reduced the exudation of amino acids. Phenols were not detected in the root exudates. There were also no differences in the qualitative composition of sugars, organic acids and amino acids in relation to cropping system. Biochemical characterization of the soils in the above cropping systems has been attempted by Nagaraja (1988) and the results showed that phenol content decreased in root region of arecanut, black pepper, cocoa and banana grown in multiple cropping as compared to monocrop. Sugar content of soils from areca, banana and cocoa were however, higher. Amino acid content of soils from cocoa under high density cropping system and arecanut and cocoa mixed cropping were significantly lower than cocoa monocrop. These beneficial changes in rhizosphere of the main crop and intercrops not only improve the soil micronutrients, but also result in increasing yields considerably.

4. Light interception and cocoa growth

Cocoa is grown as mixed crop in arecanut plantations in India. For optimum productivity, proper canopy management to maintain shape and size is required. The experiments with seedling progenies and grafts have shown with cocoa (two spacings (S1 - 2.7 x 2.7 m; S2 - 2.7 x 5.4 m) and three canopy sizes (P1 - small, P2 - medium and P3 - large) treatments, the photosynthetically active radiation (PAR) and light interception varied significantly among the treatments (Fig.2). The differences in photosynthesis (Pn) of spacing treatments were significant (Table 3). Similar results were noticed in transpiration rate (E) and stomatal conductance (gs). There was no significant difference in intercellular CO_2. Chlorophyll fluorescence indices viz., Fo, Fm, Fv and Fv/Fm showed decreasing trend with reference to spacing treatments, indicating that leaf level Pn was not affected due to the pruning regimes. Water use efficiency (Pn/E) values showed variable responses (Balasimha, 2009).

5. Carbon sequestration in areca-cocoa cropping system

The cocoa-areca mixed crop not only gives a sustainable production, but also serves as a good system for biomass production and carbon accumulation. The carbon and biomass estimations have shown that annual increments ranged from 0.55 to 2.98 t/ha/year in carbon and 1.38 to 7.11t/ha/year over the 15 year period in areca and cocoa (Table 4, Balasimha and Naresh Kumar, 2009). The quantum of carbon sequestration was between 2.02-3.89 t/ha/year and 5.14-10.94 t/ha/year in cocoa and areca, respectively. Thus there is considerable amount of net sequestration of CO_2 in the system.

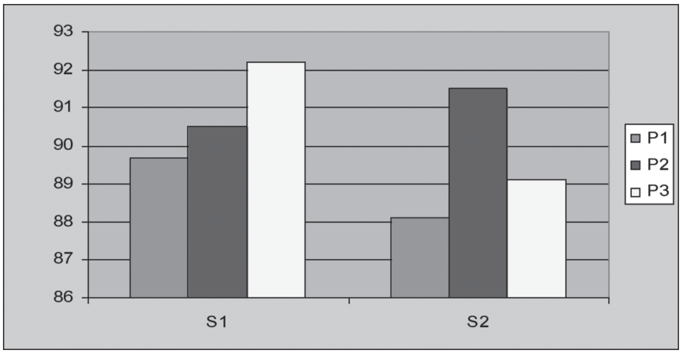

Fig.2. Light interception in cocoa grafts grown under areca canopy

Table 3. Photosynthetic characteristics in cocoa grafts

Treatment	Pn ($\mu mol\ m^{-2}s^{-1}$)	E ($mmol\ m^{-2}s^{-1}$)	gs ($mol\ m^{-2}s^{-1}$)	CO_2 internal (ppm)
Spacing				
S1	3.34	4.36	0.21	302
S2	3.84	4.38	0.20	296
Pruning				
P1	3.61	4.52	0.21	300
P2	3.82	4.54	0.21	302
P3	3.34	4.04	0.18	296
CD (P = 0.05)				
Spacing	0.37	-	-	-
Pruning	-	0.14	0.01	-

Table 4. Net primary productivity and CO_2 sequestration in cocoa and arecanut

	Annual increments (t/ha/yr) in cocoa			Annual increments (t/ha/yr) in arecanut		
	3-5 years	6-8 years	9-15 years	3-5 years	6-8 years	9-15 years
Biomass	2.66	2.06	1.38	4.21	7.11	3.34
Carbon stock	1.06	0.83	0.55	1.78	2.98	1.40
Net CO_2 sequestration	3.89	3.05	2.02	6.53	10.94	5.14

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Integrated management of diseases in arecanut based cropping systems

R. ChandraMohanan and Merin Babu

India is the largest producer and consumer of arecanut (*Areca catechu* L., Family Arecaceae) and is widely grown in Karnataka, Kerala, Assam and western parts of Tamil Nadu. The productivity of this palm is affected by a number of diseases and nutritional disorders during different stages of its growth and development. About 20 diseases causing varying degrees of damage to the palm have been recorded in India. They are associated with 40 pathogenic and non-pathogenic forms of fungi and one bacterium (Rawther *et al.*, 1982). But all of them are not important economically. Based on the nature and extent of damage, fruit rot, foot rot, inflorescence dieback and yellow leaf disease are considered to be the major diseases. Among the fungal diseases, Phytophthora diseases cause major economic loss every year. *Phytophthora* is a major pathogen of this palm being the causal agent of three major diseases viz., fruit rot, bud rot and crown rot, the latter two attack palms of all ages and are fatal, if not controlled in the initial stages of the disease.

1. Phytophthora diseases of arecanut

Fruit rot or *Mahali* is the most dreaded disease of arecanut causing direct loss in yield. Fruit rot was first recorded in the erstwhile Mysore state by Butler (1906). Since then the disease has been reported from all the arecanut growing areas of the country with varying intensities and crop loss ranging from 50-90% (Reddy and Anandaraj, 1980). Sastry and Hegde (1985a) estimated a loss of 180-875 kg nuts/ha, because of fruit rot infection. However, the loss due to fruit rot varies with the variety and locality where the crop is cultivated (Chowdappa *et al.,* 2000a). Bud rot and crown rot diseases occur frequently in fruit rot affected palms leading to the death of palms (Sastry and Hegde, 1987). Death of 52 -125 areca palms /ha, due to either bud rot or crown rot was reported by Sastry and Hegde (1985a). Similarly, Saraswathy (1994) based on her survey in Dakshina Kannada district of Karnataka, reported yield loss of 15% due to bud rot and crown rot diseases of arecanut. In a recent survey conducted by the state department of Horticulture, Karnataka, an estimated loss of 70% owing to the incidence of fruit rot has been recorded in arecanut. Bud rot and crown rot diseases cause death of the palms in severe cases resulting in 100% loss to the farmer, in addition to the replanting cost. Similarly loss due to fruit rot disease is both quantitative and qualitative leading to inferior quality nuts, unfit for consumption. Thus, three major diseases caused by *Phytophthora* spp, cause severe economical loss to farmer.

a. Symptoms

i. Fruit rot

Rotting and excessive shedding of the nuts were reported as characteristic symptoms of fruit rot by Butler (1906). Occurrence of fruit rot is generally identified by unusual shedding of immature nuts during southwest monsoon, which lay scattered near the base of the tree (Coleman, 1910). Typical symptoms appear as dark green water soaked lesions on the fruit surface near the perianth (Saraswathy, 1994). The lesions gradually spread covering the entire nuts which rot and shed from the calyx (Rawther *et al.*,1982). Fruits loose their natural green color along with their luster and the entire fruit surface turns yellow, usually after shedding from the palm (Saraswathy, 2003). In advanced stages of infection, under favourable conditions for the pathogen and the disease incidence, discolorations of the fruit stalk and inflorescence rachis are observed (Marudarajan, 1950a). Discoloration of the kernels are observed when the infected nuts are split open. However when the infection starts at the end of the monsoon season, the affected nuts may dry up and remain mummified in the bunches (Marudarajan, 1950a). These nuts are often colonized by many saprophytes and are called 'dry mahali'. Thus, apart from the quantitative loss by shedding of the nuts, the infected nuts are unsuitable for chewing due to deterioration in quality.

ii. Bud rot

Coleman (1910) during his investigations on fruit rot observed that the same pathogen also affects the spindle of the areca palm causing rotting of the growing bud, which eventually kills the palm. The disease was subsequently named as bud rot which occur often after the fruit rot season (Nambiar, 1949). The fungus enters the tender portion of the stem, either from the atmosphere / crown or from the rotten fruits, causing bud rot. Though the disease generally occurs in monsoon season, fresh infections were observed during November, becoming severe during the succeeding months (Marudarajan, 1950b). Yellowing of the spindle leaf is the initial visible symptoms in bud rot disease of arecanut (Coleman, 1910). The disease is characterized by rotting of the growing bud and the surrounding tissues. Spindle looses its natural green color and turns yellow. Such spindle can be easily pulled out and the rotten tissues emit a foul smell due to the secondary infection of the infected tissues (Coleman, 1910). As the infection spreads to the base of the adjacent leaves, they become yellow and droop, finally leaving a bare stem (Venkatarayan, 1932).

iii. Crown rot

In contrast to the bud rot symptoms, crown rot infection starts from base of the outer most leaves in the crown and proceeds inwards (Saraswathy,2004). The first visible symptom is yellowing of the outermost leaf sheath. When the leaf sheath is opened, dark water soaked lesions are seen inside. The infection then spreads to inner tender portion of the crown and the growing bud resulting in rotting of crown and finally death of palm. Crown rot occurs mainly through the spread of infection from the rachis.

a. Etiology

Phytophthora omnivora was described as the causal agent of fruit rot in arecanut by Sydow and Butler (1907), which was renamed by Coleman (1910) as *P. omnivora* var. *arecae*. Later, *P. palmivora* and *P. meadii* (Sastry and Hegde 1985b, 1987; Das and Cheeran, 1986; Dutta and Hegde, 1987; Santhakumari and Hegde, 1987) were reported to be the causal agents of the disease. Based on the RFLF studies of the ITS regions of rDNA and AFLP finger printing analysis of the *Phytophthora* spp infecting arecanut, rubber and cardamom. Chowdappa et al. (2003) ruled out the occurrence of *P. arecae* in India and proved that *P. meadii* is the major pathogen causing fruit rot of arecanut in India and that this fungus has moved from arecanut to rubber and cardamom when they were introduced subsequently in the near identical habitats. The colony characters (Saraswathy, 1994), mycelial character (Chowdappa *et al.,* 2000a) of *P. meadii* on different culture media have been studied in detail and observed that the cultural characters of *Phytophthora* spp. varied with the artificial culturing media used. Fairly striate to stellate or radial pattern with fluffy mycelial growth along with a colour difference of white to dirty white was reported when *P. meadii* was cultured on different synthetic and organic media (Saraswathy, 1994). Majority of the isolates of *P. meadii* on arecanut are heterothallic, but homothallic isolates have also been recorded (Ramakrishnan and Seethalakshmi, 1956; Saraswathy 1994). The sporangiophores in *P. meadii* are irregular with sparse branching and charecterised by swelling at the nodes or elsewhere. Sporangia are spherical or ellipsoidal, distorted or lobed and sometimes with more than one apex. They are laterally inserted with round base and with meso-spherical papilla. (Saraswathy, 1994; Sastry and Hegde, 1987). The existence of A1 andA2 mating types in *P. meadii* was reported by Chowdappa *et al.* (2000a).

b. Management

Management of the three *Phytophthora* diseases in grown up arecanut palms had always been a very difficult task, due to tall height of palms, mainly because of the problems in the correct delivery of the chemicals or other control agents at the exact point of infection. In the recent times shortage of skilled climbers trained in climbing the tall slippery tress, especially during rainy season, is also a serious concern in the management of the diseases. However there had been several successful observations on effective management of the *Phytophthora* diseases of arecanut by several workers. Coleman (1910) reported the practice of covering fruit bunches in Uttar Kannada areas to prevent fruit rot disease. Later a prophylactic spray of 1% Bordeaux mixture alone or with a sticker or spreader was found to be very effective in the management of fruit rot disease (Thomas and Marudarajan, 1952; Rao, 1960; Anandaraj, 1985b). Studies on the tenacity of the mixture, led to the observations that the spray deposits were retained up to 40-45 days on the nut surface (Anandaraj 1985b; Rao, 1960). Saraswathy (1999) studied the effect of new contact fungicides like Blitox, Captafol, Dithane M45 and Ovis -20 (a natural citronellal) and concluded that these chemicals, though were successful under *in vitro* conditions, because of their poor tenacity when sprayed in the field conditions could not be recommended for field spray. Studies on the effect of new systemic and contact fungicides in comparison with 1% Bordeaux mixture revealed that *Bordeaux* mixture was more effective and economical under field conditions (Chowdappa *et al.,* 2000b). To minimize the hardship of repeated climbing for spraying, especially during the monsoon, experiments with treatments including covering of the bunches with polyethylene covers of size 85 X 75 cms and gauge 200 thickness, prior to the monsoon and the use of systemic fungicides Aliette and Metalaxyl, revealed polyethylene covering was very effective in controlling fruit rot incidence and the fungicides had little curative effect on infected arecanuts for a short duration (Sastry and Hegde,1985a; Saraswathy, 1994; Chowdappa *et al.,* 2002). However due to the immediate high cost involved in these operations and the difficulty in climbing tall palms, the method of polyethylene covering of the bunches could not be popularized among the farmers.

Antagonistic effects of the bioagents *Trichoderma viride, T. harzianum, Myrothecium verrucaria, Aspergillus niger* and *Pseudomonas fluorescens*, were found to be effective on P. meadii under in vitro conditions (Saraswathy, 2000). Similarly the inhibitive effects of 10% aqueous plant extracts of leaves of *Lawsonia inermis* (Henna) and Ocimum sanctum (sacred basil) on *P. meadii* under *in vitro* were studied by Saraswathy (2002). However the effect of these bioagents and plant extracts could not be demonstrated under field conditions. Cultural practices are also important in the management of *Phytophthora* diseases of arecanut. Disease incidence was found to be more in waterlogged areas during rainy periods (Saraswathy, 2004). This can be greatly reduced by improving drainage in the gardens. Infected fruits on the trees and those that have fallen to the ground should be removed to reduce the inoculum for aerial infection of fruit and crown.

Management of bud rot/ crown rot is possible only if the disease is diagnosed at the initial stages of infection. The earlier recommendations for the management of the disease using mercurial compound and *Bordeaux* mixture were given by several authors (Nambiar, 1956; Naidu, 1960; Lingaraj, 1969). Recently it has been found that drenching the root zone of the palms with phosphorous acid (akomin) or tridemorph (calixin) at 0.3% concentration (3 ml/litre of water) in the initial stages of the disease as very effective in the management of bud rot and crown rot diseases. Minimum of 5 litre fungicidal solution/ palm (15 ml fungicide in 5 litre water) is required for drenching. In advanced stages of the disease 250 ml of phosphorous acid (akomin) or tridemorph (calixin) at 0.3% concentration can be poured inside the crown. However the treatments were not effective when the disease had spread to the inner meristem (Saraswathy, 2006).

2. Phytophthora diseases of intercrops

Phytophthora diseases are very important owing to the heavy economic loss they cause every year. *Phytophthora* is a major pathogen of arecanut and its intercrops viz., black pepper and cocoa. It is a major menace in arecanut 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 *Phytophthora* diseases, prophylactic spray before monsoon with recommended fungicides limit the risks associated with the disease.

i. Cocoa

In cocoa, *P. palmivora* causes major diseases viz., black pod, stem canker, chupon blight and twig die back. 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.

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 and the 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, 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).

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 (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 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

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. Therefore pruning and proper spacing between plants are important to regulate the shade.

ii. Black Pepper

Foot rot disease

Quick wilt disease/ foot rot of black pepper caused by *P. capsici* is one of the major causes of yield loss in black pepper and a study (1982-84) indicated that on an average 188 900 vines are killed annually with a loss of 119 ton black pepper/yr (Balakrishnan *et al.,* 1986). Foot rot (quick wilt disease) caused by *Phytophthora capsici* is the most destructive disease of black pepper. All parts of the vine are vulnerable to the disease and the expression of symptoms depend upon the site or plant part infected and the extent of damage.

Symptoms

Appearance of black spots characteristic fine fibre like projections at the advancing margins is the initial foliar symptom. The lesion size increases and cause defoliation. The tender leaves and succulent shoot tips of freshly emerging runner shoots trailing on the soil turn black when infected. The disease spreads to the entire vine, from these infected runner shoots and leaves, during intermittent showers due to rain splash. If the main stem at the ground level or the collar is damaged, the entire vine wilts followed by shedding of leaves and spikes with or without black spots. The branches break up at nodes and the entire vine collapses within a month. If the damage is confined to the feeder roots, the expression of symptoms is delayed till the cessation of rain and the vine starts showing declining symptoms such as yellowing, wilting, defoliation and drying up of a part of the vine. This may occur during October-November onwards. These vines may recover after the rains and survive for more than two seasons till the root infection culminates in collar rot and death of the vine.

Management

The disease can be controlled by adopting integrated disease management strategies.

a. Phytosanitation

Removal and destruction of dead vines along with root system from the garden is essential as this reduces the build up of inoculum (fungal population). Planting material must be collected from disease free gardens and the nursery preferably raised infumigated or solarized soil.

b. Cultural practices

Adequate drainage should be provided to reduce water stagnation. Injury to the root system due to cultural practices such as digging should be avoided. The freshly emerging runner shoots should not be allowed to trail on the ground. They must either be tied back to the standard or pruned off. The branches of support trees must be pruned at the onset of monsoon to avoid build up of humidity and for better penetration of sunlight. Reduced humidity and presence of sunlight reduces the intensity of leaf infection.

c. Chemical control

Any of the following chemical control measures can be adopted. After the receipt of a few monsoon showers (May-June), all the vines are to be drenched at a radius of 45-50 cm with copper oxychloride 0.2% @ 5-10 litres/vine. A foliar spray with Bordeaux mixture 1% is also to be given. Drenching and spraying are to be repeated once again during August September. A third round of drenching may be given during October if the monsoon is prolonged.Soil drenching with potassium phosphonate 0.3%or metalaxyl mancozeb is also effective for the management of quick wilt.

3. Other fungal diseases of arecanut

i. Inflorescence dieback

Wide spread occurrence of this disease has been reported from Kerala and Karnataka state. Studies carried out in the mid seventies revealed that 60 per cent of the palms are affected by this disease (Saraswathi *et al.,* 1977). Inflorescence dieback is one of the reasons for low fruit set in arecanut palms. However, the actual crop loss has so far not been estimated.

a. Symptoms

Yellowing of the rachillae is the initial symptom. The yellowing starts from the tip of the rachillae and progresses down towards the main rachis and as the lesion spreads the rachillae turn dark brown followed by drying. Hence the disease is known as inflorescence dieback. Subsequent spread of the lesion causes shedding of female flowers. In the advanced stage of the disease, infected rachis exhibits concentric rings of pinkish conidial mass of the fungus. The most susceptible stage of infection is immediately after shedding of the male flowers. The scars left after shedding of male flowers were found to be the main foci of infection. Sometimes the inflorescences were found to be partially infected. The infection rarely initiates at the basal portion of the inflorescence or through the female flowers.

Infection mostly takes place on inflorescence soon after shedding of male flowers under natural conditions. The green fruits are resistant in the beginning and become susceptible on ripening.

b. Etiology

Colletotrichum gloeosporioides Penz. is the causal organism of the disease. As the fungus is highly sporulating the disease spreads very fast during favourable conditions.

c. Management

Details studies have been conducted on the management of the disease. Spraying of the inflorescence with dithane Z78 (0.4%) and heptane antibiotic of DMOC 0.1%, heptane antibiotic + copper sulphate (each at 50 ppm) were found effective in reducing disease incidence. Two sprayings at an interval of 20-25 days are recommended. Initial spraying has to be given during the female phase. Phytosanitation is also equally important as fungicidal control. Removal and destruction of completely dried inflorescence will reduce the inoculum load in the garden and thereby reducing further fast spread of the disease (Saraswathy, 1994). Since *C. gloeosporioides* also causes pod rot disease and foliar infection of cocoa, integrated management of inflorescence dieback of arecanut is very important in the management of cocoa disease. Therefore phytosanitation and crop protection measures for *C. gloeosporioides* disease of arecanut should not be neglected.

ii. Foot rot (basal stem rot)

The disease is also known as 'anabe roga' in Kannada language which means a disease caused by a mushroom. Basal stem rot is a slow decline disease with a history of more than 100 years. The occurrence is reported from Kerala, Assam, West Bengal, Nicobar Islands (Sangal *et al.,* 1961), Karnataka State (Coleman, 1911) and from Mettupalayam areas of Tamil Nadu (Anonymous, 1960). The disease is severe in neglected, ill drained and overcrowded gardens (Venkatarayan, 1936). The disease is soil borne, but secondary spread through air borne spores is also reported (Venkatarayan, 1936).

Crop loss due to the disease is not documented systematically. Mortality of palms is reported as 94% in neglected gardens (Butler, 1906). Later researchers reported the death rate as 5% (Venkatarayan, 1936) or as 8% in neglected and waterlogged gardens (Naidu *et al.,* 1966). In endemic areas the disease incidence is as high as 20-25% (Kumar and Nambiar, 1990).

a. Symptoms

The palms cannot be identified in the initial stage of the disease. The visual symptom of the disease is yellowing of the outer whorl of the leaves which gradually dry and hang like a skirt around the stem. As the disease progresses, the entire crown becomes yellow, leaving only the spear leaf green. In the advance stages spindle also gets dried up and finally the crown topples down leaving the bare stem. Simultaneously symptoms are seen on the basal portion of the stem as small dull brown spots. These spots later coalesce to form bigger discoloured patches. In the acute stage of the disease a brown gummy liquid oozes out through these patches. The bracket shaped fruiting bodies (basidiocarps) of the fungus are formed at the base of the trunk usually after the death of the palm or on the stump or rarely on the live palm. The roots of affected palms are brittle and dry. The uptake of nutrients and water are interrupted due to rotting of tissues of root and stem, leading to the situation of pathological drought which is similar to pronounced drought condition (Venkatarayan, 1936). Such palms may not respond even to the best management practices.

b. Etiology

The pathogen causing basal stem rot (foot rot) is a bracket forming polyporus fungus *Ganoderma lucidum* (Leys) Karst. The infection is mainly through the roots and secondary spread is by spores borne on the fruiting bodies, irrigation water, repeated ploughing and other cultural operations in the garden.

c. Management

The disease can be effectively controlled in the early stages of infection by root feeding of 125 ml of 1.5% calixin. To minimize the disease incidence the adjacent palms have to be given soil drenching with 1.5% calixin at quarterly intervals (Kumar and Nambiar, 1996). The diseased palms are to be isolated by taking trenches of 30 cm vide and 60 cm deep around the affected palm to avoid root contact of healthy and diseased palms. Dead and disease advanced palms should be removed along with the root system and the basal portion of the stem along with roots should be destroyed since the infected roots and stems remain as source of inoculum for fresh infection. Besides the fungicidal treatment the soil fertility and root formation can be improved by application of FYM 15-20 kg, green leaf 15-20 kg and 2-2.5 kg neem cake in addition to the recommended dose of NPK (100:40:140) fertilizers.

iii. Leaf spot

Leaf spot in arecanut seedlings and young palms is observed throughout the year.

a. Symptoms

The symptoms appear as yellow specks of 3.0-10 mm diameter on the leaf lamina. These spores later coalesce to form bigger lesions with typical yellow halo around the lesion. Severe infection causes stunted growth and ultimately leading to death of the seedlings. The second type of leaf spot occurs during south-west monsoon season. Intensity of the disease is more on young palms of less than 10 years. This leaf spot is reported in a severe form from several arecanut gardens in Uttara Kannada district and some parts of Dakshina Kannada district of Karnataka State and parts of Kasaragod district of Kerala State. The infection is restricted to 3-4 leaves of the outer whorls. The symptoms developed as small brown to dark brown or black round spots of varying sizes. The spots are characterized by yellow halo around and in advance stages they form blighted patches. Severe infection causes drying, drooping and shredding of leaves.

b. Etiology

Fungi isolated from leaf spots include *Curvularia* sp. (Menon, 1962), *Colletotrichum* sp., *Phyllosticta* sp., *Helminthosporium* sp. (Rao, 1966; Rao and Bavappa, 1961). *Phyllosticta arecae* Hohnel and *C. gloeosporioides* are the most commonly isolated fungi from two types of leaf spots usually found in the disease endemic areas.

c. Management

Monthly sprays of mancozeb (Dithane-M45 0.3%), captafol (Foltaf 0.2%) or carbendazim (Bavistin 0.05%) during June-August were found effective in reducing the intensity of leaf spot disease during south west monsoon period.

4. *Colletotrichum* diseases of intercrops

The inflorescence dieback pathogen, *C. gloeosporioides* incites disease in some of the intercrops also. This is most noticeable and severe when *Colletotrichum* infects young cocoa pods.

i. 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.,* 1989).

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, 1983). 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.,* 1989).

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, 1984).

ii. Pollu disease (Anthracnose) of blackpepper

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. This disease is caused by *C. gloeosporioides*. Unnikrishnan Nair *et al.* (1987) reported up to 77% weight loss of berries due to early infection.The disease can be controlled by spraying Bordeaux mixture 1%.

5. Phytoplasma disease of arecanut- Yellow Leaf disease

Yellow Leaf disease (YLD) is the most serious malady affecting arecanut cultivation in Kerala and Karnataka, which considerably reduced the production and quality of the product. The exact period when the disease was observed is not known. However, the earliest information is found in the publication 'Diseases of coconut palm' by Varghese in 1934. According to Nambiar (1949), the disease was first reported in 1914 in Moovattupuzha, Meenachil and Chalakkudi area of central Kerala. Now, yellow leaf disease is prevalent in all district of Kerala, five districts of Karnataka and some parts of Tamil Nadu and Maharashtra causing heavy economic loss to the growers. It affects the normal growth and vigour of the palm. Reduction in yield up to 50% within a period of three years after the onset of the disease has been observed (Nair, 1994).

a. Symptoms

Leaves of arecanut turn yellow colour due to various biotic and abiotic factors. But symptoms of YLD can be differentiated from yellowing of leaves due to various other factors. Characteristic yellowing of leaves is the most important visual symptom of the disease and hence the name yellow leaf disease. Initially yellowing occurs in one or two leaves of outer whorl. Yellowing starts from the tip of the leaflets on either side of the leaf and gradually extends to the base. There is a clear demarcation between the green and yellow region of the leaflet at this stage. When the yellowing extends from tip to the basal portion of leaflets there will be a clear band of green tissue adjacent to the midrib. This characteristic symptom is different from the yellowing caused by other diseases and pests. The tip of the infected leaves become necrotic and eventually dry up. In advanced stage, the leaves become reduced in size, become stiff, closely bunched and abnormally puckered and the crown becomes very much reduced in size. Immature nut fall, kernel discolouration and extensive root rot are the other major symptoms (Rawther, 1976; ChandraMohanan, 1979; Nair, 1994).

Anatomical studies of leaves from diseased palms revealed multinucleated cells, disturbed tissue differentiation, blocking of palisade cells with brown pigments and degeneration of chloroplast (Nayar, 1968). The leaves of diseased palms showed smaller epidermal cells, stomata and midrib parenchyma cells, while xylem tissues in the midrib were larger. Rapid collapse of stomata and occurrence of tyloses in varying degree were recorded. Significant accumulation of starch grains indicated impaired translocation of food materials and accumulation of products of photosynthesis (Menon, 1960).

b. Etiology

Extensive and systematic research has been conducted to find out whether the disease was caused by fungi, bacteria, nematodes, viruses or by nutritional disorders. But it has been clearly revealed that none of these can cause YLD.

Electron microscopic (EM) studies showed the presence of Phytoplasma in young sieve elements of YLD affected palms (Nayar and Seliskar 1978). EM examination of root tissue of YLD affected palms invariably showed the presence of Phytoplasma whereas they were totally absent in roots of healthy palms (CPCRI, 1985 and 1986). 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).

Detailed investigations on possible vectors of the disease have revealed the constant association of a plant hopper *Proutista moesta* (Westwood) with arecanut palms. On EM examinations, Phytoplasmas were observed in the salivary gland tissue of plant hopper collected from the leaves of diseased palms while Phytoplasmas were totally absent in the salivary gland tissues of laboratory reared plant hopper as well as the insects collected from healthy areas. Transmission of the disease and vector role of *P.moesta* were confirmed by observing YLD symptoms on arecanut seedlings inoculated with *P. moesta* which was given five days acquisition access to diseased palm and 25- 36 days incubationn period (Ponnamma *et al.,* 1991 and 1997). These results lend further support to Phytoplasma etiology. The presence of Phytoplasma and its transmission were established also by dodder transmission (CPCRI, 1991).

Antibiotic therapy against YLD revealed marked reduction in foliar symptoms in neomycin, ledermycin oxytetracycline (OTC), gentamycin and hostacycline treated palms. But, there was no reduction in disease intensity in the penicillin treated palms. On the other hand, the disease intensity of the palm in this treatment increased as usual. Thus it again confirmed the phytoplasmal etiology (CPCRI, 1990 and 1991).

c. Disease Management

Since YLD is caused by phytoplasma it is not possible to control the disease by adopting conventional plant protection measures.

The perennial nature of the crop, persistence of the pathogen once it is acquired and possible transmission in brief duration of feeding by vector, rule out the effective prevention of the spread of the disease by control of vector. Diseased palms treated with antibiotics exhibited only temporary remission of symptoms and need to be applied repeatedly. Prohibitive cost of antibiotic and caution against its indiscriminate use for treating any plant disease are the other limitations of its use. Therefore, it became imperative to find out other means of containing the disease so as to obtain the maximum economic return from affected gardens.

One of the significant features of this disease is that it is not lethal but a slow declining malady. Thus YLD affected palms will die only after a long protracted period of illness. In the absence of any control measures, this nature of the disease is advantageous to adopt proper management practices to increase the vigour and yield of palms in the initial stage of disease. In managing the disease two strategies, one for the mildly affected area and other for heavily diseased area, have been formulated.

The strategy for mildly affected area is to contain the disease by removing all the diseased palms. Eradication of disease affected palms to contain the disease can be successful if continuous monitoring for occurrence of the disease and uprooting of diseased palms in the very initial stage of the disease are taken up simultaneously. If the programme is not monitored uninterruptedly the desired goal will not be achieved.

In heavily diseased area, yield of the palms can be sustained or even improved through adoption of integrated management practices - removal of disease advanced and juvenile palms, balanced fertilizer application, addition of organic manures, irrigation during summer months, practicing plant protection measures. The income from a unit area can be further increased by adopting inter and mixed cropping.

By taking into account all the results from earlier trials, a detailed experiment was initiated in 1982 at Palode (Kerala) with four management practices on two varieties of arecanut to evaluate their effect on the incidence of yellow leaf disease. Incidence of the disease was least in palms treated with higher dose of phosphorus application over and above the normal package. Mangala and its segregants were superior to South Kanara local. The effect of phosphorus in reducing the incidence of YLD was evident (CPCRI, 1991; Nair, 1994).

It is apparent that soil and nutrient management had improved the condition of disease affected palms and increased the yield to some extant or maintained the yield level. Thus, it is essential to follow management recommendations in order to reduce the disease incidence and to realize maximum economic return from the affected garden.

Based on the various field trial conducted in different locations the integrated management practices have been recommended to improve the yield of YLD affected palms in heavily disease affected areas.

d. Screening of varieties against YLD

Studies on varietal reaction to YLD were initiated as early as in 1960. In a multilocation trial conducted during 1970's, six promising cultivars such as VTL-3 (Mangala), VTL-11 (Sumangala), VTL-17 (Sreemangala), Mohitnagar, VTL-12 and VTL-13 with South Kanara local as check were evaluated and the results indicated that all of them were susceptible. Nampoothiri (1982) reported that, 52 arecanut collections derived from both exotic and indigenous sources also succumbed to YLD with varying degrees of intensity. Further, large scale screening of germplasm collection/varieties/hybrids, hybrids produced from disease escapes, *inter se*/selfed progenies of different collections involving 88 different cross combinations comprising of 2,328 palms were undertaken in YLD affected belt during 1976-1993. All of them were highly susceptible and 18 genotypes showed less than 25 percent of disease incidence. The 21 diallel cross combinations planted at CPCRI, Palode in 1976 have contracted the disease within a period of three years. The disease incidence varied from 63.9 to 100 per cent. Maximum incidence was noticed in VTL-3x VTL-13, VTL-11x VTL-13, VTL-11 x Thirthahalli, VTL-13x VTL-17 and VTL-17 x Thirthahalli (100%) and minimum in VLT-12 x Thirthahalli (63.9%). The hybrid combinations between Hirehalli dwarf mutant and promising cultivars (VTL-3, VTL-11, VTL-13, Mohitnagar and Thirthahalli) planted in 1976 exhibited certain degree of tolerance in the initial years (CPCRI, 1981). However, all succumbed to YLD within a period of 6-8 years. The disease incidence was the highest in Thirthahalli x Dwarf (62.9%) and least in Dwarf x VTL-11 (18.1%).

A field trial involving nine varieties, hybrids, Mangala and South Kanara as control initiated during 1984 at CPCRI Research Centre, Palode indicated that all of them contracted the disease within a period of three years except VTL-12 x South Kanara combination. Later, this combination also succumbed to the disease. Even after 18 years of field experimentation, none of the hybrids or varieties tested was completely resistant. But in the hot spots of YLD affected areas, in the midst of diseased palms, some high yielding palms are found without any symptoms of the disease. Hence, investigations were undertaken to identify field tolerant/resistant elite palms in hot spots of YLD affected areas.

e. Breeding for resistance against YLD

Since there are no curative or prophylactic measures available to combat YLD, the long-term option is to breed for disease resistance. Disease free elite mother palms were identified in hot spots of Kerala and Karnataka states (ChandraMohanan and Nampoothiri, 2001). They were further monitored every year for disease incidence and yield. The disease free elite palms were selfed by artificial pollination and F1 progenies were interplanted in severely (more than 90%) YLD affected gardens in the hot spots of Karnataka for evaluating their susceptibility to the disease. Simultaneously, seedlings raised from open pollinated seed nuts of disease free elite palms were also planted in severely YLD affected gardens. Though research work in this line is in progress, it will take a very long time to evolve a sufficiently large population of tolerant/resistant palms and to replace the diseased palms with tolerant/resistant ones, in a phased manner. Therefore, seedlings produced from disease free elite mother palms identified in hot spots may be used as quality planting material for the replanting programme in disease endemic areas.

6. Future Thrust

Some of the diseases of arecanut are seasonal while others occur throughout the year. *Phytophthora* diseases, especially fruit rot are found during rainy season. Inter and inter-specific variability has been reported in different species of *Phytophthora*. Analysis of the diversity of arecanut *Phytophthora* will reveal its taxonomic status. Phenotypic and molecular characterization could clarify pathogenic variability of different isolates. The accurate identification of *Phytophthora* sp. occurring in different agroclimatic region is a prerequisite to disease control. From a very long time farmers depend on Bordeaux mixture for the control of fruit rot of arecanut. An alternate method for fruit rot management which is eco-friendly and economically viable is the urgent need of the day for profitable cultivation of arecanut. Satellite survey of the YLD affected arecanut tract using Geographic Information system (GIS) would be helpful in identifying the extent of spread and intensity of the disease as well as in understanding the incidence in surrounding areas.

Identification of YLD resistant/tolerant palms and screening of these progenies should be a continuous process in research for tolerant genotypes. Assessing resistance to YLD using biotechnological tools can be tried to shorten the breeding cycle. PCR based molecular fingerprints can be exploited for determination of genetic diversity in arecanut germplasm and tagging resistant genes. Pathogen derived resistance mechanisms need to be employed to produce transgenics to resolve this stalemate. Evolving field tolerant lines coupled with suitable management practices will be final solution in tackling the YLD of arecanut.

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Pest management in arecanut palm based cropping systems

Mariamma Daniel

Introduction

The arecanut palm (*Areca catechu* Linn) is naturally growing in high rainfall regions of tropical Asia. Monoculture of this palm in a commercial level is very limited to certain pockets in Karnataka. Some kind of intercropping/multiple cropping evolved in the palm plantations are mainly due to the price fall of the main crop in early 1970s. Also farmers were inter cultivating their palm plots for their family requirements with banana, black pepper, yams, tubers and vegetables like cow pea, cucumbers, gourds etc. These farmer experiments evolved into a pattern of inter and mixed cropping with palms, annuals and perennials. Mixed cropping of arecanut palm and cocoa was an important milestone in the progress of research on this palm. The pattern of pest incidence on these intercrops as a matrix is lacking, especially the relationships between different species of fauna in multiple cropping systems. Pest problems are influenced by crop and variety of choice as well as cultural practices or degrees of intensity in cropping systems.

2. Arecanut and cocoa mixed cropping

The tall palms and spreading cocoa trees provide a micro climate beneficial to the crops and associated insects. This environment is conducive to the multiplication of natural enemies which in turn will check the population of pests. Mixed cropping is practiced usually with a spacing of 2.7 x 2.7 m for palm and 2.7 x 5.4 m for cocoa. One hectare area will, thus, hold 1372 palms and 682 cocoa trees. This crop combination is cultivated for the last 25 to 30 years in many parts of Kerala and Karnataka in holdings of half- an- acre to five ha and most of these holdings are not intensely sprayed with any kind of insecticides. The pest problems on the companion crop are almost saturated within this period in the traditional growing areas of Kerala and Karnataka.

3. Crop wise incidence of pests

The insect and non insect pest problems encountered on crop combinations are reviewed here, touching on the possible interaction of the crops and insects.

3.1. Major pests of arecanut palm

Arecanut palms under the cropping system were about 18 years of field standing and such plantations usually do not require much attention with regard to insect pest infestation. The exception is in the case of root grub areas of Kerala and Karnataka. The palms under the cropping system trial did not show any major pest attack during the five years of observation except the immature fruit drop by marmorated bug and perianth mite. Spindle leaf bug, root grubs, phytophagous mites, spadix moth and the marmorated bug are the major pests of arecanut palms and the injury caused by these pests are given briefly in Table 1 as well as below along with management aspects wherever necessary.

Table 1. Major pests of *A.catechu* and their impact on the component plants of the system

Common	Scientific name	Damage	Alternative hosts	Threat to component crops
Spindle leaf bug	*Mircarvalhoia arecae*	Feeds on spear leaf	Oil palm & ornamental palms	None
Root grubs	*Leucopholis burmeisteri & L.lepidophora*	Roots	tuber crops, coconut	Banana, cocoa,
Spider mite	*Oligonychus indicus*	Fronds	Many	None
Palm mite	*Raoiella indica*	Fronds	Coconut	None
Bunch moth	*Tirathaba mundella*	Spadices	Oil palm	None
Marmorated bug	*Halyomorpha marmorea*	Immature fruits	Many like cow pea, gourds, chilli, coccinia, okra	None now
Semi slug	*Mariella dussumieri*	Spadix, including floral parts	Polyphagous	Tender shoots of black pepper, leaves of banana

3.1.1. Spindle leaf bug (*Mircarvalhoia arecae* M&C (Miridae)): This mirid is classic in its nature of infesting only palms, that too very few genera, viz; *Areca, Elaeis, Dypsis*. This injures palms from seedling to adult stage, colonizing the axils of spear leaf, feeding and reproducing on the spear leaf. Insecticidal management is needed only in certain localities. This true bug is not seen damaging dicot plants, so does not pose a problem to other crops.

3.1.2. Phytophagous mites: Mainly two species of mites colonize the fronds of palm, the 'cholam' mite, *Oligonychus indicus* and the palm mite, *Raoiella indica*. These mites infest the pinnae, especially of seedlings and young palms. High incidence is observed during summer months. A number of indigenous natural enemies exert a good control of these mites as also enough shade and proper irrigation to young palms. These mites are not observed on cocoa trees or on other crops in the system.

3.1.3. Perianth mite (*Dolichotetranychus* sp): The infestation of this orange coloured mite causes immature fruit drop. This mite colonizes the perianth lobes and feed on them leading to immature fruit drop from November to May. This is not observed on cocoa. An insecticidal intervention is needed in some years when the injury caused by this mite is severe. Fine spray of dimethoate at 0.05 % is to be given to the immature fruit bunches.

3.1.4. Root grubs: Root grubs are polyphagous pests and serious on palms in the Western Ghats regions of Karnataka and Kerala. *Leucopholis burmeisteri* Brenske and *L.longiphora*

(Melolonthidae)are the two main species in these localities feeding on roots, perennial injury leads to foliar symptoms of yellowing and drooping of leaves, tapering stems and reduction in spadices produced within two or three years in a healthy plantation. This is at present prevalent in Dakshina Kannada, Uttara Kannada, Chikmagaluru, Shimoga of Karnataka and Kozhikode and Wynadu districts of Kerala. Being polyphagous, these grubs can switch to feeding on the roots of other crops in the system like banana, cocoa, yams and tubers. Severe damage on cocoa leading to defoliation and drying of branches was observed in perennial infestation in Belthangady region of Dakshina Kannada district. Root grubs are the only pest of palms which can cause appreciable damage to cocoa also. This could be corrected if Integrated Pest Management (IPM) practices are carried out in the infested areas.

3.1.4.1. IPM of root grubs: Adult beetles emerge from infested gardens after 8-10 days of premonsoon showers in April/May. Collection and destruction of these adults during the evening hours after sunset (1830 to 1930 hr) is the first and most important. The second step raking of soil to expose eggs, first stage grubs and adults after premonsoon shows in May-June. Raking and exposing the grubs to mechanical destruction and predation is the third step to be followed after the cessation of rains in August/September. In an area with known history of root grub infestation, insecticidal application could be given after the cessation of monsoon showers. Phorate @15 g/palm basin or chloropyriphos @ 7 ml in one litre of water may be given in severely infested plots. Application of organic manures induces soil fertility and root initiation. This will sustain the microorganisms some being insect pathogens like *Metarhizium anisopliae* and *Beauveria* sp. Application of soil amendments such as neem cake (2 kg/palm) would induce fresh root initiation and it has antifeedant properties also. Indigenous predators of this soil pest are few. One parasite commonly observed in infested plots is the scarab hawk, *Campsomeris* sp. and is prevalent in Dakshina Kannada and Chikmagalur districts. Entomophillic nematodes are also seen infecting the grubs. *Heterorhabditis* sp is isolated from this grub and is seen in Dakshina Kannada.

3.1.5. Marmorated bug (*Halyomorpha marmorea* F. (Pentatomidae)): Immature fruit drop is a serious problem in all plants and it is very pronounced in palms like coconut and arecanut palm. The pentatomid which causes this problem in arecanut palm plantations might have shifted to palm feeding from its back ground host flora since there is no other record of this genus feeding on palms. This insect is present in Dakshina Kannada, Uttara Kannada, Kasaragod, and Kannur districts and is seasonal on arecanut palm i.e. from March/ April to July. Many alternative host plants including vegetables, wild plants, and ornamentals/forest trees are present for these bugs to feed and reproduce. Though egg clusters are found laid on leaves of pepper and cocoa, the insect never feeds on these crops in the system. Some species of *Halyomorpha* are reported as minor pests of cocoa in

West Africa. This bug can turn out to be a pest of cocoa and vanilla in the changing floral scenario of the region, especially when the background flora of this insect is being destroyed (CPCRI, 1988).

3.1.6. Bunch moth (*Tirathaba mundella* Walker (Pyralidae)): The caterpillars of this moth infest the spadices of the palm feeding on tender spikes and female flowers. This causes less than three per cent damage in a plantation. The predisposing factor for the incidence of this pyralid is the injury caused to the tender spadix by the semi slug, *Mariella dussumieri* Gray. This slug which is very common on the Western Ghats region feeds on the tender spathe cover and even on tender portion of the inflorescence and the damaged points form the entry points of the pyralid since the moths lay eggs on these portions. Both the bunch moth and slugs do not harm cocoa trees though slugs may be seen moving on cocoa trees.

3.1.7. Minor Pests of arecanut palm

Members of many sternorrhynchan and few auchenorhynchan families are insects of minor importance colonizing mainly the pinnae and fruit bunches. Thrips, stem weevils and caterpillars are the other insects of minor nature (Table 2).

Table 2. Minor pests of *A.catechu*

Common name	Scientific name	Damage	Alternative hosts	Threat to component crops
Oriental scale	*Aonidiella orientalis*	Pinnae & fruits	Polyphagous	None from the cropping system
Mussel scale	*Lepidosaphes* sp	Pinnae & Fruit bunch	Many	,, ,,
Pandanus scale	*Pinnaspis buxi*	Pinnae	Pandanus & other palms	,, ,,
Black fly	*Aleurocanthus arecae*	Pinnae		,, ,,
Palm aphid	*Cerataphis brasiliensis*	Pinnae, spadix & fruitts	Many palm spp	,, ,,
Mealy bugs	*Dysmicoccus brevipes, Planococcoides lingnani*	Pinnae Pinnae, spadix & fruit bunch	Polyphagous Coconut, grasses	Pineapple
Stem weevil	*Diocalandra stigmaticollis*	Stem portion		None

3.**1.7.1. Diaspididae (Armoured scale insects):** Three genera are important viz., the oriental scale, *Aonidiella orientalis* Newm., the mussel scale, *Lepidosaphes* sp. and the Pandanus scale, *Pinnaspis* buxi. These hard scales are always present on the palm in a very low population and under control by the indigenous natural enemies like coccinellid beetle, *Chilocorus nigrita* and *C.circumdatus* and parasitoids. These insects can resurge and attain the status of secondary pest situation in arecanut palm plantation belt if indiscriminate use of insecticides is done in the ecosystem for other vegetable crops which will kill the natural enemies. The situation arose during the 1990s in many parts of Dakshina Kannda district as a result of insecticide use in arecanut and vegetables like coccinia and other local varieties. The out break condition of these scales continued for more than a decade with environmental factors facilitating its spread to all palm growing areas of the district including Udupi.

3.1.7.2. White fly (black fly) (*Aleurocanthus arecae* (Aleyrodidae): This low impact insect also can become prominent in some years by very high reproduction. This infests the pinnae of young leaves and coconut is also an alternative host. This insect closely resembles the citrus black fly, *A.woglumi*. This insect is never observed on cocoa but colonizes banana leaves.

3.1.7.3. Palm aphid (*Cerataphis brasiliensis* Hempel (Aphididae) is another insect restricted to palms. This colonizes the spadices and pinnae of palms and is under control by predators like syrphids and coccinellids.

3.1.7.4. Mealy bugs: *Pseudococcus cryptus*, *Dysmicoccus brevipes, Planococcoides lingnani* and *Icerya seychellarum* are the species present on arecanut palms but without doing much injury to the palms. These colonize pinnae and spadices mainly, but *Icerya seychellarum* infests the fruit bunches. This situation need not be addressed to a management level. Cocoa is not an alternative host plant of these mealy bugs. *D. breviopes*, the pine apple mealy bug is seen on pine apple also.

3.1.7.5.The grapevine thrips (*Rhipiphorothrips cruentatus* (Thripidae): This is the only species of thrips from arecanut palm and it damages occasionally the pinnae of young palms and injury is seen as silvery streaks. This thrips is not seen in this locality for the last two decades and is not seen on cocoa.

3.1.7.6.Leaf hoppers (*Proutista moesta* West (Derbidae): These interesting derbids are seen on the pinnae of arecanut and coconut palms and is proven as the vector of the phytoplasma causing Yellow Leaf Disease (YLD) of arecanut palm. This insect is present in all palm tracts of Kerala and Karnataka throughout the year. *P.moesta* is never observed on cocoa trees though many other leaf hoppers and plant hoppers feed on it.

3.1.7.7.Stem weevil (*Diocalandra stigmaticollis*) is a minor pest and can attain major status in some localities. It is inflicting serious damage on palms in Assam state.

Resurgence of minor pests like scale insects, black flies, palm aphid is possible in a system where pesticides are used regularly and indiscriminately for the management of pests in the area. This is mostly because of the destruction of predators and parasitoids. The best example was the resurgence of hard scale insects on palms in the 1990s after the regular use of insecticides like endosulphan in palm based systems and also on vegetable crops in Dakshina Kannada district.

4. Interactions within component crops and insect management

Biodiversity is one measure of environmental quality and cropping systems offer man made biodiversity. Species diversity in multiple cropping reduces most insect pest problems. Most of the insect problems are site specific and a check list of local back ground fauna is essential before deciding the component crops of a cropping system. Maintaining the high levels of biodiversity in flora and fauna is as important for ecological sustainability as keeping up the already adapted beneficial organisms.

The implications of certain infestation under a cropping system are varied with no impact in certain localities and with serious impacts in other localities. The normal insect fauna of the main crop of the system do not attack the component crops. This may mainly because the main crop is a monocot and the key pests of *A.catechu* are host specific or with limited host range. The exception is the case of few species like the root grubs (*Leucopholis* spp) which are site specific and the plant feeding slug which is common in the Western Ghats regions.

5. Pests of cocoa in a mixed/multiple cropping system

The local insect and non insect fauna acclimatized to cocoa trees in the last five decades are summarized here. Cocoa was always tried as companion crops along with arecanut palm and in a hectare of arecanut palms spaced at 2.7X 2.7 m, cocoa is planted at a spacing of 2.7x5.4m. In a multiple cropping system, cocoa is planted at a population of 210 trees in one ha. The incidence and injury caused to cocoa by insects is influenced by the atmospheric humidity in the area and the multispecies cropping system gives a fine microclimate.

An ecologically sound adaptation process has already occurred in Karnataka, Kerala and Tamil Nadu, but this acclimatization is a continuous process influenced by the total area under the crop and the extent of time taken for this introduction. Cocoa can be cultivated under arecanut palm canopy encouragingly since the insect fauna of the palm does not infest cocoa. The fauna so far adapted to cocoa do not pose any problem to arecanut palms or the monocot/dicot plant companions do not share same insect pests.

Mealy bugs, mirids, aphids, stem borers, leaf feeding caterpillars, beetles, and weevils are the insects which infest cocoa and do some visible damage. The auchenorrhynchan membracids, fulgorids, ricanids, flatids are insects just shifted to cocoa in the last four to five decades without inflicting any damage to it. Among these only membracids are found to explode cyclically in high numbers but then also these do not cause any serious damage (CPCRI, 1986).

5.1. Mealy bugs: This ubiquitous group of insects is the fastest to adapt to any crop introduced newly. Cocoa mealy bug, *Planococcus lilacinus* Ckll and *P.citri* Risso are the two important species colonizing the tender shoots, flower cushions, cherelles and pods. These two species are found on many weed and ornamental plants but not on palms. Infestation was seen in less than 10% of trees of the 210 total observed. But 10 to 100 % of trees may show the colonization in mixed cropping system. With the present level of mealy bug infestation, insecticidal control is not needed/practiced in cocoa plots of Kerala and Karnataka(CPCRI, 1987).

5.2. Mirid bug (*Helopeltis* spp): *H.antonii* Sign.and *H.theivora* Waterh.are polyphagous bugs and they feed on a variety of cultivated trees like cashew, tea, cocoa, cotton, neem, and cinchona. The injury by this mirid was noticed as early as the introduction of cocoa in the Kanyakumari district of Tamil Nadu. This mirid's infestation pattern is associated with many factors *viz*; weather parameters like minimum temperature, canopy architecture of trees, moisture and atmospheric humidity. It feeds on tender shoots, cherelles and pods of cocoa. Drought situation along with drip irrigation would enhence the injury levels to serious situations leading to die-back symptoms. *H.antonii* is one of the key pests of cashew in Western Ghats region of South India and *H.theivora* on tea in India. Cropping systems in the vicinity of cashew/tea plantations have the chance of this mirid attack (CPCRI, 1986, CPCRI, 1989).

5.3. Thrips are another group of insects attaining a serious nature on cocoa (CPCRI, 1994) and many fruit, vegetable and ornamental plants. Since its cultivation in south India, cocoa was not found damaged by thrips or its injury levels were very minimal. Cocoa thrips, *Selenothrips rubrocinctus* was the only species seen rarely but its damage level was very minimal. The chilli thrips, *Scirtothrips dorsalis* Hood is emerging as a major pest of cocoa. Major pests of cocoa and their impact on other crops are given in Table 3.

6. Pest problems in Multispecies Cropping System

In the first trial of the system, one hectare area with about 1300 palms with black pepper on all, 42 cocoa trees, 78 banana, 36 clove trees, 156 coffee and 480 pineapple plants were maintained. Five years observation on the general incidence of various insects and non insects on the plants under this cropping system did not indicate any serious incidence of pest. Arecanut palms in the system were about 18 yr old and these palms showed the problem of immature fruit drop caused by marmorated bug, *H.marmorea* and the perianth mite *Dolichotetranychus* sp. A five year study on the seasonal incidence of *H.marmorea* indicated that the intensity of drop gradually increased from April - May

Table 3. Major pests of cocoa and their impact on other crops

Common name	Scientific name	Damage	Alternative hosts	Threat to component crops
Cocoa mealy bug	*Planococcus lilacinus*	Flower cushions, cherelles, pods and tender shoots & leaves	Only few	None
Citrus mealy bug	*P.citri*	,, ,,	Polyphagous	
Tea mosquito bug	*Helopeltis antonii, H.theivora*	Cherelles, pods & tender shoots	Polyphagous	Rarely on black pepper
Membracids	*Gargara mixta, Leptocentrus taurus*	Tender shoots, cherelles, pods	Many weed plants	None
Citrus black aphid	*Toxoptera aurantii*	Tender shoots, eaves, flowers, young cherelles	Many	Coffee
Leaf feeding Caterpillars	*Lymantria ampla, Euproctis* spp	Tender shoots, leaves, bark of cherelles & pods	Many	None
Ash Weevils Beetles	*Myllocerus* sp *Popilia complanta*	Leaves leaves	 Coconut	 None
Red branch borer	*Zeuzera coffeae*	Tender branches		Coffee

(CPCRI, 1983, 1987 and 1994)

(about 10 to 12%), reaching a peak during June and July (29.14 and 16.95%), and decreasing thereafter with the least injury in August (6.95%) when the endosperm of the areca fruit differentiate into a solid mass. Other major pests of the palm were observed at a level where an intervention with insecticides was never needed. This is the general situation in most of the palm plantations in Karnataka and Kerala in the traditional areas of its cultivation. When the locality is with a known history of root grub infestation, all possible management practices have to be carried out, the most important being the regular field observation for the presence of this insect in the initial time of its incidence itself. The second experiment was laid out with 608 palms, 394 black pepper vines, 220 cocoa and 219 banana plants. The insects observed in the component crops of the system are listed below.

6.1. Black pepper

Vines of black pepper, *Piper nigrum* were trained on all palms in the first trial of HDMSCS. A total of 1370 vines were established in this way. In the initial years of the trial, top shoot borer, leaf thrips, aphids and weaver ants were the major insects noticed on black pepper vines.

6.1.1.Top shoot borer(*Cydia hemidoxa* Meyr) was noticed in 21.4% of vines in September 1984 just after the good establishment of the vines, but the infestation got reduced to 1.47 % of vines by August '86 and was almost absent by the fifth year of planting. Intensity was more during the period August to December when succulent shoots were available on pepper vines(CPCRI, 1985, CPCRI, 1986, CPCRI, 1991).

6.1.2.Marginal gall forming thrips (*Liothrips karnyi* (Bagnell). Seen on tender leaves, the infestation was noticed throughout the year with the highest in January to March and least during August. In the first month of pepper growth, 22.3 % of vines showed marginal galls (CPCRI, 1984).

6.1.3.Semi slug: One animal which is benefited from multispecies cropping system is the semi slug, *M.dussumieri*. The slug feeds on the tender shoots of black pepper vines and leaves of banana. Slugs were plenty in the second model of high density cropping system with palm, black pepper (384), cocoa (220) and banana (219) and with different fertilizer levels. During the wet season of the year, these slugs were observed on palms, black pepper vines, and banana. About 20 slugs were counted on banana and 11 slugs on a single pepper vine. Reducing the slug population was needed and handpicking during the morning hours of their activity and putting them in pits along with common salt was done. Within one month, population got reduced, only very few slugs were seen on pepper and banana afterwards.

Aphids and leaf eating caterpillars are of minor importance in black pepper stands. (CPCRI, 1984, CPCRI, 1985) Looper caterpillars and some other lepidopterans in the system provide prey material for the generalist predators like reduviids, spiders etc.

6.2.Coffee, clove, banana and pine apple

Coffee, clove, banana and pine apple as component crops in the system did not show any appreciable damage by any insect. This may be due to the low density of these crops in the system and the low population of their pests in the locality. Planting of banana as a companion crop in arecanut palm system, especially the variety 'kadali' is an age old practice and none of the major pests of banana are seen at Vittal.

6.3. Ants in the system and their role

Ants are important components of any cropping system and species are more pronounced in tropical conditions. A number of ants are found trafficking the plants in the cropping system (Table 4). These ants can be protective to the insects or predatory on the insects. In the initial years of the cropping system, colonies of the Asian Weaver ant,

Table 4. Dominant ant species of HDMSCS

Common name	Scientific name	Association with other insects	Nature of association	Role in the system
Asian weaver ant	*Oecophylla smaragdina*	Mealy bugs, membracids	Protective to attending insects, predatory on caterpillars & other insects	May reduce incidence of tea mosquito bugs
Crazy ant	*Anoplolepis gracilipes*	Membracids, mealy bugs, aphids	Feeds on honey dew	Displaces the Asian weaver ant gradually
Black crazy ant	*Paratrechina yerburi*	Mealy bugs Palm aphid	Builds debris nests over mealy bug & palm aphid colonies & feeds on honey dew	Protective to attending insects
Brown ant	*Myrmecaria brunnei*	Cocoa aphids	Feeds on honey dew	Protective
	Crematogaster sp *Technomyrmex* sp *Solenopsis* sp	Mealy bugs	Feeds on honey dew	

Oecophylla smaragdina were seen on black pepper, cocoa and coffee plants with ant nests on pepper leaves.

With pineapple fruiting, weaver ants were displaced by the crazy ant *Anoplolepis gracilipes* and became abundant moving on black pepper, cocoa and palms.

7. Role of natural enemies in the cropping system

In many cropping systems, insect herbivore species are found to be less abundant in multiple crops than in monocultures. Increased plant diversity fosters stability of insect populations. This stability and reduced insect pest incidence in cropping systems may be the result of increased parasitoid and predator populations, availability of alternative food for natural enemies, decreased colonization and reproduction of pests.

In the palm based cropping system, there was no increased incidence of any insect. Though qualitative data over time and space are lacking on insect abundance/decrease, alarming situation of any pest was not noticed. This may be due to the biotic agents and microclimatic influences. Shade derived from denser canopies may affect feeding of certain insects and increased relative humidity may favour entomophagous fungi. The natural enemies noticed in these cropping systems are given in Table 5. Epizootic levels of

Table 5. Indigenous natural enemies in the cropping system

Primary predators

Common name	Scientific name	Main prey	Alternative prey insect
Coccinellids	*Stethorus keralicus* *Stethorus* sp	*R. indica*	*O.indicus*, eggs and crawlers of scale insects
	Chilocorus nigrita	Armoured scale insects	Only scales
	C.circumdatus	,, ,,	Only scale insects
	Cryptogonus kapuri	Palm aphid	None
Cybocephalid	*Cybocephalus* sp	Black flies	mites
Syrphids	*Dideopsis aegrotus* *Paragus yerburiensis*	*T.aurantii* *C.brasiliensis*	Aphid species of any plants including weeds
Hemerobid	*Micromus* sp	*T.aurantii*	*Aphis* sp

Parasitoids

Eulophid	*Anastatus bangalorensis*	Eggs of *H.marmorea*	Eggs of other pentatomids
,,	*Euplectrus* sp, *Pediobius* sp	Caterpillars of *Euproctis* spp	
Ichneumonid	*Charops* sp	Larvae of *Dasychira* sp	Larvae of lymantrids

B.bassiana infection was noticed once on the membracids of cocoa, *G.mixta and L. taurus*, after its very high incidence in a few years. This pathogen infected other insects also like *H.antonii, M. arecae* and even spiders and ants. Insect pathogens will survive in the system only under suitable temperature and humidity conditions and with enough density of the pest population.

8. Conclusion and future research needs

The plant - herbivore interactions are not studied at qualitative levels. The synergistic effects of biotic, structural and microclimatic complexity of multispecies cropping system are lacking. Host plant patchiness, host diversity, density and their interrelations and confounding effects on insects have to be understood.

When the crop combinations tried are new to the locality, the biological information about insect species of various crop combinations and of the diverse natural flora in the area over time and space has to be acquired to understand the pest 'explosions' of one insect or another from time to time so as to reduce the need for insecticidal control measures. The cropping systems must evolve into a natural biodiversity zone so that plant, insect and microorganisms become richer in diversity and multitrophic level interactions bring in a balance of nature in these perennial systems.

Indigenous natural enemies of insects and non insects are of great potential importance. Though their advantage may not happen in the systems of pest control, the provision of suitable habitats for the maintenance of useful biotic agents needs to be addressed. In other words we must try to imitate just enough of the diversity of selection pressures seen acting in nature to relieve the pressure from any one agent, and thus prevent the pest getting out of control by developing resistance faster than we can revise our control measures (Smallman, 1965).

Since predators are to some extent polypahgous and require broad habitat requirement like refuges, nectar and pollen sources, perennial natural landscapes structures between cropping systems are to be maintained and studied for sustaining beneficial fauna. Data on these aspects are totally lacking in the palm based cropping systems.

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Economics of arecanut based farming systems

C. Jeyasekhar

Introduction

With the development of various production, protection and processing technologies in Indian agriculture, at present more emphasis is given for maintenance of soil fertility and productivity, increasing gross farm income and efficient utilization of farm resources through intensive cropping. This is done through farm diversification or farm intensification, which are often suggested as means for developing small and marginal farms. Haque (1996) defined farm diversification as i) shift from subsistence farming to commercial farming, ii) shift from low value food/non-food crops to high value food/non-food crops and iii) switch over from local to high yielding plant varieties. The diversification would also mean that small farms would not only undertake seasonal crop farming, but also animal husbandry, fishing, agro-forestry, either self-employed or wage earners, for supplementing their incomes. However some distinctions need to be made between farm diversification and farm intensification. Farm diversification is the method of cultivating different crops in various segments of land of the same farm, while farm intensification is another method of cultivation of different crops on the same unit of land of the farm. In case of farm intensification, two or more complementary crops are cultivated in the interspaces of the main crop. It is also referred to as intercropping or multiple cropping. Small and marginal farmers, who are more risk averse than large farmers, are expected to adopt higher degree of farm diversification or intensification for protection against natural and economic risks. This means that these farmers can make use of the production complementarities to reap the benefits of synergism through appropriate choice of crop combinations. This chapter is an attempt to review the studies related to economic aspects of arecanut based farming systems conducted for the last fifty years at CPCRI, Kasaragod and its Regional Stations and Centers.

2. Arecanut based farming systems

Arecanut (*Areca catechu* L.) is a perennial crop grown in the humid tropics of India. The crop has a gestation period of 5 - 8 years and a long economic life span of about 35 years. Hence, the flow of costs and returns are spread over a number of years with varying degree of magnitude. In order to minimize the degree of price risks and stabilize the gross farm income, the arecanut farmers are advised to adopt various cropping/farming system models through farm intensification in which, two or more complementary crops are cultivated in the inter spaces of the main crop. However, the degree of farm intensification and choice of the component crops depend on agro-climatic, edaphic, biotic and socio-economic factors. For arecanut, being a perennial crop, fixed investments like land are committed to the crop for more than four decades. Under this condition in order to improve the resource efficiency of natural as well as farm resources, it is necessary to cultivate compatible inter/mixed crops in arecanut gardens. The trend in wholesale price of arecanut indicates that the degree of price fluctuation is fairly high and hence, realizing additional income from mixed crops would help in sustaining the economic stability of arecanut gardens.

Raising other crops in the interspaces of arecanut has been a common practice. The diversity of the inter and associated crops in arecanut gardens was reported by Bavappa (1951). According to Bhat (1974), the main objective of intercropping in arecanut gardens in the earlier days was not intensive land use, but compelling social and economic situations. Hence the selection of the intercrops and the management practices adopted were not based on sound agronomic principles alone. The long pre-bearing age, low returns during the initial bearing stage, unexpected loss due to pests and diseases and natural calamities, remoteness from markets and lack of transport facilities were reported to be some of the reasons that might have induced the farmers to grow intercrops in arecanut gardens (Abraham, 1956; Khader and Antony, 1968; Naidu, 1959). This practice also helps the arecanut growers to get some additional income and cover the risk of poor yields from arecanut due to the unfavorable weather conditions and incidence of pests and diseases.

A number of field experiments were initiated in early sixties at the CPCRI Regional Station, Vittal, and the Research Centres to assess the adverse effects, if any, on the productivity of the main crop of arecanut due to intercropping with commonly cultivated tuber crops, fruit crops like banana and pineapple and spice crops like ginger and turmeric and to find out the productivity of these crops grown as intercrops and to determine the profitability of the practice.

The profitability of intercrops in arecanut was studied at erst while CARS, Peechi station during 1964. The intercrops tried were pineapple, elephant foot yam, banana and colocasia. A control crop with no intercrop was also maintained. Considering the yield and cost of raising the crop, it was observed that elephant foot yam was most profitable, banana being second in the order. Pineapple and colocasia though came up fairly well under the shade of arecanut trees, were not economical. Growing banana in arecanut gardens for different duration gave an income of nearly Rs. 200 to Rs.300 per acre per annum when grown as an intercrop (CARS, 1967). In addition the crop is also believed to benefit the arecanut by providing optimum microclimatic and soil conditions for growth of arecanut palms.

Among the tropical tubers, elephant foot yam and tapioca are more popular, as these edible tubers partially meet the food requirements, especially in the years of scarcity for rice. Further, some of the tubers like yams and colocasia are capable of giving satisfactory yields under the partially shaded condition prevailing in arecanut gardens and can tolerate the dripping of rain water from arecanut leaves (Muralidharan and Nayar, 1979). The yield in terms of quantity of harvested produce and the net income were reported for some of the tuber crops tried at various places. The available information in this regard is summarized in Table 1. Due to the variations in the agro climatic conditions under which these studies were undertaken, the yield and profitability of individual crop showed wide differences from place to place. However, elephant foot yam had shown consistently good performance in all the three places i.e., Vittal, Palode and Kannara.

Table 1. Productivity and profit of intercropping with tubers in arecanut garden

Intercrop	Location	Yield (kg/ha)	Net profit (Rs/ha)	Source of information
Elephant foot yam	Vittal	12,000	1,550	Bhat (1974)
Elephant foot yam	Palode	6,496	1,700	Abraham (1974)
Elephant foot yam	Kannara	4,245	1,398	Sadanandan (1974)
Dioscorea	Palode	6,744	1,824	Abraham (1974)
Sweet potato	Palode	712	61	Abraham (1974)
Arrow root	Vittal	4,000	1100	Bhat (1974)

Among the fruit crops grown in association with arecanut, banana is the most popular. The practice of growing banana as an intercrop in arecanut has been reported by Sundaramurthy (1950), Bavappa (1951), Brahma (1973) and Bhat (1974). An experiment to study the long term effect of intercropping with banana in arecanut garden was initiated in 1963 at the CPCRI Regional Station, Vittal. The yield of banana from one hectare of arecanut garden and the net profit obtained from the same at different places are provided in Table 2. The per hectare yield of banana and the profitability showed considerable variation due to the difference in the variety tried and the management practices adopted at the different locations.

Table 2. Yield of banana and profitability

Location	Yield (kg/ha)	Net profit (Rs/ha)	Source of information
Vittal	4,000	1650	Bhat(1974)
Kahikuchi	12,200	728	Roy(1974)
Hirehalli	-	1000	Nagaraj(1974)
Mohitnagar	-	850	Brahma(1973)

The practice of raising pineapple as an intercrop was reported by Bavappa (1951). No adverse effect on the yield of arecanut was observed due to intercropping with pineapple in arecanut gardens (Abraham, 1974; Sadanandan, 1974). The yield of pineapple and the net profit obtained at different locations are given in Table 3. Here also, the wide variation in yield recorded at different places, is probably due to the variation in management practices and the difference in the agro climatic conditions.

Table 3. Yield of pineapple and profitability

Location	Yield (kg/ha)	Net profit (Rs/ha)	Source of information
Vittal	8,000	850	Bhat(1974)
Kannara	1953	703	Sadanandan(1974)
Palode	3942	847	Abraham(1974)
Hirehalli	-	500	Nagaraj(1974)
Kahikuchi	15,700	2379	Roy(1974)

Ginger *(Zingiber officinale)* and turmeric *(Curcuma longo)* are some of the spice crops commonly intercropped in arecanut gardens. Satisfactory yield in the partially shaded conditions existing in the arecanut gardens, fair market demand, easy processing, and long storage life after processing are some of the factors that favor growing these intercrops. An experiment on intercropping carried out at CPCRI Research Centre Kannara, in an adult arecanut garden receiving summer irrigation, showed that the yield of arecanut palms were not affected by raising ginger in the interspaces (Sadanandan, 1974). Similar results were reported from Kahikuchi (Assam) also (Roy, 1974). The yield of ginger in the above places and the net profit from one hectare by intercropping with ginger are provided in Table 4.

Table 4. Yield and net profit by intercropping with ginger

Location	Yield (kg/ha)	Net profit (Rs/ha)	Source of Information
Kannara	2650	905	Sadanandan (1974)
Kahikuchi	9800	998	Roy (1974)

Bhagavan and Bhat (1989), while evaluating mixed cropping trials with two or more crops stated that it is essential to give due importance to performance of different crops in a system and also the performance of system as a whole. In bivariate analysis of data on arecanut-cocoa mixed crop trial in which spacing cum manurial treatments were imposed, it was found that yield per plant was higher when arecanut was spaced at 2.7 m x 2.7 m and cocoa at 5.4 m x 5.4 m. However, when both the crops were planted at a spacing of 2.7 m x 2.7m, even though there was a decrease in yield of individual plants, yield per unit area was significantly higher due to higher population density. The economic evaluation based on gross returns also highlights the efficacy of 2.7 m x 2.7m spacing for both the crops with average gross returns to the tune of Rs. 82,830 per hectare.

The input output analysis of the Arecanut based cropping system model at CPCRI Vittal Station raised under irrigation indicated that during the year 1989, the total direct cost on this system was of the order of Rs.23,000/ha and the total return was Rs.1,33,200/ ha (Table 5). Hence, the estimated gross margin from one hectare arecanut based system involving other perennial crops (cocoa and black pepper) and semi perennial crop (banana) was Rs.1,10,000 during 1989 (CPCRI, 1990).

Table 5. Cost and returns of arecanut based HDMSC system (1989)

Costs	Rs/ha
Labour wages@Rs 20/day	12,160
Fertilizer	3,220
Plant protection chemicals	4,130
Fuel for irrigation	890
Miscellaneous	1,900
Drying arecanut	700
Gross cost	23,000
Returns	Rs/ha
Arecanut dry	1,09,200
Arecanut seednuts	300
Cocoa	5,180
Black pepper	18,600
Gross return	1,33,280
Gross margin	1,10,280

The economics of growing black pepper in arecanut garden was worked out at CPCRI, RS, Vittal (CPCRI, 1990). The gross income was calculated taking the market price of black pepper as Rs.35/ kg of dried pepper and the market price of arecanut as 25/ kg of chali under the different spacings. The highest gross income obtained from the 1.8 m x 2.7 m spacing and with Karimunda variety which gave total income of Rs.1,33,455/ ha followed by 1.8 m x 3.6 m spacing and with Karimunda variety of black pepper (Rs.1,07,664/ ha). In the treatment combination of 1.8 m x 2.7 m with Karimunda variety of black pepper, the gross income was more from black pepper as compared to the gross income of arecanut. In control treatments, the highest gross income was obtained from 1.8 x 1.8 m (Rs.60,550/ ha). The lowest income was obtained from the spacing of 2.7 m x 3.6 m (Rs.27,085/ ha) with Uddakare black pepper variety. The net income per hectare was worked out taking the cost of cultivation for arecanut as Rs.10 per palm and Rs.5 per black pepper vine. The highest net income was obtained from the treatment combination of 1.8 m x 2.7 m spacing with Karimunda variety of black pepper and the treatment combination gave Rs.1, 02,705/ ha, out of which Rs.58,805 was derived from black pepper as an additional income, while from the arecanut, the income obtained was Rs.43,900. Among the control plots, the highest net income was obtained from 1.8 m x 2.7 m spacing (Rs.33,875/ ha). From the results it is evident that in arecanut garden growing of black pepper is a profitable proposition and from the unit area income of arecanut garden can be increased to almost double by growing Karimunda variety of black pepper with a spacing of 1.8 m x 2.7 m.

In their study on the advantages in arecanut based mixed cropping systems using Land Equivalent Ratio (LER), Monetary Advantage (MA), and Competition Ratio (CR), Das and Vijaya Kumar (1991) observed that under the irrigated system, arecanut and cocoa combination gave a monetary advantage of Rs.19,193/ha/year with an LER of 2.18. Arecanut and black pepper combination gave a monetary advantage of Rs.18,402/ha/ year with an LER of 1.50. In another study, it was observed that cocoa is a profitable mixed crop in arecanut garden and their study revealed that for the highest returns, the optimum spacing for cocoa was 2.7 m x 5.4 m by planting in alternate rows of arecanut which gave net returns of Rs.54,390/ ha (CPCRI 1991).

The analysis the economics of the arecanut based cropping system model of Vittal for 1983-84 to 1990-91 was carried out. The data revealed that the cost incurred on the management of the system did not vary much over the years. It ranged from Rs.16,000 to 27,250 per hectare (CPCRI, 1992). However, there was considerable variation in the gross margin realized. During 1983-84, it was negative whereas during 1986-87 and 1988-89 the income realized was to the tune of Rs.1,16,450 and Rs.1,17,500 /ha (Table 6).

Table 6. Cost and returns from arecanut based cropping system at Vittal (Rs/ha)

Year	Total cost	Total returns	Gross margin
1983-84	23,900	22,600	(-)1,300
1984-85	16,000	51,000	35,000
1985-86	17,350	1,11,600	94,250
1986-87	21,150	1,37,600	1,16,450
1987-88	27,250	1,23,800	96,550
1988-89	23,800	1,41,300	1,17,500
1989-90	21,350	96,700	75,350
1990-91	20,350	87,250	66,900

The impact of HDMSCS cropping system at Mohitnagar, West Bengal on the economic returns (Table 7) has revealed that net returns were higher in all the models compared to arecanut monocrop (CPCRI, 1995).

Table 7. Profitability of HDMSCS at Mohitnagar (Rs/ha)

Model	Receipt	Expenditure	Net return
Araecanut + black pepper + cocoa	87,123	16,397	70,726
Areacanut + black pepper + banana + acidlime	96,431	23,669	72,762
Arecanut + betelvine + banana + turmeric	88,759	19,775	68,984
Arecanut + black pepper + banana + coffee	89,409	18,840	70,560
Arecanut + betelvine + banana + cinnamon	86,926	15,954	70,972
Control(arecanut monocrop)	58,392	7,225	51,167

A comprehensive economic analysis of arecanut based farming systems (ABFS) under farmer's field conditions has been conducted by CPCRI. While analyzing the size of holding correlations, it was found that the number of components in the system had increased with the size of holdings and in majority of the arecanut gardens, the inter / mixed crops were not systematically cultivated (CPCRI, 2000). The study has also revealed that in comparison with small and marginal farms, the relative management of ABFS models was better in medium and large farms. The net returns from the system had increased with the increase in number of components. Arecanut + banana + dairy and arecanut + coconut + banana + black pepper + dairy were the two most commonly adopted ABFS systems. The average net returns in the case of arecanut + coconut + banana + black pepper + dairy had ranged between Rs.86,500 and Rs.1,44,800 per hectare. The pattern of adoption of ABFS models among the farmers was also studied. The factors responsible for non - systematic adoption of different ABFS models were,

1) Structural - (a) pre-dominance of small and marginal holdings, (b) crop diversification with other annuals and perennials, (c) under planting with new seedlings and (d) lack of irrigation facilities.
2) Economic - (a) dependency on both farm and non-farm enterprises and (b) increasing labour cost especially for skilled labourers.
3) Institutional - there are no specific schemes for the development of ABFS.

While analyzing the economics of different models of arecanut based HDMSCS of West Bengal, it was observed that the output from all the models were higher than the control plot (arecanut monocrop) and the net returns from the systems ranged from Rs. 94,858 to Rs.1,68,502/ ha (CPCRI, 2000).

In another study, Nampoothiri and Sairam (2001) observed that the inter spaces of arecanut planted with 2.7 m x 2.7 m can be utilized for planting coffee and the planting density of arecanut is 1,362/ ha and for coffee it is 495/ ha. In order to realize better yield from arecanut and coffee, both the crops should be supplied with adequate nutrients separately. Under optimum management conditions, coffee is a compatible mixed crop in arecanut gardens which is not only proved in the research stations but also being widely practiced by the arecanut farmers of north coastal and south Kanara regions of Karnataka and north Malabar region of Kerala. The economic analysis of arecanut + coffee mixed cropping as compared to coffee monocropping revealed that total cost for arecanut monocrop under better management conditions was Rs.41,900/ ha of which about sixty percent was towards the labour. The total cost in the case of arecanut + coffee system is Rs.61,900/ ha. The average yield of arecanut was 3,405 kg/ ha and that of coffee was 1,857 kg/ ha. Under normal conditions, the total returns for arecanut monocrop was Rs.1,70,250/ha while the same for arecanut + coffee system was Rs.2,25,960/ha. The gross margin was Rs.1,28,350/ ha for arecanut monocrop and in the case of arecanut + coffee it was Rs.1,64,060/ ha. This means that Rs. 35,710 can be additionally earned per hectare if coffee is grown in arecanut gardens. Thus, cultivating coffee as a mixed crop stabilizes gross farm income and thereby reduces negative impact of price risks of arecanut cultivation.

For studying the arecanut based cropping system model for Sub Himalayan West Bengal region, arecanut based HDMSCS was established in an existing arecanut garden spaced 3 m x 3 m and planted in 1967-68. Different component crops as given below were tested for their suitability. Non-productive component crops were eliminated after screening and recording relevant data (CPCRI, 2001). The following six models were evaluated from 1989-90 onwards

Model-I: Arecanut- -Black pepper-Champa banana-Cocoa
Model-II: Arecanut -Black pepper-Malbogh banana-Gandharaj lime
Model-III: Arecanut- Betel vine- Malbogh banana - Turmeric
Model-IV: Arecanut-Coffee- -Malbogh banana- Black pepper
Model-V: Arecanut-Cinnamon-Betel vine-Malbogh banana
Model VI: Arecanut mono-crop (control)

Further evaluation of input and net returns for each model and the different economic parameters indicated that the mean net returns over 10 years (1990-1999) in different models varied between Rs.52,473/ ha to Rs.84,705/ ha. The highest net return was recorded in Model-II followed by Model- V and Model-I. The lowest net returns was, however, recorded in control. It was also noticed that an average of 128 man days were required for arecanut monocrop. But, it varied from 272 to 377 for different models of HDMSCS, which shows that 144 to 249 extra mandays were generated. These mandays can be met from own family of the grower in the case of marginal farmer or can be employed from outside in the case of large plantation.

The field survey to study the economic aspects of ABFS was conducted during 1997-98 in 400 arecanut gardens of Kasaragod district by CPCRI (CPCRI, 2001) through a pre-tested interview schedule based on systematic sampling. It was observed that adoption of

ABFS models was less in small and marginal farms as compared to medium and large farmers. The realized net returns increased with the degree of farm intensification. The economic benefit of ABFS models was better realized when the price of the main crop was low.

Another field survey was conducted in 80 gardens in Dakshina Kannada district based on purposive sampling of farmers cultivating cocoa as a mixed crop in arecanut gardens (CPCRI, 2005). The initial cost of establishment for five years was estimated to be Rs.8, 14,875/ha of arecanut which includes labour charges (Rs.1,33,284), irrigation charges (Rs.2,02,619) other inputs (Rs.2,61,527) and interest on investment (Rs.2,17,445). In the case of cocoa, the total cost was Rs.1,05,710 including labour charges (Rs.25,896), other inputs (Rs.49,029) and interest (Rs.30,786). Under this situation, the annuity value was estimated as Rs.96,022/year for arecanut and Rs.15,061/year for cocoa. With an annual maintenance cost of Rs.63,949/year, the total cost of cultivation of arecanut comes to Rs.1,59,970/ year. The annual maintenance cost for cocoa comes to Rs. 20,143 and the total cost is estimated to be Rs.35,204/year. This together constitutes the total cost of the system to Rs.1,95,174/ year. Using the above data, the cost of production for one kg of arecanut (chali) was estimated as Rs.52 and for one kg cocoa as Rs.36. The realized Benefit-Cost Ratio and Internal Rate of Return for arecanut monocrop were 1.13 and 16%, respectively. The same in the case of arecanut + cocoa system were 1.22 and 17.2%, respectively.

4. Future research needs

Arecanut Based Farming System is a profitable technology to be adopted by the arecanut farmers. The economic significance of ABFS could be realized only at a lower rate of arecanut prices. But ABFS systems as suggested by the research institute cannot be practiced due to predominance of small and marginal farms in this system. Hence, in future, the research institute should adopt the concept of farming system research and should evolve new technologies considering the socio-economic parameters of these farmers. In order to realize economies of scale of production, co-operative farming or joint farming may be encouraged. For this, the developmental agencies like the Department of Agriculture and the Directorate of Arecanut and Spices should come forward with specific schemes. It is further inferred from the review of case studies that under the present scenario, for the development of capital intensive arecanut based farming systems, the strengths and opportunities are more for medium and large farms as compared to small and marginal farmers. Since ABFS is pre-dominated by small and marginal farmers, the future development of these farming systems would not be an easy task and needs intensive and careful planning involving research, developmental and institutional sectors.

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Transfer of technology in arecanut based cropping systems

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Introduction

Technology transfer in agriculture is a system under which various inter related components of technology and the final product (including marketing) are rendered accessible to the farmer. The system also includes institutional capacity for technology adoption, adaptation or rejection, constituting a matrix of technology components and institutional capacities for absorbing technologies. Thus, technology transfer has both functional and institutional meanings. A technology transfer programme would be considered effective when there is minimal or no gap between the potential and realized impacts of the technology. It means that monitoring of the adoption or adaptation of technologies is an integral part of the technology transfer system. Transfer of technology must, therefore, be preceded and succeeded by technology assessment, asserting that technology transfer and assessment are complementary processes. One of the prerequisites for effective technology transfer is the appropriateness of the technology, which refers to a technology package, must be technically feasible, economically viable, socially acceptable, environment friendly, consistent with household endowments and relevant to the needs of farmers. This is a dynamic concept in which the elements of appropriateness will vary over time and space. Innovation and diffusion of technologies are the prime concern of our National Agricultural Research System (NARS), which has led to the development of umpteen cross specific technologies. It is worthwhile to look into the efforts of institutes on transferring such technologies to the end user.

This chapter is an attempt to review the studies related to transfer of technology aspects of Arecanut based cropping system (ABCS) conducted at Central Plantation Crops Research Institute (CPCRI), Kasaragod and its Regional Stations and Centers. A substantial number of technologies relating to improved varieties, agro-techniques, pest and disease management and post harvest processing for value addition have been evolved by research institutes for higher return from arecanut. Timely and sustainable transfer of technologies and extent of adoption play a critical role in improving the productivity and realizing a higher return. Farmers experience various constraints, including low price/ price fluctuation, incidence of pests and diseases and ever increasing cost of cultivation for the effective utilization of available technologies. There exists a gap between the technologies generated and their utilization by the growers, especially in small holdings. To reduce the risk level of farmer, CPCRI is now recommending for growing arecanut in a system which includes mixed / inter cropping, mixed farming and high density multiple cropping system. Muliyar (1983) reported that, the arecanut growers are generally well informed and economically well placed which facilitates easy flow of information from the extension system to the technology utilization system. However, it is observed that the linkage between the research system and extension system is very weak. This is evident from the existing yield gap between ideal conditions at the research stations and the farmer's field. An effective extension strategy appropriate to the heterogeneous farming situations in ABCS is formulated by CPCRI. It has adopted a multi dimensional extension strategy for transfer of technology for the improvement of arecanut farming community which includes, training of farmers and extension personnel, refinement and demonstration of technology / products, single window delivery system for technology products, diagnostic services and information through Agricultural Technology Information Centre (ATIC), creating awareness of improved agricultural technologies among the farmers through mass media, extension publications, cyber extension, field demonstrations, kisan melas, interface/ group meetings, seminars and exhibitions etc.

2. Training

Training has been widely accepted as a means of upgrading the professional competence of extension personnel. Training of extension personnel refers to planned and systematic efforts to increase knowledge, improve skills and inculcate appropriate attitudes and develop other attributes in extension personnel to enable them to serve their clients better (Misra, 1990). Training equips the extension personnel with diagnostic, practical and problem solving skills to deliver competent and professional extension service to the farmers. Therefore, training of extension personnel has an important role to play in the transfer of technologies evolved at various research centers to the farmers.

Institutional training programmes on different aspects of production technology of ABCS for the benefit of extension personnel involved in the developmental activities are being regularly organized at CPCRI. Short duration training courses for research, teaching and extension staff provides opportunities for sharing of information and experiences at different levels, apart from imparting knowledge and skill. The institute is regularly organizing training programme on arecanut production technology, nutritional management, arecanut based inter/mixed cropping system, integrated pest and disease management, post harvest technology etc to extension personnels (Venugopalan and Thamban, 1997). One day training's along with field visits are arranged to farmers to educate them on scientific management of arecanut and ABCS. Need based training programmes relating to production, protection and processing technologies are also being organized at CPCRI. In addition to the above, special training programme on oyster mushroom cultivation from areca waste, vermicomposting technique, post harvest technology in arecanut and cocoa are also being organized at CPCRI Regional Station, Vittal (CPCRI, 1993 and 2001). The technology for mushroom cultivation on arecanut waste is being adopted by a few Self Help Groups (SHG) through the intervention of CPCRI. However, the spread of technology in other areas is negligible. As a part of the golden jubilee celebrations of CPCRI Regional Station, Vittal, monthly training/ extension programmes on arecanut/ arecanut based cropping system were organized during the year 2006 (CPCRI, 2007). The pre and post evaluation tests conducted to assess the gain in knowledge by the trainees due to the training exposure indicated the fact that the training programmes have been effective in imparting knowledge to the trainees (Venugopalan and Thamban, 1997).

3. Refinement and demonstration of technology

Lab to land programme: Lab to land programme was started at the institute during 1979 as a part of the ICAR golden jubilee celebrations with the objectives of i) transfer proven and viable farm technologies to improve the overall socio-economic conditions of the marginal/small farmers and landless labourers with special reference to the weaker section of the society, ii) educate the farmers in the adoption of improved technologies in maximizing the farm output and iii) to develop close contacts between scientists and farming community and to identify constraints in raising farm production.

The programme was implemented at different locations with a view to transfer of proven low cost agricultural and allied technologies to the identified adopted families from among the small/marginal farmers and agricultural labourers. Special emphasis was given to include as many number of Scheduled Caste (SC), Scheduled Tribe (ST) and Other Backward Community (OBC) farm families as possible under this programme with the objective of uplifting their socio-economic conditions. For each of the adopted family, a farm plan was prepared to put their land into better use. The institute provided critical inputs like superior planting material, fertilizers, pesticides and agricultural implements etc. free of cost. The technical expertise was given by scientists drawn from different disciplines.

The scientific cultivation of arecanut gardens with subsidiary crops such as banana, fodder grass, cocoa, pineapple etc. were popularized under this scheme. There were eight demonstration plots in arecanut with black pepper and cocoa planted as mixed crops. Four families were adopted at Vittal for demonstrating integrated plant protection, preparation of spray fluid and spraying were demonstrated. During 1983, 100 households spread over seven villages were selected at Vittal and the lateritic hill slopes of the area were put under arecanut. In all the 100 adopted families, agriculture was introduced as the main enterprise and livestock and sericulture had been introduced in three and eight families, respectively. The adopted families in general were very much impressed by the performance of the project. The benchmark survey conducted at the beginning of the scheme in different phases revealed that the yield in arecanut increased about 67% over the pre-experimental period (CPCRI, 1990).

Technology Assessment and Refinement through Institution Village Linkage Programme (TARIVLP): CPCRI has implemented the National Agricultural Technology Project (NATP) on "Technology Assessment and Refinement through Institution Village Linkage" which was having emphasis on ensuring farmer participation in agro-ecosystem analysis, identification and prioritization of problems and deciding appropriate technological interventions. Under the project, different interventions were implemented in farmer's fields relating to arecanut cultivation in different micro farming situations. The implementation of the project was helpful in assessing and refining the production technologies appropriate for different micro farming situations (Srinivasa Reddy *et al.* 1997).

Based on agro-system analysis, microfarming situation of upland arecanut based farming system was selected and problems of the cropping systems in terms of bio-physical and socio-economic causes were identified as a part of the TAR-IVLP programe at Kahikuchi (Ray *et al.* 2007). Arecanut is grown mostly as a farmstead crop in the target area. Close and unsystematic planting, inadequate nutrient supply, poor selection of intercrops and diseases like ganoderma were identified as key constraints in the production system leading to low return from the commodities. Technological interventions comprising intercropping with a suitable crop, maintenance of soil fertility through application of chemical fertilizers and organics were considered effective towards attaining high productivity and sustainability from the crop and the cropping system. Moreover, it was found that each of the ten interventions were compatible to the existing farming system and the internal resources of the household. Both ginger and turmeric as intercrops in the existing homestead arecanut plantation performed satisfactorily as well as the main crop under rainfed condition. In verification trial on the performance of the vermicomposting, it was observed that the intervention was compatible to the arecanut based cropping system and the arecanut bio-waste and vegetable waste from kitchen can be effectively utilized for the preparation of vermicompost. Among the varieties of black pepper grown on the arecanut, it was observed that, both varieties had almost comparable growth characters with Panniyur-1 producing more yield than Karimunda. It was observed that growing of banana and citrus (Assam Lemon) as intercrops in areca garden under rainfed condition are compatible.

Coconut and arecanut mixed cropping is not generally recommended since there are few common pests and diseases and both the palms compete with each other for light and soil moisture. However, since farmers get more income from arecanut, because of the remunerative price, most of the farmers are growing this crop combination. Dhanapal *et al.* (2001) documented the farmer's experiences and perceptions in mixed cropping of arecanut in coconut gardens and also analysed the technical feasibility of coconut-arecanut combination and the required agronomic practices for obtaining maximum benefits from the same. They have found that the monetary advantage, which is defined as the ratio between the net returns realized from the coconut-arecanut system to that from coconut monocrop is high in the case of arecanut planted in the adult coconut garden. It is inferred that growing arecanut as a component in the adult coconut garden or cultivating coconut as a border crop in arecanut garden fetches additional net returns to the farmers.

4. Front line demonstrations

CPCRI has been organizing front line demonstrations in farmers' field on different technologies in arecanut based cropping system. 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. As already mentioned in the previous section, it is a common practice among the farmers to interplant arecanut in coconut garden. An observational field trial was conducted in Assam during 1962-63 to evaluate the performance of arecanut + coconut mixed garden. Although the trial reflected better net returns (Anoymous. 1964), the practice was not recommended due to the competing nature of component crops. In another observational field trial, the better performance of "mangala" variety of arecanut in comparison with the local variety had been demonstrated in two farmers gardens at Perla and Padnoor villages of Kasaragod district (CPCRI, 1984).

The intercropping of banana and cocoa in arecanut garden was demonstrated in farmers garden at Mohitnagar, West Bengal, inorder to depict the better possible net return from the system than arecanut monocrop (CPCRI, 1984). Arecanut based high density cropping system which consists of crops like acid lime, papaya, banana, cinnamon, betel leaf and black pepper were demonstrated in FLD plots at Mohitnagar (CPCRI, 2006).

A survey was undertaken to ascertain the feasibility of vermicompost technology in the farmers homestead garden in two villages under Rani Development Block of Kamrup dist., Assam, during Feb-March, 2004. It was observed that on an average 60 kg of vermicompost could be produced from 100 kg of arecanut based biomass under farmers' field condition (Table 1). Economics of producing vermicomposting indicated the return per rupee spent is Rs.3.84. The techno-social aspects like awareness, knowledge, skill and adoption behaviour with regard to the technology for recycling arecanut biomass have been remarkably changed among the farmers during the study (Barman *et al.*, 2006).

Vermicomposting technology is spreading fast among the farming community. Farmers perceive that it is a low cost technology requiring less labour, locally available materials, easiness in adoption and high beneficial effect of compost application to plants. The vermicomposting technology using arecanut based farm waste was successfully demonstrated in 20 arecanut farmers plot in Kahikuchi (CPCRI, 2007)

Table 1. Vermicompost production characteristics in the farmers' field

Sl. No.	Characteristics	
1	Total no. of farmer actively associated	20
2	Total no. of Homestead garden considered	20
3	Total no. of vermicompost unit	20
4	Pit size of vermicompost unit	2.5 m x 1m x 0.5m
5	Total biomass deposited(kg)	100
6	Total number of earthworms released/unit	100
7	Maximum vermicompost production(kg/ unit)	71.25
8	Minimum vermicompost production(kg/ unit)	46.25
9	Mean/ Average vermicompost production(kg/unit)	59.33
10	Standard Deviation	6.95

(Barman *et al.*, 2006)

(Barman *et al.*, 2006). The specific type of earthworm *Eudrilus* sp. was supplied to farmers. The recovery of vermicompost was 64%. The net income obtained from a single pit of 2.5 m x 1 m x 0.5 m dimension was Rs.387/- in 80 days period.

The performance of growing ginger varieties namely Nadia and Goro local as intercrop in adult arecanut garden under rainfed condition was demonstrated in farmer's field in Assam (CPCRI, 2007), The Nadia variety performed better yielding 132.5 q/ha compared to Goro local (122.5q/ha). The net return obtained was Rs.91,500/ per ha and Rs.81,500/ per ha with Nadia and Goro local varieties respectively.

Growth and field performance of cocoa grafts as mixed crop in arecanut garden were demonstrated in more than 90 farmers' garden in Dakshina Kannada district under the sponsorship of Directorate of Cashew and Cocoa Development (DCCD), Kochi. It was observed that the growth and establishment of grafts in the field was good and the average mortality rate was less than 4%. The percentage of flowering/ bearing was to the tune of 28%, 70% and 100% during 2^{nd}, 3^{rd} and 4^{th} years, respectively (CPCRI, 2005).

The recommended management practices for Yellow Leaf Disease (YLD) were implemented in three Operational Research Project (ORP) plots in Haleneranki village, Puttur Taluk. Pepper was planted as a mixed crop in all three plots. YLD incidence was not noticed in these plots (CPCRI, 1993).

Crop diversification with intercropping of medicinal and aromatic plants in arecanut plantation is found to be profitable and increases the productivity per unit area in terms of chali equivalent to the tune of 272 kg/ha to 1,524 kg/ha. Farmers are advised to grow variety of medicinal plants in small areas based on local market, while aromatic plants should be grown in large areas for higher profitability. Medicinal and aromatic plants like Brahmi, Shatavari, Vetiver, Nilagirianthes, Long pepper, Lemon grass, Basil, Davana etc. can be successfully grown in arecanut plantation. The medicinal and aromatic plants could give a net return of 1.99 times to 4.25 times of rupee spent (CPCRI, 2008, Sujatha *et. al.,* 2011).

5. Agricultural Technology Information Centre

Agricultural Technology Information Centre (ATIC) is established to provide the required technology information, diagnostic and advisory services and supply of quality planting material through a single window delivery system. The ATIC services were formally initiated in the year 2000. A large number of farmers and clients are utilizing the facilities available at the centre such as purchase of quality planting materials and other technological inputs and products in addition to availing guidance on the establishment of gardens. Crop management technology and crop protection were the major areas of interest shown by the farmers. In addition, a large number of farmers have shown interest in understanding the comparative performance of different varieties for ensuring better establishment of the garden. This center also sells large number of CD ROM on the cultivation practices of mandate crops (Rajagopal and Arulraj, 2003).

6. Awareness programme

Information communication through mass media: Effective utilization of mass media like Radio, TV, Newspapers and Farm Magazines is made to create awareness among cultivators about various production technologies. Further, extension pamphlets, CD ROMs, video cassettes etc. are also prepared by CPCRI for effective dissemination and popularization of the available cultivation technologies. A special programme “Manikya chempazhuka” the Krishipadham serial on scientific arecanut cultivation practices under “Vayalum Veedum programme” of All India Radio, Kannur was prepared and was broadcast through all radio stations of Kerala state during April to June, 2001.

Exhibitions, Seminars, Kisan Melas and Group Meetings: CPCRI regularly organizes exhibitions, seminars, kisan melas and group meetings with the co-operation and involvement of various agencies. Such programmes strengthen the efforts for the dissemination of information on cultivation of arecanut and also provides opportunities for interaction between farmers, scientists and extension personnel.

Consultancy - Field visits: Scientists of CPCRI regularly visit farmers’ fields for providing technical guidance as well as identifying and suggesting solutions to field problems. This also provides opportunity for assessing constraints in field implementation of the recommended production technologies and in turn in the refinement of the technologies.

Farm advisory services: Under this service, the farmers’ queries through letters, phone calls and e-mail on various aspects of production, protection and processing technologies of the mandate crops are replied.

Cyber extension: The Information Technology is being increasingly utilized in the Transfer of Technology process in India during the recent years. CPCRI launched its web site in April 2000 and it is encouraging to note that the web site facilities are being increasingly used by the farming community and other clients. A "user analysis" of email services at CPCRI indicated that farmers from Tamil Nadu, Karnataka and Kerala utilized the services to the maximum extent possible followed by students and entrepreneurs. They used the services mainly for obtaining information on the cultivation details, processing technologies and other institute programmes (Arulraj and Ravikumar, 2004). Scientist-farmer interface programmes are strengthened through cyber extension activities using the group video conferencing system through ISDN which was installed at ATIC. Crop management technologies like fertilizer application and pest and disease management, product diversification and market information were the important thematic areas on which the farmers needed information through the cyber extension programmes. E-mail facility is also used to reply to the queries of farmers on different aspects of production, protection and processing of palms and cocoa (CPCRI, 2007).

7. Future strategies

Due to low observability of the impact of technology and less immediacy of returns, new extension strategies are to be adopted to popularize perennial crop based technologies. Coordination of various research/extension agencies is essential for the successful implementation of such strategies.

Capacity development programmes: Need based training programmes with appropriate methodologies are to be organised for farmers on various aspects of production, protection and post harvest processing technologies. Participatory methods can be effectively employed to unearth the areas of improved technologies in which farmers require exposure. Training programmes are also required for the extension personnel engaged in the development of this crop to keep abreast with the latest technological advances. The concept and practice of entrepreneurship development also should be included in such training programmes. These training programmes would be able to empower them to start microenterprises for income and employment. Coordination between research, development and extension agencies, Local Self Governments and farmers' organizations are also necessary for the successful conduct of demonstration progarmmes. 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. An active participation of the beneficiaries on the generation of technology can ensure that it is user-friendly. Participatory mode of implementation begins with the selection of a suitable village, followed by a detailed agro-ecosystem analysis of the selected village, diagnosing the problems of each production system and prioritizing these problems; identification of technological interventions based on problem-cause relationship; the development of action plans and their implementation and detailed socio-economic evaluation including farmers' reactions and perceptions about the interventions. Various PRA tools such as social, physical and land use map, village transect, time line analysis, seasonality analysis, problem-cause diagram, matrix ranking, trend analysis and livelihood analysis can be employed for the participatory assessment and refinement of technologies. There is scope for implementation of such a participatory approach in arecanut for the performance assessment of various technologies related to improved varieties, intercropping, nutrient management, cropping systems, pest and disease management and post harvest processing.

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