

EFFECT OF TREE BASED FARMING SYSTEMS ON PHYSICAL AND CHEMICAL PROPERTIES OF SOIL

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1. INTRODUCTION

Tree crops are perennial in nature and occupy the same land for decades. Traditionally farmers grow miscellaneous crops in the interspaces of tree crops viz. coconut, arecanut, cashew, etc. and often maintain livestock as well as poultry. The wisdom and experience of traditional farmers gained from such farming practices provided the base for detailed scientific studies which have evolved tree crop based farming systems involving inter-cropping, mixed-cropping and integrated farming. Among the systems developed, the cash crop based one is usually a combination of miscellaneous tree crops along with coconut, arecanut, cashewnut, cacao, rubber and oil palm. However, with regard to food production the combination of tree crops is not satisfactory, the exception being intercropping in the early stages of the maincrop.

Farming systems influence the environment in several ways. While some systems cause soil degradation and pollution problems, some may reduce the hazards of erosion and ensure better efficiency in the utilization of the 'native' and applied nutrients especially in woody perennial based cropping systems. Since the environment resources necessary for the growth of all the plants in a system are usually in short supply, competition almost always takes place at some stage in the development of a plant community. When the immediate supply of a single necessary factor falls below the combined demands of the plant community, inter-plant competition begins. The time at which the competition will commence depends on (i) level of supply of resources, e.g. soil fertility, radiation, moisture balance and (ii) nature of plant community, plant population per unit area and spatial arrangements (Beets, 1982).

2. COCONUT BASED CROPPING/FARMING SYSTEMS

Coconut palms which are generally spaced 7.5 m apart on the square do not utilize crop production resources like soil, air space and solar radiation fully. Studies conducted at the Central Plantation Crops Research Institute (CPCRI), Kasaragod have revealed that about 75 per cent of the roots of a well managed adult palm are concentrated within a radius of 2 m from the bole (Kushwaha et al, 1973). This works out to about 22 per cent of the soil area in one ha. The remaining 78 per cent area, which is not fully utilised by the palms could be profitably used for raising compatible crops. However, the actual area available for inter-cropping would depend upon the density of planting (Table 1).

Table 1. Land space used by coconut trees per ha with various plant densities

Plant density ha ⁻¹	Land space needed by coconut	
	m ²	Percentage
100	1257.14	12.8
120	1508.57	15.1
140	1760.00	17.6
160	2011.43	20.1
180	2262.86	22.6
200	2514.29	25.1

Source : Darwis S.N. 1988

Based on the growth and canopy development, the life span of coconut palms could be divided into three distinct phases. The first phase lasts upto eight years during which period only a small fraction of incident solar radiation is intercepted by the growing palms. The second phase covers the period eight to 20 years when the interception increases with the age of palms reaching about 80 per cent in the beginning and continues at this level till the 20th year. During the third and last phase, the interception gradually decreases due to increased trunk height and gradual reduction in crown size reaching about 50 per cent around the 40th year of planting (Nelliatt et al, 1974). A number of shade tolerant crops could be grown in

the inter spaces of coconut palms utilising the diffused sun light available in the initial years and after 20 or 25 years.

The CPCRI has suggested four coconut based cropping systems covering inter-cropping, mixed-cropping, multistoreyed cropping and high density multispecies cropping. Apart from these systems, coconut based mixed farming system has also been developed and recommended for adoption by the farmers. When annuals or seasonal crops are grown under coconut it is designated as inter-cropping and when perennials are grown it is called mixed cropping. In the multistoreyed cropping system, crops having varying morphological frame work and rooting habit are mix planted in such a manner that their canopies intercept solar radiation at varying heights and their roots forage soil at different zones. When many annual and perennial plant species are grown together in a definite pattern to accommodate maximum number of plants per unit area of land for production of biomass having high economic value and diverse end uses like food, fodder, fuel and timber, the system is known as multispecies cropping. And, lastly, when livestock and poultry are raised with the help of fodder or pasture grown in the coconut garden, it is called mixed farming.

In the absence of scientific information on the total nutrient needs of crops in a cropping/farming system as a whole, fertiliser rates are restricted to the needs of pure stands of these crops. Thus, one hectare of a monocrop of coconut (175 palms) receives the recommended levels of nutrients within a limited area of about 22.24 per cent leaving the rest of the area not being effectively utilised by coconut roots. This area, if inter-cropped with miscellaneous crops, will receive additional nutrients through the fertilisers and manures applied to the inter-crops. Though most of the coconut root growth is restricted to about 2 m from the bole, the fertilisers applied to inter-crops and the cultural operations carried out will be indirectly contributing to the nutrition of coconut. Quantification of such benefits involves use of tagged nutrients with stable or radioactive isotopes. Such information, though available for annual crop based systems, is difficult to obtain for tree based farming systems in view of the high cost of conducting such experiments. Nevertheless, the beneficial effect of improved soil chemical environment becomes apparent from the increased yield of coconut obtained under different cropping systems, general improvement in soil fertility and enhanced soil life.

Nair and Rao (1977 a and 1977 b) have investigated in detail the microbiology of the rhizosphere of sole crop of coconut and coconut-cacao crop mix. They observed that activity of nitrogen fixing bacteria like *Beijerinckia* and phosphate solubilisers like *Pseudomonas* sp. and *Aspergillus niger* was very much enhanced in the mixed crop stands. They also reported higher levels of organic carbon in the rhizosphere of coconut-cacao crop mix (Table 2). Recent studies on coconut based high density multispecies cropping system (Nambiar *et al.*, 1989) have revealed a general increase in all the P fractions as well as K fractions in soil during the three year period of study.

Soil fertility and microbiological investigations conducted so far on coconut based cropping systems suggest scope for rationalising fertiliser recommendations. Preliminary results from coconut based high density cropping system experiment

Table 2. Organic carbon content of rhizosphere soils of coconut and cacao in the mixed cropping experiment at CPCRI

Cropping system	Rhizosphere of	Organic carbon %
Coconut alone	Coconut	0.42
Coconut + cacao single hedge	Coconut	0.48
	Cacao	0.50
Coconut + cacao double hedge	Coconut	0.53
	Cacao	0.60
No crop	Non rhizosphere	0.39

Table 3. Soil chemical properties of coconut based multistoreyed cropping system and coconut monocropping system

(a) Coconut-pepper-cinnamon-pineapple system

Cropping system	Soil depth (cm)	Ph	Organic carbon %	Available nutrients (ppm)	
				P	K
1. Coconut (in the system)	0-25	5.80	0.57	23.0	67.9
	25-100	4.95	0.31	13.5	50.0
2. Cinnamon	0-25	5.10	0.55	18.5	60.0
	25-100	5.05	0.41	11.7	50.0
3. Pepper	0-25	5.54	0.48	21.0	65.0
	25-100	4.91	0.37	8.9	55.0
4. Pineapple.	0-25	5.25	0.49	19.8	56.0
	25-100	4.96	0.44	7.3	51.0
5. Coconut (monocrop)	0-25	5.15	0.50	17.5	31.0
	25-100	4.45	0.37	4.32	17.3

(b) Coconut-pepper-cacao-pineapple system (mean of three replications)

Cropping system	Soil depth (cm)	Ph	Organic carbon %	Available nutrients (ppm)	
				P	K
1. Coconut (in the system)	0-25	5.23	0.99	25.8	121.5
	25-50	4.58	0.50	22.0	89.5
	50-100	4.29	0.47	8.5	79.0
2. Cacao	0-25	5.26	0.70	19.8	51.5
	25-50	4.70	0.61	6.4	34.5
	50-100	4.40	0.44	1.0	31.0
3. Pineapple	0-25	5.00	0.61	14.4	31.0
	25-50	4.29	0.55	11.2	33.5
4. Coconut (monocrop)	0-25	5.15	0.50	17.5	31.0
	25-50	4.59	0.38	4.2	13.5
	50-100	4.24	0.33	4.2	31.0

Source : Bopiah, B.M. 1988

at Kasaragod indicate that the high level of productivity achieved in this system could be sustained with a lower level of fertiliser input. The mean yield of coconut during 1985-'88 under full, two-third and one-third of total recommended dose of fertilisers was 151, 149 and 156 nuts/palm/year, respectively.

The influence of coconut based multistoreyed cropping system and coconut monocropping on some soil chemical properties is presented in Table 3.

In the coconut-pepper-cinnamon-pineapple system differences in organic carbon content were not pronounced as component crops were not much influenced by each other by way of leaf litter shedding. In general, organic carbon status was poor. However, compared to monocrop-coconut, the coconut crop in the system had higher soil available phosphorus and potash. The coconut-pepper-cacao-pineapple system, however, had higher organic carbon content compared to monocrop of coconut. When the coconut monocrop had 0.40 percent of organic carbon to a depth of 1 m, the coconut basins in the system had recorded 0.65 percent organic carbon, indicating the benefit accrued from cacao due to shedding of large quantities of leaf litter.

The beneficial interactions of mixed cropping on soil fertility have also been reported from Sri Lanka (Liyanage and Dassanayake, 1992) in terms of better physical, chemical and biological properties (Table 4). The increase in the moisture content of the soil and earthworm activity was conspicuous. These features had an indirect influence on the microclimate to the benefit of the maincrop and the component crops.

Table 4. Effect of mixed cropping on soil fertility parameters

Cropping system	Soil characteristics						
	Physical			Chemical			Biological
	Bulk density (g/cc)	Moisture (%)	Organic C %	Total N (kg ha ⁻¹)	Available P (ppm)	Available K (ppm)	Earthworm population/M ²
Coconut monoculture	1.56	0.06	0.86	957	9.6	55	28
Coconut + Cacao	1.26	18.55	1.42	1184	29.4	70	214
Coconut + Coffee	1.23	12.91	1.36	1022	27.8	59	218
Coconut + pepper	1.27	11.20	1.27	1461	55.9	47	191
Coconut + clove or banana	1.19	11.30	1.20	1154	32.3	70	204
Coconut + cinnamon	1.25	10.69	1.44	1249	28.9	63	233
SE	0.195	1.20	0.275	8.7	2.4	-	-

Source : Liyanage, M.de.S. and Dassanayake, K.B., 1992.

In the studies carried out at the CPCRI it was observed that the response of palms to fertilisers is inversely related to the pre-experimental yield level of palms under monocrop conditions. However, with mixed cropping of coconut + cacao, the pattern of yield of palms was almost directly proportional to the pre-treatment yield for all yield groups (Table 5).

Table 5. Yield of coconut palms of different yield groups before and after planting cacao as a mixed crop

Yield group of palms (Pre experiment yield) No. of nuts palm ⁻¹ year ⁻¹	Average yield of nuts palm ⁻¹								
	Coconut alone			Coconut + Cacao in single hedge			Coconut + Cacao in double hedge		
	PEY	EY	Increase	PEY	EY	Increase	PEY	EY	Increase
30	19	57	38	22	74	52	15	85	70
30-60	50	125	75	42	141	99	53	118	65
60	88	178	90	83	170	87	78	190	112

PEY : Pre experimental yield, average for two years, - 1968 and 1969

EY : Experimental yield (after planting cacao), average for three years - 1972-73 to 1974-75

Cacao has been identified as a suitable component crop in coconut gardens as it improves the productivity of coconut (Table 6). Though single and double hedge systems of planting have been advocated in normally spaced (7.5 m x 7.5 m) coconut gardens, the single hedge system is preferred as the possibility of root competition with the main crop for soil resources is likely to be less.

Table 6. Influence of mixed cropping of coconut with cacao on productivity of coconut

Cropping system	Coconut (Nuts palm ⁻¹ year ⁻¹)	
	Pre-experiment period (1966-70)	Experimental period (1972-87)
Coconut - sole crop	68.0	106.6
Coconut + cacao single hedge	56.7	108.3
Coconut + cacao double hedge	39.1	88.5

Varghese *et al.* (1978) have estimated that the amount of organic matter added to the soil through shed leaves and prunings of cacao under single and double hedge systems of mixed cropping of cacao in coconut holding was 818 and 1985kg (oven dry weight) ha⁻¹ year⁻¹. As much as 50 kg N, 11 kg P₂O₅ and 35 kg K₂O ha⁻¹ could be returned to the soil every year through leaf fall of cacao under double hedge system. Addition of large amounts of organic refuses also helps to improve the organic matter content of soils. They have further observed lower range of fluctuations in soil temperature in the crop mix.

Studies conducted by Nair and Balakrishnan (1977) have revealed that the microclimate inside a crop mix is more equitable than that in monocropped stands. The crop mixes recorded lower mean maximum temperature, higher relative humidity and reduced evaporative demand. In coconut based mixed farming system where milch animals are integrated and green fodder is cultivated in the interspaces, biological recycling of nutrients especially nitrogen takes place benefiting the entire system. In farms where biogas (gobar gas) plant is maintained, the

refuse from the tank i.e., the slurry is recycled within the system to the benefit of the fodder grass and coconut. Estimates from a one hectare model of mixed farming system at Kasaragod showed that about 14.6 tonnes of cowdung and 3600 litres of urine were recycled in a year when five crossbred milch cows were maintained. This altered the soil chemical profile of the system to the advantage of both the crops. The increase in organic carbon content of the soil and other beneficial changes in soil fertility under a grass cover are well illustrated by the results of the study (Table 7).

Table 7. Soil chemical properties of coconut based mixed farming and coconut monocropping system

Crop	Soil depth (cm)	pH	Organic C%	Available nutrients (ppm)	
				P	K
Coconut (system)	0-25	5.50	0.71	22.0	88
	25-50	5.10	0.50	18.4	97
	50-100	5.00	0.26	16.2	50
Napier grass	0-25	5.35	0.36	17.2	23
	25-50	5.30	0.19	18.4	32
	50-100	5.43	0.18	1.9	24
Coconut monocrop	0-25	5.55	0.22	13.2	60
	25-50	5.28	0.15	12.0	56
	50-100	4.44	0.10	8.4	40
Coconut monocrop interspaces	0-25	5.48	0.18	9.9	27
	25-50	4.93	0.09	0.8	23
	50-100	4.80	0.06	0.7	13

Mean of 3 replications

Source : Bopaiah, B.M., 1988

A general increase in pH and organic carbon status of the soil and enhanced microbial activities (bacteria, fungi and actinomycetes) were observed in all the mixed farming trials carried out by the C.P.C.R.I.

In mature coconut plantations improved pasture species is maintained for grazing by animals. Observations recorded in Sri Lanka have shown that improved pasture species like *Brachiaria miliformis* (cori grass) and *B. brizantha* cultivated in coconut gardens where cattle are allowed to graze has increased coconut yields by six per cent relative to control. Under such conditions, only shade tolerant legumes can persist. Grazing animals enhance nitrogen cycling via nitrogen inputs in urine and dung. According to Liyanage *et al.* (1988), mixed farming benefited the low income group farmer by contributing 73 kg of dung and 30 l of urine for each palm per year which could substitute for entire nitrogen and part of phosphorus and potassium, thus saving about 69 percent on the cost of fertiliser. Its impact on fertility parameters was revealed as changes in pH, organic carbon, nitrogen and phosphorus (Table 8) to result in 11.4 percent increase in the yield of palms.

Table 8. Effect of mixed farming system on soil chemical characteristics

Farming system	pH	Organic C %	Total N %	Available P (ppm)
Integrated system	6.0	1.63	0.101	27
Monoculture system	5.9	0.96	0.077	10

Experiments with fodder grass (hybrid napier-Gajaraj) and legumes (*Mimosa invisa*, *Pueraria javanica* and *Centrosema pubescens*), as intercrops and integrating cattle in coconut gardens have improved the soil physical and chemical properties in a root (wilt) disease affected tract in Kerala, India.

The aggregate analysis of soil indicated differences between the treatments but was not statistically significant. Chemical properties showed highly significant differences in the status of organic carbon, exchangeable Ca and Mg. Available K was higher in the legume plots compared to plots devoted to Napier grass.

The health of the palms was found increased with reference to nutritional status, foliar colour, regeneration of roots etc. Though the progress of disease could not be arrested, the changed soil chemical conditions and microbial activity could increase the yield of disease affected palms by 26 percent.

In a crop mixing experiment with hybrid napier as fodder grass in coconut holdings, there was a favourable alteration in the soil microflora and the micro-organisms colonising on the surface of the coconut roots. Both the total bacteria, nitrogen fixing bacteria and phosphate solubilising fungi showed a significant increase in the rhizosphere of experimental palms compared to the control. The incidence of microflora as observed in the root zone of experimental palms is shown in Table 9.

Table 9. Distribution of microflora in the rhizosphere of coconut palm

Treatment	Coconut & Grass		Coconut alone	
	Healthy	Root (wilt) affected	Healthy	Root (wilt) affected
Organisms/ condition of palm				
Bacteria	2.70×10^6	1.96×10^6	6.80×10^5	5.80×10^5
Fungi	1.23×10^4	1.20×10^4	1.00×10^4	6.80×10^4
N ₂ - Fixing bacteria	1.46×10^4	1.77×10^4	6.04×10^3	8.71×10^3
Phosphate solubilising				
Fungi	6.51×10^3	5.26×10^3	2.40×10^3	1.00×10^3
Bacteria	4.82×10^4	4.61×10^5	2.93×10^4	4.00×10^4
Actionomycetes	4.87×10^3	2.40×10^3	6.48×10^3	2.00×10^3

* Significant at 5 percent level

3. ARECANUT BASED CROPPING/FARMING SYSTEMS

Similar to coconut, arecanut palm is also amenable to multispecies cropping. Sannamarappa (1983) estimated that in a 17 year old arecanut garden, 58 to 61

percent of the incident light passed through the canopy at a spacing of 1.8 to 3.6 m and it increased to 64 to 66 percent at wider spacings. Bhat and Leela (1969) reported that at 2.7 x 2.7 m spacing, nearly 80 percent of the roots were found within a radius of 75 cm from the base. This works out to 31 percent of the land area available and nearly 69 percent of the area is not effectively used by the areca palms.

Table 10. pH and available nutrient content (0-100 cm) in soil under different treatments

Treatment	pH	Organic C (kg m ⁻³)	Available nutrients (gm ⁻³)					
			P	K	Cu	Zn	Fe	Mn
Monocrop Areca basin	6.3	8.4	22.2	353	10.3	11.2	34.3	105.6
interspace	5.7	6.5	1.5	153	7.9	1.6	32.0	60.6
T1 Areca basin	6.1	9.1	47.6	200	14.2	5.3	78.8	107.4
Cacao basin	5.5	6.2	9.3	155	11.2	6.6	44.8	108.5
Interspace	5.7	5.9	5.5	170	5.4	0.8	30.9	65.4
T2 Areca basin	5.5	11.0	72.5	152	18.5	2.8	62.4	88.2
Cacao basin	4.9	8.9	97.9	293	15.0	2.9	88.8	113.4
Interspace	5.5	7.7	3.3	132	9.1	1.0	46.0	61.9
T3 Areca basin	5.9	8.4	23.4	130	16.3	14.5	42.3	114.4
Cacao basin	5.4	7.3	17.2	89	14.3	8.5	59.4	143.6
Interspace	5.5	6.1	1.6	98	11.4	1.8	37.7	94.8
T4 Areca basin	5.9	15.3	81.3	259	32.5	30.9	121.1	229.9
Cacao basin	5.2	8.9	55.0	180	21.7	9.8	81.6	152.9
Interspace	5.7	7.8	5.5	120	13.7	3.5	49.8	77.5
LSD Areca basin	0.11	2.99	N S	58.3	10.1	12.3	26.8	78.2
Cacao basin	0.17	1.29	24.9	78.9	6.1	4.7	13.7	N S
Interspace	0.09	1.08	2.2	39.2	3.3	1.1	5.1	8.5

P = 0.05

Table 11. Spacing and manurial schedule of the arecanut-cacao treatments

Treatment	Crop	Spacing (m)	Manurial schedule (a) g/palm/year		
			N	P ₂ O ₅	K ₂ O
T ₁	Arecanut	(b) 2.7 x 2.7	100	40	140
	Cacao	2.7 x 5.4	100	40	140
T ₂	Arecanut	2.7 x 2.7	100	40	140
	Cacao	2.7 x 5.4	200	80	280
T ₃	Arecanut	3.3 x 3.3	100	40	140
	Cacao	3.3 x 3.3	200	80	280
T ₄	Arecanut	3.3 x 3.3	100	40	140
	Cacao	3.3 x 3.3	200	80	280

(a) N - as urea P - as superphosphate and K - as muriate of potash

(b) In addition, 12 kg green leaves and 12 kg cattle manure were added to the basin of every arecanut palm, each year in september. Fertilisers were applied in two doses, half during February and half during September

Arecanut and cacao are compatible crops. Manikandan *et al.*, (1985) examined the nutrient profile in such a system after 13 years of planting as influenced by spacing of arecanut and cacao and supply and exhaustion of nutrients. The details of observations recorded in the study are shown in Table 10 and 11.

It is evident from the results presented that organic carbon content and available P status of the interspaces were influenced positively by cacao litter fall. Interestingly, available K status of the soil was low in mixed cropping compared to monocropping. Arecanut palms and cacao are heavy feeders of potassium and probable luxury consumption and immobilisation of K in plants (Von Uexkull, 1978) and root competition in mixed cropping may lead to lower available K status in mixed cropping compared to monocropping (Manikandan *et al.*, 1985). Von Uexkull (1978) observed that a good crop of cacao would remove over 170 kg ha⁻¹ K and even good soils will not be able to supply K at such rates (plus K immobilised in the living tree) for long. Hence higher K dressings are needed for component crops in areca-cacao mixed crop system.

An assessment of the system on one hectare basis indicated the higher requirement/uptake of K by both crops and its consequent importance in the nutrition of arecanut-cacao system. Inclusion of Zn in the system if the crops are closely planted is also desirable (Table 12).

Table 12. Net gain (+) or loss (-) in the system over monocropping in 1 ha, 1 m depth of arecanut due to mixed cropping with cacao

Available nutrients	Nutrient content of treatments (kg ha ⁻¹ m ⁻³)			
	T ₁	T ₁	T ₃	T ₄
Organic C	- 1715	+ 17819	+ 5055	+ 30169
P	+ 72.7	+ 284.2	+ 12.8	+ 200.3
K	- 367	- 488.8	- 1071.4	- 608.4
Cu	+ 1.4	+ 40.1	+ 43.8	+ 104.2
Zn	- 7.9	- 20.7	+ 18.6	+ 58.4
Fe	+ 129.3	+ 266.3	+ 121.5	+ 379.8
Mn	+ 133.5	+ 78.4	+ 405.5	+ 523.6

4. CACAO-SHADE TREE COMBINATIONS

In cacao plantations intensive transfer of nitrogen through biomass recycling has been recorded. In these plantations most of the N needed to sustain cacao production is absorbed from the upper soil or litter layers. Shade trees like *Erythrina* take up nitrogen from deeper soil layers not exploited by cacao, and may thus enhance nitrogen availability for cacao by transferring this nitrogen to the soil surface via litter fall. In a properly managed adult cacao plantation under *Erythrina* shade, the entry of nitrogen through litter fall plus input via rainfall could be greater than those removed by a harvest of even 1500 kg dry beans ha⁻¹. Under most situations, the contribution of cacao litter fall is substantial to the extent of 50-90 kg N ha⁻¹.

Erythrina enriches the nitrogen content of soil and this enrichment extends to a

considerable distance from the trunk of these trees. The *Erythrina* sp. through its seeds, flowers, branches and leaves contribute further to the amount of nitrogen available to cacao tree (Table 13).

Table 13. Nitrogen content of *Erythrina* plant parts

Plant part	% N
Recently fallen leaves	2.74
Fallen flowers	3.32
Seeds	6.15
Nodules	3.95*

* Mean of six observations

Aranguren *et al.*, (1982) reported that in northern Venezuela, the N input to the soil by shade tree leaf litter alone exceeded the net output by harvest of cacao almonds by a factor of more than six. The flux of nitrogen in the form of litter fall occurred continuously during the year with marked peaks (Table 14). Shade tree leaves made up 61 percent of total nitrogen in the litter on the soil. Mineral source of total nitrogen was 35×10^3 kg N ha⁻¹ yr⁻¹, 40 percent of which was found in the

Table 14. Nitrogen transfer rates (kg N ha⁻¹ month⁻¹) in litter fall fractions in a Venezuelan cacao plantation under shade trees

Month	Leaves		Twigs	Flowers and fruits	Total
	Shade Trees	Cacao			
March	25.2	2.2	6.2	6.6	40.2
April	14.3	3.5	3.0	8.3	29.1
May	10.6	3.8	4.4	8.4	27.2
June	14.8	5.4	7.0	9.5	36.7
July	6.5	3.7	2.8	7.3	20.3
August	25.5	3.7	10.4	6.9	44.5
September	6.6	2.7	2.6	6.6	18.5
October	10.7	3.9	4.0	5.3	23.9
November	15.6	3.1	2.2	3.0	23.9
December	8.3	1.2	3.1	1.8	14.6
January	15.9	2.2	3.5	1.6	23.2
February	14.0	1.2	2.2	1.1	18.5
Total	168.0	36.6	51.4	66.4	320.6

first 20 cm depth.

Considering the monthly litter fall (20.9×10^3 kg dry leaf during the year) Aranguren *et al.*, (1982) indicated that major nitrogen contribution to the soil was 50 percent from shade tree leaves leading to a N transfer of 321 kg N ha⁻¹. Nitrogen output by harvest was 45 kg N ha⁻¹ yr⁻¹ with some 20 kg N ha⁻¹ yr⁻¹ returned to the field with pods and shells after processing.

In addition to nitrogen recycling reported, analysis of cacao leaf litter indicates that considerable quantities of other nutrients can also be added making the system

Table 15. Some characteristics of soil and nitrogen store in a Venezuelan cacao plantation

Soil depth (cm)	pH	Organic C	Total N	
			%	(10 ³ kg N ha ⁻¹)
0-20	7.4	1.50	0.62	13.9
20-40	7.1	0.29	0.47	9.7
40-60	6.1	0.21	0.18	10.6

self sustainable to certain extent.

5. COFFEE BASED CROPPING SYSTEMS

In coffee plantations where shade is provided through *Erythrina* sp. and *Inga* sp. with little or no fertilisation, the nitrogen output by harvest can be exceeded by nitrogen transfers from shade tree leaves alone, while total inputs including all litter and nitrogen in throughfall can be over ten times higher than the net nitrogen output by harvest. Aranguren *et al.*, (1982) examined some such coffee plantations which received no fertilisers for 10 years and indicated a substantial nitrogen store in the 0-60 cm soil depth. The nitrogen flow associated with litterfall was dominated by the shade tree fraction accounting for a transfer of 86 kg N ha⁻¹ yr⁻¹ of the total of 189 kg ha⁻¹ yr⁻¹. The decomposition of litterfall was rapid and some evidence of

Table 16. Nitrogen transfer rates (kg N ha⁻¹ month⁻¹) in litterfall fractions in a Venezuelan coffee plantation

Month	Leaves		Twigs	Flower and Fruits	Total
	Shade	Cacao			
January	5.8	1.3	1.4	0.2	8.7
February	10.9	0.3	1.7	1.1	14.0
March	11.2	3.1	3.3	4.0	21.6
April	3.8	2.3	2.3	2.5	10.9
May	6.2	2.3	3.1	2.5	14.1
June	5.4	0.8	6.7	1.6	14.5
July	7.9	4.9	6.8	5.2	24.8
August	7.7	4.2	8.2	1.1	21.2
September	-	-	-	-	-
October	6.7	0.7	4.4	0.7	12.5
November	7.1	4.6	4.5	1.7	17.9
December	5.8	3.4	1.3	1.3	11.8
Total	78.5	27.9	43.7	21.9	172.0

synchrony was found between peaks of nitrogen transfer to the soil (Table 16) by litter and periods of high nitrogen demand by the crop plants.

The litter recycling in coconut, arecanut, cacao and coffee based systems provides organic substrate for the growth of micro-organisms. The better solubilisation of phosphate, fixation of nitrogen and production of organic com-

pounds as well as antibiotic substances in the rhizosphere would influence the productivity of the crop community in the system.

6. OIL PALM AND RUBBER BASED SYSTEMS

In commercial plantations of rubber and oil palm fast growing leguminous cover crops are cultivated. Tan and Ng (1973) had shown that leguminous cover crops have enhanced the yield of fresh fruit bunches (ffb) of oil palm, the yield increase being 6 percent on coastal soils and ranged from one to two t ha⁻¹ over a period of 5-10 years in coastal marine clayey soils of Malaysia.

The residual effect of legume covers, both natural and planted, in oil palm plantations was reported to persist upto 10 years (Table 17).

Table 17. Effect of covers and nitrogen on yield of oil palm*

Cover crop	Level of N applied (kg)	Cumulative yield (tons ffb ha ⁻¹)	Yield in 9th year	N (%) in fronds (1978)
Legume (pure for two years)	0	149	8.3	2.11
	803	196	12.9	2.19
	1606	228	20.2	2.48
Natural (without <i>Mikania</i>)	0	104	5.5	2.89
	803	167	12.0	2.20
	1606	194	16.4	2.29
Natural (with <i>Mikania</i>)	0	119	7.2	2.05
	803	174	12.6	2.21
	1606	194	14.6	2.32
Natural (mown)	0	104	6.0	2.06
	803	158	11.2	2.06
	1606	192	15.8	2.48

* Planted November 1967; harvest commenced July 1970; yield is for a period upto December

Over a period of ten years of harvesting, the cumulative yield of ffb of a stand of oil palm grown in association with a legume cover was 196 tonnes, whereas the nitrogen applied to it was 803 kg. On the other hand, to get a similar yield in an area with natural cover with or without *Mikania* double that amount of nitrogen had to be applied to the palms.

Pushparajah (1982) referring to the work carried out in Malaysia stated that besides nitrogen economy, legume covers had long-term beneficial effect on the physical properties of soil also, such as bulk density, porosity, infiltration, moisture retention and reducing leaching losses.

In rubber plantations of Malaysia when a shade tolerant legume cover *Calapogonium caeruleum* was introduced, it persisted for eight years and the total nitrogen return was as high as 695 kg ha⁻¹ from third to eight year (Table 18).

Table 18. Organic matter and nitrogen from legume cover (a)

Year after establishment	Drymatter (b) of litter t ha ⁻¹	Total N in (c) litter kg ha ⁻¹
0-2	10.5	284 (16)
3	9.6	267 (101)
4	6.0	163 (127)
5	4.5	123 (101)
6	2.9	83 (75)
7	1.6	46 (45)
8	0.4	13 (13)
Total	35.5	979 (478)

(a) Mixture of *Pueraria phaseoloides* and *C. caeruleum*

(b) *P. Phaseoloides* accounted for about 40 percent of total litter return, most of these returns being in first 3 years

(c) Data from 3rd to 8th year from Tan *et al.*, (1979).

Date from 1st and 2nd year from Pushparajah (1979).

Figures in parenthesis refer to N from *C. caeruleum*.

Watson *et al.*, (1963) reported that 170 kg excess nitrogen in soil was facilitated by growing *Calopogonium muconoides*, *C. pubescens* and *Pueraria phaseoloides* as cover crops in Malaysia and according to Broughton (1977) the enrichment to the tune of 151 - 200 kg N ha⁻¹ was possible in *Hevea* plantation.

Thus, large benefits in nitrogen economy are possible for farmers growing rubber and oil palm by maintaining leguminous covers. Pushparajah and Tan (1979) estimated that for Malaysia, the use of leguminous cover crops could entail a theoretical savings of 64,665 tonnes of nitrogen per year. Similar benefits are possible in oil palm plantations as well which are under a legume cover.

7. CONCLUSION

From the results of various studies it is evident that considerable scope exists for reducing reliance of tree crops on fertiliser nutrients especially nitrogen if a suitable cropping/farming system is practised. A closer monitoring of the system will enable the cultivator to scale down the inorganic fertiliser inputs. In the high density cropping systems, over a period of years, the component crops can even become self-sustaining with reference to nutritional requirement if moisture is not a limiting factor.

The effect of leguminous cover crops in the nutrient economy of oil palm and rubber plantations was found to last for many years. This calls for the need to study the root system of tree crops (coconut, oil palm, arecanut and rubber) and its ability to exploit soil and fertiliser inputs.

The contribution of fine root decay to nitrogen cycling also needs to be determined. Extensive sampling using soil coring under trees and use of infield root observation facilities may provide valuable insight into nitrogen cycling/rooting relationship (Stephenson and Raison, 1988).

Less research has gone into the dynamics of nutrients in tree cropping systems involving coconut, arecanut, cashew, oil palm and rubber, and reserves of nutrients in the soil during different phases of the development of a system for objective judgement of nutrient budgeting.

Partitioning of nutrient uptake in tree crops needs better understanding. Harvested produce remove considerable potash, chlorine and nitrogen and there is every need to balance inputs and outputs by proper management for sustainable productivity.

Considering the complementary effect of growth sharing substances in a plant community, the approach of applying fertilisers according to estimated requirements of each individual crop may not be the most efficient and economical way of utilising the nutrients that are either externally applied or inherently present in the soil. Khanna and Nair (1977) proposed nutrient cycling models for pure stand of coconut and coconut + cacao combination based on system approach. Such models take into consideration the fluxes of nutrients viz., inputs and outputs besides growth increments, plant cycling fractions (through fall, contribution from leaf litter) and offer means to scale down the inputs.

REFERENCES

- Aranguren, J. (1980). Contribution de la caída de hojarasca al ciclo de nutrientes in cultivos bajo arboles de Sembra. M.Sc. Thesis. Caracas: Institute Venezueland de Investigaciones Cientificas. pp. 285.
- Aranguren, J., Escalente, G. and Herrera, R. (1982). Nitrogen cycle of tropical perennial crops under shade trees. I. Coffee. *Plant Soil* 67: 247-258.
- Aranguren, J., Escalente, G. and Herrera, R. (1982). Nitrogen cycle of tropical perennial crops under shade trees. II Cacao. *Plant Soil* 67: 259-269.
- Bopaiiah, B.M. (1988). Microbiological studies in relation to high density multispecies cropping system in coconut. Ph.d. Thesis, University of Mysore, India.
- Broughton, W.J. (1977). Effect of various covers on soil fertility under *Hevea brasiliensis* and on growth of the tree. *Agro-Ecosystems* 3: 147-170.
- Beets, C. Willem, (1984). Multiple cropping and tropical farming systems. Grower publishing Company Limited, Hants. Great Britain pp. 156.
- Bhat, K.S. and M. Leela, (1968). The effect of density of planting on the distribution of arecanut roots. *Tropical Agriculture*. 46: 55-61.
- C.P.C.R.I. (1976). Central Plantation Crops Research Institute, Final report of Agrostology Project (1970-75). CPCRI Regional Station, Kayamkulam, Kerala.
- C.P.C.R.I. (1982). Central Plantation Crops Research Institute, Annual Report for 1979, Kasaragod, India.
- C.P.C.R.I. (1991). Central Plantation Crops Research Institute, Mixed farming in coconut garden. Tech. Bull. 25 pp. 6
- Darwis, S.N. (1988). Tanaman Sela di antara Kelapa (Intercrops under coconut) cited in Management of soil in coconut based farming systems (Darwis, S.N. and Tarigans, D.D.) In : *Proc. of the XXVII Cocotech Meeting*, (Ed. Sumith De Silva), APCC, 1990, pp. 503-514.

- Gopalasundaram, P., Thomas Varghese, P. and Hegde, M.R. (1992). Experiences in coconut based farming systems in India. In : *Proc. Intl. Sym. Cocon. Res. Dev.* II (in press), Oxford and IBH Publishing Co., New Delhi.
- Khanna, P.K. and Nair, P.K.R. (1977). Evaluation of fertiliser practices for coconuts under pure and mixed cropping systems in the west coast of India. In : *Proc. of Conference on Classification and Management of Tropical soils*, Malaysian Soc. Soil Sci., Kuala Lumpur, pp. 457-466. (Ed. K.T. Joseph)
- Kushwaha, B.L., Nelliath, E.V., Markose, V.T. and A.P. Sunny, (1973). Rooting pattern of coconut. *Indian Journal of Agronomy* 18 : 71-74.
- Liyanage, L.V.K., Jayasundara, H.P.S. and Fernando, D.N.S. (1988). Integration of pasture, fodder and cattle with coconut in small holdings of Sri Lanka. *CORD* 5 (2): 53-67.
- Liyanage, M. de. S. and Dassanayake, K.B. (1992). Experiences on coconut based farming system in Sri Lanka. In : *Proc. Int. symp. Cocon. Res. Dev.* (in press) Oxford & IBH Publishing Co., New Delhi.
- Manikandan, P., Joshi, O.P., Hameed Khan, H., Mohapatra, A.R. and Biddappa, C.C. (1985). Nutrient profile in an arecanut-cacao system on a laterite soil. *Trop. Agri. (Trinidad)* 64 (1): 13-16.
- Muralidharan, K. (1990). Intercropping in arecanut. *J. Plant. Crops* 17 (suppl.): 25-28.
- Nair, P.K.R. and T.K. Balakrishnan, (1977). Ecoclimate of a coconut plus cacao crop combination on the West Coast of India. *Agricultural Meteorology* 12: 455-462.
- Nair, S.K. and N.S.S. Rao, (1977) a. Microbiology of the root region of coconut and cacao under mixed cropping. *Plant and Soil* 46: 511-519.
- Nair, S.K. and N.S.S. Rao, (1977) b. Distribution and activity of phosphate solubilising microorganisms in the rhizosphere of coconut and cacao under mixed cropping. *Journal of Plantation Crops*, 5 : 67-70.
- Nambiar, C.K.B., Biddappa, C.C., Bopaiah, M.G. and C. Kailasam, (1989). Influence of high density multispecies cropping on the P and K forms in the soil. *Journal of plantation Crops* 17: 36-43.
- Nelliath, E.V., Bavappa, K.V.A. and P.K.R. Nair (1974). Multistoreyed cropping. A new dimension in multiple cropping for coconut plantations. *Wld. Crops*, 26 : 262-266.
- Pushparajah, E. (1982). Legume cover crops as a source of nitrogen in plantation crops in the tropics. In : *Non symbiotic nitrogen fixation and organic matter in the tropics*. Symposia Papers I Trans. 12th Int. Congress of Soil Sci. 1982. pp. 189-197.
- Sannamarappa, M. and A. Muralidharan (1982). Multiple cropping in the Arecanut Palm. (Eds. K.V.A. Bavappa, M.K. Nair and T. Prem Kumar), CPCRI, Kasaragod. pp. 133-149.
- Shama Bhatt, K (1979). Mixed cropping in arecanut. In : *Multiple cropping in coconut and arecanut gardens*. E.V. Nelliath and K.S. Bhat (Eds.), pp. 35-38, CPCRI, Kasaragod.
- Stephenson, R.A. and Raison, R.J. (1988). Nitrogen cycling in tropical evergreen tree crops ecosystems. In : *Advances in nitrogen cycling in agricultural ecosystems*. (J.R. Wilson. Ed), C.A.B. International, pp. 325-332.

- Tan, Y.P. and Ng, S.K. (1972). *Proc. Conf. Fertility and Chemistry of tropical soils.* Malaysian Soc. Soil. Sci. Kuala Lumpur, Malaysia, pp. 50-59.
- Varghese, P.T., Nelliath, E.V. and Balakrishnan, T.K. (1978). Beneficial interactions of coconut-cacao combination. In: *Proc. PLACROSYM - I*, pp. 383-392, Indian Society for plantation Crops, Kasaragod, India.
- Von Uexkull, H.R.(1978). Potassium requirement of some tropical tree crops (oil palm, coconut palm, rubber, coffee and cacao). In: *Potassium Research Review and Trends* Bern. Proc. IIth Congr. Int. Potash Inst. 291-234.
- Wan Embong, (1977). Utilisation of ground vegetation in rubber plantation for animal rearing. *Proc. RRIM Planters Conf.*, Kuala Lumpur, Malaysia, 18 : 28-49.
- Watson, G.A., Wong, P.W. and Narayanan, R. (1963). Effects of cover plants on soil nutrient status and growth of *Hevea*. II. The influence of application of rock phosphate, basic slag and magnesium limestone on the nutrient content of leguminous cover plants. *J. Rubber Res. Inst., Malaysia*, 18: 28-39.
- Will, G.M. (1959). Nutrient return in litter and rainfall under some exotic conifer stands in New Zealand. *New Zealand J. Agric. Res.* Z: 719-734.
- Wycherley, P.R. and Chandapillai, M.M. (1969). *J. Rubber Res. Inst. Malaysia*, 21 (2): 140.
- Yew, K.H., Tan, T.K. and Mohd. Hashin (1981). Effects of interline vegetation and management on oil palm performance. Preprint. *Intl. Conf. on Oil Palm in Agriculture in the Eighties.* Incomp. Soc. of Planters and Palm Oil Res. Instt., Malaysia.