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Soil Health Management in Coconut

V. Selvamani, H.P. Maheswarappa and P. Chowdappa

I). Introduction

The coconut palm (*Cocos nucifera* Linn.) is grown widely in Asia and Pacific region and globally it is cultivated in around 93 countries. In India, coconut is grown in 1.97 million hectares (2014-15) with a production of 14,067 million nuts and an average productivity of 7,141 nuts ha^{-1} $year^{-1}$ (CDB, 2015). Majority of the coconut growing farmers are small farmers with a land holding lesser than one hectare. Coconut farming and allied activities provide livelihood security to millions of people in India. Hence, achieving and sustaining higher productivity and profitability from coconut farming is a paramount goal in serving this farming community. The price fluctuation, declining fertilizer response owing to the deteriorating soil health, increasing cost of fertilizers and lack of availability of organic manures are few of the major factors challenging to meet this goal.

Red and laterite and sandy soil types are the major soils in which the coconut is being cultivated. These are the soil types having naturally poor soil fertility status. On the other hand, coconut being a perennial crop with a lifespan of around 60 years and having simultaneously both vegetative and reproductive growth throughout the year, extracts more nutrients from the limited soil volume. Thereby, the soils which are having naturally poor nutrient reserve, loss their productivity potential very soon leading to the decline from the initial productivity of the plantations over the years if not properly manured. Even in the manured plantations, application of only few nutrients that too in an imbalanced way leads to the nutrient deficiency/toxicity in both fertile and poorly fertile soils. As a consequence of applying fertilizers regardless of the nutrient removal by coconut and the nutrient supplying power of the soil, leads to mining of the soil nutrients. In addition to this, abandoning the practice of biomass recycling resulted with deterioration of the soil physical, physico-chemical and biological properties. Hence, lack of scientific soil management results with declining soil health and productivity.

Understanding the nutrient removal, biomass availability, fertilizer/ manure requirement, appropriate soil and moisture conservation measures, efficient methods of fertilizer application to improve nutrient use efficiency will enable to formulate soil nutrient management strategies towards improving and sustaining soil health in an eco-friendly way. Implementing these soil management strategies will be a way foreword in ensuring sustained higher coconut productivity and livelihood of coconut farmers.

2). Soil and climatic requirement

2.1). Soil: The ideal coconut growing soils are well drained and aerated with a minimum depth of 80 to 100 cm, pH range between 5 to near neutral, adequate nutrient availability and water holding capacity (Fremond, 1964).

2.1.1). Soil depth: The depth of the soil is one of the important soil physical criteria for the sustained productivity. Around 73 per cent of roots of coconut are found within 2 m radius and most of them were confined to 31-120 cm depth (Kushwah *et al.,* 1973). In middle aged palm, 96 per cent of the roots present in 0-120 cm depth (Maheshwarappa *et al.,* 2000). More number of main roots was found in the layer of 31-60 cm depth and decreases in the deeper layers (61-90 and 91-120 cm) (Dhanapal *et al.,* 2000). Hence, a minimum depth of one meter soil is a pre-requisite for planting coconut which gives a good physical support and better anchorage against gusts of winds (John, 1949, 1952 and Ganarajah, 1953). A minimum depth of 80 to 100 cm, was observed as ideal by Fremond (1964). The soil physical constrains like hard soil pan, bed rock or permanent water table within one metre depth are unsuitable for coconut.

2.1.2). Soil pH: Coconut palm adapts to a wide range of soil acidity. The ideal soil pH for coconut growing soils ranges between 5 to near neutral (Fremond, 1964). The pH of representative Indian soils is reported to be in the range of 5.2 to 8.0 (Menon & Nair, 1952). Coconut can be cultivated in the soil pH range of 5 to 8 (Manciot *et al.,* 1979).

2.1.3). Electrical conductivity: Coconut being a semi-halophytic plant can tolerate soil salinity upto 0.6 per cent which is beyond tolerable limits to many other crops. Hence, the total soluble salts in the soil is not a serious problem for coconut cultivation (Sankaranarayanan *et al.,* 1958).

2.1.4). Soil fertility: Coconut responds very well to judicious fertilizer application and irrigation. Therefore with appropriate management, coconut can be grown even on the poorest soils with good soil drainage and aeration in sub soil (John, 1949, 1952). Since, coconut is grown in the tropical condition most of the soils under coconut is deficient in the organic matter except the soils of the humid tropics like lateritic soil of the hilly region and the alluvial soils. Manciot *et al.* (1979) suggested a threshold value of 1.0 per cent organic carbon for coconut soils. The soil nitrogen supply is directly related to the soil organic fractions. However, it varies with soil type. Soil phosphorus levels does not pose a serious problem to coconut cultivation. Adequate potassium supply must be ensured for higher coconut productivity. Among the secondary and micro nutrients, supply of magnesium, sulphur, boron and zinc are very important since they are generally in short supply in many of the coconut growing tropical soils.

2.2). Climate: Mean annual temperature of 27°C with a diurnal variation of 5-7°C is ideal for coconut growth. Temperature below 15°C results in abnormalities of the fruit. Well distributed annual rainfall of 1800 to 2500 mm is favourable but can withstand very high rainfall if the soil is well drained soils. Under irrigation, coconut can be grown with low and poorly distributed rainfall. Coconut requires 120 hours of sunshine per month and 2000 hours or more per year. Relative humidity (RH) around 80-90 per cent is ideal. RH below 60% affects opening of stomata. Generally coconut can be grown upto the altitude of 600m, can also be grown at higher elevations near equator.

3). Soils of coconut plantations

3.1). Soil characteristics and productivity potential: The major soil types under coconut in the world are red, laterite, sand, alluvium, coralline, volcanic, clayey and peaty soils.

3.1.1). Red and Laterite soils: Largest areas under coconut is concentrated on the red and laterite soils in India, Sri Lanka and many other countries worldwide. These soils are loose, porous and well drained with poor water retention power. Since highly leached, having acidic pH with excess amounts of aluminium, iron and manganese. They have low cation exchange capacity and poor nutrient retention power. In these tropical acid soils, micronutrients like Fe, Mn, Cu and Zn are easily soluble and readily available and are not generally found limiting in the nutrition of the palm.

3.1.2). Sandy soils: The coastal sands are the second major soil group under coconut landcover commonly found in the coastal belt of almost all coconut growing countries in the world. This soil is single-grained in structure, low in clay, silt and organic matter content. Therefore, has very low water and nutrient retention power. The leaching loss of applied nutrients is very heavy in high rainfall areas. Hence, this group of soils are deficient in almost all essential nutrients.

3.1.3). Alluvium: Alluvial soils are the third major important soil found under coconut. The river or estuarine alluvial deposits with sufficient amount of coarse and fine sand are considered to be the best for coconut cultivation. Coconut is cultivated extensively in the deltaic regions of Godavary, Cauvery, Krishna, Mahanadi, Brahmaputra and Ganga in India where the soils are deep and loamy. The excellent plantations are located in the alluvial soils like the ideal loams of the river alluvia and the estuarine deposits in Srilanka, exceptionally fertile alluvial limestone derived soils in the Philippines (Cooke, 1936) and in the marine alluvial soils of Indonesia. These soils are well drained, deep and highly fertile. Hence, these soils pose minimum production constraints to coconut productivity.

3.1.4). Coral soils: In India, the soils of Lakshadweep (Arabian sea) and some parts of Andomen and Nicobar islands belong to Coralline soils. This soil type covers most of the atolls (Polynesia). It is a mixture of coral, sand and rock, almost entirely calcareous, which poses unique problems of nutrient assimilation and deficiencies (Newton, 1967). Their fertility depends on the amount of organic matter and the degree of weathering. Coral soils are poor in organic matter and most of the plant nutrients except phosphorus, calcium and magnesium. But the coconut production is excellent due to the supply of almost all plant nutrients through underground partially saline water. The management of these soils is very difficult due to the highly sensitive ecosystem prevailing in the island habitats.

3.1.5). Volcanic Soils: The volcanic soils on which the coconut is cultivated are generally fertile found mainly in Indonesia and Philippines. The volcanic soils of Indonesia are noteworthy. The volcanic soils of Indonesia found in the plains of Anggio on Sangir Island which produced about 3 tonnes of copra per hectare. In the Philippines, fine coconut plantations are found in Southern Luzon surrounding Mount Banahao in Tayabas, and Mount Mayon in Albay which are volcanic in origin (Child, 1974).

3.1.6). Clay soils: The clay soils are generally considered as the least suitable for coconut cultivation, and those with high clay subsoil should be avoided. In Sri Lanka, estuarine clays are considered to be unsuitable for coconut. These soils become waterlogged during monsoon and baked and cracked during dry weather (Child, 1974). Similar situations are also found to exist in Mozambique. Deep ploughing, husk burying, draining and leguminous cover cropping are some of the practices suggested for improving such areas (Child, 1974).

3.1.7). Peat soils: In India peaty or Kari soils are found in some parts of Alleppey and Kottayam districts of Kerala. These soils are characterised by strong acidity (PH 3.0-4.5) and high content of organic matter. They are very rich in total nitrogen, but often deficient in phosphorus and calcium. The level of potassium is generally satisfactory. Coconuts are usually grown on raised bunds. With regular soil reclamation and management practices coconut performs well on such soils. Soils containing more than 80 per cent of organic matter in Malaya are described as peat soils (Cooke, 1930) and they are considered not really suitable for coconut cultivation.

3.2). Soil constraints and management strategies

In India, coconut is mainly grown in laterite and lateritic, coastal sand, red sandy loam, coral and alluvial soils. These soils come mainly under four soil orders *viz.* Alfisols, Entisols, Ultisols and Inceptisols. These are mainly acidic in nature with low fertility status. The soils suffer from varying degree of nutrient/moisture stress.

3.2.1). Physical constraints: Coconut grown under coastal sandy soil without manuring results in lower yield due to poor physico- chemical characters *viz.*, high bulk density, poor aggregate stability, poor water holding capacity, high soil temperature and poor soil fertility status (Srinivasa Reddy and Upadhyay, 2002). Even regular application of chemical fertilizers failed in building up soil nutrient status in littoral sandy soil mainly due to low nutrient retention capacity of the soil (Srinivasa Reddy *et al.,* 1999). The very low clay content leads to high infiltration and percolation rate coupled with low CEC and low organic carbon content, this soil type is subject to high leaching loss of applied nutrients during monsoon and severe moisture stress during summer, pose a great challenge to cultivate in this soil type. Improvement of the soil organic matter content is a prerequisite for the successful management of coconuts on such soils. Hence, sustainable crop production could be achieved in this soil type through adoption of cropping systems approach along with soil moisture conservation methods. Fodder grass can be successfully grown as an intercrop in coconut gardens under coastal sandy soils by adopting appropriate soil moisture conservation measures. Burial of one layer of dried coconut husk in trenches and/or applying 5 cm thickness of coir pith in the planting zone significantly increases green and dry fodder yield due to higher soil moisture, nutrient availability especially potassium and enhanced biological activities in the rhizosphere when soil moisture conservation measures were implemented (Subramanian *et al.,* 2007).

Effect of soil compaction on the growth and activity of coconut *(Cocos nucifera* L.) roots in two soil series, namely, *Andigama* series (gravelly soil) and *Madampe series* (sandy loam soil) in Sri Lanka was studied by Vidhana Arachchi *et al.* (1999). The root activity in the *Madampe series,* with respect to moisture absorption was higher than that of the *Andigama series* due to low compaction of the former. Soil compaction higher than 250 N/cm^2 restricted the activity of coconut roots in the gravelly soil. They also reported that high moisture extraction by coconut roots was confined to a depth ranging from 20 to 120 cm and of 20 to 250 cm in soils of *Andigama* and *Madampe series,* respectively, due to differences in soil compaction levels. Soil compaction limits the water absorption ability of coconut roots vertically from the base of the tree, rather than coconut root growth and penetration. Intercropping with *Gliricidia sepium* under coconut showed the possibility of improving degraded soil conditions of gravelly Andigama series which is having poor physical characters restricting palm growth and yield in intermediate zone of Sri Lanka. Coconut root growth also increased in A, AB and B horizons. These studies strongly suggested that *Gliricidia sepium* plays a major role in improving physical characters of infertile gravelly soils (Vidhana Arachchi and De S. Liyanage, 1996).

3.2.2). Soil acidity and salinity related constraints

3.2.2.1). Soil acidity: Almost all red and lateritic soils under coconut, which are formed under humid tropical conditions, have Al^{3+} as the dominant cation, and hence, their pH is very low (4.2-5.8). This highly leached soils are deficient in many of the essential plant nutrients, particularly potassium and magnesium. The high Al and Fe revert the soluble phosphates into insoluble ones. The soil acidity can be managed by applying liming material based on the lime requirement of the soil. For acid sulphate soils, suppression of aluminum could be achieved only by using magnesium silicate. This facilitates inactivation of Al as aluminum silicate and the magnesium sulphate thus formed can be leached out of the system. According to Nambiar *et al.* (1975), the application of seaweed as manure reduce the acidity to a certain extent.

3.2.2.2). Soil salinity:

In low lying areas where the soils are frequently inundated by sea water or submerged with brackish water during certain seasons of the year, the resulted excess salinity may create some production problems. Drainage facilities and check bunds can reduce the inundation. Coconut cultivated in non-traditional saline/alkaline areas face considerable limitation due to the dominance of sodium, carbonates and bicarbonates. The application of acid forming chemical amendments such as sulphur or gypsum helps in reducing the salt problem. Application of more organic matter in the planting pits along with soil-sand mixture in equal amounts also observed to reduce the salt problems.

3.2,3). Soil fertility constraints: Generally, the sandy soils contain very low amount of soil nitrogen. Leaching loss of nitrate is very high in sandy soil followed by sandy loam and red soils. The available phosphorus status of 15 soil series and four soil orders (Ultisol, Entisol, Alfisol and Oxisol) in the major coconut-growing regions of Sri Lanka were found to be very low in almost all soils except some of the sandy soils (Entisols) which had marginal to moderate P content (Loganathan *et al.*,1984). Liming and calcium containing phosphatic fertilizers can meet the calcium requirement in highly acidic soil. The availability of Ca in coral soils is very high and often antogonise the uptake of K, Mg and Na by coconut. Organic amendments are recommended for improving the fertility of calcareous soils. In India, both magnesium and sulphur are either deficient or tending towards deficiency in most of the soils in Kerala, Karnataka, Maharashtra and North Eastern States of India. The deficiency of sulphur has been reported from Papua and New Guinea (Southern, 1969) and some of the East African and South East Asian countries (Ollagnier and Ochs, 1972). The concentrations of copper and zinc are low in black and coral soils. Boron deficiency is emerging in most of the laterite, red, alluvial and coastal sandy soils in the humid tropics.

4). Soil health management

4.1). Nutrient requirement: Quantification of nutrient exhaust usually provide useful guidelines for optimizing the quantity of the individual nutrients and their proportion in which they have to be applied to sustain the soil fertility and coconut productivity. The nutrient exhaust studies showed that the proportionate requirement of NPK of the palm in terms of N, P_2O_5, K_2O is 2:1:3. The quantitative order of requirement of major nutrients for adult bearing palm is K>N>Ca>Mg>P. Potassium dominates the nutrient requirement of the palm while P requirement is found to be the least (Pillai and Davis, 1963 and Ramadasan and Lal, 1966).

The annual exhaust computed from one hectare of 173 palms in sandy loam soil is 65.6, 29.7, 84.5, 47.4 and 20.3 kg of N, P_2O_5, CaO and MgO respectively taking into account the nuts, fallen leaves spathes and the stem growth (Pillai and Davis, 1963). The amounts of macronutrients lost through the removal of plant components from the field of *Typica x*

Typica coconut palms yielding an average of 17, 38 nuts ha^{-1} $year^{-1}$ in Srilanka, were 116.79 kg N, 14.02 kg P, 245.43 kg K, 40.47 kg Ca, and 33.66 kg Mg per haectare per year. The amounts of micronutrients lost were 1.14 kg Fe, 0.63 kg Mn, 0.13 kg Cu, 0.44 kg Zn and 0.26 kg B per hectare per year (Somasiri *et al.,* 2003).

Potash was found to be removed most, followed by nitrogen, calcium, magnesium and phosphorus. The quantity of nutrients removed varies with the soil type and yield. Palms growing on coastal alluvium removed 70 kg K_2O ha^{-1} but the average removal from red sandy loam and laterite was around 53 kg K_2O ha^{-1} (Ramanandan and George, 1982). The total nutrient exhausted in the coconut based cropping system ranged from 130.45, 18.29 and 172.64 kg of N, P and K respectively per hectare in the full dose of recommended fertilizer to 97.11, 13.06 and 125.45 kg $ha^{-1}$of N, P and K respectively in the no fertilizer treatment (Subramanian *et al.,* 2005).

4.2). Nutrient management: Long term studies have indicated that cultural practices alone are superior to no cultivation and no manuring. Cultural practices alone, like cultivation of interspaces twice a year and weed control using herbicides produced poor yields ranging from 10.7 to 32.3 nuts $palm^{-1}$ $year^{-1}$ as compared to fertilizer treatments coupled with cultural practices which produced yields ranging from 83-107.9 nuts $palm^{-1}$ $year^{-1}$, indicating that cultural practices alone could not sustain higher productivity. Soil and leaf analysis of palms under different cultural and fertilizer treatments strongly suggests that for satisfactory growth and productivity of palms in the red sandy loam soil mere cultural treatments alone cannot improve the nutritional status of palms and supplementing the nutrition with inorganic fertilizer and organic manures is necessary to sustain productivity (Khan *et al.,* 1996).

4.2.1). Primary nutrients: Nitrogen improves the rate of leaf production, production of bunches, female flowers and yield of nuts. The soil nitrogen supply is directly related to the soil organic fractions, however, it varies with soil type. Soil phosphorus content varies with the geomorphology and parent material of the soil. The phosphorus status of laterite, lateritic, and red soils is medium but the supplying power would be fairly high. The soils of semi-arid regions contain dominantly the Ca-P. In the case of sandy soil, the total as well as available soil phosphorus is very low whereas it is high in the case of alluvial black and swampy soils. In the case of alluvial and swampy soil, the organically bound phosphorus is higher than that of inorganic fractions. Organic phosphorus content is increased under mixed farming and multiple cropping in coconut gardens. A general build up of available soil phosphorus was observed irrespective of sources of phosphorus fertilizer applied to a typical laterite soil of Malabar area of Kerala (Khan *et al.,* 1985). The build up of soil available P content was observed with increased applied P levels. The increase was of 363 Mg kg^{-1} of available P in the plot received fertilizer application of 437 g and it was 253 Mg kg^{-1} when 218 g of P $palm^{-1}$ $year^{-1}$ was applied. Whereas, the soil available P content in the unfertilized plot was only 36 Mg kg^{-1} (Srinivasa Reddy *et al.*, 2001). The soil potassium content depends on the nature and composition of the parent material from which the soil is formed (Graham and Fox, 1971). It is found to be low to medium in coconut growing soils of humid tropics, but it is high in alluvial soils and those formed under semi-arid conditions such as black soils. The quantity-intensity relationship and the potential buffering capacity of soil potassium regulate the potassium availability to coconut. Potassium adsorption is comparatively more and uniform in laterite soils than in red sandy loam, river alluvium and coastal sands cultivated to coconut. The magnitude of the constants K and 1/n and the difference in the values of Freundlich adsorption isotherm was attributed to the contents and nature of clay minerals in these soils. Desorption of applied K showed a constant release (Hameed Khan *et al.*, 1982). These soils are dominated by kaolinite clay minerals, which have no interlattice binding sites for K, and hence cannot hold any non-exchangeable K (Patil *et al.*, 1976). The influence of clay minerals in K supply to the nutrient pool was also indicated by Ramanathan and Krishnamoorthy (1976).

In a long term fertilizer experiment in red loam soil, early bearing and significantly higher nut yield was recorded with increased levels of potassium application. The yield was 7, 68 and 77 nuts $palm^{-1}$ $year^{-1}$ in the 21^{st} year after planting under no fertilizer, 450 g K_2O and 900 g K_2O $palm^{-1}$ $year^{-1}$ respectively (Wahid *et al.*, 1988). Potassium adsorption studies in a red sandy loam soil (*Arenic Paleustult*) under various fertilizer regimes in coconut under coconut based cropping system at Kasaragod revealed that the optimum K application to maximize the soil solution K for optimum plant nutrition ranged from 662 ppm (full dose) to 692 ppm (no fertilizer) (Upadhyay *et al.*, 2005). The potassium supply can be regulated in sandy soil by suitable management practices. Higher build up of available potassium in littoral beach sandy soil was observed when inorganic fertilizers were applied with different organics. Maximum build up was obtained when potassium was applied along with coconut pith (Nambiar *et al.*, 1983).

Bopaiah *et al.* (1998) studied the effect of slow release N and P fertilizers (different combinations of urea, urea formaldehyde, neem coated urea, lac coated urea mixed along with coir dust, tar, single super phosphate, mussorie rock phosphate and muriate of potash). Among the slow release N fertilizers ureaform, neem cake coated urea and coir dust mixed with urea have been found to remain for a long period in the sandy soil, thus facilitating availability of N in the more permeable soil. Mussorie phosphate is equally efficient as super phosphate in sandy soil.

The Mitscherlich-Bray model is popularly used in most of the field crops. This principle was employed to evaluate the nutrient requirement of three high yielding genotoypes of coconut by Khan *et al.* (1986). They indicated that the nutrient requirement of D x T hybrid was relatively lower than that of Talls to produce the same quantity of yield (Table 1). Tall x Dwarf hybrid behaved intermediate between DxT and WCT. They further evaluated the efficiency of soil and fertilizer nutrients with respect to productivity. It is also possible to forecast coconut productivity for a given quantity of nutrient inputs.

Table. 1: Fertilizer recommendation based on Mitscherlich- Bray equation.

Cultivar	Nutrients	Baule Units			
		Fertilizer to be applied/palm/year (g)			
		(50%)	(75%)	(87.5%)	(93.75%)
WCT	N	3700	851	1332	1813
	P_2O_5	370	851	1332	1813
	K_2O	741	1703	2665	3626
COD x WCT	N	75	214	352	490
	P_2O_5	75	214	352	490
	K_2O	150	427	704	980
COD x WCT	N	144	333	521	710
	P_2O_5	144	333	521	710
	K_2O	288	666	1043	1420

(Khan *et al.*, 1986)

A long term experiment conducted by Srinivasa Reddy *et al.* (2001) in littoral sandy soil reported that annual application of fertilizers for a period of 32 years to coconut resulted in a marked increase in the available phosphorus and potassium status in soil, but a marginal change in soil available nitrogen status. The yield of coconut increased with the higher levels of nutrient application, and the highest yield was recorded in the treatment of 1000:437:1667g of N, P, K palm^{-1} yr^{-1}. The application of fertilizers through drip fertigation resulted in a marked increase in available nitrogen, phosphorus and potassium status in soil. Coconut yield was significantly higher in 100 per cent NPK fertigation (131nuts/palm/year) which was on par with 75 and 50 per cent NPK applied through drip irrigation. Hence, through fertigation 50 per cent saving of chemical fertilizers is possible which ensures the higher efficiency of nutrients in crop production (Subramanian *et al.*, 2012).

A study on the effect of fertigation on the productivity of coconut was conducted at Horticulture Research Station, Arsikere, Karnataka. The mean nut and copra yield per palm over five years was significantly higher with the application of 100 per cent NPK through drip irrigation which was on par with 75 per cent NPK but significantly higher than application of 25 and 50 per cent NPK through drip irrigation. Net returns and benefit-cost ratio in 75 per cent NPK through drip irrigation were on par with the application of 100 per cent NPK through drip irrigation, but significantly higher than 100 per cent NPK through soil application. Hence, indicated the possibility of saving 25 per cent of the recommended fertilizers by adopting fertigation which ensures higher productivity in coconut (Basavaraju *et al.*, 2014).

Under the soil water deficit conditions, maintenance of sufficient levels of N and K contribute to the growth of the coconut seedling through improved gaseous exchange, CO_2 assimilation and better partitioning of assimilated carbon into shoot and roots. Potassium and Cl are important for maintenance of water status of coconut seedlings by improved stomatal regulation, water uptake and osmotic adjustment of tissues under water deficit conditions (Jayasekara *et al.*, 1993).

4.2.2). Secondary nutrients: Among the secondary nutrients, magnesium and sulphur are very important as far as coconut productivity and production problems are concerned. Due to leaching losses these nutrients are generally in short supply in many of the coconut growing humid tropical soils. Soils very low in organic matter and continuously cropped without sulphur containing fertilization are likely to suffer S-deficiency. Sulphur management can be achieved by using sulphur containing fertilizers like super phosphate, ammonium sulphate, diammonium phosphate, magnesium sulphate etc. while formulating the fertilizer schedule for coconut. Organic matter is one of the potential sources of sulphur on decomposition. Sulphur treatments increased the total yield of fruits and weight of copra, but decreased the weight of kernel per nut (De Silva *et al.,* 1985). Major fraction of sulphur is held in the organic form. Therefore, the sulphur management in the soil can be best achieved through proper organic farming technology. The Ca content in most of the coconut growing soils of the world is satisfactory. The calcium added through phosphatic fertilizer is considered to be quite adequate for sustaining the Ca-demand of the palm. In very acid soils, regulated additions of liming materials are needed for correcting the soil acidity and other related problems. Fairly high amount of calcium is being recycled through litter falls and prunings of cocoa and other intercrops grown in coconut gardens. Thus, the management of calcium is not a serious problem in coconut growing soils. Therefore, Ca supply to the palms is not a serious problem for the management of coconut soils. But its concentration beyond certain limit would decrease the coconut yield probably due to its interaction effects with other nutrients.

4.2.3). Micronutrients: In the tropical acid soils, iron, manganese, copper and zinc are easily soluble and readily available under acid conditions. The availability of iron and manganese are generally high in acid laterite and red soils, moderate in alluvial, volcanic, peat and clay soils, low in coastal sandy soils and very low in coral soils. In acid laterite and red soils, their contents may often reach to toxic levels, particularly under anaerobic conditions. The high calcium carbonate content of the coral soils blocks the assimilation of Fe and Mn by the palm. The concentrations of copper and zinc are moderate in acid laterite and red soils, high in the case of alluvial soils and low in black and coral soils. The requirement of molybdenum for coconut is very small and its problem has not been felt in coconut farming anywhere in the world. Boron deficiency is widespread in most of the acid laterite, red, alluvial and coastal sandy soils.

4.2.4). Balanced nutrition: Growth and yielding potential of palms is related to the availability of the most limiting nutrient. The plant nutrient limitation may occur through the low nutrient content in soil or the antagonisitc effect of the high content of other nutrients. Therefore, to ensure the sufficient supply of all the nutrients depends on the balanced nutrient status in the soil. A critical evaluation of nutritional factors involved in coconut productivity was carried out by Mathewkutty *et al.* (1997) in West Coast Tall palms aged 25 to 35 years. The relationships of individual nutrient contents in respect of 10 elements were worked out. It was observed that continuous use of conventional fertilizers have lead to a stage of negative response for them owing to the deficiency of non recommended/ applied elements like Mg and S and excess of Ca, Fe and Mn limits coconut yield. This points importance of balanced nutrition for problem management and better productivity in coconut. The effect of nutrient management in high density multispecies cropping system involving 18 crops under different fertilizer application rates over a period of three years, showed build up of phosphorus. Similar trend was also observed in mixed farming and coconut-cocoa mixed cropping systems at CPCRI, Kasaragod (Bavappa *et al.*, 1986). Similarly, the studies of Khan *et al.* (1990) showed that the available soil phosphorus (0-30 cm) had been increased from 84 ppm to 121 ppm when annual fertilization of P was done at the rate of 320 g P_2O_5 $palm^{-1}$ for 14 years. But in plots where P was not applied, it had been decreased from 84 ppm to 21 ppm during the same period which emphasise P application should be regulated by constant monitoring on built up through soil testing. They suggested that the P application should be skipped at the level of 20ppm of soil available P.

Application of muriate of potash increased the leaf K and Cl contents, but decreased the Mg and Ca contents under Srilankan conditions (Loganathan and Arputharajah, 1986). The magnesium budget and balance in coconut based high density multispecies cropping system declines very fast to the extent of 50 per cent over a period of 3 years. Further the systems involving coconut – grass and coconut – cocoa also showed a similar pattern of decline with respect to Mg (Bavappa *et al.*, 1987). The interaction between plant available potassium and magnesium in highly leached red yellow podzolic soils with laterite in Southern coastal area of Sri Lanka and its effect on coconut palm was studied by Somasiri (1997), the results showed that the application of potassium decreased the quantity of both exchangeable and water extractable magnesium and application of magnesium fertilizer decreased the quantity of exchangeable potassium in soils which is attributed to low cation exchange capacity and base saturation of the soils. Due to heavy input of K^+ and NH^{4+} fertilizers, displacement of Mg from its exchange site occurs and resulting in leaching loss of Mg (Ochs and Ollangnier, 1977).

The uptake of cations by the palm was found to be governed by their ratios in soil. Highly significant correlations were obtained between K/Na, K/(Ca +Mg) and K/Mg in soil and their corresponding ratios in their leaf. The leaf potassium level was affected by the combined level of Na, Ca and Mg (Wahid *et al.*, 1974). A threshold level of 0.2-0.5 m.e/100 g of exchangeable Mg out of 1.0 m.e/100 g of total exchangeable cations is suggested (Mancot *et al.*, 1979a). The suggested ratio for the exchangeable Mg/K for ideal coconut soils is 2.5 and a minimum Ex. Mg/K ratio of 2.0 for the satisfactory supply of Mg to the palm (Cecil, 1981).

The critical limit for hot water soluble boron was 0.1 ppm (Pillai *et al.,* 1983).

4.2.5). Deficiency and mangement: In the state of Assam and West Bengal the available boron content is below the critical limit (Chakrabarthy *et al.,* 1970). In Kerala 12 per cent of coconut soils are reported to be deficient in boron (Cecil and Pillai, 1978). In West Bengal where the pH ranged from 4.9 to 5.0, highly deficient gardens showing symptoms of crown choking recorded 0.19 ppm B and in healthy gardens the boron level was 0.22 ppm (Baranwal *et al.,* 1989). Studies carried out at Kayangulam showed that boron deficiency causes reduction in coconut productivity and the deficiency could be cured by the application of 300g and 500g borax per palm per year in two split doses for seedlings and adult palms respectively. The deficiency symptoms associated with B were completely recovered by borax application (Kamalakshi amma *et al.,* 2002). Micronutrient deficiency (Cu and Zn) was observed in Coconut Rapid Decline (CRD) disorder affected palms. Two years after micronutrient or common salt treatment, number of total fronds and functional green fronds in the canopy were increased. The stomatal diffusive resistance of these palms was also reduced after two years showing an improvement in palm water status (Wijebandara and Ranasinghe, 2004).

Leaf analysis enables us to directly measure the nutritional status of the palms. The nutrient supply then can be adjusted to bring the levels of nutrients in the tissues back to within the determined limits. It is difficult to define standard nutrient contents with wide application because of variations due to climate, soil condition, crop management etc. Hence it is appropriate to define the optimum nutrient level for a particular cultivar in a closely defined condition. The critical limits worked out by the IRHO for the West African Tall palms using the 14^{th} leaf were 1.8 – 2.0 per cent N, 0.12 per cent P, 0.8 – 1.0 per cent K, 0.50 per cent Ca, 0.30 per cent Mg, 50 ppm Fe and 60 ppm Mn (Thampan, 1982). The sulphur content in the sixth leaf from the apex of coconut palms was found to be the most sensitive index to sulphur (De Silva *et al.,* 1985). The critical nutrient concentration range for B in the third leaf is 8-10 ppm and the deficiency could be corrected by soil application of sodium tetraborate (Jayasekara and Loganathan, 1988).

The optimum nutrient requirement for individual nutrients can vary over a considerable range, depending upon factors such as the age of the palms, soil moisture regime, ratio to other nutrient concentrations type of planting material etc., (Fairhurst, 2003). Hence the optimum leaf nutrient concentration must be determined for each agro-ecological environment taking local soil and climate conditions into considerations. The critical limit of leaf N, P, K, Ca, Mg and S was estimated for the coastal sandy soil track of Odisha by Acharya and Dash (2006). They reported that the critical limits were 1.52 to 1.54, 0.134 to 0.135, 1.20 to 1.23, 0.36, 0.24 to 0.25 and 0.116 to 0.118 per cent respectively for leaf N, P, K, Ca, Mg and S. Similarly the critical limits for the micro nutrients were 310 to 315, 310 to 315, 7.2 to 7.3 and 18.7 to 19.0 ppm for Fe, Mn, Cu, Zn respectively.

4.3). Biomass recycling and INM: Around 6 to 8 tonnes of coconut wastes in the form of leaves, spathe, bunch waste, husk of nuts are available from one hectare of well managed coconut garden. Along with coconut wastes, wastes from other annuals and perennials grown as inter/mixed crops in the coconut gardens can also be recycled. When animal components are included in the coconut mixed farming system, more biomass with varying nutrient status are available. The natural decomposition of organic by-products resulting from coconut cultivation and the nutrient release is very slow due to the presence of lignin and polyphenols in it. CPCRI has identified a local strain of earthworm related to African Night Crawler (*Eudrilus* sp.) which is quite efficient in converting coconut leaves into granular vermicompost (Prabhu *et al.,* 1998). Hence, biomass recycling through vermicomposting is an efficient method of coconut waste recycling. Coconut leaves vermicompost has C: N ratio of 9.95, 1.8 % N, 0.21 % P and 0.16% K and organic carbon content of 17.84. As much as 4000 kg of good quality vermicompost can be produced from the wastes generated from 1 ha of healthy coconut garden every year by this earthworm that can meet a considerable percentage of nutrient need of the coconut palm. The clear brown coloured liquid collected after the passage of water through a column of actively vermicomposting substrate with earthworms is the vermiwash. Coconut leaf vermiwash is alkaline and contains N, P, K, Ca, Mg, Zn, Mn in appreciable quantities. It also has sugars, amino acids, and phenols along with the plant growth promoting hormones *viz.,* indole acetic acid, gibberellic acid and humic acid. Fresh vermiwash harbours a large number of fluorescent pseudomonad bacteria that help in plant growth promotion and protection (Gopal *et al.,* 2007).

Mimosa invisa and *Calopogonium. mucunoides* grown as cover crop in 1.8 m radius basin area surrounding the palm can produce 20.5 kg and 12.8 kg of above-ground wet biomass and 134.8 g N and 70.0 g N per basin, respectively, when harvested after 140 days growth for incorporation. Higher N_2-fixation efficiency is shown by *M. invisa* as evidenced by nodule biomass and acetylene reduction activity of the nodulated root system (George V. Thomas *et al.,* 2001). Growing Cowpea as low cost green manure crop in the basins of coconut and its nutrient contribution and organic matter has been studied in coconut basins in root (wilt) affected garden and in HDMSCS garden (Maheswarappa *et al.*, 2003). Their study reported that, cowpea has added 24.6 kg of fresh biomass in the coconut basin which in turn contributed 134, 12.3 and 113.7 g NPK per basin area. The participatory rural appraisal data also showed high ranking for this technology (59 scores) among different root (wilt) management techniques. The technology was demonstrated in three districts of root (wilt) affected area.

Application of recommended dose of chemical fertilizers with 20 kg of organics resulted in 60 per cent increased nut yield over control (Srinivasa Reddy and Upadhyay, 2002). Application of 50 per cent of N as composted coir pith along with 50 per cent of recommended dose of chemical fertilizers recorded higher nut yield. Application of 100 per cent composted coir pith/palm/year on N basis or application of 50 per cent composted coir pith + 50 per cent of recommended dose chemical fertilizers was optimum for getting maximum nut yield (Venkitasamy and Khan, 2002). Application of Glyricidia as green manure increased available soil nitrogen which is higher than the application of inorganic manure alone but did not show any significant effect on available soil phosphorus and potassium. Highest yield was observed where 50 per cent N was substituted through Glyricidia along with 50 per cent of N, full dose of P and K through chemical fertilizers (Subramanian *et al.,* 2005).

The effect of integrated nutrient management on COD x WCT hybrid coconut with different combinations and three levels each of N (0, 500, 1000 g /palm/year, where 50% N was substituted by vermicompost on N equal nutrient basis), P_2O_5 (0, 250, 500 g/palm/year) and K_2O (0, 1000, 2000 g/palm/year) was studied. The results revealed that all the growth and yield parameters were high under higher level of K application. The highest average nut yield of 111 nuts/palm/year and benefit cost ratio of 2.02 were recorded in the treatment N1P2K2 (500 g N wherein 50% N substituted by vermicompost, 500 g P_2O_5 and 2000 g K_2O/palm/year. The integrated nutrient treatments improved the soil pH, organic carbon content, available N, P and K content of the soil and the leaf NPK status (Nath *et al.,* 2012).

4.3.1). Coconut based cropping systems (CBCS)

The most important challenges in soil health management is the availability of the organic manure *in situ*. The high cost of external organic manure input considerably increases the cost of production of the produce which hinder the interest of the farmer to apply organic manure as per the recommended soil health management practices to improve the soil health. In this context, CBCS which involves cultivating compatible crops in the interspaces of coconut offers a plenty of biomass available *in situ* to meet the organic matter requirement and to maintain the soil health in a very economically profitable manner. Hence, this system offers a very practical solution to the challenges of the soil health management. The scientific approach in analysing the effect and identifying the best soil health management practices under this system will brighten the possibility of sustaining the soil health without compromising the productivity and profitability of the coconut plantations.

4.3.1.1). Effect on Soil moisture: Water requirement of any crop is very much influenced by the evaporative demand of the climate. When other crops are introduced under coconuts there will be a perceptible change in the microclimate of the area favouring a reduced rate of evapotranspiration. Consequently, the overall water use efficiency increases in a multi-cropping system and under certain situation, the combined water requirement of all the crops in the system may remain almost the same to that of coconut alone in the same area (Thampan, 1980). In a mixed cropping trial conducted at the CPCRI, Kasaragod, India, involving a crop combination of coconut, cocoa, pepper and pineapple, the observation over a period of seven years revealed that there was considerable reduction in the irrigation requirement once the crop-mix got established. Crop growth and productivity were not affected when irrigation was given at wider intervals as compared to the frequency adopted during the initial years of the trial (Nelliat, 1978). Beneficial changes in ecoclimatic parameters have been reported in coconut+cocoa combination compared to monocrop (Nair and Balakrishnan, 1977). The crop mixes recorded lower mean maximum temperature, higher relative humidity and reduced evaporative demand. Varghese *et al.* (1978) have reported that soil temperature at 30 and 60 cm depths was 3 to 6°C lower and the variation in the mean monthly soil temperature was the least in the mixed cropping system of coconut+cocoa compared to the monoculture of coconut.

4.3.1.2). Effect on soil fertility: The importance of intensive cropping lies in the nutrient economy as the extensive cover in the plantation floor increases the plant recycling fraction of nutrients (Khanna and Nair, 1977). Therefore, the nutrient requirement of the crops should be met with an appropriate INM practice tailor made based on the nutrient supply from the soil and through biomass recycling in the system. Hence, it is necessary that the dose of inorganic fertilizers recommended for each crop should be adjusted within the INM practice in order to maintain the soil fertility and productivity of the crops in the system. The amount of shed leaves collected in one year period amounted to 818 kg and 1785 kg/ha/year (oven dry), respectively under single and double hedge systems of cocoa. The recycling of the biomass in the system improved the organic carbon content and the soil fertility considerably under the mixed crop and was reflected in the enhanced yield of coconut. Based on the nutrient composition of the cocoa leaves, under the double hedge system, about 50 kg N, 11 kg P_2O_5 and 35 kg K_2O/ha/year were returned to the soil through leaf fall (Varghese *et al.*, 1978). In coconut based HDMSCS (Coconut based high density multispecies cropping system), the recyclable biomass available is the highest under INM practices comprising 2/3rd of recommended fertiliser and biomass recycling treatment in different crops compared to the other fertiliser treatments (Table 2) (Subramanian *et al.*, 2005).

Table 2. Total annual biomass available for recycling from 1 ha of coconut based HDMSCS under different fertilizer levels (t ha^{-1})

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

(Subramanian *et al.*, 2005)

Research findings have indicated that under coconut based HDMSCS and mixed farming systems, pepper variety Panniyur -1, clove and pineapple performed better under 2/3rd recommended fertilizer dose (CPCRI, 2004, Palaniswami *et al.*, 2007, Reddy *et al.*, 2002). Yield of coconut ('Laccadive Ordinary') was highest when INM comprising 50 per cent through organic waste recycling and 50 per cent of recommended dose through fertilizers were applied compared to only inorganic or organic sources were used (Maheswarappa *et al.*, 2001). Similarly when Bajra Napier hybrid - CO3 grown as intercrop in coconut garden under red sandy loam soil resulted in significantly higher fodder yield with the application of 50 per cent NPK through vermicompost and farm yard manure + 50 per cent NPK through chemical fertilizer and was comparable with fully organic treatments and significantly differed from only chemical fertilizers application (Subramanaian *et al.*, 2008).

The Hybrid Napier grass NB 21 and Guinea grass *(Panicum maximum)is* most productive under coconut, can add 50 tonnes of green fodder to the system per ha per year and also it can withstand prolonged cloudy weather prevailing in Malabar region during the rainy season (Maheswarappa *et al.*, 2001). In coastal sandy soil when hybrid bajra napier grown as intercrop with moisture conservation measures resulted in the green fodder yield of 92 t ha^{-1} $year^{-1}$ (Subramanian *et al.*, 2009). Investigation was carried out to study the impact of inorganic fertilizer substitutions by vermicompost on productivity of coconut under laterite soil. Among different combinations, application of vermicompost in combination with inorganic fertilizer either at 25 % Vermicompost (VC) + 75 % NPK (65 nuts) or 50 % VC + 50 % NPK resulted in significantly higher nut yield (Maheswarappa, *et al.*, 2011). Nutrient management for intercropping *Heliconia stricta* in the coconut garden was studied. Out of five treatment combinations it was found that application of vermicompost @ 200 g $plant^{-1}$ + neem cake @100 g $plant^{-1}$ is the best treatment for *Heliconia stricta* cv. Iris (Nihad *et al.*, 2013).

On root (wilt) disease affected palms of West Coast Tall variety, the effect of applying full dose of fertilizers (500:300:1000 g NPK/palm/ year) was compared with 50 % fertilizers + organic manures as vermicompost and incorporation of local variety of green manure cowpea (*Vigna unguiculata* L. Walp.) raised in the palm basin. The results showed an increase of 17 % in yield in palms receiving both fertilizers and organic manures compared to 7 % increase in palms receiving only fertilizers (Krishnakumar and Maheswarappa, 2010). The HDMSCS in root (wilt) affected region having various component crops such as elephant foot yam, pineapple, banana, black pepper and nutmeg were raised as component crops with coconut. The overall coconut yield under the system improved by around 17 % during the fourth year of experiment when compared to the initial yield of 53 nuts/palm due to the management practices including recycling of organic biomass produced through vermicomposting and basin raising and incorporation of green manure crop (Krishnakumar *et al.*, 2011).

4.3.2). Coconut based Integrated farming system

In addition to inorganic inputs, the animal activities contribute considerable quantities of animal biomass in the form of cow dung, poultry manure and urine and cowshed washings. Cowdung alone accounts for 14 tons, contributing to 98 kg nitrogen, 70 kg phosphorus and 105 kg potash.

Similarly poultry droppings recycled in to the system. The coir pith bedding material in the poultry sheds analysed 1.85 % N, 2.04 % P and 1.87% K. Vermicompost with 1.8 % N, 0.3% P and 0.6 % K can be produced with 70 per cent recovery from 2.1 tons of coconut leaflets produced in the system. This can supply 155.06 kg nitrogen, 76. 72 kg phosphorus and 141 kg potash. The requirement of inorganic inputs for one ha of coconut, fodder grass unit *viz.,* 210 kg N, 38.5 kg P and 173.8 kg K, respectively can be supplemented to the extent of 74.29, 100 and 81.78 % of N. P, and K through recycling of animal and plant wastes in one hectare of coconut garden (Table 3). By recycling on farm wastes, chemical fertilizer requirement is drastically reduced. In addition to this the soil health can be improved and productivity can be sustained (Khan *et al.,* 2002).

Table 3: Nutrient inflow in coconut based mixed farming system

Items	Quantity	N (kg)	P (kg)	K (kg)
A) Nutrient contribution by the components of the system				
Cow dung	14 tonnes	98.00	70.00	105.00
Poultry	295 kg	1.92	2.36	2.08
Cows urine and cowshed washings	50000 litres	30.00	-	28.00
Total		129.92	72.36	135.08
B) Nutrient substitution through recycling of the coconut fronds (minus petiole)				
Coconut Leaves (vermicompost)	1.45 tonnes	26.14	4.36	6.94
Total (A+B)		155.06	76.72	141.02
C) Inorganic addition to the system				
i) Coconut palms	0.5:0.32:1.2*	181.2	81.08	147.96
ii) Grass*	160: 20: 20	131.2	16.4	16.4
Total (i + ii)		312.4	97.48	164.36
Percent supplementation of inorganics through waste recycling				
Percent supplementation		74.29	Entire	81.78

(Source: Khan *et al.,* 2002)

Apart from improving the soil nutrient status, biomass recycling in the mixed farming system generally improves soil physical properties besides improving the productivity of coconut. Improvement in soil physical properties were observed by adopting mixed farming system. There was build up of organic carbon, N,P,K and Fe status in soil whereas there was decrease in the available Ca, Mg,Mn,Cu and zinc. The leaf nutrient status and yield was observed to be improved (Maheswarappa *et al.,* 1998). Studies conducted at CPCRI kasaragod under coconut grass system where recycling of organic wastes was carried out and the results revealed that there was enrichment of organic carbon, nitrogen, manganese and copper in the surface soil. Whereas potassium, calcium, phosphorus and magnesium were on net loss over control (Biddappa *et al.,* 1993). Field experiment on studying the effect of application of composted coir pith (CCP) alone and in combination with NPK (50%) resulted in the increase in organic carbon of the soil and higher K content of coconut leaf. The nut yield produced with the application of CCP +NPK was significantly higher compared to other treatments (Upadhyay *et al.*, 2009). Increase in maximum water holding capacity of soil (from 24.0 to 33.6%), improvement in porosity of soil (38.2 and 39% 44.5 and 46.0%) and reduction in bulk density of soil (1.54 g cc^{-1} to 1.40 g cc^{-1}) both in coconut manuring circles (basins) and grass cultured plot. Higher water holding capacity, reduction in the bulk density and higher hydraulic conductivity was observed under mixed farming treatments compared to monocropping of coconut (Palaniswami *et al.,* 2008).

4.4). Soil Rhizosphere management

Organic manure application improves the soil microbial properties. Addition of organic manures like vermicompost, coir pith compost, farm yard manure, neem cake, green manures etc. favours the growth of beneficial microorganisms like nitrogen fixers, phosphate solubilizing bacteria in the rhizosphere as well as VA-mycorrhizal colonization in the coconut rhizosphere. These organic manures can be applied along with biofertilizers. Coir-pith compost and other coconut wastes enriched with nitrogen-fixing bacteria like *Beijerinckia indica* and also phosphate-solubilizing bacteria, improves the microbial activity in coconut basins. The recommended dose of biofertilizers for coconut is 100g of carrier based inoculant per palm. Biofertilizers should be applied in the coconut basin, twice in a year (pre-monsoon and post-monsoon), by mixing with top soil followed by application of organic amendments such as vermicompost @ 20 kg/coconut palm (Alka Gupta *et al.*, 2010).

In situ N-mineralisation in the Coconut Based Cropping System with clove, banana and pineapple as component crops where the wastes produced were vermicomposted and applied to all crops was studies by

Palaniswami *et al.*, (2010). The results showed that the rate of N-mineralisation was higher in coconut basin area (2.2 ppm –N per day) upto 1/3rd of recommended fertiliser dose. However, in lower dose of fertilizer, clove soil had higher N- mineralisation rate (3.43 ppm –N per day).

Associative N_2 fixing *Azospirillum* spp. was found colonising the roots of coconut and black pepper in varying intensities under different cropping systems such as HDMSCS, multi-storeyed cropping and mixed farming (Ghai and Thomas, 1989). They exhibited significant level of nitrogenase activity thereby contributes substantial amounts of nitrogen to the cropping system by way of biological nitrogen fixation. The isolates from coconut roots were identified as *Azospirillum brasilense* and those from black pepper as *Azospirillum lipoferum.* A sp. of *Beijerinckia* was found to be the dominant N-fixing bacterium in the rhizospheres of coconut and cocoa as well as on the root surface. A *Pseudomonas* sp. and *Aspergillus niger* isolated from coconut rhizosphere have the ability to solubilise tricalcium phosphate. *A*n isolate of *Escherichia* sp. was found closely associated with the root surface. Two isolates, *Aspergillus flavus* and *A. fumigatus,* produced Gibberellin like substances (GLS) (Nair and Rao (1977a and b).

Even under coconut root (wilt) affected condition, compared to monocrop, coconut intercropped with fodder hybrid enhanced phosphate solubilizing bacteria in root region of the palm (Potty and Jayasankar, 1976, Potty *et al.,*1977*)*. Increase in the beneficial microflora was observed in the root (wilt) affected area while adopting mixed farming practice. The highest number of soil bacteria was observed in *Stylosanthes* gracilis plots. But the nitrogen fixing organisms were maximum in the hybrid napier + *Centrocema pubescens* plots. With low level of denitrifiers and comparatively high proliferation of nitrifiers observed in the hybrid napier + *S. gracilis* combination proved to be the best among other combinations (Sahasranaman *et al.,* 1983). Bopaiah and Shetty (1991) found that bacterial counts were higher in the roots of coconut and Napier grass of mixed farming than in coconut monocropping. The microcroflora and enzyme activities decrease with increasing depth. The bacteria and fungi counts were more in the root region of grass-cultured plots compared but the actinomycetes count did not show much variation between mixed farming and monocropping system. The nitrogen fixer and phosphate solubilizing bacteria were more in the mixed farming system as compared to coconut monocropping system. Addition of dairy and poultry wastes resulted in higher organic carbon (%) content of the soil in the mixed farming system which favours beneficial microbial. Urease, dehydrogenase and phosphatase enzyme found to be greater in the rhizosphere soil than in the root zone soil which indicates that the soil biological activity is good under mixed farming system.

Higher microbial biomass carbon and dehydrogenase activity observed in the root zone of coconut/ Napier grass in the mixed farming than in coconut in the monocropping system. The microbial distribution in the coconut basin and the interspaces in the coconut garden (Table 4) showed that all the three microbial population bacteria, fungi and actinomycetes were found to be very high in the mixed farming with 100% organic farming treatment followed by the 50% organic substituted treatment and the population was low in inorganic fertilizer alone applied treatments (Palaniswami *et al.*, 2008).

Table 4. Microbial activity in the coconut based mixed farming sytem

Treatments	Bacteria (10^5 cfu/g soil)		Fungi (10^3 cfu/g soil)		Actinomycetes (10^5 cfu/g soil)	
	Coconut basin	Inter space	Coconut basin	Inter space	Coconut basin	Inter space
T1-monocrop + Recommended fertilizer	13.45	10	6.86	4.16	9.62	6.16
T2- mixed farming+50% Organic + 50% Inorganic	18.22	21.64	6.6	7.23	7.83	8.35
T3- mixed farming + 100% organic	23.17	29.22	18.16	19.31	11.33	14.26
T4- mixed farming +100% Inorganic	11.76	14.66	7.12	8.35	7	12.94

(Source: Palaniswami *et al.*, 2008)

A study conducted to isolate and identify spore associated bacteria (SAB) and evaluate their functional role in AMF-host interactions with respect to germination of spores in Coconut based cropping systems under organic management practices in farmer's field in Kasaragod district, Kerala and high density multi species cropping system (HDMSCS), CPCRI farm. The results revealed that AMF spore load of a particular cropping system increase with the number of intercrops. Spore associated bacteria (SAB) were isolated from the cytoplasm of surface sterilized spores of *Glomus* and *Gigaspora* spp. Identification based on BIOLOG and 16S rRNA sequencing revealed the presence of bacteria - *Citrobacter amalonaticus, Staphylococcus arlettae, Bacillus subtilis, Bacillus amyloliquefaciens,* in association with spores of *Glomus* spp. *Corynebacterium coyleae, Bacillus cereus* and *Bacillus subtilis* were found to be associated with *Gigaspora* spp. *In vitro* studies to determine the germination potential in spores showed the maximum results with *Bacillus cereus* GiPHD1 and *Citrobacter amalonaticus* GLNCB1 with 40% increase over control (Ambili *et al.*, 2012). Zaidi *et al.*, (2009) reported that among the heterogeneous and naturally abundant microbes inhabiting the rhizosphere, the phosphate solubilizing microorganisms (PSM) including bacteria have potential to meet the P demands of plants in sustainable agriculture. Phosphate solubilizing microorganisms were found to be widely distributed in coconut growing soils (Thomas *et al.*, 1991) and the predominant bacteria solubilizing phosphate in coconut soils were *Pseudomonas* spp. and *Bacillus* spp. (Nair and Subba Rao, 1977).

In the rhizosphere of vanilla grown as intercrop in coconut under different organic manure application, no significant difference for either bacterial or actinomycetes population was noticed among the treatments. The fungal population differed significantly among the treatments and the highest population level was found with application of biogas slurry (62.1x103 cfu g^{-1} soil), which was on par with application of cow dung slurry (59x103 cfu g^{-1} soil). The highest population of P-solubilisers (98x103 cfu g^{-1} soil) was recorded in the biogas slurry treatment, and it was the lowest in control and vermiwash application treatments (Maheswarappa *et al.*, 2016).

4.5). Organic farming strategies

Organic farming has been driven mainly by the growing consumer demand for organic produces and also the growing interest in the soil health management to improve and sustain the productivity of the soil. The fundamental target on the organic farming is to produce crop with minimal or no synthetic chemical inputs. The basic concept in nutrient management under organic farming is to efficiently manage the natural resources available in the farm through biomass and animal waste recycling and soil nutrient release through biological agents, addition of nutrients through biological nutrient fixers etc.

Effect of organic source of nutrition when vanilla is grown as intercrop in coconut garden was studied in sandy loam soil. Among the different sources of organic manures, recommended NPK fertilizer and no fertilizer treatments tested application of cow dung slurry (6 tonnes ha^{-1}) resulted with significantly higher mean fresh yield of bean followed by the application of vermicompost (5 kg $plant^{-1}$) + biofertilizers (*Bacillus* and *Azospirillum*) and vermiwash which were on par (Maheswarappa *et al.*, 2016). Effect of different nutrient management strategies were studied in the HDMSCS model comprising coconut, black pepper, pineapple, banana, clove, annual crops like, turmeric, ginger and vegetable crops (brinjal, pumpkin, and elephant foot yam), sweet corn and baby corn which were grown in the space available during different seasons. Three treatments *viz.*, T1: 2/3rd of recommended NPK fertilizer + recycling biomass (vermicompost), T2: 1/3rd of recommended NPK fertilizer + recycling biomass (vermicompost) + bio-fertiliser + green manuring +vermiwash and T3: Fully organic with recycling biomass (vermicompost) + bio-fertiliser + green manuring + vermiwash+ husk burial + mulching coconut basin were tested. Coconut yield indicated non significant difference among the treatments. Hence, fully organic management could produce comparably similar yield of inorganic fertilized plots and highest economic return (Maheswarappa *et al.*, 2013).

4.6). Site specific nutrient management

In agriculture, the present goal of sustainable high productive agriculture needs scientific management of the soil resources for the agricultural growth to ensure food security for now and in future. Factors affecting crop yield and quality are site specific (Reetz and Fixen, 2000). Spatially and temporally dynamic soil management practices are two important factors in a successful site-specific management strategy. Identifying spatial variability in soil fertility is important to rationalize nutrient use and optimize productivity especially in the case of existing perennial plantations like coconut.

The plantation crops like coconut being perennial in nature mine nutrients from limited volume of soil for a long time and hence, to sustain the high productivity, soil nutrients status should be monitored and have to be replenished. A survey to assess and map the soil fertility status was carried out in the coconut plantations of Coimbatore and Tiruppur districts of Tamil Nadu state, India. Thematic maps on soil fertility constraints were prepared. The developed maps showed that 62 and 30 per cent of soils of coconut land cover found to be in moderately alkaline and alkaline conditions respectively. Around 96 per cent area was in non-saline condition. Organic carbon status was low in 65 per cent of the coconut land cover. Available N, P, and K were low in 65, 0.8 and 0.02 per cent area respectively and S was deficient in 0.05 per cent area. Fe deficiency was recorded in 7 per cent of the area and there was no Mn deficiency in the study area. Available Zn, Cu and B were deficient in 89, 62 and 5 per cent area respectively. Leaf nutrient testing will be a promising tool to identify the existing crop nutrition related constraints in the perennial plantations like coconut and site specific nutrient management options to improve the crop productivity. The nutrient deficiency maps were developed for macro and micronutrient management. Thematic maps showed that N status was deficient in 95.99 per cent, P in 86.19 per cent, K in 1.42 per cent and Mg in 0.81 per cent area of the coconut land cover area. Ca and S were observed to be sufficient. Fe was found to be deficient in 0.64 per cent, Mn in 0.84, Zn in 0.54 per cent, Cu status in 2.62 per cent and B in 10.72 per cent of the coconut land cover area (Selvamani, 2014a & b).

Micronutrients play a significant role in nutrition of coconut plants. There are reported incidents of Copper (Cu) and Zinc (Zn) deficiency in the coconut triangle in Sri Lanka. A study was conducted to determine the Cu and Zn contents in soil and coconut leaves in the coconut triangle. The results revealed that, 72.27% and 37.96% soil samples were below the critical Cu level of 0.4 mg/kg and Zn level of 0.5 mg/kg, respectively. Moreover, 68% and 84% leaf samples were below the critical Cu level of 5 mg/kg and Zn level of 30 mg/kg respectively. There was a significant positive correlation $(p<0.05)$ between soil pH and Zn content in top and sub soils. Cu content in top soil showed a significant positive correlation with organic carbon content $(p<0.05)$. Therefore, Cu and Zn levels in some of the areas in the coconut triangle, are deficient and the availability of these nutrients depend on pH and organic carbon of the soil (Jayasinghe *et al.*, 2014).

The spatial information on soil properties is very useful in formulating site specific nutrient management strategies to improve the coconut productivity by addressing the site specific soil constraints.

5). Soil quality management for the environmental protection

The coconut based farming systems serves as a buffer against drastic changes in ecoclimate which will have considerable effect on the various biological processes occurring in the rhizosphere of crops (Nair and Balakrishnan, 1977; Varghese *et al.*, 1978). The direct percolation loss of 113.8kg K ha^{-1} in a pure stand of coconut is reduced to 54.5 kg ha^{-1} in the case of crop combinations. The better exploration of the soil volume by roots in crop combination may possibly reduce the loss of nutrients through percolating water (Khanna and Nair, 1977).

5.1). Erosion: An experiment conducted at CPCRI Research Centre, Kidu at an elevation of 219 m above MSL and has a slope of 12-16 %. The average rainfall received at the experimental location was around 4000 mm. The experiment was conducted to study the effectiveness of various soil and water conservation measures like half moon type with pineapple border, Catch pit with pineapple border, trench filled with coconut husk with 2 lines of pineapple,+border, drip irrigation daily @ 66% of EO for coconut with grass in the interspace, cover crop with vegetables and irrigation as per farmers practice with grass in the inter space. Runoff is one of the ways the nutrients are lost from the plantations. In coconut plantations it was observed that trench filled with coconut husk with 2 lines of pineapple border recorded the lowest soil erosion (0.20 t/ha) and runoff (18.45 mm). The runoff ranged from 18.45 mm in trench filled with coconut husk with two lines of pineapple border to 237.49 mm in absolute control treatment. The runoff water analysis observed that mean content of NPK were ranged from 1.57 – 3.81, 0.11 –5.27 and 5- 12 ppm NPK respectively. The sediment yield varied from 300 ppm to 2986 ppm. The nutrient loss ranged from 0.36 kg ha^{-1} to 7.98 kg ha^{-1} N, 0 .04 kg ha^{-1} to 12.52 kg ha^{-1} P and 1.11 kg ha^{-1} to 28.50 kg ha^{-1} K. The least soil loss was observed in the treatment, husk filled in trench with pineapple border. The highest runoff was observed under the control treatment where no conservation measures were taken up (7.23 t/ha) followed by the vegetable intercrop. In the plot where vegetable was grown for dual purpose (soil conservation and extra income) the crop failure and soil disturbance led to more run off and soil loss. The soil loss observed under grass plots was in the medium range compared to different treatments, which may be attributed to the soil disturbance for fertilizer/ manure application to the grass. In general, with increased runoff percentage the soil loss also increased. The least soil loss was observed in the treatment husk filled in trench with pineapple border. Among the different treatments, husk filled in trench with pineapple border was observed to be the best in soil and water conservation measure. The cultural operation where soil is disturbed increases the soil loss during the monsoon season. Performance of grass is better during summer than other seasons (Dhanapal *et al.*, 2002).

5.2). Pollution: Toxic levels of non essential trace elements like Al, Ba, Cd, Cr and Pb would interfere with the plant nutrition through competition for uptake, inactivation of enzyme, displacement of essential elements from functional sites (Epstein, 1969). Heavy metals interact with micronutrients at the solution phase and root surface or at the translocation phase from roots to leaf. The influence of root feeding of Cd, Al, Cr, Ba, Bi and Pb on the micronutrient concentration in coconut crown was studied by Biddappa *et al.,* (1988). They observed that in general, the concentration of Fe, Mn, Zn and Cu increased due to heavy metal root feeding. Significant higher concentration of Fe in coconut leaf was observed under Cr root feeding. Similarly increase in leaf Mn due to Bi, leaf Zn due to Ba and leaf Cu due to Pb root feedings were also recorded.

The heavy metal status of coconut growing soils of Kerala showed significantly higher content of DTPA extractable Ba, Cr, Cd, Pb, Sr and V in soils under coconut root (wilt) disease compared to healthy area (Biddappa and Khan, 1985). Deposition of heavy metals was observed in root (wilt) diseased palms in the studies using scanning electron x-ray microprobe analyser (Biddappa and Cecil, 1984 and Biddappa,1985). High deposition of Al, Mn, Cu, and Co in the roots and Cr, Ti, Pb, Bi and Ga in the cabbage tissues of diseased palms was also found in comparision with the identical tissues of healthy palms. Valiathan *et al.* (1992) reported lower level of magnesium and higher concentrations of cerium in the leaves of root (wilt) diseased coconut palms. The possibility of Cd and Sr toxicity was ruled out in the disease complex (Verghese, Sankaranarayanan and Menon 1957, 1959b). Studies involving the energy dispersive X-ray fluorescence technique in the non-nutrient elemental composition of soil (0-30 cm) and plant tissues of healthy and root (wilt) diseased palms from a few selected locations indicated that Ni and Sr were present at a higher concentration in the root of diseased palms compared to healthy (Wahid *et al.,* 1983). Foliar levels of rare earth elements Gadolinium (Gd) was significantly less in palms of root (wilt) disease affected tract than in those of healthy tract (Wahid *et al.,* 1998).

5.3). Carbon sequestration: Climate change will affect coconut through higher temperatures, elevated CO_2 concentration, precipitation changes, increased weeds, pest, and disease pressure, and increased vulnerability of organic carbon pools. But, yields are projected to go up in Kerala, Tamil Nadu, Karnataka and Maharashtra. Apart from this coconut plantations especially under coconut based cropping system are a prominant system to sequester the carbon in the above ground standing biomass as well as in the belowground. Carbon sequestration in the soil organic carbon pool is appreciable in the coconut based cropping system.

Increased sequestration of C in agricultural soils has a potential role to reduce the climate change caused by the rising atmospheric carbon level. Evaluating the best crop management practices that can enhance soil organic carbon (SOC) sequestration will improve the amount of carbon fixed as SOC. Moreover, increased SOC improves soil structure, fertility, and water-holding capacity and thereby enhances and sustains the soil health and crop productivity. In the integrated nutrient management experiment, after organic recycling, builtup of soil carbon in coconut basin was observed (Palaniswami *et al.*, 2010).

Investigation was conducted at Horticulture Research Station, Arasikere, Karnataka, during *kharif* and *summer* seasons of 2012-14 to study the performance of different cropping sequences with vegetable crops and effect of integrated nutrient management practices on soil carbon sequestration and above ground carbon sequestration under coconut based cropping system (CBCS). The study revealed that Carbon sequestration by coconut palm (above ground) was the highest under CBCS when compared to monocropping. Soil carbon sequestration recorded at 0-15 cm depth was significantly the highest under S_4 treatment (Organic alone-5 ton FYM+50% N by vermicompost+50% N by CCP+vermiwash spray + Azatobacter) (10.30 Mg C/ha and 10.74 Mg C/ha during 2012-13 and 2-13-14) and M_2S_4 interactions (green manure-cucumber and organic alone) (11.56 Mg C/ha) when compared to other nutrient management practices (Naveen Kumar, 2015).

6). Future strategies in soil health management

Since, soil properties are spatially and temporally highly dynamic, the response for any soil management intervention will be site specific. Hence, the soil management strategies should be tailor made for each condition. Precision soil management at farm level to address the within farm variation in the soil properties coupled with the strategies to ensure the supply of the required crop nutrient all through the year for coconut will be the state of the art technology. Considering the practical implications existing at present in developing these technologies and putting into practice in the farmers field, variable technologies to address the variations among the regional level relatively homogeneous soil management units will be a considerably better strategy. Basic studies on the interactions between the factors influencing the nutrient uptake by coconut will enhance our efficiency in developing advanced management practices to improve productivity across various soil types. Strengthening the research in improving the nutrient use efficiency through nanofertilizer techniques may be useful to ensure nutrient supply and reducing the nutrient losses. Further strengthening the research on supplying balanced and sufficient nutrition through organic farming in order to maintain the higher yield and soil fertility in a long run, is having the potential to meet the growing demand for the organic products without risking the soil fertility.

Developing soil management techniques using the scientific advancement in the area of nanoscience, sensors and communication technologies will enable the farmers to harness the anticipated technological boom in those sectors into coconut farming.

7). Summary and conclusions

Coconut is an important crop which is grown in many countries and providing livelihood to the poor farmers. To improve the coconut productivity, the innate soil constraints should be ameliorated. The red, lateritic and sandy coconut soils are suffering with soil acidity, low CEC and poor nutrient reserve. Long term researches have shed the light on importance of manuring to coconut from the observed highly positive yield response and soil fertility improvements for the manuring. Studies on nutrient removal by coconut provides guidelines for the fertilizer input required. The effect of soil nutrient imbalance on the availability of nutrients emphasize the need based balanced fertilizer supply to coconut soils. The built up of soil available P in acidic red soils under continuous phosphatic fertilizer application strengthens the need to realize the soil test based fertilizer application. The potassium supply in the acid soils are poor, coconut being a huge feeder of potassium needs constant supply of potassium. Secondary and micronutrient deficiencies are emerging as potential yield limiting nutrients for coconut. Biomass recycling studies under coconut based cropping systems shows promising results in achieving the nutrient supply with the available biomass. Minimising the biomass exported out of farm especially coconut husk may improve potassium supply to palms through organic farming. Microbial studies showed that biomass recycling improved the beneficial microorganism in the rhizosphere and thereby enhances the nutrient availability. Fertigation technique showed higher nutrient use efficiency. Soil and water conservation measures improved the yield of coconut in sandy soil and checks the losses through run off and erosion in sloppy soils. Site specific soil management strategies can improve the coconut yield in an eco-friendly way.

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