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Review Article

ORGANIC MATTER RECYCLING IN PLANTATION CROPS

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ABSTRACT

The plantation crops viz. coconut, arecanut, cocoa, spices, cashewnut, tea, coffee, oilpalm and rubber which are yielding economic produces throughout the year, deplete the soil of its precious nutrient reserve as well. The total nutrient depletion has been worked out to be approximately 149.7, 52.2 and 219.0 thousand tonnes of N, P and K respectively. Barring the economic produce, plantation crops produce large quantities of usufructs/waste/byproduct which can be recycled back to the field, thereby meeting a part of crop nutrient demand. Around 7.5 million tonnes of coir pith, 0.18 million tonnes of coffee husk, 0.43 million tonnes of areca waste and 0.45 million tonnes of cocoa waste are available annually, thereby, accounting for approximately 60.96, 3.45 and 35.38 thousand tonnes of N, P and K per year respectively. Composting is an efficient way of waste management by reducing C:N ratio, bulkiness and increasing nutrient content also. There is ample scope to conserve the available byproducts for sustaining the production in plantation crops. This paper primarily deals with the potential available for organic matter recycling in plantation crops through on-farm waste/byproduct management and its subsequent re-utilization in the form of organic manure.

INTRODUCTION

Organic farming in India has been practiced since time immemorial. With the advent of green revolution, the chemical inputs have become the mainstay of Indian agriculture. Nevertheless, this led to a decline in the use of organic manure. Dependence on chemical fertilisers has brought with it many problems facing modern agriculture. Though not so profound, yet soil degradation is one of its outcome. The other is farmer's concern for macro nutrients viz. NPK and negligence in supply of other nutrient inputs, thereby, leading to nutrient imbalances. At present the fertiliser use in plantation crops is $9.8x10^4$ t N, $5.1x10^4$ t P_2O_5 and $1.2x10^5$ t K_2O which will increase to $1.2x10^5$ t N, $6.4x10^4$ t P_2O_5 and $1.5x10^5$ t K_2O by 2000 AD (Nair *et al.*, 1996)

At present, there is an increasing consciousness amongst people regarding health, hygiene and environmental pollution. But the modern agricultural techniques employing fertilisers, pesticides and herbicides often resulted in loss of environmental quality, water pollution and problem of pesticidal residue in consumable parts. Hence, there is a need to propagate, a system of eco-friendly farming. Apart from these, the spurt in prices of fertilizers owing to withdrawal or reduction of subsidies and increasing farm energy requirements has once again revived interest among farmers to adopt organic waste recycling through on-farm waste management. The present review focuses primarily on the potentiality of recycling of on-farm waste/usufructs generated in plantations in the form of organic manures.

Problems associated with fertiliser use

Earlier, fertilizer application was largely limited to nitrogenous materials. But, later on, long term fertilizer experiments highlighted the weakness of single nutrient application approach. As other nutrients become deficient, the Mitscherlich's law becomes operative and the deficiency of the most limiting nutrient element determines the productivity level. Tandon and Narayan (1990) undertook an exercise on the nutrient status of Indian soils based on their extent of deficiencies which need attention (Table 1). Evidently, larger gains from application of fertilisers would ensure when deficiency of nutrients found limiting in the soil is made good.

It has also been inferred from long term continuous fertiliser application that nutrient accumulation in soil can prove toxic to plants or can interfere with the uptake of other essential nutrients. Accumulation of both zinc and phosphorus occurred with their continuous application (Biswas and Benbi, 1989). A build up of phosphorus can prove antagonistic to zinc and iron nutrition of crops. Similarly, high levels of zinc can cause iron chlorosis (Katyal and Randhawa, 1983). In either case, crop productivity is adversely affected.

Studies by Lindsay *et al.* (1962) and Das and Das (1966) indicated that application of nitrogen, phosphorus and potassium over long period of time reacts with and degrades the soil colloidal particles to form NH_4-K tarnakites. This results in the reduction of colloidal constituents of the soil which has

Table 1. ***Nutrient status of Indian soils and the extent of deficiencies which need attention***

Nutrient	Soil Fertility Status
Nitrogen	Low in 228 districts, medium in 118 and high in 18 districts
Potassium	Low in 47 districts, medium in 192 and high in 122 districts
Phosphorus	Low in 170 districts, medium in 184 and high in 17 districts
Magnesium	Low in Kerala, other southern states are in very acid soils
Sulphur	Deficiencies scattered in 90-100 districts
Zinc	50% of 1,50,000 soils analyzed found deficient
Iron	Becoming important on calcareous soils
Boron	Parts of Bihar, Karnataka and West Bengal.

Source: Tandon and Narayan, 1990

an adverse bearing on nutrient retention and release properties.

At present, per hectare consumption of fertiliser in plantation crops is approximately 68 Kg which is low (Nair *et al.* 1996). However, fertiliser pollution aspect has not been considered seriously till now. Studies by Singh *et al.* (1987) in Punjab points to a strong association between fertiliser nitrogen use and nitrate content of ground water. They observed that, compared to none in 1975, 10% well water were classified as unsafe for drinking according to WHO standard of 10 mg NO_3-N/l. This suggests the need to maintain a close watch on the build up of nitrates in ground water.

Fertilisers are also the source for heavy metal contamination of the soil. Cadmium, of all the heavy metals deserves a special mention because of its inadvertent additions through phosphatic fertilisers. In turn, phosphatic fertilizers, derive cadmium from the rock phosphates. In India, experiments on cadmium accumulations in soils are lacking. Nevertheless, long term Swedish Field experiments indicated that cadmium accumulation in soil due to phosphatic fertilization over a period of 17 years vary from 20-87g/ha depending upon rate of fertilizer phosphorus used (FAO, 1975). Considering, long term perspective, it can be argued that cadmium will accumulate in the soil and would result in considerable increased uptake by crops. The cadmium content may reach levels which though not phytotoxic, may be harmful to the animals and human beings.

Similarly other heavy metals such as mercury, lead, selenium, nickel and chromium also harms all living beings. Populations of bacteria, fungi and actinomycetes are reduced in soils heavily contaminated with mercury, copper and zinc (Sarkar, 1990).

Regular use of fertilisers which are physiologically acid or are acid producing may result in lowering of soil pH over a period of time. Application of ammonium phosphate continuously over a period of five years to coconut palms has lowered the pH of soil compared to other P carriers like Superphosphate, nitrophosphate and rock phosphate (Khan *et al.* 1985). Ammonium sulphate is a physiologically acid fertilizer, while, urea is an acid producing fertilizer. Regular use of such fertilizers would result in microsite drop in pH (Abrol and Katyal, 1990). The impact is greater on poorly buffered acid soils and more so with those fertiliser treatments which led to lowest productivity. After 16 years of regular application of a low CEC acid soil with urea, the grain yield was reduced to zero (Lal & Mathur, 1988). Liming was necessary to sustain satisfactory yield levels in such soils.

Inferences from long term fertilizer experiment (LTFE) has indicated that long term use of inorganic fertilizers has been found to damage physical properties of soils. Result of LTFE on a Typic hapludalf (Palampur) highlighted that after a decade, eventhough no adverse effect on relative infiltration rate, cumulative infiltration and average WHC was observed with any of the fertilizer application treatment, soils receiving a combination of FYM and NPK fertilizers tended to excel over other treatments (Table 2).

Importance of organic matter application for soil health and plant nutrition

In the present day agriculture supplementary and complementary role of organics is being increasingly felt for sustainable productivity and keeping the soil health in order (Modgal and Singh, 1990). The nutrient requirement for plantation crops is estimated to increase from 420 thousand tonnes ($N+P_2O_5+K_2O$) at present to 755 thousands tonnes by 2000 AD. Though the supply of nutrients through fertilizers would increase rapidly, it would meet only 50% of the total nutrient requirement by 2000 A.D. Therefore, our major dependance for plant nutrients will be on organic sources which could supply 165 thousand tonnes of the nutrients (Nair *et al.* 1996). Secondly, major changes in pricing policies in 1992, resulted in sharp decline in subsidies on fertilizers, thereby adversely affecting the fertilizer use. The $N:K_2O$ ratio which was 6.8:1 in 1989, widened further to 10:1. This resulted in the clock of balanced fertilizer application being turned back by at least a quarter of century (Tandon, 1995). Organic manures being a store house of nutrients, albeit in small quantities, can go a long way in improving the nutrient resources of the soil.

Table 2. ***Effect of a decade of fertilizer application on certain properties of soil***

Treatment	Infiltration rate (mm/d)	Cumulative infiltration (mm)	Relative Available water
Control	85	171	110
N	90	283	100
NP	109	255	112
NPK	106	359	127
NPK + FYM	189	509	140
NPK + Lime	118	258	180
CD (P=0.05%)		103	160

Source: Acharya *et al.* (1988)

Maximization of economic returns has now become key to success in agriculture. The current practices recommended for crops to maximize production are largely through system of chemical farming i.e. high input technology which may be appropriate for estate farming but not for small holdings. The limited funds and other constraints such as risk due to crop losses and fluctuating prices of the commodities often discourage small holders to apply chemical inputs. But, in integrated farming system, recycling of organic wastes viz., crop residue, animal dung, urine etc. leads to a substantial saving in cost of fertilizer input thereby increasing the cost-benefit ratio. In an integrated farming system comprising pasture, fodder and cattle in coconut small holding of Sri Lanka, it was observed that the cost of fertilizing of coconut palm was Rs. 2.49/palm as compared to Rs. 8.1/palm annually in coconut monoculture. This led to a saving of 69% on the cost of inorganic fertilizer for coconut

(Liyanage *et al.*, 1989). In coconut-cocoa system, it has been observed that 818 to 1785 kg/ha/year (oven dry basis) of cocoa litterfall can be recycled annually, thereby improving organic C content and soil fertility, which was reflected in coconut yield increase (Varghese *et al.* 1978). In intensive cropping in coconut with cocoa, dead root mass and fallen cocoa leaves provide substrate for microbial growth. The better solubilization of phosphorus, fixation of nitrogen and production of growth substances (GLS and IAA) in the rhizosphere would have been a reason for increased coconut yield (Nair, 1979).

Organic manures apart from supplying plant nutrients also have a profound impact on moisture retention, root growth and nutrient conservation. When organic manures are applied to coarse textured soils, there is a decrease in the bulk density due to better aggregation properties. Studies conducted at CPCRI, Kasaragod, has demonstrated that all the organic sources viz. forest leaves, coconut sheddings, cattle manure and coir pith in conjunction with inorganics improved significantly the soil physical conditions over control (inorganic) treatment in Littoral sandy soil (Anonymous, 1981) (Table 3). Water retention at 0.2 and 1.0 bar was higher in soil samples collected from the basins of coconut palms receiving organic matter regularly for the past seven years, than in samples from the basins of palms not receiving any organic matter (Anonymous, 1978). Application of coconut husk and coir dust to the palms increased soil available water, porosity and decreased bulk density of both lateritic and sandy soil (Liyanage *et al.* 1993) (Table 4).

Table 3. ***Influence of organic matter on soil physical parameters***

Treatments	Hydraulic conductivity (cm/hr)	Water holding capacity (%)	Bulk density (g/cc)
Coir dust + NPK	181	33.80	1.37
Coconut sheddings + NPK	195	27.10	1.49
Forest leaves + NPK	176	27.20	1.50
Cattle manure + NPK	151	26.50	1.56
NPK alone	133	23.40	1.60

Long term experiments have conclusively proved the ability of the bulky organic manures to neutralize the rapid yield fall with the continuous use of chemical fertilizers. Use of FYM prevented the occurrence of Zinc (Katyal and Randhawa, 1983) and sulphur deficiencies (Nambiar and Abrol, 1989). There were significant differences between the treatment means in the case of organic carbon, available N, Fe, Mn and exchangeable Ca and Mg. The absolute values were very low for the soils receiving NPK alone, compared to those receiving organic manures (Table 5).

Addition of neem cake, FYM and bonemeal together with dolomite resulted in an overall beneficial nutrient balance and good establishment and yield of pepper vines (Sadanandan, 1986). In coconut-pepper mixed cropping system, following integrated nutrient management (black pepper vines were manured at 5 kg FYM, 0.5 kg each of neem cake and bonemeal and N, P, K at 100, 40, 140 g per year per vine and coconut palms manured at the rate of 50 kg green leaves, 25 kg FYM and N, P, K at 0.34,

Table 4. ***Effect of coconut husk and coir dust on soil physical properties.***

Treatments	Av. water (%)	Porosity (%)	Bulk density (g/cc)
I. Laterite soil			
a) Control	2.7	38.2	1.55
b) Husk pits	4.3	52.0	1.36
c) Coir dust pits	8.5	58.0	1.18
II. Sandy soil			
a) Control	1.91	40.7	1.50
b) Husk pits	3.41	62.4	1.13
c) Coir dust pits	4.35	48.9	1.35

Source: Liyanage *et al.* 1993

Table 5. ***Influence of organic manuring on the nutrient contents of soil***

Nutrients/ Treatments	Coir dust + NPK	Coconut shedding + NPK	Forest leaves +NPK	Cattle manure +NPK	NPK alone (control)
Organic carbon (%)	0.170	0.143	0.159	0.173	0.06
Av. N(ppm)	43.6	48.6	50.3	50.6	27.0
Exch.Ca (ppm)	94.7	88.7	127.3	106.3	62.1
Exch. Mg. (ppm)	8.32	7.34	10.0	11.2	5.68
Av. Fe (ppm)	71.9	38.6	47.4	62.3	18.4
Av. Mn(ppm)	1.97	4.05	4.64	7.52	1.9

0.17, 0.68 kg per palm per year) the soil available nutrients and also the overall productivity of coconut and black pepper increased by 53 and 172 per cent respectively (Sadanandan *et al.* 1991).

It has been estimated that by systematically recycling all the usufructs produced by coconut, it is possible to plough back 20.7 kg N, 10.5 kg P_2O_5 and 30.8 kg K_2O per ha annually (Jothimani, 1994). In general, crop residues contain approximately 25% N and P, 50% S and 75% K of total absorbed nutrients by plant (Tandon, 1991). Thus, they are more important sources of potash as compared to nitrogen and phosphorus. In case of coconut, it was observed that husk accounted for 67 percent of the potassium and 85 per cent of chlorine. This indicates that considerable reduction in fertilizer requirement can be achieved by leaving the husk in the field where it is quickly broken down, releasing the locked up nutrients to be recycled (Ouvrier and de Taffin, 1985). One hundred husks would be able to provide 1 kg of potash apart from 270 g N and 150 g P_2O_5 in the same period (Jothimani, 1994). Effect of husk burial will be observed from 3rd year onwards and beneficial effect lasts for 5-6 years.

Most of the plantation crops being grown in high rainfall tracts, have to cope up with low pH problems. This may lead to aluminium, manganese or iron toxicity. It has been observed that acid soils rich in native organic matter, or amended with large quantities of organic residues, give low Al^{3+} conc. in soil solution and permit good growth of crops under conditions where toxicities could otherwise occur (Bloom *et al.* 1979). Manganese toxicity which occurs in low pH regimes is reduced by thick organic mulch on cardamom plantations (Aiyar, 1966). The organic matter content also gives the tilth to the soil which are otherwise very poor in this respect.

Various estimates have shown that 40-45 days old green manure crop can supply upto 80-100 kg N/ha. Even if half of this N is crop usable, a green manure crop could substitute for 50 to 60 kg fertilizer - N/ha (Abrol and Katyal, 1990). The rooting system and canopy characteristics of palm crops are conducive for raising a number of green manure crops either in basin or interspaces. If grown in basins of coconut palm, 15-20 kg green matter per basin will be added, supplementing about 100-150g nitrogen per palm. When grown in interspaces about 3-4 tonnes of green matter will be added, which will be equivalent to 20-111 kg N, 4-21 kg P_2O_5 and 15-67 kg K_2O per hectare (Jothimani, 1994). Similarly, growing of congo signal grass in between rows of pepper vines reduced soil erosion, soil temperature and foot rot incidence of black pepper. This practice increased subsoil moisture, thereby, alleviating the moisture stress and improving the fertility status of the soil. Secondly, maintenance of grass results in a yield of about 30 t of green fodder annually leading to increases in the system productivity (Sadanandan *et al.* 1992).

Growing of multipurpose, nitrogen fixing trees in coconut garden like *Leucaena* and *Gliricidia* is both beneficial to the grower as well as in sustaining the soil productivity. Liyanage and Jayasundra (1988) reported that *Gliricidia* topping applied @ 30 kg/palm meets total requirement of nitrogen and a part of phosphorus and potassium requirements, thus, reducing the cost of fertilizer by about 40%.

It has been recommended to grow leguminous cover crops in the arecanut garden to assimilate the atmospheric nitrogen and enrich the soil (Mohapatra *et al.* 1970). Information on such cover crops which can be raised in arecanut gardens or in vacant spaces adjoining the arecanut gardens along with their nutrient composition is presented in Table 6.

Incorporation of organic manures in basin of plantation crops leads to proliferation of microbes in the rhizosphere of arecanut palms, thereby, increasing efficiency in the nutrient release (Bopaiah and Bhat, 1981).

In widely spaced crops like coconut, arecanut, oilpalm, weed infestation is very high. In high rainfall areas, there is a established practice of allowing the weeds to grow in the field and then ploughing the same after rainfall, thereby recycling the nutrients back to the system apart from conserving soil during rains and improving soil physical problems. Bhat and Mohapatra (1989) highlighted the nutrient contribution of weeds growing in arecanut garden and stated that 14 kg fresh weed supplied 32g N, 7g P_2O_5 and 52g K_2O per palm per year (Table 7).

Table 6. ***Yield of green matter, nutrient content and amount of nutrients added by different green manure crops.***

Name of the crop	Mean yield of green matter (tonnes/ha) (1970-72)	Nutrient composition (%)			Nutrient addition (kg/ha)		
		N	P	K	N	P	K
Calopogonium muconides	7.1	2.6	0.23	2.8	40.5	7.9	51.9
Pueraria sp.	14.4	3.3	0.24	1.6	99.3	16.5	59.1
Stylosanthes gracilis	12.8	3.3	0.24	1.6	99.3	16.5	59.1
Mimosa invisa	12.6	3.9	0.34	2.0	111.7	21.6	67.9
Sesbania speciosa	5.2	2.7	0.17	1.1	31.3	4.5	15.6
Centrocema pubescens	6.9	2.5	0.24	1.8	43.4	9.2	36.0
Crotolaria anagryoides	3.4	2.8	0.27	2.1	20.5	4.5	18.6

Source: Mohapatra *et al.* 1970

Table 7. ***Nutrient composition of weeds and nutrient addition to areca palms by their recycling.***

Nutrient element	Nutrient composition (%)	Nutrient added to areca palm through 14 kg fresh weed
Nitrogen (N)	1.83	32g
Phosphorus (P_2O_5)	0.39	7g
Potash (K_2O)	3.00	52g

Source: Bhat and Mohapatra, 1970

In plantation crops management, mulching is an important cultural practice. This improves the soil physico-chemical conditions. Soil samples collected from areas covered with leaf either at depths of 0-5 cm, 5-10 cm and 10-15 cm from plantations in Karnataka and Kerala, revealed high mineral nitrogen as well as major plant nutrients under mulched conditions (Zachariah, 1978). Similarly, mulching of turmeric with *Dalbergia* leaves increased yield of crop (Jha et al. 1984). Similar results were also obtained with dhaincha leaves (Aiyadurai, 1966). Mulching treatments hasten germination by a week and allow less number of weeds, thereby increasing yield. In tea, it was observed that mulching with Guatemala grass (200 kg 50 m^{-2}) resulted in significant increase in feeder root production of mature tea in north east India (Dey and Gohain, 1978).

Nutrient removal

Plantation crops being long duration crops, require more nutrients in readily available form for producing higher yields. It has been observed that negligience in early stages of growth rarely gives high yield as compared to the plants which received adequate care and management right from planting. As crop grows/advances in age, its nutrient requirement also increases. The nutrient removal by different plantation crops are given in Table 8.

The above table clearly reveals the extent of nutrient removal at a particular level of production. Taking the present level of production, the total nutrient removed by plantation crops works out to be 149.71, 52.44 and 218.97 thousand tonnes of N, P and K respectively (Table 9).

Fertility status of soil

Most of the tracts where plantation crops are grown are lateritic, red or coastal sands. Tandon and Ranganathan (1988) have summarized the general characteristics and range of available nutrients in soils under plantation crops (Table 10). The pH of these soils ranged from acidic to neutral. Mostly, they are acidic in reaction. Being acidic, water soluble phos- phorus is quickly fixed through formation of aluminum and iron compounds. Cation exchange capacity is very low, thereby, leading to low retention of cations like K, Ca and Mg, which are leached down, especially in coarse textured soils under high rainfall.

From a perusal of Table 10, it is also clear that the native fertility of nutrients in soil can only sustain certain yield levels, which in many cases are low. Plantation crops being high value crops, have high inputs and labour requirement. So, even small yield losses can mean large financial losses. For tea, in South India, it was observed that for a yield level

Table 8. ***Nutrient removal by different plantation crops.***

Crops	Yield level	Nutrient removal (kg/ha)		
		N	P	K
Oilpalm	25 t fruit bunches	93.5	11.0	92.7
Coconut	40 nuts palm-1	50.0	4.5	62.5
Cocoa*	1125 kg dried beans	25.5	5.0	50.0
Coffee*	1125 kg coffee	40.0	7.3	50.3
Tea*	1350 kg dried leaves	62.5	4.5	28.3
Rubber*	1928 kg dried rubber	19.1	3.8	15.5
Arecanut	--	79	12	65.5
Cashew	1000kg nut	88	10.75	35
Cardamom	1000 kg	120	2.7	138

*Source - Turner and Gillbanks (1988), Rethinam (1990)

Table 9. ***Total nutrient removal by plantation crops.***

Crops	Production (Million tonnes)	Nutrient removal ('000 tonnes)		
		N	P_2O_5	K_2O
Coconut (1993-94)	12335*	66.54	28.4	162.7
Arecanut (1992-93)	0.248	13.24	5.7	13.26
Black pepper (1993-94)	0.046	0.011	0.002	0.01
Cardamom (1993-94)	0.0067	0.778	0.04	1.08
Cashew (1994-95)	0.371	30.69	8.92	14.64
Tea (1990-91)	0.752	26.69	4.4	12.08
Coffee (1994-95)	0.180	6.37	2.67	9.61
Rubber (1993-94)	0.435	4.32	1.96	4.2
Cocoa	0.0074	0.32	0.149	0.65
Oilpalm (1991-92)	0.0040	0.748	0.202	0.742
Total		149.71	52.44	218.97

* in million nuts

of 800 kg made tea/ha or less, native fertility is sufficient. But for higher yield levels, application of fertilizer nutrients other than N, P and K also become important and enter the fertilizer schedule (Table 11).

Table 11: ***Soil limiting factors in relation to the productivity of tea in South India***

Productivity (made tea) (kg/ha)	Limiting factor
Below 800	Nil
800-1000	N & K
1000-2000	N, P, K, Zn - liming
2000-3000	N, P, K, Zn+ liming with material containing $MgCO_3$
3000-4000	N, P, K, Zn, Mg, Si,'B+ Liming; transport process within the soil.
Above 4500	N, P, K, Zn, Mg, Si, Mo, B+ Liming: transport processwithin the soil.

Source: Tandon & Ranganathan (1988)

Table 10. ***General characteristics and range of available nutrients in soils under plantation crops.***

Soil/nutrient Characteristics	Range	Remarks/method
A. *General*		
pH	3.9-7.0	Varies with rainfall
E.C. (mmhos/cm)	0.01-0.3	No salt accumulation
Organic matter(%)	1.0-10.0	Varies with altitude, latitude and cultural practices.
CEC (meq/100g)	2.0-15.0	More than 50% CEC owing to organic matter
Clay mineral	Predominantly Kaolinitic	Very low amount of K-fixing clay minerals
Soil texture	Sandy to clay	Varies with rainfall
Soil group	Latosol/ Alluvial	Belongs to Oxisol, Utisol, Inceptisol and Entisol
B. *Nutrient (Available fraction)*		
N (%)	0.01-0.05	Alkaline permanganate
P(ppm)	1-25	Bray & Kurtz-P2 modified.
K(ppm)	30-250	Morgan's reagent
Ca(ppm)	400-1500	1M $NaCl$-NH_4OAc
Mg(ppm)	25-55	-do-
S (ppm)	23-55	-0.1M $CaCl_2$-
Zn (ppm)	0.1-2.0	DTPA
Fe (ppm)	6.0-12.0	-do-
Mn (ppm)	0.2-6.0	-do-
Cu (ppm)	0.1-2.0	-do-
B (ppm)	0.3-3.8	Water
Si (ppm)	3-13	1M NaCl

On farm wastes/byproducts in plantation sector

The plantation crops, being mainly perennial crops produce a huge amount of waste biomass (Table 12). It has been estimated that a coconut garden with 175 trees/ha generates usufructs biomass to the extent of 7000 kg in the form of dried leaves, sheathes, spadices, inflorescences and coconut husks. The coconut husk is used for extracting coir. But, the waste material viz. the pith is usually dumped without any use. During monsoon tannins oozing out of such

Table 12: *Availability of onfarm wastes/ byproducts in plantation sector in India*

Crop	Quantity of waste available	
Coconut* (excluding coir pith)	11.2	million tonnes
Areca leaves (dried)	0.13	-do-
Areca rachis	0.08	-do-
Areca husk	0.22	-do-
Cocoa shed leaves	360.03	tonnes
Cocoa prunings	12056.33	-do-
Cocoa pod husk	32900	-do-
Coir pith **	7.5	million tonnes
Coffee husk $	0.18	-do-
Tea waste #	0.22	-do-

*includes spadices, bunch wastes, sheath, inflorescences and husks

**Kamaraj (1994)

$Calculated considering equal amount of coffee husk is produced as coffee beans.

#Calculated considering 30% of total tea production is tea waste.

heaps, creates problems of environmental pollution. The studies conducted at various places have suggested that coirpith can serve as important source of organic manure for agricultural crops (Savithri and Khan, 1994). It has been estimated that in India, 7.5 million tonnes of coir pith is produced annually (Kamaraj, 1994). In general, pith is acidic in nature, having low bulk density and high porosity. Nutrient composition of coconut leaves, coconut sheddings and coir pith is given in Table 13.

In arecanut gardens, the total availability of usufructs including rachis, leaves and husks is approximately 0.433 million tonnes annually. The non-marketed produce in arecanut garden viz. areca shed leaves, sheath, husk and arecanut bunch waste supplies approximately 94.9g, 10.0g and 109.63g of N, P_2O_5 and K_2O per palm pe year (Table 14).

Similarly, total waste biomass generated from cocoa and coffee, which can be recycled

Table 13: *Nutrient content of Coconut usufructs.*

Source	N	P	K	Fe	Mn	Zn	Cu
		%			ppm		
Coir pith	0.28	0.03	1.03	1164	53	194	3.8
Coconut leaves	0.89	0.06	0.45	917	464	38	3.5
Coconut sheddings	0.66	0.10	0.50	781	94	25	5.0

Source: Anonymous (1994)

Table 14: *Nutrient content and quantity of nutrients added by non-marketed produce in arecanut garden (per palm per year).*

Name of byproducts	Mean dry wt. of biomass (kg) $year^{-1}$ $palm^{-1}$	Nutrient (%)			Nutrient added/ g $year^{-1}$ $palm^{-1}$		
		N	P	K	N	P	K
Arecanut shreds	4.0	1.59	0.16	1.01	63.6	6.4	40.4
Leaf sheath	1.7	0.66	0.08	1.51	11.2	1.4	25.6
Arecanut husk	1.7	1.00	0.12	2.40	17.0	2.0	40.0
Arecanut bunch	0.3	1.04	0.07	1.10	3.1	0.2	3.63
Total nutrients added					94.9	10.0	109.63

Source: Bhat and Mohapatra (1989)

is approximately 0.05 and 0.18 million tonnes of cocoa wastes and coffee husk res- pectively. The nutrient composition of cocoa wastes and coffee husk is given in Table 15.

Tea waste to the extent of 0.22 million tonnes is available in India. Oilpalm, a relatively new crop in India is cultivated in about 8000 ha (1991-92). But, based on the expert committee constituted by Govt. of India under Dr KL Chadha, 5.75 lakh ha of area is identified suitable for oilpalm cultivation in India (Chadha and Rethinam, 1994). Varghese and Rethinam (1994), stated that cut fronds constituted a major source of organic manure in oilpalm plantations yielding 10 tonnes of drymatter per ha, a nutrient value equivalent to 58 kg urea, 30 kg rock phosphate, 120 kg KCl and 70 kg Kieserite per ha. So, from a predicted area of 5.75 lakh hectare, total quantity of cut fronds available will be 5.75 million tonnes. Thus, in terms of fertilizers, it accounts for about 33.35, 17.25, 69 and 40.25 thousand tonnes of urea, rock phosphate, KCl and Kieserite respectively.

Cardamom is a pseophyte, which is commonly grown as undergrowth of trees in the forest generally high in fertility status due to addition of leaf fall and its recycling (Zachariah, 1978). It is estimated that on an average 5-8 tonnes of dry leaves fall from shade trees annually in a hectare of cardamom estate adding 100-160 kg nitrogen, 5-8 kg phosphorus, 100-160 kg potash, 10-16 kg calcium and 25-40 kg magnesium per ha, if modest estimate of leaf nutrient status in forest litter is taken as N-2.0%, P_2O_5-0.1%, K_2O-2.0%, CaO-0.2% and MgO-0.5% respectively (Korikanthimath, 1994).

Total nutrient supply

As mentioned above, the waste materials are also carriers of essential nutrients to the crops, conserving the nutrients and making it available for a longer period. The composition of these wastes varies with the soil fertility status, management practices followed in the garden, time of collection and various other environmental factors. From the data given in the Table 15, it is clear that coir pith serves as a reservoir of nutrients supplying 51, 9.5 and 27 thousand tonnes of N, P and K respectively. Being highly lignocellulosic in nature, the nutrient release will be slow, thereby, increasing the efficiency of nutrient utilization by plant.

Table 15: ***Quantity of nutrients supplied by coir pith, areca, cocoa wastes and coffee husk.***

Byproducts	Quantity available	Chemical(%) composition			Total nutrient supplied (tonnes)		
		N	P	K	N	P	K
Coir pith*	7.5 million tonnes	0.68	0.026	0.36	51000	9500	27000
Areca leaf	0.1317	1.31	0.21	1.16	1720	277	1530
Arecahusk	0.2224 "	1.06	0.42	1.48	2360	930	3290
Areca rachis	0.0832 "	1.42	0.16	1.70	1180	130	1410
Cocoa leaves	360.033 tonnes	1.00	0.08	1.20	3.6	0.29	4.29
Cocoa prunings	12056.33 "	1.75	0.13	2.10	210.99	15.67	253.18
Cocoa pod husks	32900 "	0.99	0.17	3.00	325.52	55.90	986.43
Coffee husk	0.18 million tonnes	2.31	0.05	0.5	4158	90	900

* Source: N, P & K content in coir pith - Ravichandran (1988)

Work done at CPCRI, Kasaragod, has indicated the potential nutrient supplying capacity of the areca and cocoa wastes (Table 15). It has been estimated that available areca byproducts can supply 5260, 1337 and 6230 tonnes of nitrogen, phosphorus and potassium respectively to the agricultural system. Cocoa waste recycling can supply 540.11, 71.86 and 243.94 tonnes of nitrogen, phosphorus and potassium respectively. Recycling coffee husk can supply 4158 tonnes of nitrogen, 90 tonnes phosphorus and 900 tonnes of potassium to the soil.

Waste management through composting

Waste/usufructs from plantation crops accounts for more than 30-50% of the produce. Till now, these wastes had been utilized in one form or the other for practical use. With the advancement of technology and upliftment of the standard of living, the waste and byproduct utilization has declined considerably, as a result wastes are left in the field causing environmental problems. These wastes and surplus residues can be recycled back to the soil by various methods such as mulching, *in situ* incorporation and composting which leads to improvement in soil physico-chemical and biological properties, thereby having a profound impact on yield of the crop.

Composting is one of the most important method of recycling the residues back to the soil. In broad terms, compost is biologically decayed refuse like leaves, twigs, roots, stubble, crop residue etc. It leads to the production of brown and dark coloured humified material which is valuable for replenishment of plant nutrients in the soil organic matter, thereby improving the soil health.

Composting depends upon C:N ratio of the organic source, and is influenced by blending/shredding, moisture, temperature, microbes involved and aeration. The most important aspect is C:N ratio in composting. C:N ratio of 30 in raw materials could be most desirable for efficient composting (Gaur *et al.*, 1984). Any organic material with wider C:N ratio leads to diminished microbial activity, thereby increasing the number of cycles required to degrade carbonaceous materials. In such cases, an external nitrogen source must be added, facilitate to increased microbial activity. The C:N ratio of some of the available materials from plantation crops is given in Table 16. It can be clearly inferred that except for coir pith, other waste material have desirable C:N ratio for efficient composting. However, coir pith requires a starter dose of nitrogen.

Various techniques like hot fermentation, cold digestion, microbial, chemical digestion and vermicomposting have been standardized for the preparation of organic fertilizers from the crop wastes. The techniques primarily involve chemical and biological processes to break down the complex organic molecules to the simpler forms.

Vermicomposting involves the use of earthworms, the natural bio-reactors. The earthworms feed on wastes and produce vermicast with immobilized microflora and enriched with plant nutrients, vitamins, enzymes, antibiotics and plant growth hormones. It has been estimated that 1000 tonnes of moist organic matter can be converted by earthworms into 300 tonnes of compost (Tapiador, 1981). The trials in India on vermicomposting of paddy straw and plant twigs showed a significant narrowing down of C:N ratio and appreciable increase in total N and total and available phosphorus (Gaur *et al.* 1991).

The quality of the compost prepared varies with the methodolgy adopted and the C:N ratio of the organic material used and can be enhanced by the use of low grade

Table 16: ***Carbon-Nitrogen ratio of the byprocuts***

Substrates	Org.C(%)	N(%)	C:N ratio
Coffee husk	37.20	2.31	16.10
Cocoa pod husk	36.179	2.289	15.81
Coir pith	27.882	0.29	95.94
Areca waste*	29.078	1.31	22.70

* Excludes areca husk

rock phosphate at the beginning of the composting and inoculation of compost heap with nitrogen fixers and phosphate solubilizers after about one month of composting. Gaur and Singh (1982) showed that application of rockphosphate or/and inoculation improved the total nitrogen status of compost showing an average increase of about 4 kg N/ton of finished compost as compared to composting done without any amendment.

Composting of coir pith

Coir pith, a highly lignocellulosic material, has wider C:N ratios ranging from 112:1 (Nagarajan *et al.*, 1985) to 58:1 (Ravichandran, 1988). The wider C:N ratio coupled with low N content, presence of soluble tannin related phenolic compounds (8-12%), its low biodegradability are some of the problems associated with the direct application of coir pith to the field crops (Fan *et al.*, 1982). In such cases composting is the best way before it is applied to the soil. Being highly lignocellulosic, microbial inoculants suitable for degrading these compounds may hasten the process and efficiency of decomposition.

Studies carried out by Sesha Reddy (1985) showed that some species of *Pleurotus* had the capacity to produce laccase and degrade part of cellulose and lignin present in the coir dust. Using radioisotopes, some of the basic characteristics of coir dust degradation is established for *Pleurotus sajor caju*. Cellulose and hemicellulose present in coir dust supported the initial growth of the fungus and the two were the co-substrate for the lignin degradation. *Trichoderma* and *Aspergillus* were found to be the potent degraders as indicated by the low values of C:N ratio (Savithri and Khan, 1994). An additional advantage associated with *Trichoderma* sp. was its ability as a biocontrol agent of soil borne fungal pathogens (Savithri and Khan, 1994). For improving the manurial value of coir waste, urea addition was found to be more effective than addition of superphosphate and biogas slurry (Nagarajan et al. 1985). Addition of rock phosphate to the acidic coir pith material favoured the availability of phosphorus, while addition of zinc sulphate+ iron sulphate provided situations for the formation of natural organic complexes of zinc and iron (Savithri and Rani Perumal, 1993 and Ramaswamy and Son, 1993).

CONCLUSION

Organic farming has been in vogue since ancient times. But, population pressure necessitated a shift towards chemical farming to meet the target production in a short time. Emphasis on chemical inputs and bias towards major nutrients led to nutrient imbalances over a wide tract in India. At present N, P, K, S and Zn are considered to be universally deficient. Nevertheless, other nutrient deficiencies have also been observed. The adverse effect of long term chemical fertilizer use on soil physico-chemical properties and subsequently on crop growth needs no further emphasis. Application of organics will go a long way in improving the soil physico-chemical and biological characteristics. It delays the occurrence of nutrient deficiencies as well as reduces the effect nutrient toxicity on the crop.

Plantation crops being perennial in nature, there is a continuous depletion of nutrients from the soil. Based on present production level, it has been observed that the total nutrient removal in plantation sector is approximately 149.7, 52.2 and 219.0 thousand tonnes of N, P and K respectively. Secondly, the soils supporting plantation crops are resource poor soils. Meeting the nutrient needs through fertilizer application becomes very costly apart from the adverse effect on soil and produce quality. Plantation crops produce large quantities of waste/byproduct which can meet a part of the nutrient demand of the crop. It has been estimated that in India around 7.5 million tonnes of coir pith, 0.18 million tonnes of coffee husk, 0.43 million tonnes of areca waste and 0.45 million tonnes of cocoa waste are available annually. These wastes/by-products can supply 60.96, 3.45 and 35.38 thousand tonnnes of N, P and K respectively, thereby, meeting a part of crop nutrient needs. Composting is an efficient way of waste management. It reduces the C:N ratio and bulkiness of the organic matter, thereby improving the quality of compost. Various composting techniques are available viz. hot fermentation, cold aerobic, microbial digestion and vermicomposting Depending on the methodology used the quality of compost will vary. Currently emphasis is on maintaining the sustainibility of land resources and development of a farm holding as a viable unit. In this context, recycling the available byproducts in the farm for higher yields is essential.

REFERENCES

ABROL, I.P. and KATYAL, J.C. 1990. Managing soil fertility for sustained agriculture. In: Proceedings of the International Symposium on Natural Resources Management for a Sustainable Agriculture Vol. II 6th-10th February, 1990, New Delhi, pp. 235-263.

ACHARYA, C.L. BISHNOI, S.K. and YADUVANSHI, H.S. 1988. Effect of long term application of fertilizers and organic manures and inorganic amendments under continuous cropping on soil physical and chemical property in an Alfisol. *Indian J. Agric. Sci.* 58:509-516.

AIYADURAI. 1966. A Review of Research on Spices and Cashewnut. Regional Office, Directorate of Spices & Cashewnut, Ernakulam. pp 209.

AIYER. A.K.Y.N. 1966. *Field Crops of India.* VIth Edn., Bangalore Print and Pub. Co. Ltd., Bangalore.

ANONYMOUS, 1994. Annual Report for 1993-94, Central Plantation Crops Research Institute, Kasaragod, Kerala. 68 p.

ANONYMOUS, 1982. Annual Report 1982 Central Plantation Crops Research Institute, Kasaragod, Kerala. 68 p.

ANONYMOUS, 1981. Annual Report 1981 Central Plantation Crops Research Institute, Kasaragod, Kerala. 40 p.

ANONYMOUS, 1978. Annual Report 1978 Central Plantation Crops Research Institute, Kasaragod, Kerala. 39 p.

BHAT, N.T., and MOHAPATRA, A.R. 1989. Supplying nutrients through organic manures, inorganic fertilizers and their combination on arecanut crops. *J. Plantn Crops* 16 (Suppl.): 443-47.

BISWAS, C.R. and BENBI, D.K. 1989. Long term effects of manure and fertilizer on wheat based cropping systems in semiarid alluvial soils. *Fert. News* 34(4): 33-38.

BLOOM, P.R., McBRIDE, M.B. and WEAVER, R.M. 1979. Aluminium organic matter in acid soils: Salt extractable aluminium. *Soil Sci. Soc. Am. J.* 43: 813-815

BOPAIAH, B.M. and BHAT, N.T. 1981. Effect of continuous application of manures and fertilizers on rhizosphere microflora in arecanut palm. *Pl. Soil* 63: 497-99.

CHADHA, K.L. and RETHINAM, P. 1994. History of Plantation and Spice crops. In: *Advances in Horticulture* Vol. 9(I) K.L. Chadha and P. Rethinam (Eds). Malhotra Publishing House, New Delhi, pp. 1-50.

DAS, D.K. and DAS, S.C. 1966. Mineralogy of clays from black, brown and red soils of Mysore. *J. Indian Soc. Soil Sci.* 14: 43-49.

DEY, S.K. and GOHAIN, K.K. 1978. Effect of phosphate, mulch and weed control on production of feeder (absorbing) roots, uptake of phosphate by tea and available soil phosphate. In: Proc. PLACROSYM I at Kotayyam. March 20-23: 1978. pp. 132-140.

FAN, L.J., YOUNG-HYUN LEL and GHARNAY, M.M. 1982. The nature of lignocellulosics and their pre-treatment for enzymatic hydrolysis. *Adv. Biochem. Engg.* 23: 157-187.

FAO. 1975. Effects of intensive fertilizer use on the human environment. *Soils Bull.* 26: 120-131.

GAUR, A.C. and RAMENDRA SINGH. 1982. Integrated Nutrient Supply System. *Fert. News* 27(2): 87.

GAUR, A.C., NEELAKANTAN, S. and DARGAN, K.S. 1984. Organic manures. ICAR, New Delhi pp-42-71.

GAUR, A.C., SADASIVAM, K.V., MAGU, S.P. and MATHUR, R.S. 1991. Progress Report. AICP on Microbiological Decomposition and Recycling of farm and city wastes, IARI, New Delhi-110 012.

JHA, R.C., SHARMA, N.N. and MAURYA, K.R. 1984. Effect of sowing dates and mulching materials on the yield of turmeric. Proc. PLACROSYM-V: 495-498.

JOTHIMANI, S. 1994. Organic farming in coconut. *Indian Coconut J.* 25(7): 48-49.

KAMARAJ, C.M. 1994. Exportable coir products in Tamil Nadu. The *Coconut Wealth* 1(6): 6-8.

KATYAL, J.C. and RANDHAWA, N.S. 1983. Micronutrients. FAO Fertilizer and Plant Nutrition Bull 7. Food and Agricultural Organisation of the United Nation, Rome, Italy.

KHAN, H. HAMEED, SANKANARAYANAN, M.P., JOSHI, O.P., GEORGE, M.V. and NARAYANA, K.B. 1985. Comparative efficiency of selected phosphates as P carriers for coconut (*Cocos nucifera* L.) *Trop. Agric.* 62(1): 57-61.

KORIKANTHIMATH, V.S. 1994. Nutrition of Cardamom. In: Advances in Horticulture Vol. 9 (1), KL Chadha and P. Rethinam (Eds). Malhotra Publishing House, New Delhi. pp. 467-476

LAL, S and MATHUR, B.S. 1988. Effect of long term manuring, fertilization and liming on crop yield and some physico-chemical properties of acid soil. *J. Indian Soc. Soil Sci.* 36: 113:119.

LINDSAY, W.L., STEFANSON, H.F. and FRAZIER, A.W. 1962. Identification of reaction products from phosphate fertilizers in soils. *Soil Sci. Amer. Proc.* 26: 446-452.

LIYANAGE, L.V.K. and JAYASUNDERA, H.P.S. 1988. *Gliricidia* as a multipurpose tree for coconut plantations. *Coconut Bull.* 5(1): 1-4.

LIYANAGE, L.V.K., JAYASUNDERA, H.P.S., MATHES, D.T. and FERNANDO, D.N.S. 1989. Integration of pasture, fodder and cattle in small holdings. *Cord* V(2): 53-66.

LIYANAGE, M, DES, JAYASEKARA, K.S. and FERNANDOPULLE, M.N. 1993. Effects of application of husk and coir dust on the yield of Coconut. *Cocos* 9: 15-22.

MODGAL, S.C. and SINGH, C.M. 1990. Crop Residue Management. In: Agronomic Research towards Sustainable Agriculture. K.N. Singh and R.P. Singh (Eds) pp. 7-23.

MOHAPATRA, A.R., BHAT, N.T. and ABOOBACKER, V.P. 1970. Some aspects of green manuring for arecanut. *Arecanut and Spices Bull.* 2: 6-20.

NAGARAJAN, R., MANICKAM, T.S.; KOTHANDRAMAN, G.V., RAMA SWAMY, K. and PALANISWAMY, G.V. 1985. Manurial value of coir pith. *Madras agric. J.* 72: 533-535.

NAIR, M.K., BIDDAPPA, C.C., PALANISWAMI, C. and UPADHYAY, A.K. 1996. A critical review of plant nutrient supply needs, efficiency and policy issues for the plantation crops for the year 2000 and 2025 AD. Paper presented in Brain Storming Workshop at CRIDA, Hyderabad on 19-21 April, 1996.

NAIR, P.K.R. 1979. Intensive multiple cropping with coconuts in India-Principles, programmes and prospects. Verlag Paul Parey. Berlin and Hamburg. 1979. pp. 147.

NAMBIAR, K.K.M. and ABROL, I.P. 1989. Long term fertilizer experiments in India - An Overview. *Fert. News* 34(4):11-20.

OUVRIER, M. and De TAFFIN, G. 1985. Evaluation of mineral elements of coconut husks left in the field. *Oleagineux* 40 (8 & 9): 423-430.

RAMASWAMY, P.P. and SON, T.T.N. 1993. Enrichment of coir waste with micro and macro nutrients. In: National Seminar on Developments in Soil Science. Abstracts, pp-66-67. Indian Society of Soil Sciences, Bangalore.

RAVICHANDRAN, B.C. 1988. Evaluation of decomposed corrpith on the grain yield maize. M.Jc.(Ag) Thesis. Univ. Agric. Sciences, Bangalore.

THINAM, P. 1990. Potassium in Plantation Crops. Paper presented in the Seminar on Potassium for Plantation Crops. 6-8 November, 1990. (Eds.): Mahatim Singh and Mishra, M.K., Bangalore. Potash Research Institute of India. pp 7-15.

ADANANDAN, A.K. 1986. Efficiency of P sources for pepper (Abst.) In: Proc. Ist National Seminar on Slow Release fertilizers in Plantation crops. Central Plantation Crops Research Institute, Kasargod, 25-26 Nov. 1986. pp.45.

ADANANDAN, A.K., ABRAHAM, JOSE, ANANDARAJ, M. and HAMZA S. 1991. Effect of coconut-pepper mixed cropping on soil fertility and crop productivity (Abst.). International Symposium on Coconut Research and Development II, CPCRI, Kasaragod, 26-29 November, 1991, pp. 54-55.

SADANANDAN, A.K., REDDY, B.N., KORIKANTHIMATH, V.S. and HAMZA, S. 1992. Nutrient management for sustained productivity of spice crops in India (Abst.) International Symposium on Nutrient management for sustained productivity, Punjab Agricultural University, Ludhiana, 10-12 February, 1992. pp 1-5.

SARKAR, M.C. 1990. Long term effect of fertilizers on soil eco-system. *Fert. News* 35: 81-85.

SAVITHRI, P and RANI PERUMAL. 1993. Use of poultry droppings enriched waste for inceptisol soils. In: National Seminar on Developments in Soil Science. Abstracts: pp. 64. Indian Society of Soil Science, New Delhi.

SAVITHRI, P and H. HAMEED KHAN. 1994. Characteristics of coconut coirpith and its utilization in agriculture. *J. Plantn.* Crops 22(1): 1-18.

SINGH, I.P., BIJAY SINGH and BAL, H.S. 1987. Indiscriminate fertiliser use vis-a-vis ground water pollution in Central Punjab. *Indian J. Agric.* Econ. 42: 402-409.

SESHA REDDY. 1985. Enzymology of lignin degradation in coir dust by *Pleurotus sajor caju.* M. Sc.(Ag.). Thesis, Tamil Nadu Agricultural University, Coimbatore.

TANDON, H.L.S. 1991. Fertilizer equivalents of FYM, Green Manures and Biofertilisers. *Fert. News* 36:69-79.

TANDON, H.L.S. 1995. Trends in integrated Crop nutrition. In: The Hindu Survey of Indian Agriculture. pp. 149-151

TANDON, H.L.S. and PRATAP NARAYAN. 1990. *Fertilizers in Indian Agriculture - Past, Present and Future (1950-2000).* Fertilizer Development and Consultation Organisation, New Delhi. pp. 160+viii.

TANDON, H.L.S. and RANGANATHAN, V. 1988. Fertilizers and their management in Plantation Crops. In: Fertilizers Management in Plantation Crops-A Guide Book (Ed. HLS Tandon). Fertilizer Development and Consultation Organisation, New Delhi. pp. 26-60.

TAPIADOR, D.D. 1981. Vermiculture and its potential in Thailand and other Asian countries. First National Earthworm Growers Convention, Metro Manila, Philippines, Feb. 1981.

TURNER, P.D. and GILLBANK, S.R.A. 1988. Oilpalm cultivation and management. Incorp. Soc. Planters, Kualalumpur.

VARGHESE, P.T. and RETHINAM, P. 1994. Nutrition of oilpalm. In: Advances in Horticulture Vol. 9(I) KL Chadha and P. Rethinam (Eds). Malhotra Publishing House, New Delhi. pp 407-422.

VARGHESE, P. THOMAS, NELLIAT, E.V. and BALAKRISHNAN, T.K. 1978. Beneficial interactions of coconut-cocoa crop combination. In: Proc. PLACROSYM I. RRII, Kottayam, March 20-23, 1978. (Eds) EV Nelliat and others. pp.383-392.

ZACHARIAH, P.K. 1978. Fertiliser management for cardamom. In: Proc. PLACROSYM I. RRII, Kottayam, March 20-23, 1978. (Eds) EV Nelliat and Others. pp. 148-156.