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Soil Health Management in Arecanut and Cocoa

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1). Introduction

In general, the crop productivity and income generation are given more attention than soil health by the researchers as well as farmers. In recent years, it is increasingly realized that soil health is key to ecosystem functions, sustained crop productivity and promoting health of plant, animal and human beings. The interactions among plant, inputs and soil control the soil health. Maintenance of soil quality and health in perennial crops like arecanut and cocoa is a major challenge due to intensive land use in small and marginal holdings. Arecanut (*Areca catechu* L.) is a commercial crop having social importance in India. It is cultivated in 0.452 m ha with a production of 0.622 m t in South and North east regions of India (GOI, 2014). Arecanut is predominantly cultivated in acidic laterite soils that account for 80% of soils under arecanut in traditional arecanut growing areas. During the last decade, there was rapid expansion of arecanut area in clay soil belt of non-traditional areas and in paddy fallows. Cocoa is cultivated in 77, 000 ha as an intercrop in palm based cropping systems in variety of soil types such as laterite, clay, saline and alluvial soils. The productivity of both arecanut and cocoa is either stagnant or declining largely due to loss of soil health and soil quality. Stagnant productivity, reduced nut recovery, nutrient imbalances and disorders are becoming major constraints in arecanut production.

Cultivation of exhaustive crops like arecanut and cocoa continuously on the same land results in soil exhaustion. The soil fertility decline is widespread in tropics (Hartemink, 2006). Though the decline in soil fertility is less in plantation crop belt (Hartemink, 2003), the differences in dynamics of soil chemical properties are noticed in different plantation crops (Hartemink, 2005). Management interventions are required at regular intervals for maintenance of soil health especially in perennial plantation crops. Adverse effects on soil health and quality arise from nutrient imbalances, excessive fertilization, soil pollution and soil loss processes. Thus, it is essential to replenish nutrients regularly both through organic and inorganic sources. In this chapter, the changes in soil health due to different cultivation approaches along with soil quality are presented and discussed.

2). Important soil health indicators

2.1). Biological: Biological indicators of soil quality include soil organic matter, respiration, microbial biomass (total bacteria and fungi) and mineralizable nitrogen. Soil enzyme activities are considered as integrative indicators of soil health. Soil organic carbon enrichment occurs in plantation belt due to reduced soil temperatures and *in situ* decay of roots.

2.2). Chemical : In order to achieve high crop yields, soil nutrient balance or optimum soil fertility is important. The soil pH, organic carbon, EC of soil and nutrient concentration in soil are some of the important chemical soil health indicators. Optimum nutrient norms developed for different soils give scope for identifying deficit or excess of nutrient concentrations and for adopting precision agricultural practices that might save inputs by way of skipping nutrient application (Bhat *et al.,* 2012).

2.3). Physical: For better soil health in arecanut and cocoa ecosystems, soil physical properties such as texture, bulk density, porosity and water-holding capacity are very important due to sensitivity of these crops to both deficit and excess water. The performance of arecanut in clay soil belt is not as good as in well drained lateritic soils due to soil compaction, poor aeration and water stagnation leading to poor root production. Arecanut cultivation is spreading rapidly in clay soil regions of non-traditional areas in Karnataka. The problems like disorders and poor root growth due to water stagnation are also increasingly noticed in clay soils (Bhat and Sujatha, 2014).

3). Soil and climatic requirement

Selection of suitable soil for arecanut cultivation is most important as extraction of nutrients from deeper depths and distances is difficult in this palm due to shallow root system and low root CEC. Arecanut needs deep and well-drained soils for better root growth and distribution. Arecanut roots traverse down to about three meters under well drained deep soil conditions, while the roots confine to 1.40 meters under shallow soil condition (Bhat and Leela, 1969; Bhat, 1978). Soils with sticky clay, sandy, alluvial, brackish and calcareous nature are not suitable for arecanut cultivation. The active root zone is within 50 cm depth and distance from the trunk in drip irrigated arecanut (Bhat and Sujatha, 2008). The tap root system in cocoa is deep with roots spreading up to 2 m from the stem both horizontally and vertically. Arecanut and cocoa prefer slightly acidic soils to neutral pH soils. Saline and alkali soils are not suitable. Arecanut and cocoa are mostly crops of humid tropics, but these crops are cultivated in regions with 750 to 4500 mm rainfall. The optimum temperature range is 14°C-36°C for these crops. Traditionally arecanut is grown in tracts with heavy rainfall.

3.1). Soil characteristics in arecanut and cocoa growing tracts : During pre-independence period, arecanut was predominantly cultivated in gravelly laterite soils of red clay type of Southern Kerala and Coastal Karnataka. After independence, the cultivation of arecanut was spread to other areas in South India. In plain regions of Karnataka, it is cultivated in fertile clay loam soils. In Malaysia and Fiji, arecanut is cultivated in the hot, moist, rich alluvial areas of the coastal belt. Bhat and Mohapatra (1971) characterized major soil groups of arecanut growing tract during 1970-80's (Table 1).

Table 1. Important soils types in arecanut belt

Location	Soil group	pH
Vittal (South Kanara)	Lateritic	5.2
Peechi (Kerala)	Alluvial, lateritic	5.6-6.8
Palode (Kerala)	Lateritic	4.2-5.0
Mohitnagar (West Bengal)	Alluvial	4.5-6.0
Kahikuchi (Assam)	Lateritic	4.4-4.8
Hirehalli (Karnataka)	Clay loam	6.2

(Source: Bhat and Mohapatra, 1971)

Texturally the soils of Hirehalli are clay loam and that of Vittal are sandy clay loam, while those from Peechi, Palode, Mohitnagar and Kahikuchi are sandy loams (Mohapatra, 1977). Arecanut is mostly grown in red/lateritic soils in and around western ghat region, West Bengal and Assam, and clay loams in plains of Karnataka (Mohapatra, 1977; Mohapatra and Bhat, 1982). Soils in the western ghat region are mainly derived from granite, gneisses and schists (Babu, 1981). The soils are sandy loam to clay loam and well drained. The soils in arecanut belt are poor in native soil fertility with abundant sesquioxides and low bases. Further, heavy rainfall aggravates the problem by leaching away of nutrients like N and K. In these soils, N and K are highly mobile and labile, while P is highly immobile and fixed. Even though the parent materials have their distinctive influence on the development of acidity in soils, rainfall and temperature in general appeared to be more dominant factors. Intense leaching of bases accompanying the high rainfall conditions, presents a distinct acid character to the soils. The CEC of the soils is quite low. Kaolinite is the dominant clay mineral and as such there are no K fixation sites. Khadilkar *et al.* (1964) described the soil profiles from arecanut growing areas of Kolaba and Ratnagiri districts of Maharashtra. The major soils are lateritic, mildly acidic, rich in total N and micronutrients and low in bases, P and K. The alluvial soils from the coastal region are found to be neutral, base saturated and rich in organic matter. The physico-chemical properties of laterite soils of Puttur region in South Kanara district indicated that the soils are acidic with higher copper and iron contents (Badrinath *et al.,* 1998). Further, zinc, manganese and boron content ranged between deficient to adequate.

Information gathered on the soil fertility status of the arecanut growing regions from the Arecanut Research Stations situated in different states of the country gives an idea about the fertility status of the arecanut belt (Mohapatra, 1977; Mohapatra and Bhat, 1982). In general, higher soil organic carbon is noticed in arecanut belt during 1970-90's. Available P is medium in the soils of Peechi (Kerala), Mohitnagar (West Bengal) and Kahikuchi (Assam), whereas, it is low in soils of Vittal, Hirehalli (both in Karnataka) and Palode (Kerala). Soils from all the regions except that of Mohitnagar are found to be medium to high in available K status. The pH of the soil is acidic to neutral except that at Hirehalli where it is neutral to alkaline. The total CaO and MgO contents of soils from Vittal and Palode are lower than those of others. The Al_2O_3 content is more than that of Fe_2O_3 in all the soils (Table 2).

Table 2. Nutrient status of soils (0-25cm depth) of experimental stations under arecanut

	Vittal (Karnataka)	Hirehalli (Karnataka)	Peechi (Kerala)	Palode (Kerala)	Mohitnagar (West Bengal)	Kahikuchi (Assam)
pH	5.3–5.6	6.5-8.2	5.1-5.6	4.9-5.0	5.7-6.2	5.1-5.3
Organic carbon (%)	0.7-1.1	0.3-1.4	1.0-2.0	0.7-1.4	0.1-2.2	0.5-1.8
Total N (%)	0.05-0.09	0.04-0.19	0.06-0.16	0.06-0.13	0.14-0.22	0.03-0.12
Available P_2O_5 (ppm)	3.8-7.1	Trace-5.5	50-81	Trace-3.0	9.2-69.1	9.6-29.0
Available K_2O (ppm)	34-85	30-108	115-130	81-91	8-55	70-190
Cao (%)	0.07-0.30	0.30-0.38	0.53	0.15-0.23	0.23-0.30	0.15-0.30

MgO (%)	0.6-1.7	0.6-1.1	1.7-2.3	0.6-1.1	1.7-2.9	1.1-2.3
Fe_2O_3 (%)	8.8-12.0	7.2-19.2	8.0-11.2	4.8-7.2	4.0-7.2	2.4-8.0
Al_2O_3 (%)	12.0-21.4	11.3-39.0	17.1-24.6	18.0-30.9	4.8-14.5	6.5-13.6

(Source: Mohapatra and Bhat, 1982)

Continuous use of inorganic fertilizers led to slight acidification of soils in arecanut tract (Mohapatra and Bhat, 1990). But regular application of organic manures results in proliferation of microbial organisms like bacteria, fungi and actinomycetes in laterite soils and congenial soil conditions (Bopaiah and Bhat, 1981). Recent analysis of soil fertility status of arecanut growing regions in Karnataka indicated that the organic carbon and soil test nutrients are above optimum levels except in case of potassium (Bhat and Sujatha, 2014; Bhat *et al.,* 2012). The status of soil organic carbon and micronutrient availability is high in arecanut growing regions (Bhat and Sujatha, 2014; CPCRI, 2013, CPCRI, 2014). This highlights the need for saving inputs by avoiding blanket recommendations or skipping application of excess nutrients and organic manures.

3.2). Soil constraints and management strategies: The cultivation of arecanut on slopy lands/paddy fallows/eroded lands in Western ghats and clay soil regions is a major constraint. Generally, these lands are not suitable for monocot palms as per Land Capability Classification. If the farmer's preference is for cultivation on these problematic lands, adoption of management strategies like improvement of soil aeration, proper drainage and breaking hard pan in paddy fallows, and soil and water conservation measures like terracing and planting of vetiver on slopy lands is necessary. It can be grown in fertile clay loam soils with special care and microsite improvement to tackle problems like water stagnation, poor soil aeration and slow infiltration. In paddy fallows, seepage of water and continuous water stagnation above field capacity level in the root zone cause severe problems to plant growth and nutrient uptake (Bhat and Sujatha, 2014 and Bhat *et al.*, 2016).

Due to reports on potassium depletion in lateritic and shallow black soils of India (Naidu *et al.,* 2011) and in plantation ecosystems (Sujatha and Bhat, 2013b; Sujatha and Bhat, 2015b; Sujatha *et al.,* 2015; Sujatha and Bhat, 2016), it becomes necessary to consider the crop needs to sustain crop productivity and to maintain soil health. Low nutrient retention and moisture holding capacities are important constraints in laterite soils because of low cation exchange capacity, faster infiltration rate and high hydraulic conductivity and porous nature of soils. Leaching of basic cations like potassium, calcium and magnesium due to heavy rainfall reduces the crop in humid tropics. It is well known that K deficit results in low nitrogen use efficiency, and susceptibility to drought, pests and diseases. The recent report indicates deficit of K and Zn in Indian soils (Naidu *et al.*, 2011). All management strategies should consider these constraints and measures like organic manure application, mulching, drip irrigation and drip fertigation are needed to improve resource use efficiency.Frequent application of K fertilizers or drip fertigation would ensure higher K use efficiency.

4). Nutrient requirement, deficiency and management

4.1). Arecanut: The long term field trials conducted during 1970's and 1980's concluded that application of 100 g N, 40 g P_2O_5 and 140 g K_2O along with 14 kg of green leaf per palm per year is optimum for arecanut in case of local variety with *chali* or kernel yield of around 2 kg per palm on a laterite soil. For high yielding varieties with yield level of above 3 kg kernel per palm per year, application of higher fertilizer doses up to 200:80:240 g of N, P_20_5 and K_20/palm/year is suggested (Sujatha *et al.*, 1999). The nutrient requirement of arecanut based on biomass partitioning and nutrient uptake pattern is estimated for high yielding Sreemangala cultivar by Bhat and Sujatha (2012). The results indicated that arecanut is heavy feeder of N and K compared to P, Ca and Mg and the total uptake of macronutrients is in the order of N > K > Ca > P > Mg. The nutrient removal of N (236 kg ha^{-1}), P (20 kg ha^{-1}) and K (90 kg ha^{-1}) by arecanut is substantial in high yielding Sreemangala cultivar (Bhat and Sujatha, 2012). Recycling of leaf and other wastes in arecanut through vermicomposting is necessary to avoid nutrient loss from the plantation. The reports of K deficit in soil and plant due to continuous application of only organics (Sujatha and Bhat, 2013b, 2015b and 2016) might cause serious problems to soil and plant health in the long run.

Though availability of nutrients in the soil is above optimum, the appearance of disorders like crown choking, crown bending and oblique nodes is noticed in arecanut due to antagonistic nutrient interactions (Bhat and Sujatha, 2014). Reduced Zn uptake by arecanut due to very high soil test P in clay soils causes widespread crown choking. These problems develop in areas with excess soil fertility and in paddy converted areas due to water stagnation. Zinc deficiency is mainly responsible for development of disorders in arecanut. Crown choking can be identified at initial stages with appearance of dark green leaves with erect nature and reduced leaf size. Excess availability of nitrogen, phosphorus and other nutrients hinder uptake of zinc and cause disorders. In soils with low Zn content, soil application of zinc sulphate @ 10 g per palm reduces the disorder in the initial stages. In case of severe reduction in leaf size and crown choking, spraying of 0.5 % zinc sulphate (5 g per litre of water) mainly on fresh foliage can be done so that new leaves will emerge normally. Combined deficiency of zinc and calcium causes crown bending. Nut splitting is due to less potassium and application of potassium is required to correct nut splitting as both husk and kernel require high potassium. Thus, soil health is important that can be maintained through balanced nutrition.

Drip fertigation ensures maintenance of soil fertility status at or near to optimum, higher nutrient use efficiency, and better soil and plant health in arecanut. This was evident from the reports of less P fixation, mobility of P and K beyond 30 cm depth and distance from dripping point, higher agronomic nutrient use efficiency, saving in nutrient input and water use, better root growth and enrichment of soil organic carbon due to drip fertigation (Sujatha and Abdul Haris, 2000; Bhat *et al.*, 2007a; Bhat *et al.*, 2007b; Bhat and Sujatha 2008). The advantages of adopting drip-fertigation are reduced labour charges on fertilizer application, weeding and irrigation and diesel charges due to less operational hours (Bhat and Sujatha, 2006). With adoption of drip fertigation technology, the nutrient requirement can be reduced to 50% during pre-bearing stage and 75% of the recommended dose during bearing stage.

4.2). Cocoa: The fertilizer dose and schedule is same for arecanut and cocoa in a laterite soil. A fertilizer level of 100:40:140 g $N:P_2O_5:K_2O$ per tree per year through soil application is optimum for achieving maximum yield in cocoa when it is intercropped with arecanut (Bhat, 2002; Sujatha and Bhat, 2013a). Unlike in arecanut, cocoa responds to drip fertigation of full recommended dose on a laterite soil after initial bearing stage (CPCRI, 2015). Cocoa requires 1/3rd and 2/3rd of recommended dose of fertilizer in the first and second year of planting. From third year onwards, full dose of fertilizer should be given. But cocoa cultivation has been spreading rapidly as intercrop in coconut and oil palm plantations in Andhra Pradesh and Tamil Nadu since 1995. The fertilizer dose is to be fixed based on soil type and yield level for these soils. Due to higher bean yields of cocoa in alluvial soils of Andhra Pradesh, the nutrient removal by the crop makes the basis of fertilizer application to cocoa to maintain soil health.

Disorders due to micronutrient deficiencies are also reported in cocoa.

Important disorders are zinc (Zn) and iron (Fe) deficiencies. Zinc deficiency is predominantly seen in all cocoa growing regions (Chandramohanan *et al.*, 1981) either due to less availability of Zn or due to high availability of P in soil. In perennial crops, it is difficult to control deficiency of any nutrient after the symptoms develop. In view of this, soil application of zinc sulphate @ 10 -20 g per tree once in two years is advisable based on the age of the tree in soils with less Zn availability. But, Zn deficiency is commonly noticed in cocoa growing areas of Andhra Pradesh due to higher P availability in these soils and antagonistic nutrient interactions. In such case, skipping of P application is ideal to sustain the yield levels and soil fertility.

Calcium deficiency is one of the causes for cherelle wilt in cocoa (Uthaiah and Sulladamath, 1980). Foliar and soil application of calcium reduces cherelle wilt and increases the number of cherelles carried to maturity. The symptoms of Zn deficiency include chlorosis, crinkling of leaves with wavy margin, little leaf, sickle leaf, premature defoliation and die back of twigs. The earliest remedy for Zn deficiency was foliar spraying with a solution of 300 g of zinc sulphate and 150 g of lime in 100 litres of water (Chandramohanan *et al.*, 1981). Iron deficiency is occasionally seen and can be cured by repeated spraying of 1 per cent aqueous ferrous sulphate solution.

5.) Soil health management

5.1). Soil rhizosphere management : Soil rhizosphere, which is the zone of maximum microbial activity and nutrient availability, should be made congenial for root growth and uptake of nutrients and water. The good agricultural practices required for the management of soil rhizosphere are mentioned below.

- Loosening of soil in basins: Soil aeration is most important for production of fine roots, which are required for uptake of nutrients and water. Roots contact only 1% of soil volume and only fine roots of less than 1 mm thickness will take water and nutrients. Majority of the fine/feeder roots of arecanut are concentrated within 30 cm depth and 60 cm distance from the trunk. The presence of few fine roots is reported in arecanut in clay soil belt (Bhat and Sujatha, 2014).
- Basin opening is important for application of manures and fertilizers wherever the soil hardens after monsoon season. The fertilizers should be applied in the basin at 40-50 cm distance around the trunk. The basins of the palms should be forked for

incorporation of manures and fertilizers with the soil. Addition of nutrients and organic matter in the active root zone followed by forking of the soil is advised for increasing the nutrient use efficiency.

5.2). Soil application of fertilizers: In arecanut and cocoa, nutrient application in terms of quantity, time and method is most important for soil health maintenance. Fertilizers and organic manures should be applied when the soil has sufficient moisture. In unirrigated crop, fertilizers can be applied during May-June and September-October. When the crop is irrigated, the pre-monsoon application can be advanced to February-March. As far as possible, fertilizer application during peak nut formation period (December-May) is ideal. The organic manures should be applied during September-October in basins around the base of the palm/tree.

- Green manure addition or recycling of organic matter is important for improving the soil fertility status.
- Soil moisture: Soil moisture availability at field capacity level is to be ensured in root zone by irrigation for nutrient uptake. Mulching is required to reduce soil temperature and evaporation during post monsoon season.

5.3). Nutrient management in sole and cropping system: Nutrient balance in soil-plant system is important for sustaining the yield and soil fertility in perennial plantation ecosystems. Nutrient management strategies need to be planned for arecanut taking in to account the soil fertility, leaf nutrient status, nutrient uptake pattern and yield level. It is advisable to consider nutrient deficiency/toxicity before the development of visual symptoms with the help of plant and soil analysis. Otherwise it may be too late to reverse the situation effectively by the time visual symptoms appear on palms. Soil testing is important to avoid deficit or excess presence of nutrients in soil. Excess soil fertility status is more dangerous than deficiency. Recent studies in farmer's fields and on-station experiments highlighted the importance of need based nutrient application rather than blanket recommendations to save inputs and to maintain soil health (Bhat *et al.*, 2016). Due to antagonistic nutrient interactions in soil, uptake of some nutrients will be hindered. If soil test values of phosphorus and potassium are below 30 kg P_2O_5 and 300 kg K_2O per ha on a laterite soil in arecanut basins, P and K are reaching deficit level and yields might reduce if nutrients are not applied sufficiently at this stage. Leaf sampling is required if problem of nutritional disorders due to deficiency or toxicity are noticed in few palms in the entire garden.

However, recent reports indicated that the nutrient removal (241 g N, 22 g P and 112 g K) and total uptake (352 g N, 36 g P and 304 g K) per palm per year in arecanut are higher than present nutrient recommendations (100 g N, 17 g P and 117 g K) considering the nutrient losses, nutrient immobilization and use efficiency (Bhat and Sujatha, 2012). Fertilizer recommendations for arecanut based high density cropping system have so far been generally based on the schedules recommended for the sole component crop. There is greater scope for internal recycling of organic matter and nutrients due to higher production of crop residues in HDMSCS. The initial 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 (CPCRI, 1996). 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) 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) for fruit yield of 50 tonnes per hectare. The nutrient balance studies in arecanut based model in third and sixth year of establishing HDMSCS indicated better scope for internal recycling of nutrients (Bavappa *et al.,* 1986; Abdul Khader *et al.,* 1992). Integrated application of organic matter recycling in the form of vermicompost and 2/3rd dose of inorganic NPK is advocated for sustainable crop yields in the system (Bhat and Sujatha, 2007). The studies on nutrient requirement of the HDMSCS as a whole are lacking and the system should be considered as a closed system for better soil health, input saving and reduced cost of cultivation.

5.4). Organic farming strategies and biomass recycling in arecanut monocrop

5.4.1). Cover crops: 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 (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. *Calopogaonium* 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.

5.4.2). 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. On an average, 5.0 to 8.5 tonnes of leaf wastes are available from one ha of arecanut plantation per year. Direct application of these wastes in the garden will take long time for decomposition and will not meet the nutrient demand of the crop immediately. These organic wastes can be composted using two species of earthworms *Eudrilus eugeniae* and *Eisenia foetida* (Chowdappa *et al.*, 1999). The wastes are converted into fine granular, odourless vermicompost within 60 days with the recovery of about 80% vermicompost from these wastes. This can be effectively used as organic source of nutrients for arecanut palms or to intercrops. It was reported that arecanut wastes recycled in the form of vermicompost is rich in N, P, Ca, Mg and micronutrients and have a potential to meet 50 % N, 32.5 % P and 26 % K requirement besides supplying considerable micronutrients (Chowdappa *et al.,* 1999). About 4 kg of vermicompost per palm per year meets the N and P demand of arecanut. Potassium needs to be added through other sources like MOP, arecanut husk or *gliricidia*. If organic farming is the preference, further studies are required on organic nutrition with the use of locally available *gliricidia* (2.3% K) and arecanut husk (1% K) as potential K sources. The long-term study in arecanut indicated that yields in organic nutrition are around 85% of the yields obtained with inorganic nutrition on a laterite soil due to less K supply by vermicompost produced from arecanut wastes (Sujatha and Bhat, 2012, 2013b and 2015b). Thus, recycling of arecanut wastes as vermicompost with K enrichment is necessary for improved productivity and soil health.

5.5). High Density Multispecies Cropping system (HDMSCS) and mixed farming in arecanut

The intensive cropping system involving arecanut, cocoa, pepper, clove and banana is a successful crop combination that generates considerable quantity of organic wastes. The recyclable biomass production from arecanut based HDMSCS is estimated at 14.3 t ha^{-1} $year^{-1}$ (Bavappa *et al.,* 1986). The quantity of recyclable biomass reduces after 15 years of adoption of HDMSCS and varies from 8.72 to 10.35 t $ha^{-1}year^{-1}$. The wastes available from arecanut and cocoa gardens contain reasonable quantities of N, P and K (Biddappa *et al.,* 1996). The review indicated that large quantity of organic matter available in arecanut and cocoa can be effectively utilized by recycling (Sujatha *et al.,* 2015). The recyclable biomass can be converted in to vermicompost with 82 to 87 % recovery. The nutrient content in vermicompost is 1.71 % N, 0.21 % P and 0.43 % K (Bhat and Sujatha, 2007).

Cocoa is a tropical tree and produces leaves throughout the year. The biomass production varies with age and growing conditions. In arecanut ecosystem, cocoa normally produces 14 kg leaf/pruned biomass, 4 kg pod husk and 2 kg beans per tree per year on dry weight basis. This comes to about 9.1 t of leaf, 2.6 t of pod husk and 1.3 t of beans per hectare. In coconut ecosystem, cocoa adds litter fall to the extent of 818 to 1985 kg ha^{-1} $year^{-1}$. Maximum biomass recycling in the form of pruned biomass and litter fall is reported from cocoa in arecanut + cocoa system (Abdul Haris *et al.,* 1999). The cocoa leaves can be converted into compost using earthworms with a recovery percentage of 74 (Chowdappa *et al.,* 1999). The nutrient content in vermicompost is higher than normal compost and leaf biomass of arecanut and cocoa (Chowdappa *et al.,* 1999).

5.6). Soil fertility management

Soil fertility management depends on climate, soil type and crop yield level. The published reports clearly indicate that the soil fertility status varies with the presence of component crops, management practices and soil type in arecanut. Shama Bhat (1983) noticed improvement in soil fertility status in terms of soil pH, soil organic carbon (SOC), available P and K in arecanut+cocoa mixed cropping system compared to interspaces and fallow land. Manikandan *et al.* (1987) noticed enrichment in SOC and reduction in soil pH and available K in the arecanut-cocoa system suggesting higher K requirement of both crops after 13 years. The available P is higher in arecanut basins of arecanut+cocoa system than sole arecanut (Manikandan *et al.,* 1987). The authors suggested the need for inclusion of Zn in the fertilizer schedule of arecanut +cocoa system to reduce the depletion of Zn from soil in the system and to sustain productivity and soil health.

Drip fertigation is ideal for arecanut and cocoa in terms of yield, profits and input saving. Drip fertigation maintains soil health by reducing nutrient losses and increasing nutrient use efficiency due to frequent addition of nutrients and higher root production (Bhat *et al.,* 2007a; Bhat and Sujatha, 2009; Sujatha and Bhat, 2013a; Sujatha and Bhat, 2015a). This is evident in long term studies on drip fertigation with clear increase in soil pH and organic carbon in arecanut and arecanut-cocoa system (Bhat and Sujatha, 2009; Sujatha and Bhat, 2015a). Recycling of waste biomass in the form of vermicompost to arecanut improves soil fertility status in terms of pH, SOC and the availability of soil test Ca, Mg, Mn and Cu but decreases the availability of major nutrients like P and K, and soil test Fe and Zn (Sujatha and Bhat, 2012 and 2016). This implies that need based application of nutrient inputs and organic manures can be adopted to sustain productivity and to maintain soil health.

Organic nutrition alone improves soil fertility status in terms of pH, SOC, P, Ca, Mg and micronutrients and depletes soil test K. Inorganic nutrition alone maintains soil fertility status in terms of SOC and optimum nutrient availability except for slight decrease in soil pH. The soil fertility status with drip fertigation of vermicompost extract (VCE) is similar to that of vermicompost application in sole arecanut and arecanut-cocoa systems. In perennial crops, inorganic nutrition improves root growth and the SOC status due to *in situ* root decay (Bhat *et al.,* 2007a; Bhat and Sujatha, 2008). Significant positive correlation of yield with soil K in arecanut (r=0.31) and cocoa (r=0.273) suggest the need for continuous replenishment of K. The results suggest that drip fertigation of NPK sustains the soil fertility status in arecanut and cocoa. In arecanut +vanilla system, the significant changes in soil fertility are increase in soil pH, SOC and Bray's P with organic application and maintenance of soil fertility status is noticed with inorganic nutrition (Sujatha and Bhat, 2010). When optimum nutrient limits for laterite soils are considered (Bhat *et al.,* 2012), the results of long term trials in arecanut and arecanut based cropping systems highlight the need for need based nutrient application to maintain soil fertility and to reduce cost of production.

Intercropping of medicinal and aromatic plants in arecanut ecosystem has more positive effect on soil pH registering increase of 0.3–0.9 units but has differential effect on soil organic carbon status. The SOC status enriches with intercropping of crops like *Aloe vera*, *Artemisia pallens*, *Piper longum* and *Bacopa monnieri* and depletes with intercropping of grasses and rhizomatic MAPs. This indicates the need for crop rotation and need based application of organic and inorganic nutrients (Sujatha *et al.*, 2011a). High rates of outputs from the cropping system deplete the soil of its nutrient store in long run and make the system ecologically unsustainable (Nair, 1999). The system involving component crops like cocoa, banana and clove has high nutrient requirement and places a great demand for nutrients on the soil + fertilizer system. Several reports highlighted the positive impact of arecanut based cropping system on soil quality indicators like increase in soil pH and SOC (Muralidharan, 1980; Manikandan *et al.,* 1987; Abdul Khader *et al.,* 1992; Bhat and Sujatha, 2007; Sujatha *et al.,* 2011b, Bhat and Sujatha, 2011a, b). *In situ* addition of organic matter through recyclable organic wastes and dead and decayed roots results in organic carbon enrichment in the system. Intercropping with leguminous green manure crops or cover crops is suggested for maintenance of soil health through recycling of nutrients in the soil profile, prevention of soil erosion and improved soil fertility (Bopaiah, 1982; Mohapatra and Bhat, 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.

Cropping system approach is important for soil fertility management in arecanut belt. The findings of several long-term trials are worthwhile and indicate that inter/mixed cropping influences nutrient cycling, soil fertility and carbon cycling. The potential of cocoa to recycle considerable biomass in terms of litter fall and pruned biomass is highlighted by Abdul Haris *et al.* (1999) and Balasimha (2007).

5.7). 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 adopted. The distribution of microflora in soil profile and the nature of rhizosphere microorganisms of arecanut monocropping system are reported (Bopaiah and Bhat, 1981; Bopaiah and Koti Reddy, 1982 and Bopaiah, 1991). The vermicompost prepared from plantation wastes is rich in nutrient content and microbial load (Chowdappa *et al.,* 1999). Higher bacterial abundance was noticed with application of NPK + Organic matter recycling in crop basins. The overall increase in microbial biomass C, soil microflora and enzymatic activities in ABCS is noticed with application of inorganic NPK and organic matter recycling in the form of vermicompost (Bhat *et al.,* 2008). 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 microbial quotient (C_{mic}/C_{org}) is improved over 20-yr period in all component crops of ABCS.

The improvement in soil fertility status in terms of soil pH, soil organic carbon and available P is noticed in HDMSCS after 20 years (Bhat and Sujatha, 2007). But, significant depletion of soil test K in all crop rhizospheres in HDMSCS reveals 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 (Bhat and Sujatha, 2007). Organic matter recycling in ABCS makes the system self-sustainable over a long term period with respect to N and P availability but K exhaustion is a concern (Bhat and Sujatha, 2007). Generally, the P availability is low in acidic laterite soils. With recycling of organic residues, organic P availability will be more, as organic phosphates are less readily fixed than inorganic P. Integration of NPK application and organic matter recycling in ABCS results in higher availability of P and similar P nutrient status in all crop basins (Bhat and Sujatha, 2007) due to higher phosphatase activity (Bhat *et al.*, 2008). The reduction in availability of K indicates the heavy K feeding nature of cocoa (Nelliat, 1978). Manikandan *et al.* (1987) also noticed a negative balance in available K in arecanut-cocoa system indicating the higher requirement of K. The exhaustion of K probably indicates the necessity of including K in the fertilizer schedule of the system to maintain soil health as all the component crops are heavy K feeders and organic matter recycling cannot supplement for K requirement of crops.

Arecanut based mixed farming system involving animal components like dairy and fishery is efficient in terms of ecosystem services like higher output and economic benefits per unit area and unit time, enrichment of SOC, efficient resource use, better soil health, carbon sequestration and water use (Sujatha and Bhat, 2015b).

6). Site specific nutrient management

Recent studies indicated that soil fertility status is imbalanced in arecanut growing regions due to wide spread adoption of organic farming practices, depletion of soil K, increased cost of production and nutrient imbalances causing disorders/diseases (Sujatha and Bhat, 2012 and 2013b; Bhat and Sujatha, 2014; Sujatha *et al.*, 2015 and Bhat *et al.*, 2016). Thus, site specific nutrient management becomes most important for maintenance of soil health in arecanut and cocoa due to weather aberrations, excess/deficit soil fertility, increased cost of inputs and labour, and price fluctuations. It requires information on soil test data, nutrient and biomass partitioning, leaf nutrient status, genotype, yield level and climatic conditions. Documentation of data enables to identify and quantify the variability in the fields for adopting site specific nutrient management.

Establishment of optimum soil nutrient norms for laterite soils (Bhat *et al.*, 2012), leaf nutrient norms for arecanut (Bhat and Sujatha, 2013), biomass partitioning and nutrient uptake pattern (Bhat and Sujatha, 2012) and identification of natural and management constraints give scope for site specific nutrient management and precision agriculture practices.

The systematic implementation of best management practices into a site-specific system provides the best opportunity to develop a truly sustainable agriculture system. Various technologies are available to help make decisions related to nutrient management, from soil sampling to fertilizer/input application to yield measurement. These tools enhance the ability to develop the site-specific nutrient management plan for each field. For precision agriculture, the necessary tools like biomass partitioning, nutrient uptake pattern, and optimum soil and leaf nutrient norms are studied in detail in arecanut and cocoa. For better soil health and optimum yields, the most realistic strategy would be to maintain plant nutrient levels at or very close to the optimal levels, although the optimum nutritional ranges may be used as guidelines.

6.1). Nutrient uptake pattern

Nutrient uptake pattern in arecanut (Table 3) and cocoa (Table 4) suggests that the removal and uptake of N and K are higher and regular application of N and K either through organic or inorganic source is most important to sustain yields and soil fertility. The nutrient use efficiency of these crops are reported as very low i.e. 10-15% for nitrogen, 25-30% for phosphorus and 20-25% for potassium. Based on use efficiency of N and K and nutrient removal by arecanut and cocoa, it is clear that nutrient losses of N and K are very high and the application rates of fertilizers do not match uptake pattern. This might result in soil nutrient mining and nutrient imbalances. Nitrogen is supplied by many sources like atmospheric N, irrigation water and different forms of N after mineralization. As organic P accounts for 90% of total P in soil, slow mineralization of P meets the crop demand. The sources of K supply are only fertilizers and irrigation water, but the nutrient uptake of K by arecanut (Bhat and Sujatha, 2012) is higher than supply.

Table 3. Nutrient removal from arecanut

Nutrient	Total uptake at high yield level (3.58 kg /palm)	Total uptake at average yield level (2.0 kg /palm)	Nutrient exported for1000 kg dry kernel yield
N	352 g	196	20 kg
P	36 g	20	2 kg (4.6 kg P_2O_5)
K	303 g	169	16 kg (19.2 kg K_2O)
Ca	122 g		3 kg
Mg	30 g		1.2 kg
Cu	883 mg		74 g
Zn	645 mg		1275 g
Fe	15.13 g		10 g
Mn	1586 mg		52 g
B	698 mg		56 g

Table 4. Nutrient removal from cocoa

Nutrient	Nutrient exported through 1000 kg dry beans	Nutrient removal per tree by 30 cocoa pods (1 kg)	Nutrient removal per tree at 2 kg dry bean yield	Actual supply
N	48.4 kg	48.4 g	479	100
P	5.7 kg	5.7 g	36	17
K	95.6 kg	95.6 g	429	117

The nutrient removal by the crop makes the basis of fertilizer application to cocoa. In India, the quantities of N, P and K removed by cocoa pods with 1 kg of dry beans will work out to 48.4, 5.7 and 95.6 g, respectively (Table 4). For a crop yielding about 2 kg of dry beans per tree (about 60 pods) per year, the average crop removal by pods would be around 96.8, 11.4 and 191.2 g each of N, P_2O_5 and K_2O. One cocoa tree removes 479 g N, 36 g P and 429 g K per year which includes nutrients removed through leaves, pod husk and beans.

6.2). Leaf nutrient limits for arecanut

Optimum leaf nutrient concentrations and ranges are established for arecanut (Bhat and Sujatha, 2013) and this could be used for precision agriculture and for diagnosing the deficiencies or toxicities. The leaf concentrations for N (2.70%), P (0.23%), K (1.12%), Ca (0.61%) and Mg (0.2%) are optimum for bearing arecanut. Optimum micronutrient concentrations are 146 ppm for iron (Fe), 56.5 ppm for manganese (Mn), 2.6 ppm for copper (Cu), 45.8 ppm for zinc (Zn) and 39.5 for boron (B).

6.3). Soil nutrient limits for laterite soils for judicious use of inputs

Optimum soil nutrient limits are vital for diagnosing nutrient constraints, judicious use of fertilizers and reducing environmental pollution. Optimum nutrient values are higher for laterite soils in arecanut tract than generalized guidelines for interpretation of soil analysis data due to low CEC (Bhat *et al.,* 2012). Arecanut tolerates higher micronutrient concentrations in soil (Bhat *et al.,* 2012), but not in leaf (Bhat and Sujatha, 2013).

6.4). Technologies for efficient resource use

6.4.1). Need based nutrient application: In laterite soil region, where, the soil is rich in soil organic carbon and micronutrients, it is advisable to apply organic manures once in 2 or 3 years. In arecanut plantation with above 2% soil organic carbon levels, urea application can be skipped if organic manure application is the preference of farmers every year. It is important to note that organic manure application alone cannot meet K demand of arecanut as organic manures contain very less K except *glyricidia* and arecanut husk. Double dose of fertilizers especially N and K can be applied for high yielding arecanut palms with kernel or *chali* yield more than 2.5 kg per palm per year. Lime application is needed only if soil pH is below 5. Due to low buffering capacity of laterite soils and leaching of Ca in heavy rainfall areas, lime needs to be applied every year. If arecanut is irrigated during post monsoon, irrigation water supplies Ca and Mg which is sufficient to maintain pH in arecanut basins. Soil fertility status in clay soil region of arecanut is above optimum. It is advisable to regulate NPK fertilizer application. There is no need to apply lime/gypsum, magnesium sulphate or micronutrient mixtures separately as organic manures and irrigation water supply sufficient calcium, magnesium and micronutrients (Bhat and Sujatha, 2014 and Bhat *et al.*, 2016).

7). Soil Quality Management for the Environmental Protection

7.1). Erosion /leaching/eutrophication

7.1.1). Nutrients in irrigation water : Arecanut is an irrigated crop in humid tropics and irrigation water is a good source of nutrients like calcium, magnesium, potassium etc (Bhat and Sujatha, 2009) as leaching of cations occurs due to low CEC and heavy rainfall in monsoon season. Irrigation during post monsoon season leads to pH changes in low buffering laterite soils.

7.1.2). Leaching losses of soil and nutrients in HDMSCS: The studies indicated that the leaching of nutrients from the soil is a serious problem in high rainfall areas in humid tropics. The potential of HDMSCS in reducing leaching losses was studied at Vittal (Mohapatra and Bhat, 1990). Leaching losses of water soluble nutrients in HDMSCS are estimated at 0.1 kg P, 116 kg K, 81 kg Ca and 37 kg Mg per ha as compared to leaching losses in arecanut monocrop with fertilizer application through combination of organic and inorganic sources, which 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.The quantity of nutrients in the leachate is estimated at 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 in HDMSCS and 5 kg N as NH_4N, 93 kg K, 15 kg Ca and 9 kg Mg per ha in unfertilized monocrop of arecanut.

7.2) Pollution

7.2.1). Heavy metal addition due to impurities in fertilizers: Continuous application of phosphorus fertilizers might cause an inadvertent addition of heavy metals which are present as impurities and increase the heavy metal contents in soil and transfer these metals to the human food chain. This becomes a serious problem in perennial plantation crops due to continuous use of rock phosphate in acidic laterite soils and single super phosphate. Phosphatic fertilizers contain cadmium, arsenic, chromium, lead and zinc (Javied *et al.*, 2009). Rock phosphate contains the highest levels of heavy metals. Soil pollution might occur due to blanket recommendations, leaching of nutrients, excess soil fertility and indiscriminate use of pesticides in plantation belt. Excess soil fertility status is more dangerous than deficit soil fertility as it hinders the uptake of important nutrients due to antagonistic nutrient interactions in soil.

7.3). Carbon sequestration : The plantation crops occupy the land for more than three decades and accumulate carbon in both above and below ground parts. The reports indicate that the carbon sequestration potential of arecanut as monocrop as well as with the presence of inter/mixed crops is substantial. Recent estimates indicated that the total carbon stocks in arecanut varies from 129 to 169 t ha^{-1} in arecanut plantations of different ages (Sujatha and Bhat, 2015b). Further, soil carbon stocks (119-137 t ha^{-1}) are higher than standing above ground carbon stocks (10-21 t ha^{-1}) at 0-30 cm soil depth.

The standing biomass of arecanut - cocoa system estimated at 23.15- 87.10 t ha^{-1} in 5th-15th year old plantations (Balasimha and Naresh Kumar, 2013) indicates the high carbon sequestration potential of arecanut-cocoa system. The standing above ground biomass varies from 41 t ha^{-1} in 12-yr old (Bhat and Sujatha, 2012) to 50 t ha^{-1} in 15-yr old arecanut plantation (Sujatha and Bhat, 2016). In cocoa, such standing carbon stocks varied from 1.66 t ha^{-1} in the 4th year after field planting to 13.34 t ha^{-1} by 10th year. In arecanut, annual increment in carbon stock is 1.4-3.0 t ha^{-1} year^{-1}, where as in cocoa, carbon stock increment is 0.6 -1.0 t ha^{-1} year^{-1} (Balasimha and Naresh Kumar, 2013). Thus, nutrients immobilized in standing biomass are very high and nutrient additions should consider both immobilized nutrients and nutrient removal. In order to maintain soil health, nutrient recommendation should consider total biomass accumulation and nutrient removal pattern.

8). Future strategies in soil health management

The nutrient recommendation to crops should consider the age and yield of crop. The soil health should be related to the yield. The soil health management should include need based application of organic and inorganic nutrients, recycling of organic wastes, inter and mixed cropping to improve soil health, to reduce soil and water erosion in the plantations. Microclimatic moderation due to inter/mixed crops and increase in soil pH results in reduction of soil borne pathogenic microbes. Adoption of cropping systems or mixed farming approach is a better management strategy for maintenance of soil health in arecanut ecosystem in view of climate change and ecological imbalance. The role of cocoa in soil health maintenance in palm based cropping system needs to be studied in detail.

9). Summary and conclusion

The review highlights that soil health is most important for sustainable yields in perennial plantation crops and the agronomic approaches are to be adopted in tune with crop needs based on soil type and climate. It is necessary to adopt need based management rather than following blanket recommendations to sustain yield levels and soil health. Recycling of arecanut and cocoa wastes as vermicompost safeguards the soil health and environment. The plantation farmers should consider crop diversification in terms of cropping systems and recycling wastes generated from the system to improve soil health for sustainable yields and soil fertility maintenance.

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