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Cropping systems approach for improving resource use in arecanut (*Areca catechu*) plantation

S SUJATHA[1], RAVI BHAT[2] and P CHOWDAPPA[3]

ICAR–Central Plantation Crops Research Institute, Regional Station, Vittal, Karnataka 574 243

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ABSTRACT

Arecanut (*Areca catechu* L.) is a highly profitable plantation crop but faces recurring problems due to several crop, climatic and soil constraints resulting in reduced productivity and profitability. In this review, we summarize the results of several experiments conducted in India on arecanut based cropping system indicating the advantages, disadvantages and implications of adopting cropping system on productivity, soil fertility, profitability and resource use. According to this critical review, 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. Short statured crops like tuber crops, rhizome crops, vegetables, flower crops can be successfully grown in arecanut during pre-bearing stage. Perennial crops like cocoa, banana, black pepper, acid lime and cardamom were successful component crops for grown up arecanut plantations. Value added crops like vanilla, and medicinal and aromatic crops (MAPS) come up very well in arecanut. Intercropping of MAPS contribute to productivity increase of 11-53 % and realize net return per rupee investment up to 4.25. Efficient high density cropping models involving component crops like cocoa, banana, pepper, acid lime, cardamom etc. developed for different arecanut growing regions in India in terms of resources use are discussed. Recyclable biomass produced from arecanut based cropping system varies between 8.72 to 10.35 tonnes/ha/year. The recycling potential of organic matter from some cropping system models is also discussed. The present review indicates that cropping system approach is indispensable for arecanut farmers to improve resource use and profits in the context of climate change and WTO.

Key words: Arecanut, Banana cropping system, Cocoa, Pepper

Arecanut (*Areca catechu* L.) is a commercial plantation crop having social importance in India. It is cultivated in 0.446 m ha with a production of 0.601 m tonnes in South and North east regions of India (GOI 2014). The challenge is to increase yield and income per unit area rather than production from a single crop. Adoption of cropping system approach is indispensable to increase the productivity per unit area and to avoid risks due to soil, climate and economic constraints. 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 cropping system depends on the relative shade tolerance of component crops. The research work towards the same is being done in India but continuous 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 the land for more than three decades. Arecanut is predominantly cultivated in laterite soil belt and to some extent on clay soils. Laterite soils have inherent soil constraints such as waterlogging, 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 practice of well planned and executed inter/mixed cropping is fundamental for increasing the productivity and income per unit area under these conditions. The reviews stressed the importance of intercropping or livestock as a source of additional income during off-season and also as a safeguard against the uncertainties of returns from monoculture plantations (Thomas and Balasimha 2011, Bhat and Sujatha 2011a,b, Sujatha and Bhat 2010, 2012, Sujatha *et al.* 2011a,b). According to these critical reviews, 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. The review on inter/mixed cropping in arecanut showed ample evidence for maximum resource use efficiency and generation of supplemental income from the plantations. This paper covers

[1]Principal Scientist (e mail: s_sujatha68@rediffmail.com), [2]Head, Division of Crop Production. [3]Director, ICAR-CPCRI, Kasaragod, Kerala 671 124.

comprehensive review of research work done on cropping/ farming systems in arecanut covering both the beneficial effects and problems.

Scope and beneficial effects of cropping systems in arecanut plantation

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. 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 (Bhat and Sujatha 2011a, b; Sujatha *et al.* 2011b). Previous reports on rooting pattern and light interception indicate that 60-68% of land and 57% of light are unutilized in sole arecanut. The microclimate existing in the arecanut is congenial for intercrops with reduced evaporation rate, and air and soil temperatures and increased humidity. In arecanut +cocoa system, the wind velocity is only 9 % of that in open area. The arecanut palms provide excellent protection to the intercrops against wind and vice versa. Wind causes sporadic damage to adult palms by breaking the stem mostly in sun scorched arecanut palms that can be controlled with the presence of mixed crops. Crops like cocoa and banana limit the damage of sun scorching effect in initial years and pepper in the later years. Thus, there is an excellent opportunity for a temporal and spatial distribution of crop species in arecanut.

Economic advantages of arecanut based multiple cropping systems were highlighted. The LER computed for arecanut+cocoa system is very high (2.18) compared to arecanut+banana (1.45) and arecanut+pepper (1.5). This indicates that arecanut + cocoa system is ideal for achieving better resource use efficiency. At the same time, cocoa and pepper are found 1.7 and 2 times more competitive than arecanut. This necessitates the importance for providing recommended nutrition and irrigation to both the base and mixed crops. Under irrigated conditions, arecanut-cocoa and arecanut-pepper mixed cropping gives considerable monetary advantage. The cropping system should be biologically suitable and economically viable. For example, the survey revealed that coconut –arecanut mixed system, though economical and preferred by farmers, is not recommended due to common pest, disease and morphological features resulting in competition for resources and making the system biologically unsuitable.

Intercropping of annuals/biennials/short statured perennials in arecanut

In heavy rainfall regions, successful cultivation of crops such as turmeric, pepper and cardamom in arecanut gardens is reported. The tuber crops like elephant foot yam and *Dioscorea* perform better than sweet potato. The poor performance of sweet potato is attributed to shade conditions and gravelly nature of soil. Intercrops like banana, elephant foot yam, pineapple and arrow root increased the productivity per unit area. Crops like banana, ginger, chilli, colacasia, upland paddy, turmeric, elephant foot yam and *Dioscorea* are more adapted for intercropping in arecanut gardens. In low rainfall plain regions of Karnataka, *Dioscorea* and elephant foot yam are ideal intercrops in arecanut but yield decline of ginger and turmeric is noticed due to continuous cultivation. All results suggest the need for crop rotation when exhaustive tuber and rhizome crops are intercropped. Turmeric and sweet potato perform better with higher yield levels at 60% population intensity than at 40% intensity without affecting arecanut yields. In majority of studies in different regions, no deleterious effect of intercropping on arecanut is noticed. In plains of Karnataka, yield increase of 37% is reported in arecanut due to intercropping with cinnamon. Further the authors reported that intercropping of four varieties of coffee (arabica S-6, arabica S-1936, San Ramon and robusta) have shown similar effects on yield of arecanut.

Intercropping of medicinal and aromatic plants (MAP)

The results of 4-yr trial (Sujatha *et al*. 2011a) 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*) perform better as intercrops in arecanut. However, senna (*Cassia anguistifolia*), safed musli (*Chlorophytum borivillianum*), aswagandha (*Withania somnifera*) and geranium (*Pelargonium* sp) do not come up well as intercrops in arecanut. In terms of net profit per rupee investment, all medicinal and aromatic plants are superior and system productivity can be considerably enhanced with intercropping (Sujatha *et al.* 2011a). All medicinal and aromatic crops contribute to productivity increase of 10.7% in basil to 53% in shatavari in terms of kernel equivalent yield/ha of arecanut garden. Intercropped shatavari in arecanut accrues highest net income followed by *Nilagirianthus ciliatus*, bramhi and vetiver. Root crops like shatavari and vetiver deplete soil organic carbon and need to be rotated every 3 years. 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 different medicinal crops in small areas based on local demand.

Intercropping of vegetables, flower crops and turmeric

Among vegetables intercropped in arecanut in Asom, the net return per rupee investment on labours is maximum for brinjal (15.8) followed by cabbage and radish (Ray *et al*. 2011). The pooled data indicated that economic efficiency (per day return basis) is highest (395) in cabbage followed by cauliflower and radish. Net return per rupee investment varies from 4.61 to 6.25 in flower crops like gladiolus, chrysanthemum and marigold and the economic efficiency is highest (417) for gladiolus followed by chrysanthemum. Better labour utilization and economic efficiency is possible by growing vegetables like brinjal, cabbage, cauliflower and radish, and flower crops like marigold and chrysanthemum under young areca plantation in view of the market demand. Medicinal and aromatic crops like patchouli, long pepper and vanilla can be grown successfully in arecanut garden under Asom conditions.

In sub Himalayan West Bengal, screening of summer and winter vegetables as intercrops in arecanut plantation indicated that spinach yields (20 tonnes/ha) better registering maximum benefit cost ratio of 1.39 than other leafy vegetables amaranthus and mustard in winter (Sit *et al.* 2011). Spinach can also be taken as ratoon crop with a total of 4-5 cuts. Among the root crops, maximum yield (65 tonnes/ha) is registered in radish followed by turnip and carrot with benefit cost ratio of 2.33 (radish), 2.09 (turnip) and 1.64 (carrot). Among cole crops, maximum yield is recorded in cabbage (43.7 tonnes/ha) with a benefit cost ratio of 3.44. Solanaceous vegetables like tomato, brinjal, chilli and capsicum can be grown successfully with benefit cost ratio of more than one. Among leguminous vegetable crops, maximum benefit cost ratio is noticed in dolichos bean (1.39) followed by french bean (1.08). Powdery mildew problem is observed in french bean and cowpea.

During the summer season, different gourds like pumpkin (₹ 65 480/ha), ash gourd (₹ 27 225/ha), bottle gourd (₹ 25 962/ha) and snake gourd (₹ 24 850/ha) are ideal for intercropping in arecanut due to higher cash outflows and benefit cost ratios (1.17- 2.39, 1.59 and 1.53). When intercrop and sole crop yields are compared on unit area basis, vegetables like spinach, mustard and snake gourd are better yielders in arecanut garden than in the open condition. The yields of vegetables like, basella, cauliflower and knol khol are similar in both the conditions. Though the performance of flower crops like gladiolus, aster, halychrysum, calendula, anthurium, French and African marigolds, sunflower and salvia is 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. Cultivation of pineapple and turmeric in the inter space of arecanut is profitable but not arrowroot in irrigated and un-irrigated conditions in sub Himalayan Terai region of West Bengal (Sit *et al*. 2011). Intercropping of turmeric varieties, viz. Suguna, Sudarsana, CLS 2A and Kasturi in arecanut is suggested by Sit *et al.* (2011) for sub Himalayan Terai region of West Bengal.

Inter/mixed cropping of perennials in arecanut

Arecanut +cocoa system

The review by Sujatha *et al.* (2011b) revealed following findings. Initial studies on cocoa during 1960's and 70's outlined how cocoa can effectively be grown in arecanut plantation to increase returns per unit area. Land Equivalent Ratio (LER) increases to 1.74 in arecanut + cocoa system giving 74% yield advantage over monocropping of arecanut. Crop genotypes may differ in their performance in mixed cropping system with arecanut as growth and yield vary from variety to variety. The germplasm introductions of cocoa from Malaysian and Nigerian estates have performed better in arecanut. From different progeny trials, it was noticed that Nigerian collections are superior yielders with better quality and drought tolerance with a moderate canopy indicating their feasibility in the cropping design of arecanut. The hybrids perform well both as seedlings and grafted plants. With regard to suitability of planting material, both seedlings and grafts performed equally well as mixed crops in arecanut.

For optimum productivity of both arecanut and cocoa in mixed cropping system, ideal spacing and pruning regime are important to avoid competition. The combination of 2.7 m × 2.7 m for arecanut and 2.7 m × 5.4 m for cocoa over 2.7 m × 2.7 m for both the crops is advocated in view the agronomic advantages and economic returns. Experimental results indicated that there are no significant differences between quincunx and square methods of alignment and arecanut yield is not affected by these cropping systems. In earlier studies on canopy architecture in cocoa, it was found that big canopy with spreading nature seems to be ideal for cocoa mixed cropped in arecanut plantation. Subsequent studies on the canopy management in seedling progeny of cocoa for optimum productivity indicated that large canopy is essential for higher net photosynthesis, LER and yield. It was concluded from a long term study that a spacing of 2.7 m × 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 2011). From the above results, it is clear that spacing and pruning become important determinants of yield in cocoa.

Cocoa is an exhaustive crop and removes large quantities of nutrients especially K (Sujatha and Bhat 2012). The nutrient mining by arecanut is 79 kg N, 28 kg P_2O_5 and 79 kg K_2O/ha and by cocoa 43.8 kg N, 8 kg P and 64.3 kg K/ha. 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. A study for 10 years on drip irrigation and fertilizer requirement of cocoa grown as mixed crop 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/tree/year would be optimum for cocoa. The failure of cocoa under rainfed conditions at Palode, Kerala and better performance of cocoa under irrigated and high fertility conditions at Kannara, Kerala stressed the necessity for adequate availability of moisture and nutrition for successful cultivation of cocoa. In arecanut +cocoa system, the lateral root distribution is up to 50 cm in arecanut and 125 cm in cocoa with better exploitation of the root regions of 51-100 cm depth.

The arecanut + cocoa system not only gives a sustainable production, but also serves as a good system for biomass production and carbon accumulation. The carbon and biomass estimations in areca and cocoa over 15 year period have shown that annual increments ranged from 0.55 to 2.98 tonnes carbon/ha/yr and 1.38 to 7.11 tonnes biomass/ha/yr (Balasimha 2011). The quantum of carbon sequestration is between 2.02-3.89 tonnes/ha/yr and 5.14-10.94 tonnes/ha/yr in cocoa and areca, respectively. Thus there is considerable amount of net sequestration of CO_2 in the system.

Arecanut + banana system

Banana is usually grown as nurse or shade crop in arecanut plantations and its advantages are reported earlier (Sujatha *et al.* 2011b). The yield of main crop is not adversely affected by growing banana. Banana cultivars such as Robusta, Mysore poovan, Red banana and Karpuravally are found suitable for intercropping in arecanut gardens of Karnataka and Kerala and the variety Red banana gives 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. In West Bengal, the yield of banana cv. Malbhog is higher registering maximum net return per rupee investment (1.96) than Champa banana and Dwarf Cavendish without affecting arecanut yield (Sit *et al.* 2011).

Arecanut + pepper system

Pepper is raised exclusively as mixed crop in homestead gardens in Kerala and Karnataka by trailing on coconut and arecanut. Black pepper is an excellent crop for mixed cropping with arecanut and high economic returns can be expected. Studies carried out at CPCRI have also revealed that pepper is the most compatible and profitable perennial spice crop for mixed cropping in arecanut (Sujatha *et al.* 2011b and Sit *et al.* 2011). Further, it was observed there is no detrimental effect on the yield of arecanut palms due to trailing of black pepper on them. The advantages of 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.

A study was conducted to investigate the performance of four varieties of pepper as a mixed crop in 19-yr old arecanut plantation with six planting densities. Pepper as a mixed crop did not adversely affect the yield of arecanut. As regards to the yield of pepper, 1.8 m × 2.7 m spacing has given significantly more yield followed by 1.8 m × 3.6 m spacing. Among the cultivars of pepper, Karimunda gave the highest yield followed by Panniyur1. The cultivars Uddakare and Malligesara are poor yielders. Reduction in economic yield of pepper due to *Phytophthora* diseases is reported. This necessitates the need for testing new varieties of pepper as mixed crop for tolerance to shade and diseases in arecanut plantation. On an average, black pepper yields 1.0 kg/vine as intercrop in arecanut (Sit *et al.* 2011). Betel vine can also be grown profitably in arecanut at sub Himalayan Terai region of West Bengal (Sit *et al.* 2011). In sub humid Himalayan region of West Bengal, maximum net return/rupee investment is obtained from black pepper (5.46) followed by cocoa (4.60) and banana (1.96) under irrigated condition (Sit *et al.* 2011).

Arecanut + vanilla intercropping system

Cultivation of vanilla was considered one of the most attractive propositions during 2003-2008 due to highly remunerative price scenario and huge export potential. But the trend has changed after 2008 and cultivation of vanilla might gain importance due to increasing demand for natural vanillin. It can be successfully grown as an intercrop in arecanut plantations in India with proper nutrition and irrigation. The results of five year study on water and organic nutrition of vanilla in arecanut plantation indicated that micro-sprinkler irrigation at 1.0 Ep is significantly superior over 0.5 and 0.75 Ep (Sujatha and Bhat 2010). Organic manure application in the form of vermicompost and FYM, and recommended NPK produce green bean yield at par with recycling of gliricidia prunings. The benefit:cost (B:C) ratio is highest with recommended NPK (2.27) followed by recycling of gliricidia prunings (2.10), vermicompost (1.87), vermicompost+ arecanut husk mulching (1.80) and FYM (1.64). In this era of WTO, value added crops like vanilla and medicinal and aromatic plants would prove to be highly remunerative intercrops.

High density multi species cropping system (HDMSCS)

It is a system of growing of more than two crops having different stature and rooting habits are grouped to form compatible combinations so as to enable interception and utilisation of light at different vertical intervals and facilitate foraging the soil at different layers and columns. The research on HDMSCS was initiated in 1980s at different Research Stations of CPCRI.

HDMSCS models for coastal regions and plains of South India

The comprehensive study on arecanut based high density multispecies cropping system (HDMSCS) with cocoa (*Theobroma cacao* L.), banana (*Musa* spp), clove (*Syzygium aromaticum*), black pepper (*Piper nigrum* L.) and coffee (*Coffea arabica*) as component crops for over 20 years revealed that cocoa, banana and pepper are found suitable for multi-storeyed cropping system (Bhat and Sujatha 2011 . There is better scope to increase nutrient recycling in arecanut based high density multispecies cropping system (HDMSCS). 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. Due to higher shade levels in arecanut, clove has grown tall with a yield level of 1.0 kg/tree making harvesting difficult and uneconomical. The study clearly indicates the need for higher light requirement of both clove and pineapple. 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 price crash or failure of arecanut, mixed crops would be playing a vital role in maintaining or improving the returns.

HDMSCS models for plains of Karnataka

Two arecanut based HDMSCS models consisting of pepper, cocoa, coffee, mulberry and elephant foot yam (Model-I) and banana, betelvine, lemon, coffee and tapioca (Model- II) were tried at Hirehalli, Karnataka (Bhat and Sujatha 2011). Cocoa and black pepper or banana, betelvine and lemon crops are found to be profitable mixed crops for Maidan parts of Karnataka. Mixed cropping with coffee is also found to be profitable. It was observed that arecanut yield was increased by 7 to 20% in arecanut based cropping systems, besides progressive increase in yields of intercrops.

HDMSCS models for Asom and Sub Himalayan Terai region

In HDMSCS model (arecanut + black pepper + banana + turmeric + pineapple) at Asom (Ray *et al.* 2011), higher production and returns are noticed with full dose of recommended fertilizer application to all crops than two-third and one-third dose of recommended fertilizers. Pineapple cultivation as component crop is uneconomical. The modified arecanut based HDMSCS models with inclusion of lemon and spices (arecanut + black pepper + banana + lemon + clove and arecanut + black pepper + banana + lemon + nutmeg) are highly profitable with highest benefit cost ratio of 3.22-3.60 at 2/3rd recommended fertilizer application along with recycling available biomass in the form of compost. It has been reported that crops like turmeric, black pepper, ginger, cowpea, banana and citrus are found to grow well in arecanut gardens and provide additional income to farmers. Recyclable biomass production per ha per year from the arecanut based HDMSCS models is quantified at 8-16 in coastal Karnataka (Bhat and Sujatha 2011) and 8.8 to 10.6 in Asom (Ray *et al.* 2011). In sub Himalayan terai region of West Bengal (Sit *et al.* 2011), monetary benefits per unit area are higher in all HDMSCS models (arecanut + pepper + banana + cocoa, arecanut + pepper + banana + acid lime, arecanut + betelvine + banana + turmeric, arecanut + pepper + banana + coffee and arecanut + betelvine + banana + cinnamon) than arecanut monocrop. Higher monetary benefit of 118% is obtained from HDMSCS involving crops like arecanut, betelvine, banana and cinnamon followed by arecanut + black pepper + banana + acid lime system. In sub Himalayan terai region, performance of cocoa and coffee is satisfactory as component crops in arecanut based HDMSCS.

Resource use in arecanut based high density multispecies cropping system (HDMSCS)

Successful cultivation of mixed crops like cocoa, black pepper, clove, lemon and banana in arecanut based High density multispecies cropping system (HDMSCS) is well documented (Bhat and Sujatha 2011). Arecanut based HDMSCS accommodates 1 300 arecanut palms with pepper vines trained on them, 210 cocoa, 180 clove, 390 banana and 2 400 pineapple plants in one hectare area. It increases resourse use efficiency, employment opportunities and income and makes the system more sustainable. Other tangible benefits noticed from the system are improvement in microclimate, reduction in leaching losses of water and nutrients due to runoff and improvement in soil fertility due to increased recycling of biomass. Several reports indicated that inter/mixed crops are not detrimental to the main crop of arecanut and emphasized the economic viability of HDMSCS. The nutrient balance studies done in arecanut based HDMSCS model indicated better scope for internal recycling of nutrients. The review by Bhat and Sujatha (2011) emphasized the potential of organic waste recycling in arecanut based cropping system (ABCS).

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 are lacking. HDMSCS should be considered as closed system for nutrients and organic matter for saving in input and reducing cost of cultivation. The studies on nutrient requirement of ABCS (arecanut + pepper + cocoa + banana) indicated that 2/3rd of recommended fertilizer dose for each component crop is sufficient for optimum yield levels. The soil fertility status before initiation of HDMSCS and after six years of establishing the system indicated improvement in soil fertility status with the adoption of HDMSCS. The study conducted at Vittal highlighted that the recyclable biomass produced from the system varies between 8.72 to 10.35 tonnes/ha/year. Organic matter recycling (OMR) maintains sufficient mineral N and available P levels in soil at par with integrated nutrient management treatments. 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 and leaching losses. Further, the nutrient status of the soils at Vittal under monocrop and HDMSCS indicated improved soil fertility under HDMSCS as compared to monocrop. Arecanut based HDMSCS improves soil fertility status in terms of soil pH, soil organic carbon and available P.

Leaching losses and rainfall partitioning

The leaching of nutrients from the soil is a serious problem in high rainfall areas and the reduced leaching losses in HDMSCS is reported (Bhat and Sujatha 2011). 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, the understanding of plant effects on the repartitioning of rain water may help in the optimization of land use systems and management practices. The washings from arecanut canopy supplies 4.5 kg K and 6.0 kg Ca/ha. 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 (Bhat and Sujatha 2011b). 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. 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.

Implications of cropping systems on soil fertility

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. Cultivation of exhaustive crops like arecanut, banana and cocoa continuously on the same land results in soil fertility depletion. Thus, it is essential to replenish nutrients regularly both through organic and inorganic sources. 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. The impact of arecanut based cropping system on soil quality indicators is well documented (Bhat and Sujatha 2011, Sujatha *et al.* 2011a, Sujatha and Bhat 2010, 2012, 2015). Increase in soil pH is noticed due to inter/mixed cropping by these researchers. 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.

Increased root proliferation in arecanut due to intercropping would increase organic matter content in soil. It was 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. It was further noticed that intercropping with *Pueraria javanica* and *Mimosa invisa* in arecanut gardens could add on an average 10 kg green manure/palm which could meet 69 to 89 % of N requirement, 28 to 43% P and 29-38 % of K. Fungal and bacterial population was relatively more under intercropping situations than in sole crop of arecanut. The potential of cocoa to recycle considerable biomass in terms of litter fall and pruned biomass, and the better nutrient quality of vermicompost made from arecanut and cocoa wastes was highlighted by Sujatha and Bhat (2012), Sujatha and Bhat (2013a) and Sujatha and Bhat (2015).

The wastes available from arecanut and cocoa gardens contain reasonable quantities of N, P and K annually (Bhat and Sujatha 2011). The arecanut and cocoa leaves from the system can be converted into compost using earthworms with a recovery percentage of 74 to 87. The composted leaves were found rich in nutrients, including micronutrients, which was more than the normal compost. Maximum biomass recycling in the form of pruned biomass and litter fall is possible in arecanut + cocoa mixed cropping system. The studies pertaining to the soil nutrient status revealed positive aspects of arecanut + cocoa system. Soil pH, SOC, available P and K increase 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 as attained 13 years after planting indicates a negative balance in available K in the system suggesting higher requirement of K by both crops. Reduced soil pH and improved organic carbon status are noticed 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 system showed higher concentration than sole arecanut. 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.

Overall, positive impact of arecanut based cropping system (ABCS) is 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 2011) compared to the reported value of 4.70 and 4.45 in 1988. The system results in enrichment of organic carbon with 58 to 105 % increase over 20-year period. *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.

Soil microflora and enzyme activities

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 such as bacteria, fungi, actinomycetes, N_2-fixers and P-solubilizers are more in high density multiple cropping compared to arecanut monocrop. The microbial biomass is also higher in multiple cropping system and the asymbiotic N_2 fixers isolated from arecanut based high density multiple cropping system have the N_2 fixing capacity in the range of 2.8 to 11.8 mg N/100 ml of medium. The study by Bhat *et al.* (2008) revealed that arecanut based HDMSCS resulted in proliferation of microorganisms and increased enzymatic activities.

The biochemical characterization of the soils in the cropping systems showed that phenol content decreases in root region of arecanut, pepper, cocoa and banana growing under multiple cropping compared to monocrop. Sugar content of soils from areca, banana and cocoa were higher.

from cocoa soils under mixed cropping was significantly lower than cocoa monocrop. The beneficial changes like higher sugar content and lower amino acid content in the rhizosphere of the main crop and intercrops not only improve soil microclimate but result in enhancing yields of crops. Vermicompost produced from plantation wastes has maximum microbial load compared to normal compost. It was concluded that organic matter recycling with graded nutrient levels in ABCS helps in improving soil health in terms of soil microflora and enzymatic activities (Bhat *et al.* 2008). Application of inorganic fertilizers up to 2/3rd of recommended dose for each component crops is congenial for better microbial activity.

Interactions within component crops and insect management

Cropping systems in perennial crops offer biodiversity to some extent and species diversity in multiple cropping reduces most insect pest problems (Mariamma 2011). Most of the insect problems are site specific and a check list of local background 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. The normal insects of the main crop of the system do not attack the component crops. The key pests are host specific or with limited host range and the exception is 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.

Socio-economic considerations

In the tropical countries the farm holdings are small and perennial crops like arecanut and cocoa occupy the land for several years. A small farmer cannot afford to lose the crop due to any of the climatic disasters or pest and disease attack as he is wholly subsistent 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. The profitability of arecanut based HDMSCS in terms of benefit-cost ratio and yield advantage was highlighted by several workers. The creation of employment opportunities is of significant importance as cultivation of plantation crops is labour intensive. The labour requirement for arecanut alone was 377.8 man days/ha/yr. The labour requirement increased by 70% when cocoa, pepper and clove were grown and by 103% when cocoa, pepper, clove, banana, pineapple and coffee were grown along with arecanut. 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.

Conclusions and future line of work

Recurring problems like erratic rainfall, pests and diseases, and price fluctuations are affecting the production and profitability of arecanut. Cropping system approach is an ideal option for arecanut farmers for increasing the productivity and income per unit area as arecanut has limited alternative uses and export potential. Crops like cocoa, 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 due to cropping system approach are congenial microclimate, enrichment of soil organic carbon, increased productivity and income. In coastal region the successful system involves arecanut, pepper, cocoa and banana. In plain regions, the system includes arecanut, pepper/betelvine, banana, lemon, tapioca. Studies are required to quantify whether the input requirement in terms of water and pesticides can be lowered in inter/mixed cropping systems. A judicious mix of cropping systems with associated enterprises like dairy would bring prosperity to the arecanut farmer.

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