Research Article

Journal of Plantation Crops, 2008, 36 (3): 281-289

Soil microbiological and enzymological response to organic matter recycling and chemical fertilization in arecanut based cropping system

Ravi Bhat[1]*, S. Sujatha[1] and George V. Thomas[2]

Central Plantation Crops Research Institute

Regional Station, Vittal – 574 243, Karnataka

Abstract

Soil microbiological and enzymological response to organic matter recycling and chemical fertilization in arecanut based cropping system in a laterite soil was evaluated in 2002 after imposition of treatments for three years at Central Plantation Crops Research Institute, Regional Station, Vittal. Treatments included organic matter recycling (OMR) and its combination with different graded levels of NPK. Significant variability in microbial population, microbial biomass C, microbial quotient, phosphatase and dehydrogenase activities was noticed due to nutrient management in basins of various component crops in arecanut based cropping system. In general, the population of soil microflora was considerably higher in basin of various crops like arecanut, cocoa, clove, banana and coffee than in interspaces irrespective of treatments. Microbial biomass C (µg C g^{-1} dry soil) was significantly higher in cocoa basin at 0-30 cm depth (536.2) and 30-60 cm depth (241.4) among crops and 2/3rd of recommended NPK+OMR (469.8 and 235.1 at 0-30 and 30-60cm, respectively) among nutrient management treatments. Cocoa registered higher microbial quotient value of 3.90. Combination of OMR and 2/3rd NPK level increased microbial quotient both at 0-30cm (2.95) and 30-60cm (2.05) soil depth. The highest phosphatase activity (74.7 µg p-nitrophenol g^{-1} soil h^{-1}) was found in cocoa basin applied with 2/3rd recommended NPK + OMR. Increase in inorganic fertilizer application up to 2/3rd of standardised dose resulted in increased dehydogenase activity from 17.5 to 25.4, while it reduced with 100% NPK application in all crop basins except in banana.

Keywords: Arecanut, Cropping system, Enzyme activity, Microflora, Organic matter recycling

Introduction

The importance of microorganisms in soil nutrient cycling and their role in plant nutrition has been realized for a long time. The nature and activity of microflora in a given environment depends upon the crops grown and management practices. The activity of basin and root zone microflora can affect the nutrient availability and uptake pattern (Nair and Subba Rao, 1997). Arecanut (*Areca catechu* L.) is predominantly grown in acidic laterite soils with a productivity level of 1409 kg ha^{-1}. The important problems associated with these soils are P fixation, heavy rainfall during monsoon season resulting in nutrient losses through run off, leaching of basic cations and poor nutrient retention capacity due to low CEC (3-15 c mole kg^{-1}) (Tandon and Ranganathan, 1988).

Studies of enzyme activities in soil are important as they indicate the potential of the soil to support biochemical processes, which are essential for the maintenance of soil fertility. The nature and activity of microflora in a given environment depends upon the crops grown (Grayston *et al.*, 1998) and management practices (Esperschutz *et al.*, 2007). The distribution of microflora in soil profile and the nature of rhizosphere microorganisms of arecanut monocropping system have been studied (Bopaiah and Bhat, 1981; Bopaiah and Koti Reddy, 1982). The intensive cropping system involving arecanut, cocoa, pepper, clove and banana is a successful crop combination and it generates considerable quantity of organic wastes. It is assumed that organic matter recycling in the form of vermicompost would be helpful in proliferation of the microbial activity in these soils as vermicompost prepared from plantation wastes was rich in nutrient content and microbial population

[1] *Senior Scientist (Agronomy).* [2] *Director, CPCRI, Kasaragod – 671 124* * *Corresponding author; Email: bhatravi@gmail.com*

(Chowdappa *et al.*, 1999). Besides, organic carbon input from crop roots, rhizosphere products and crop residues can have a large effect on soil microbial biomass and its activity, which in turn, affect the ability of soil to supply nutrients to plants through soil organic matter turnover (Bonde and Roswall, 1987).

Microbial biomass plays an important role in nutrient cycling and organic matter stabilization in soils (Janzen *et al.*, 1998; Jedidi *et al.*, 2004). Kremer and Li (2003) reported that sustainability of soil health is based, in part, on the efficient management of soil microorganisms to improve soil quality. Enzyme activities have been found to be very responsive to different agricultural practices such as organic amendments, crop rotation (Miller and Dick, 1995) and organic cultivation (Beyer *et al.*, 1992). Though the microbiology of acid soils is reviewed in general (Rai and Jha, 1996), the microbiology studies in plantation based cropping system under different nutrient management systems is lacking. In the present investigation, soil microbiological response to graded levels of chemical fertilizers and the impact of nutrient management through organic matter recycling in the form of vermicompost in various crop basins of areca based cropping system was monitored after three years of treatment imposition.

Materials and Methods

The investigation was carried out at Central Plantation Crops Research Institute, Regional Station, Vittal, Karnataka, India (12° 15'N latitude and 75° 25'E longitude, 91 m above MSL). The average annual rainfall at this place is 3670 mm distributed over 120 days. The rainfall during the experimental period varied between 2873 mm in 2002 to 3709 mm in 1999. The soil of the experimental site is sandy clay loam (laterite) with a pH of 5.25, 1.3% organic carbon, 42 ppm N, 15.0 ppm P and 56.8 ppm K.

The experiment was conducted during 1999-2003 in an existing arecanut garden established during 1965. The arecanut was planted at a spacing of 2.7 m x 2.7 m. Cocoa and clove were planted during 1983 at a spacing of 5.4 m in two separate rows. Coffee was planted at 1.2 m spacing in every third row of arecanut. Banana was planted at 5.4 m intra-row spacing in cocoa and clove rows alternatively. Black pepper, banana and coffee were planted in 1999 as mixed crops. Black pepper was planted in arecanut basin 75 cm away from the base on northern side of the palm.

The experiment was laid out in randomized block design with four treatments and five replications. The treatments included T_1 - Organic matter recycling (OMR), T_2 - 1/3rd of recommended NPK + OMR, T_3 - 2/3rd of recommended NPK + OMR and T_4 – 100% recommended NPK + OMR. The net plot size was 131.2 m^2. Each treatment consisted of 18 arecanut palms, 18 black pepper, 3 cocoa, 3 clove, 6 banana and 11 coffee plants. The chemical fertilizers were applied in two splits i.e.,1/3rd in May and 2/3rd in September. The recommended fertilizer dose for arecanut, black pepper and cocoa is 100 g N, 40 g P_2O_5 and 140 g K_2O per tree per year. The fertilizer recommendations for clove, banana and coffee are 300 g N, 250 g P_2O_5 and 750 g K_2O, 160 g N, 160 g P_2O_5 and 320 g K_2O and 30 g N, 20 g P_2O_5 and 30 g K_2O per tree per year, respectively. The sources of fertilizers included urea (46 % N), rock phosphate (20 % P_2O_5) and muriate of potash (60 % K_2O). The recycled biomass included the leaves, bunch waste and husk of arecanut, pruned biomass and litter fall of cocoa, clove litter fall, suckers, leaves and pseudostem of banana and weed biomass. The waste material collected from the garden from each treatment was separately converted into vermicompost using African night crawler earthworm (*Eudrilus euginae*) in three months period and recycled back to all component crops during September. The quantity of compost applied to each palm/tree per year was 1.5 kg in T_1 treatment, 2.0 kg in T_2 and T_3, and 2.5 kg vermicompost in T_4. This was based on the quantity of vermicompost prepared out of the recyclable biomass from the system, which varied from 8,724-10,354 kg ha^{-1} $year^{-1}$.

After three years of treatment imposition from 1999 to 2001, the basin samples were collected in May, 2002 for various studies from the root zones of different crops at 45 cm lateral distance and at two vertical depths (0-30 and 30-60 cm) using a core sampler for microbiological and chemical analysis. However, the microbial enumeration was done only for first depth (0-30cm). Three replicate samples were collected randomly from each treatment. The samples were thoroughly mixed and bulked. After removing visible plant residues and pebbles, a representative soil sample was passed through a 2-mm-mesh sieve and stored in plastic bags at 4°C in a refrigerator until processed for analysis. Soil moisture content at the time of sampling was estimated by gravimetric method and expressed as per cent on dry weight basis as averaged over all crop basins in the system.

Initial soil samples were analysed for pH, organic carbon, available P and K using standard procedures (Jackson, 1973). The serial dilution plating method was followed to enumerate the microbial population. The enumeration of culturable bacteria, fungi and

actinomycetes was done using soil extract agar, Martin' rose Bengal agar and Kuster's agar, respectively (Allen, 1957) and the results were expressed as colony forming units (CFU) per gram dry soil. The soil microbial biomass was determined following the chloroform fumigation-incubation method (Jenkinson and Powlson, 1976) and the biomass C was calculated (Jenkinson and Ladd, 1981). Microbial quotient represents the ratio of soil microbial biomass C (C_{mic}) to soil organic carbon (C_{org}) and expressed as C_{mic}/C_{org} percentage.

Acid phosphatase activity was determined using the method described by Tabatabai and Bremmer (1969). Mineralizable C was estimated from the quantity of CO_2-C mineralized from soil during 7-d incubation at 27°C. Dehydrogenase activity was determined using TTC (2, 3, 5-triphenyl tetrazolium chloride) as a terminal acceptor of protons and electrons from organic compounds being oxidized (Gerba and Brendecke, 1995). Statistical analysis was done using standard analysis of variance (ANOVA) technique. Though the experiment was laid out in RBD, the analysis was done taking crop basin as one of the variables for better understanding of the results. Correlation and regression analysis was done for microbial biomass C and organic C.

Results and Discussion

Soil microflora

In general, the population of bacteria, fungi and actinomycetes were considerably more in basins of various crops irrespective of treatments than interspaces (Fig. 1). Variations in basin microbes among different plant species in ABCS may be related to plant specific differences in physico-chemical conditions induced in the basin, root exudate patterns and heterogeneity and quantity of carbon resource entering through root exudates and litter fall and nutrient acquisition patterns.

Significant differences in microbial counts were observed due to nutrient management in basins of various component crops in arecanut based cropping system. Application of chemical fertilizers above 1/3rd dose significantly reduced the bacterial and fungal population in the system. Higher bacterial abundance was noticed with application of 2/3rd NPK + OMR in case of arecanut basin and recommended NPK + OMR in case of cocoa basin. Application of 1/3rd NPK along with OMR maintained significantly higher bacterial number (10^5 CFU g^{-1} dry soil) in clove (312.5) and coffee (154.2) basins. OMR alone maintained maximum bacteria in banana (171.2) basin. In contrast, fungal population was significantly increased with integrated use of inorganic fertilizers and OMR over only OMR in cocoa basin. Among the crop basins, banana maintained significantly higher actinomycetes counts followed by coffee and clove. Combination of 2/3rd NPK + OMR significantly increased actinomycetes population in arecanut and clove, while recommended NPK + OMR maintained significantly higher actinomycetes in cocoa and banana.

The microbial population did not exhibit any definite

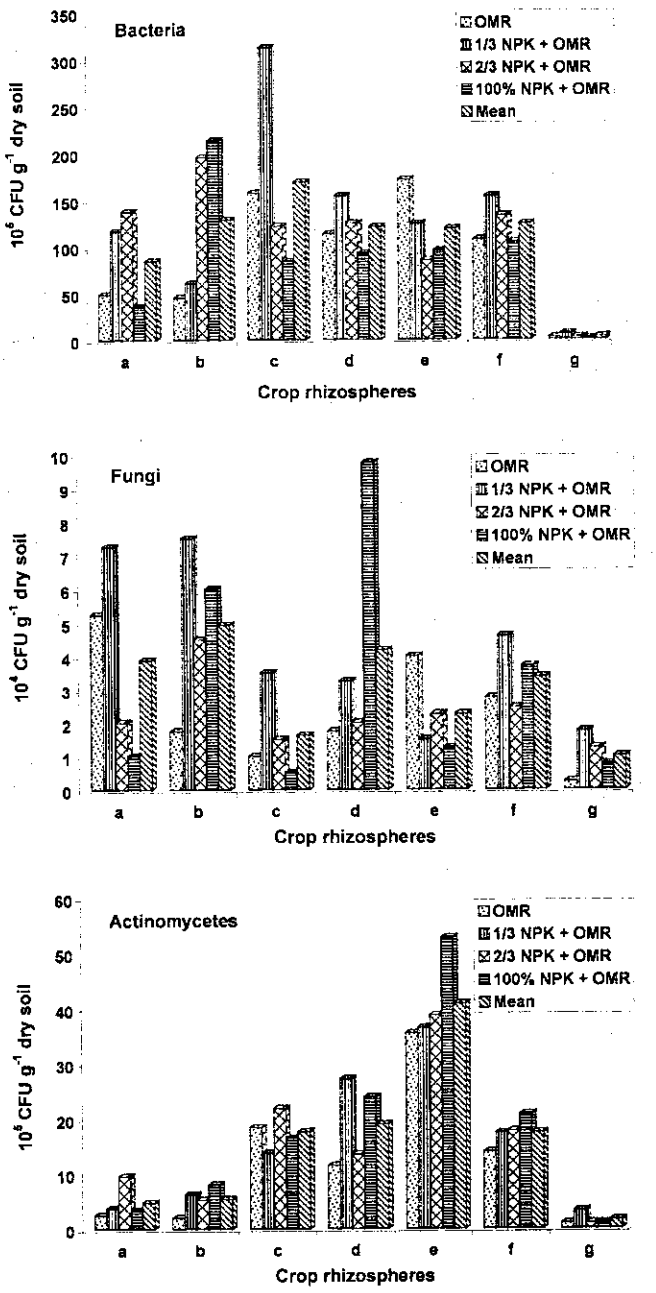

Fig. 1. Microbial population as influenced by crop basins and organic matter recycling in 2002 after 3 years of treatment application (CD (P=0.01)). (a) areca + pepper (b) cocoa (c) clove (d) coffee (e) banana (f) crop mean (g) interspace

	Crops(C)	Treatments(T)	C x T
Bacteria	1.69	1.51	3.39
Fungi	0.82	0.73	1.64

trend with application of inorganic fertilizers. The overall increase in microbial population in ABCS could be due the microbes added through vermicompost. Chowdappa *et al.* (1999) reported higher microbial counts in vermicompost prepared from organic wastes of arecanut and cocoa. Overall in the system, bacterial abundance remained greater in 1/3rd of recommended NPK+OMR. Multi-year application of inorganic fertilizers and OMR in a cropping system slightly increased the soil pH to 5.22 (Bhat and Sujatha, 2007) compared to the reported value of 4.88 in 1988 (Abdul Khader *et al.*, 1992). This could have contributed to increased bacterial population (Bopaiah and Bhat, 1981).

Microbial biomass C and Microbial quotient (C_{mic}/C_{org})

Significant variability ($P<0.01$) in microbial biomass was observed due to different crop basins, nutrient management and their interaction at both soil depths (Table 1). Microbial biomass C (µg C g^{-1} dry soil) was significantly higher in cocoa basin at 0-30 cm depth (536.1) and 30-60 cm depth (241.4) among the crops and 2/3rd of recommended NPK+OMR (469.8 and 235.1 at 0-30 and 30-60cm, respectively) among the nutrient management treatments. Interaction effect indicated significantly higher microbial biomass C at 2/3rd of recommended NPK+OMR at 0-30cm depth (556.6) and at 1/3rd of recommended NPK+OMR at 30-60cm depth (272.2) in cocoa basin. In general crop basins (440.1 and 217.0 at 0-30 and 30-60 cm depth, respectively) registered 11 times higher microbial biomass C as compared to interspaces (40.8 and 19.2 at 0-30and 30-60cm depth, respectively). The data in Table 2 reflect significant variability in microbial quotient due to different crop basins and nutrient management at 0-30 cm soil depth. At 30-60 cm depth, only crop basins showed significant variation in microbial quotient. Cocoa registered higher microbial quotient value at 0-30cm (3.90%) and 30-60cm soil depth (2.18%). Application of 2/3rd recommended NPK + OMR significantly increased microbial quotient both at 0-30cm (2.95%) and 30-60cm (2.04%) soil depths.

The greater microbial biomass C in various crop basins than in interspaces at 0-30 cm soils depth might be due to surface cultivation of soil in different crop basins leading to better aeration at 0-30 cm depth. Microbial biomass C was two times higher in 0-30 cm depth than at 30-60 cm depth. Microbial biomass values in the present study are in line with the published data in tropical soils receiving organic and inorganic inputs (423 mg/ kg soil) (Goyal *et al.*, 1999). In this study, microbial biomass C accounted for 1-4 % of soil organic carbon in different crop basins in different depths (Table 2). These values are in agreement with reports that soil microbial biomass C comprises only 1 to 4% of soil organic carbon (Anderson and Domsch, 1989; Sparling, 1992). Anderson and Domsch (1989) stated that the ratio of soil microbial

Table 1. Microbial biomass (µg C g^{-1} dry soil) as influenced by crop basins and nutrient management in arecanut based cropping system in 2002 after 3 years of treatment application

Treatments (T)	Crop basin (C)						
	0-30cm soil depth						
	Areca + pepper	Cocoa	Clove	Coffee	Banana	Mean	Interspace
OMR	388.9	530.4	412.9	427.4	327.3	417.4	31.5
1/3rd NPK + OMR	444.0	551.0	441.5	468.0	365.4	454.0	42.1
2/3rd NPK + OMR	455.8	556.6	473.5	481.3	381.9	469.8	49.9
100% NPK + OMR	398.5	518.6	423.5	433.7	321.3	419.1	39.8
Mean	421.8	536.1	437.7	452.6	349.0	440.1	40.8
CD (P=0.01)	C	2.24	T	2.00	C x T	4.47	
	30-60 cm soil depth						
OMR	220.2	213.1	212.4	236.3	134.2	203.3	10.8
1/3rd NPK + OMR	238.3	272.2	242.0	239.5	139.1	226.2	21.1
2/3rd NPK + OMR	277.9	256.7	247.1	245.9	147.9	235.1	29.2
100% NPK + OMR	220.2	223.5	215.1	220.4	137.7	203.4	15.7
Mean	239.1	241.4	229.2	235.5	139.8	217.0	19.2
CD (P=0.01)	C	1.53	T	1.37	C x T	3.06	

Table 2. Microbial quotient (C_{mic}/C_{org}) in percentage as influenced by crop basins and nutrient management in arecanut based cropping system in 2002 after 3 years of treatment application

Nutrient treatment (T)	Crop basin (C)					
	0-30cm soil depth					
	Areca + pepper	Cocoa	Clove	Coffee	Banana	Mean
OMR	1.94	3.31	2.24	2.55	1.93	2.39
1/3rd NPK + OMR	2.30	4.54	2.79	2.56	2.20	2.88
2/3rd NPK + OMR	2.44	4.14	3.00	2.95	2.22	2.95
100% NPK + OMR	2.62	3.63	2.82	2.89	2.19	2.83
Mean	2.33	3.90	2.71	2.74	2.14	
CD (P=0.01)	C	0.504	T	0.42	C x T	NS
	30-60 cm soil depth					
OMR	2.03	2.06	1.79	1.84	1.09	1.76
1/3rd NPK + OMR	1.79	2.22	1.88	1.92	1.23	1.81
2/3rd NPK + OMR	2.02	2.32	2.11	2.19	1.63	2.04
100% NPK + OMR	1.58	2.10	2.09	1.74	1.56	1.81
Mean	1.86	2.18	1.96	1.92	1.38	
CD (P = 0.01)	C	0.319	T	NS	C x T	NS

biomass C to organic C is a good indicator of changes in microbial performance caused by environmental conditions. The structure and distribution of C in soil affect biological activity and probably the microbial biomass. Microbial biomass C and microbial quotient were remarkably high in cocoa followed by clove. This could be due to higher carbon inputs in these crops. None of the component crops in ABCS reduced C_{mic}/C_{org}, and there was a higher positive correlation of C_{mic} with C_{org} ($y=-72.601x^2+65.297x+1.8463$, $r^2 = 0.735$), which supports the concepts that C usually is the limiting factor for microorganisms in agricultural soils.

Phosphatase activity

Significant variation in phosphatase activity was noticed due to nutrient management in basin of various crops at both soil depths (Table 3). Interaction effect also was found significant. The highest phosphatase activity (µg p-nitrophenol g^{-1} soil h^{-1}) was detected in cocoa basin (70.2) followed by arecanut (61.4) and clove (60.7) at 0-30 cm depth while, coffee (19.8) and banana (20.8) basins registered significantly lower phosphatase activity. Application of mineral fertilizers up to 2/3rd of recommended dose along with OMR resulted in significantly higher phosphatase activity (52.0) at 0-30cm depth than other nutrient management treatments (42.0 to 47.1). Interaction effect indicated higher phosphatase activity (74.7) in cocoa basin applied with 2/3rd recommended NPK + OMR. Similar trend was noticed at 30-60 cm depth also. However the activity reduced at 30-60cm depth. This decrease might be due to the distribution of microorganisms in the soil profile (Khaziev and Burangulova, 1965) and organic matter content (Arutyunyan and Galstyan, 1974).

Earlier study indicated that phosphatase activity significantly increase after the application of organic manures (Guan, 1989), while soil organic matter content and soil microbial activities, vital for the nutrient turnover and long term productivity of soil, are enhanced by the balanced application of nutrient and manure (Kanchikerimath and Singh, 2001). Though phosphatases are induced predominantly under P-limited conditions (Schinner *et al.*, 1996; Nannipieri *et al.*, 1978), in the present study combining OMR with chemical fertilizer had congenial environment for phosphatases up to 2/3rd of recommended NPK. Low phosphatase activity with OMR and high activity with inorganic fertilizer applications was noticed in this study. Similar increase in phosphatase activity with application of inorganic fertilizer has been reported by Praham *et al.*, (2002). Significant differences of phosphatase activity in different crop basins indicate the potential of crops for greater efficiency in obtaining phosphorus.

Table 3. Phosphatase activity (µg p-nitrophenol g^{-1} dry soil h^{-1}) as influenced by crop basins and nutrient management in arecanut based cropping system in 2002 after 3 years of treatment application

Treatments (T)	Crop basin (C)						
	0-30cm soil depth						
	Areca + pepper	Cocoa	Clove	Coffee	Banana	Mean	Interspace
OMR	58.6	69.2	47.8	17.5	16.7	42.0	5.2
1/3rd NPK + OMR	61.7	71.6	61.4	20.3	20.2	47.1	6.7
2/3rd NPK + OMR	67.0	74.7	69.8	24.7	23.8	52.0	7.9
100% NPK + OMR	58.2	65.3	63.7	16.7	22.8	45.3	4.8
Mean	61.4	70.2	60.7	19.8	20.8		6.1
CD (*P*=0.01)	C	1.41	T	1.26	C x T	2.82	
	30-60 cm soil depth						
OMR	34.1	33.4	22.5	7.7	7.0	20.9	2.6
1/3rd NPK + OMR	34.1	38.0	25.6	8.7	12.0	23.7	8.0
2/3rd NPK + OMR	48.5	42.8	31.9	9.1	13.1	29.1	8.8
100% NPK + OMR	29.8	40.9	37.4	8.0	7.0	24.6	5.0
Mean	36.6	38.8	29.4	8.4	9.8		6.1
CD (*P*=0.01)	C	1.21	T	1.08	C x T	2.41	

Dehydrogenase activity

Dehydrogenases represent a class of enzymes that give us information about the influence of natural environmental conditions of the microbial activities of the soil. Dehydrogenase activity appears to be more related to the metabolic state of microbial population of the soil than to the activity of specific free enzymes acting on a particular substrate. Like other enzyme activities, the dehydrogenase activity also differed significantly among crop rhizospehers and nutrient management treatments besides significant interaction between them (Table 4). The dehydrogenase activity was highest in cocoa (24.7) followed by clove (21.7) and banana (20.9). Significantly lower dehydrogenase activity was noticed in arecanut+pepper (15.1). Increase in inorganic fertilizer application up to 2/3rd of standardised dose resulted in increased dehydogenase activity from 17.5 to 25.4, while

Table 4. Dehydrogenase activity (µg formazan g^{-1} dry soil h^{-1}) as influenced by crop basins and nutrient management in arecanut based cropping system in 2002 after 3 years of treatment application

Treatments (T)	Crop basin (C)						
	0-30cm soil depth						
	Areca + pepper	Cocoa	Clove	Coffee	Banana	Mean	Interspace
OMR	12.58	23.13	17.90	17.19	16.87	17.53	5.24
1/3rd NPK + OMR	16.02	26.32	21.00	20.06	19.60	20.60	6.57
2/3rd NPK + OMR	22.04	28.37	28.56	24.29	23.81	25.41	7.37
100% NPK + OMR	9.83	21.07	19.45	14.94	23.22	17.70	4.67
Mean	15.12	24.72	21.73	19.12	20.88		5.96
CD (*P*=0.01)	C	1.19	T	1.07	C x T	2.39	
	30-60 cm soil depth						
OMR	5.96	8.24	9.00	7.54	7.10	7.57	2.47
1/3rd NPK + OMR	8.09	8.78	10.73	8.45	12.48	9.70	8.15
2/3rd NPK + OMR	10.83	9.60	12.68	9.98	14.08	11.43	8.80
100% NPK + OMR	6.13	6.06	9.93	9.07	8.07	7.85	4.23
Mean	7.75	8.17	10.59	8.76	10.43		5.91
CD (*P*=0.01)	C	0.96	T	0.86	C x T	1.91	

it reduced with 100% NPK application in all crop basins. Among crop basins, higher dehydrogenase activity was found in cocoa than in other crop basins.

Dehydrogenases are considered to play an essential role in the initial stages of the oxidation of soil organic matter by transferring hydrogen and electrons from substrates to acceptors.

The increased microbial activity in cocoa basin indicates the beneficial effect of growing cocoa as mixed crop in arecanut plantations, which adds large biomass to the soil as litter fall and improves overall microclimatic condition (Balasimha, 2004). The increase in dehydrogenase and phosphatase activities with increasing dose of chemical fertilizers as well as organic amendments is reflections of organic matter build up which leads to increase in microbial activities (Frankenberger and Dick, 1983; Tarafdar *et al.*, 1989; Pascual *et al.*, 2002).

Carbon mineralization

There were significant differences in carbon mineralization (μg CO_2 100 g^{-1} soil) activity due to crop basins, nutrient management levels and their interaction (Table 5). Unlike phosphatase activity, the activity of carbon mineraliztion was higher in arecanut+pepper basin (52.7), and lower in banana basin (29.0) at 0-30cm soil depth. Carbon mineralization activity increased significantly up to 2/3rd NPK (47.8) and reduced with application of standardized dose of NPK (39.7). Significantly higher carbon mineralization activity was detected at 2/3rd NPK +OMR in arecanut+pepper basin (56.7) than other treatment combinations at first depth. The trend was similar at 30-60 cm soil depth also. Significant variation in carbon mineralization due to nutrient management in different crop basins reflects the availability of easily-decomposable substrates, cultivation practices and shade levels. In contrast to phosphatase activity, carbon mineralization was higher in arecanut basin than in cocoa and clove. This suggests the need to apply more organic matter regularly to arecanut.

Conclusion

It is clear from the study that adoption of organic matter recycling with graded nutrient levels in arecanut based cropping system helps in improving soil health in terms of soil microflora and enzymatic activities. Application of inorganic fertilizers up to 2/3rd of standardized dose for each component crops is congenial for better microbial activity. It is realized that in order to make chemical fertilization programmes successful according to the emerging value-system in agriculture, a critical balance must be maintained between optimizing nutrient availability in the basin, while minimizing potential for deleterious effects on soil biological activity. These results could serve as a basis for increasing both biological and enzymatic soil activities and in turn crop yields in laterite soils.

Table 5. Carbon Mineralization (μg CO_2 100 g^{-1} dry soil) as influenced by crop basins and nutrient management in arecanut based cropping system in 2002 after 3 years of treatment application

Treatments (T)	Crop basin (C)						
	0-30cm soil depth						
	Areca + pepper	Cocoa	Clove	Coffee	Banana	Mean	Interspace
OMR	50.53	39.17	36.46	44.97	25.41	39.31	16.00
1/3rd NPK + OMR	52.51	41.80	47.65	47.18	29.05	43.64	21.64
2/3rd NPK + OMR	56.71	50.77	49.99	49.92	31.75	47.83	35.49
100% NPK + OMR	51.11	37.66	35.54	44.35	29.96	39.72	29.95
Mean	52.72	42.85	42.41	46.61	29.04		25.77
CD (*P*=0.01)	C	1.32	T	1.18	C x T	2.63	
	30-60cm soil depth						
OMR	29.84	16.10	14.69	21.13	6.74	17.70	7.82
1/3rd NPK + OMR	31.91	21.87	21.83	25.18	8.30	21.82	9.92
2/3rd NPK + OMR	35.73	26.75	27.19	25.81	10.79	25.25	15.91
100% NPK + OMR	30.14	14.93	12.04	20.79	4.83	16.55	12.70
Mean	31.90	19.92	18.94	22.23	7.66		11.59
CD (*P*=0.01)	C	1.14	T	1.02	C x T	2.27	

Acknowledgements

The authors would like to thank the Director, Central Plantation Crops Research Institute, Kasaragod, India for cooperation and World Bank sponsored National Agricultural Technology Project (NATP) for funding this project.

References

Abdul Khader, K.B., Balasimha D. and Bhat, N.T. 1992. Resource use in arecanut based high density multispecies cropping system. *J Plantn. Crops* **20**: 19-24.

Allen, O.N. 1957. *Experiments in soil bacteriology*. pp. 117. Burgress Publication Co. Minneapolis. Minn., U.S.A

Anderson, T.H. and Domsch, K.H. 1989. Ratios of microbial biomass carbon to total organic carbon in arable soils. *Soil Biol Biochem* **21**: 471-479.

Arutyunyan, E.A. and Galstyan, A. SH. 1975. Determination of the activity of alkaline and acid phosphatase in soils. *Agrochimija* **5**: 128 – 133.

Balasimha, D. 2004. Cropping Systems. pp. 103-130. In: *Arecanut*. (Eds.) Balasimha, D. and Rajagopal, V. Central Plantation Crops Research Institute, Kasaragod, India.

Beyer, L., Wachendorf, C., Balzer, F.M. and Balzer-Graf, U.R. 1992. The effect of soil texture and soil management on microbial biomass and soil enzyme activities in arable soils of Northwest Germany. *Agrobiol Res* **45**: 276-283.

Bhat Ravi and Sujatha, S. 2007. Soil fertility status as influenced by arecanut based cropping system and nutrient management. *J Plantn. Crops* **35**: 158-165.

Bonde, T.A. and Roswall, T. 1987. Seasonal variation of potentially mineralizable nitrogen in four cropping systems. *Soil Sci Soc America J.* **51**: 1508-1514.

Bopaiah, B.M. and Bhat, N.T. 1981. Effect of continuous application of manures and fertilizers on rhizosphere microflora in arecanut palm. *Plant Soil* **63**: 497-499.

Bopaiah, B.M. and Koti Reddy, M. 1982. Distribution of microflora population in the rhizosphere of arecanut. *J Plantn. Crops* **10**: 127-128.

Chowdappa, P., Biddappa, C.C. and Sujatha, S. 1999. Efficient recycling of organic wastes in arecanut (*Areca catechu* L.) and cocoa (*Theobroma cacao* L.) plantations through vermicomposting. *Indian J Agric Sci.* **69**: 563-566.

Esperschutz, J., Gattinger, A., Mader, P., Schloter, M. and Fliebach, A. 2007. Response of soil microbial biomass and community structures to conventional and organic farming systems under identical crop rotations. *FEMS Microbiol Ecol* **61**: 26-37.

Frankenberger, W.T. Jr. and Dick, W.A. 1983. Relationship between enzyme activities and microbial growth and activity indices in soil. *Soil Sci Soc Amer J.* **47**: 945-951.

Gerba, C. P., and Brendecke, J. W. 1995. *Environmental Microbiology*. 175 pp. Academic Press, San Diego, CA.

Goyal, S., Chander, K., Mundra, M.C. and Kapoor, K.K. 1999. Influence of inorganic fertilizers and organic amendments on soil organic matter and soil microbial properties under tropical conditions. *Biol Fertil. Soils* **29**: 196-200.

Grayston, S.J., Wang, S., Colin, D.C. and Anthony, C.E. 1998. Selective influence of plant species on microbial diversity in the rhizosphere. *Soil Biol. Biochem.* **30**: 369-378.

Guan, S.Y. 1989. Studies on the factors influencing soil enzyme activities: I. Effects of organic manures on soil enzyme activities and N and P transformations. *Acta Pedol Sinica* **26**: 72-78.

Jackson, M.L. 1973. *Soil Chemical Analysis*. 498 pp. Prentice Hall of India Pvt. Ltd., New Delhi.

Janzen, H.H., Campbell, C.A., Gregorich, E.G. and Ellert, B.H. 1998. Soil carbon dynamics in Canadian agroecosystems. pp: 57-80. In: *Soil Processes and the Carbon Cycle*. (Ed.) Lal, R. CRC Press, Boca Raton.

Jedidi, N., Hassen, A., van Cleemput, O. and M'Hiri, A. 2004. Microbial biomass in a soil amended with different types of organic wastes. *Waste Manag Res* **22**: 93–99.

Jenkinson, D.S. and Ladd, J.N. 1981. Microbial biomass in soil measurement and turnover. pp 415-471. In: *Soil Biochemistry 5*. (Eds.) Paul, E.A. and Ladd, J.N. Marcel Dekker, New York.

Jenkinson, D.S. and Powlson, D.S. 1976. The effect of biocidal treatments on metabolism in soil. A method for measuring soil biomass. *Soil Biol Biochem* **8**: 209-213.

Kanchikerimath, M. and Singh, D. 2001. Soil organic matter and biological properties after 26 years of maize – wheat – cowpea cropping as affected by manure and fertilization in a Cambisol in semiarid region of India. *Agric Ecosys. Environ.* **86**: 155-162.

Khaziev, F. KH. and Burangulova, M.N. 1965. Activity of enzymes which dephosphorylate organic phosphorus compounds of soil. *Prikl. Biokhim. Mikrobiol.* **1**: 373 - 379.

Kremer, R.J. and Li, J. 2003. Developing weed suppressing soils through soil quality management. *Soil Tillage Res.* **72**: 193-202.

Miller, M. and Dick, R.P. 1995. Thermal stability and activities of soil enzymes as influenced by crop rotations. *Soil Biol. Biochem.* **27**: 1161-1166.

Nair, S.K. and Subba Rao, N.S. 1977. Microbiology of root region of coconut and cacao under mixed cropping. *Plant Soil* **46**: 511-516.

Nannipieri, P., Johnson, R.L. and Paul, E.A. 1978. Criteria for measurement of microbial growth and activity in soil. *Soil Biol. Biochem.* **10**: 223-229.

Pascual, J.A., Moreno, J.L., Hernandez, T. and Garcia, C. 2002. Persistence of immobilized and total urease and phosphatase activities in a soil amended with organic wastes. *Bioresour. Technol.* **82**: 73-78.

Parham, J.A., Deng, S.P., Raun, W.R. and Johnson, G.V. 2002. Long-term cattle manure application in soil. I. Effect on soil phosphorus levels, microbial biomass C, and dehydrogenase and phosphatase activities. *Biology and Fertility of Soils* **35**(5): 328 – 337.

Rai, S.N. and Jha, K.K. 1996. Microbiology of acid soils. pp. 89-98. In: *Acid Soils of India*. (Eds.) Mahapatra, I.C., Mandal, S.C., Misra, C., Mitra, G.N. and Panda, N. Indian Council of Agricultural Research, New Delhi.

Schinner, F., Ohlinger, R., Kandeler, E. and Margesin, R. 1996. *Methods in Soil Biology*. 429 pp. Springer- Verlag, Berlin.

Sparling, G.P. 1992. Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. *Austr. J. Soil Res.* **30**: 195-207.

Tabatabai, M.A. and Bremmer, J.M. 1969. Use of p-nitrophenylphosphate for assay of soil phosphatase activity. *Soil Biol. Biochem.* **1**: 301-307.

Tandon H.L.S. and Ranganathan V. 1988. Fertilizers and their management in plantation crops. pp. 26-80. In: *Fertilizer management in plantation crops – A guide book.* (Ed.) Tandon H.L.S. Fertilizer Development and Consultation Organization, New Delhi.

Tarafdar, J.C., Kiran, B. and Rao, A.V. 1989. Phosphatase activity and distribution of phosphorus in arid soil under different land use pattern. *J. Arid Environ.* **16**: 29-34.