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Diagnosis and management of soil fertility constraints in coconut (*Cocos nucifera*) : A review

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ABSTRACT

Coconut (*Cocos nucifera* L.) is an important perennial plantation crop and to improve the 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. A study 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 is 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 recycling through vermicompost. Minimizing 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.

Key words: Biomass, Coconut, Fertigation, Nutrient management, Soil health, Vermicompost

The coconut palm (*Cocos nucifera* L.) globally cultivated in around 93 countries and in India, it is grown in 2.1 million ha (2015-16, 3rd estimates) with a production of 14 075 million nuts and an average productivity of 6 702 nuts/ha/year (CDB 2016). 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. 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 foreward in ensuring sustained higher coconut productivity and livelihood of coconut farmers.

Soil requirement

Red and lateritic 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. 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).

The depth of the soil is one of the important soil physical criteria for the sustained productivity. Around 73% 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% of the roots present in 0-120 cm depth (Maheshwarappa *et al.* 2000). More number of main

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roots was found in 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 (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.

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 and Nair 1952). Coconut can be cultivated in the soil pH range of 5 to 8 (Manciot *et al.*1979). Coconut being a semi-halophytic plant can tolerate soil salinity up to 0.6% which is beyond tolerable limits to many other crops. Hence, the total soluble salts in the soil are not a serious problem for coconut cultivation (Sankaranarayanan *et al.* 1958).

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. Since, coconut is grown in the tropical condition most of the soils are 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% organic carbon for coconut soils. The soil nitrogen supply is directly related to the soil organic fractions whereas, soil phosphorus level does not pose a serious problem to coconut cultivation and adequate potassium supply must be ensured for higher coconut productivity. Among the secondary and micronutrients, 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.

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 and suffer from varying degree of nutrient/moisture stress.

Physical constraints

Coconut grown under coastal sandy soil without manuring results in lower yield due to poor physicochemical 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 of 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 loses of applied nutrients during monsoon and severe moisture stress during summer. Improvement of the soil organic matter content is a pre-requisite 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. Incorporation 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 roots in two soil series, namely, *Andigama* series (gravelly soil) and *Madampe series* (sandy loam soil) 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 (Arachchi and Liyanage 1996).

Soil acidity and salinity related constraints

Soil acidity: Almost all red and lateritic soils under coconut, which are formed under humid tropical conditions, have $A1^{3+}$ as the dominant cation, and hence, their pH is very low (4.2-5.8). 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 aluminium 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.

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. Application of more organic matter in the planting pits along with soil-sand mixture in equal amounts also observed to reduce the salt problems.

Soil fertility constraints

Generally, the sandy soils contain very low amount of soil nitrogen and 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. 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 was 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.

SOIL HEALTH MANAGEMENT

Nutrient requirement

Quantification of nutrient exhaust usually provides 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 02:1:3. 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, 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* × *Typica* coconut palms yielding an average of 17, 38 nuts/ha/year in Sri Lanka, were 116.79 kg N, 14.02 kg P, 245.43 kg K, 40.47 kg Ca, and 33.66 kg Mg/ha/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 / ha/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 but the average removal from red sandy loam and laterite was around 53 kg K_2O/ha (Ramanandan and George 1982). Variation in the capacity of nutrient removal pattern depending upon targeted yield has been documented in horticultural crops including plantation crops. Removal of K from soil was observed to be 3-4 times higher in perennial crops than N and P compared to annual crops. Hence, nutrient removal patterns uphold two cardinal points, one in many crops magnitude of removal of K is higher than N or P and two that highlight towards necessity of tailoring fertilizer requirement as per crop. In a study made in India, considering the nutrient removal rate projections, in the year of 2016-17, the fertilizer requirement for horticulture crops will be 7.56 million tonnes (Malhotra and Srivastava 2015).

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/year as compared to fertilizer treatments coupled with cultural practices which produced yields ranging from 83-107.9 nuts/palm/year, 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). Fertilizer management technologies have been developed for different horticulture crops in the different countries and provinces based on scientific principles (Srivastava and Malhotra 2014, Meena *et al.* 2006, Aishwath and Malhotra 2013). Optimum requirement of fertilizers for different fruits and vegetable crops have been worked out by different workers and described in the review (Malhotra and Srivastava 2015). Inorganic and organic fertilizer can be found in different types of products like compound, straight, controlled released, blended, granulated, water soluble and liquid fertilizer (Malhotra 2016, Srivastava *et al*. 2014, 2015). The liquid fertilizers, as special class of fertilizers provide an enormous possibility of tailoring nutrient use across critical growth stages, a pre-requisite for better nutrient-use-efficiency. Customized fertilization/ fertigation is another potential reality, besides its suitability in site specific nutrient managements. In this background, these issues have been addressed in the review (Malhotra, 2016).

Primary nutrients: 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 of available P in the plot received fertilizer application of 437g and it was 253 Mg/kg when 218 g of P/palm/year was applied. Whereas, the soil available P content in the unfertilized plot was only 36 Mg/kg (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 (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 situ N-mineralization 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 studied by Palaniswami *et al.* (2010). The results showed that the rate of N- mineralization was higher in coconut basin area (2.2 mg/kg –N/day) upto $1/3^{rd}$ of recommended fertiliser dose. However, in lower dose of fertilizer, clove soil had higher N- mineralisation rate (3.43 ppm–N/day).

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/year in the 21^{st} year after planting under no fertilizer, 450 g K_2O and 900 g K_2O/palm/year, 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.

A long-term experiment conducted Kasaragod in littoral sandy soil indicated 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/yr (Srinivasa Reddy *et al.* 2001).

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 × T hybrid was relatively lower than that of Talls to produce the same quantity of yield. Tall × Dwarf hybrid behaved intermediate between D x T 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.

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% NPK fertigation (131 nuts/palm/year) which was on par with 75 and 50% NPK applied through drip irrigation. Hence, through fertigation 50% 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% NPK through drip irrigation which was on par with 75% NPK compared and application of 25 and 50% NPK through drip irrigation, net returns and benefit-cost ratio in 75% NPK through drip irrigation were on par with the application of 100% NPK through drip irrigation, but significantly higher than 100% NPK through soil application. Hence, indicated the possibility of saving 25% 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).

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.

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.

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 to 121 ppm when annual fertilization of P was done at the rate of 320 g P_2O_5/palm for 14 years. But in plots where P was not applied, it had been decreased from 84 to 21 ppm during the same period which emphasise P application should be regulated constant monitoring on built up through soil testing. They suggested that the P application should be skipped at the level of 20 ppm 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% 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 and Jacob 1982). 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.* 1979 a). 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).

Deficiency and management

Based on long-term observations, 70-80 ppm of mineralizable nitrogen in the main fertilizing zone of coconut basin (1.8 m radius from bole) is found to be adequate for optimum nutrition with reference to N. Soil P level of 10 ppm (Bray-1) can sustain sufficient level of P in palm and 50-68 ppm of soil available K was observed as critical limit (Khan *et al.* 1986). It has been recommended that when the available soil P (Bray-I) in the 0-90 cm soil is less than 10 ppm the full recommended dose of 320g P_2O_5, and if it is between 10 and 20 ppm, a maintenance dose of 160g P_2O_5/ppm/year may be applied. If it is more than 20 ppm, P application can be skipped. A foliar content of 0.11-0.12% P (frond 14) can be regarded as critical for coconut under Indian conditions (Khan *et al.* 1990). A nutrient spray to the foliage will provide the needed nutrients immediately, allowing the plants to begin growth. Under certain conditions, foliar application is considered better than conventional soil application (Malhotra 2016) like; acute shortage of nutrient supply, nutrient imbalances, nutrient either absent or immobilized and nutrient imbalances.

Regarding the critical limits of leaf nutrient status, Cecil (1984) suggested 0.3% Ca in frond 14 as critical level for regulating the Ca requirement of the palm under West Coast conditions of India. Cecil (1981, 1988) suggested that a critical level of 1.8-2.0% N, 0.12% P, 0.8-1.0% K, 0.3% Ca, 0.2% Mg and 0.15% S (frond 14) may be adopted as a diagnostic aid for regulating nutrition of the palm under West Coast condition of India. Pillai *et al.* (1975) reported mean values of 6.5 – 7.7 ppm Cu and 8.8 – 11.9 ppm Zn. 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% respectively for leaf N, P, K, Ca, Mg and S. Similarly the critical limits for the micronutrients 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.

Leaf analysis enables us to directly measure the nutritional status of the palms then nutrient supply 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% N, 0.12% P, 0.8–1.0% K, 0.50% Ca, 0.30% 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).

In the state of Asom and West Bengal the available boron content is below the critical limit (Chakrabarthy *et al.* 1970). In Kerala 12% 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 in CPCRI (RS) Kayangulam showed that boron deficiency causes reduction in coconut productivity and the deficiency could be cured by the application of 300 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). In Asom also deficiency of B symptoms were recovered by the application of borax in the farmers field (Indrajit Barman *et al*. 2008). 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). 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.

Biomass recycling and INM

Recyclable biomass in the form of leaves, spathe, bunch waste, husk of nuts are available in coconut garden. Along with this, biomass 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. At CPCRI, scientists have identified a local strain of earthworm related to African Night Crawler (*Eudrilus* sp.) which is quite efficient in converting coconut leaves into granular vermicompost (Prabhu *et al.* 1998). 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. 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 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. 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. The highest yield was observed where 50% N was substituted through Glyricidia along with 50% of N, full dose of P and K through chemical fertilizers (Subramanian *et al.* 2005).

Application of recommended dose of chemical fertilizers with 20 kg of organics resulted in 60% increased nut yield over control (Srinivasa Reddy and Upadhyay 2002). Application of 50% of N as composted coir pith along with 50% of recommended dose of chemical fertilizers recorded higher nut yield. Application of 100% composted coir pith/palm/year on N basis or application of 50% composted coir pith + 50% of recommended dose N, P_20_5 chemical fertilizers was optimum for getting maximum nut yield (Venkitasamy and Khan 2002). 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).

The effect of integrated nutrient management on COD × WCT hybrid coconut with different combinations and three levels each of N (0, 500, 1 000 g/palm/year, where 50% N was substituted by vermicompost on N equal nutrient basis was studied. The highest average nut yield of 111nuts/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 2 000 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). Influence of 25 or 50% of N equivalent in the form of vermicompost along with 50% of recommended NPK has resulted in higher nut yield (Maheswarappa *et al*. 2011).

Coconut based cropping systems (CBCS): The most important challenges in soil health management are 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 hinders 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 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.

(i) 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 1981). 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.

(ii) 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 is 818 kg and 1,785 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 fertilizer treatments (Subramanian *et al.* 2005). Under coconut root (wilt) affected garden also Maheswarappa (2008) reported considerable biomass from the cropping system including weed biomass, which can be recycled in the form of vermicompost.

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 the highest when INM comprising 50% through organic waste recycling and 50% 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 CO 3 grown as intercrop in coconut garden under red sandy loam soil resulted in significantly higher fodder yield with the application of 50% NPK through vermicompost and farmyard manure + 50% NPK through chemical fertilizer and was comparable with fully organic treatments and significantly differed from only chemical fertilizers application (Subramanian *et al.* 2014).

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/year (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 + neem cake @100 g/plant is the best treatment for *Heliconia stricta* cv. Iris (Nihad *et al.* 2013).

On root (wilt) disease affected coconut 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 (Maheswarappa 2008 and Krishnakumar *et al.* 2011).

Coconut based integrated farming system: In addition to inorganic inputs, the components of the system, viz. the animal activities viz*.,* 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 tonnes, contributing to 98 kg nitrogen, 70 kg phosphorus and 105 kg potash. Similarly poultry droppings recycled in to the system. Vermicompost with 1.8 % N, 0.3% P and 0.6 % K can be produced with 70% recovery from 2.1 tonnes of coconut leaflets produced in the system. This can supply 155.1 kg nitrogen, 76.7 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. The coir pith bedding material enriched with poultry droppings in the poultry sheds had 1.85 % N, 2.04 % P and 1.87% K and was recycled in the sytem. 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, Maheswarappa *et al*. 1998 and 1999). 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 was 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 and Subramanian *et al*. 2014)**.** 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). Increase in maximum water holding capacity of soil (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 to 1.40 g/cc) both in coconut manuring circles (basins) and grass cultured plot was noticed under mixed farming treatments compared to monocropping of coconut (Palaniswami *et al.* 2008).

Soil rhizosphere management

Addition of organic manures like vermicompost, coir pith compost, farmyard 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 and 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- and post-monsoon), by mixing with top soil followed by application of organic amendments such as vermicompost @20 kg/palm (Alka Gupta *et al*. 2010). 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).

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 therby 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 species 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. An 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).

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. Increase in microbial population under integrated farming system has been reported by Subramanian *et al*. (2014).

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)**.** 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 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).

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. *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). Maheswarappa *et al*. (2014) have reported higher population of fungi and phosphate solubilizers in the vermicompost treated rhizosphere of coconut basin. 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 (62.1×103 cfu/g soil), which was on par with application of cow dung slurry (59×103 cfu/g soil). The highest population of P-solubilizers (98×103 cfu/g soil) was recorded in the biogas slurry treatment, and it was the lowest in control and vermiwash application treatments (Maheswarappa *et al.* 2016).

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. Among the different sources of organic manures studied on the performance of vanilla crop grown as intercrop in coconut the results revealed that, application of cow dung slurry (6 tonnes/ha) resulted with significantly higher mean vanilla fresh yield of bean followed by the application of vermicompost (5 kg/plant) + 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) + biofertilizer + green manuring +vermiwash and T3: Fully organic with recycling biomass (vermicompost) + biofertilizer + green manuring + vermiwash+ husk burial + mulching coconut basin were tested. coconut yield indicated non significant difference among the treatments. Hence, fully organic nutrient management could produce comparably similar yield of inorganic fertilized plots and the highest economic return (Maheswarappa *et al.* 2013). Application of nutrients through organic sources in coconut based integrated farming resulted in increase in the microbial population (Subramanian *et al*. 2014).

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.

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. The developed maps showed that 62 and 30 % of soils of coconut land cover found to be in moderately alkaline and alkaline conditions respectively. Around 96% area was in non-saline condition. Organic carbon status was low in 65% of the coconut land cover. Available N, P, and K were low in 65, 0.8 and 0.02% area, respectively, and S was deficient in 0.05% area. Fe deficiency was recorded in 7% 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% 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%, P in 86.19%, K in 1.42% and Mg in 0.81% area of the coconut land cover area. Ca and S were observed to be sufficient. Fe was found to be deficient in 0.64%, Mn in 0.84, Zn in 0.54%, Cu status in 2.62% and B in 10.72% of the coconut land cover area (Selvamani 2014a and 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).

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 113.8 kg K/ha in a pure stand of coconut is reduced to 54.5 kg/ha 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).

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 4 000 mm 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 2 986 ppm. The nutrient loss ranged from 0.36 kg/ha to 7.98 kg/ha N, 0 .04 kg/ha to 12.52 kg/ha P and 1.11 kg/ha to 28.50 kg/ha 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. 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. 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 (Dhanapal *et al.* 2002**)**.

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 analyzer (Biddappa and Cecil 1984 and Biddappa 1985). High deposition of AI, Mn, Cu, and Co in the roots and Cr, Ti, Pb, Bl and Ga in the cabbage tissues of diseased palms was also found in comparison 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 *et al*. 1957, 1959). 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).

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 (Das *et al.* 2016, Malhotra 2017). Apart from this, coconut plantations especially under coconut based cropping system are a prominent 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 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 tonnes FYM+50% N by vermicompost+50%N by CCP+vermiwash spray + *Azotobacter*) (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 treatments (Naveen Kumar 2015).

FUTURE STRATEGIES IN SOIL HEALTH MANAGEMENT

Soil properties are spatially and temporally dynamic in nature, the response for any soil management intervention will be site, specific. Hence, the soil health management strategies should be tailor made for each condition. By and large majority of the coconut farmers do not use fertilizers and thus the nutrients being mined by the plants are not replenished. 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. Strengthening the researches in improving the nutrient use efficiency through nanofertilizer techniques may be useful to ensure nutrient supply and reducing the nutrient losses. Further research on supplying balanced and sufficient nutrition through organic farming involving beneficial microbes 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 affecting the soil fertility. Soil helath management practices which play a greater role in increasing the soil carbon sequestration needs to be studied in different locations with different cropping systems. 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.

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