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Short-term effects of nutrient management regimes on biochemical and microbial properties in soils under rainfed ginger (*Zingiber officinale* Rosc.)

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ABSTRACT

The aim of the study was to determine the short-term effects of contrasting nutrient management regimes on sensitive soil biochemical and microbial parameters under an annual rainfed crop (ginger, *Zingiber officinale* Rosc.) grown in raised beds. The nutrient management regimes employed in the study were organic nutrient management (ONM), chemical nutrient management (CNM) and integrated nutrient management (INM). ONM involved organic manures (farmyard manure (FYM), vermicompost, neem cake, ash) and biofertilizers (*Azospirillum lipoferum* and *Bacillus phosphaticum var megaterium*), CNM involved exclusive use of chemical sources of NPK and INM involved a combination of chemical sources of NPK + FYM. The study also included a control where no fertilizers, whatsoever, were applied. The variables studied were soil organic carbon (SOC), dissolved organic-C (DOC) and -N (DON), microbial biomass-C (C_{MIC}), -N (N_{MIC}) and -P (P_{MIC}), net N mineralized (N_{MIN}), soil respiration (SR) and activities of dehydrogenase (DHA), acid phosphatase (Ac-P), β-glucosidase (βG), urease (UR) and arylsulphatase (AS). Various ratios of these biochemical/microbial indices *viz*., DOC:DON, C_{MIC}:SOC (Q_{MIC}), C_{MIC}:N_{MIC}, SR:C_{MIC} (metabolic quotient, qCO_2) were also examined. The influence of nutrient management regimes was most evident on SOC, DOC, DON, soil microbial and biochemical properties. The levels of SOC and DOC were significantly greater in ONM and INM compared to CNM and control. Conversely, DON level was markedly higher under CNM compared to ONM and INM. CNM also positively influenced N_{MIC} but decreased C_{MIC}, P_{MIC} and SR levels. N_{MIN} followed an identical trend as microbial biomass and SR; being greatest in INM and ONM. Likewise, the DOC:DON, C_{MIC}:SOC (Q_{MIC}) and C_{MIC}:N_{MIC} ratios were greatest in ONM and least in CNM. Contrarily, higher qCO_2 in CNM and control suggested microbial communities which are energetically less efficient with high maintenance C requirement. Results on enzyme activities revealed that not all the treatments affected the enzyme activities to the same degree. The activities of DH, Ac-P and βG were in the order ONM > INM > CNM, while the activities of UR and AS were in the order CNM > INM > ONM. The strong effects of nutrient management regimes implied that soil biochemical/microbial parameters are sensitive enough to detect changes in soil quality even in the short-term.

1. Introduction

Intensive cultivation and subsequent changes in soil quality is a common phenomenon and hence there is worldwide interest in assessing the shifts in soil quality due to agricultural operations (Dick, 1992). Soil quality depends on a large number of physical, chemical, biological and biochemical parameters and its characterization requires the selection of the properties most sensitive to changes in management practices (Elliott, 1994). Out of the vast array of these indicators, biochemical properties that reflect the size and activity of microbial processes are considered as sensitive and significant (Dick, 1992) because biologically mediated processes in soils are central to their ecological functions and play a key role in the mineralization of organic C and nutrient cycling (Monaco et al., 2008). Besides, compared to physical and chemical properties, changes in the size and activity of the soil microbial biomass due to changes in environmental conditions, land use and management are more rapid and swift (Sparling, 1992). Hence, microbial biomass content and its related indices are considered as sensitive early indicators for organic C accumulation (Marinari et al., 2006; Melero et al., 2006).

Also, these biochemical properties are more sensitive to environmental stress, play a major role in degradation, and provide rapid and accurate estimates on soil quality (García et al., 1999). Among the soil biochemical properties the most relevant are those involved in transformation of organic matter (Leirós et al., 2000). The biochemical parameters include variables directly related to microbial activity (microbial biomass C and N, respiration etc.), and the activities of extracellular hydrolytic enzymes involved in the C, N, S and P

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cycles in soil. These soil biochemical and microbiological parameters are considered as potential indicators of soil quality and management impacts in numerous studies (Gil-Sotres et al., 2005; Mäder et al., 2002; Truu et al., 2008).

Long-term studies on the response of these soil biochemical/microbial variables to organic and conventional amendments are many (Madejón et al., 2009; Melero et al., 2006; Monaco et al., 2008). Nevertheless, the biochemical properties especially soil microbial biomass and enzyme activities, in particular dehydrogenase have been considered to be sensitive indicators for detecting changes even in the short-term (Gil-Sotres et al., 2005; Zagal et al., 2009). We report here data on biochemical and microbial properties, under short-term field conditions (eight months), in response to various nutrient management regimes in soils under rain fed ginger (*Zingiber officinale* Rosc.) grown on raised beds. Ginger is a tropical rhizomatous crop adapted for cultivation even in regions of subtropical climate. This crop thrives best in well drained friable loamy soils rich in humus. In the humid tropics of Kerala, India, ginger is usually grown as a rainfed crop on raised beds of 15 cm height, 1 m width and of convenient length. Being a nutrient exhaustive crop, it is not grown in the same field year after year. Different types of nutrient management are followed for ginger cultivation. It is either exclusively fertilized with inorganic inputs or applied with a combination of inorganic inputs and farmyard manure or it is supplied with only organic manures involving a combination of organic manures and biofertilizers.

The major objective of the study was to determine the short-term effects of nutrient management regimes *viz*., chemical nutrient management (CNM), integrated nutrient management (INM) and organic nutrient management (ONM) on various biochemical/microbial variables reflecting soils quality and to determine the inter-relationships between these variables in soils of raised beds growing rainfed ginger. Chemical nutrient management consisted of exclusive use of chemical sources of NPK, INM consisted of chemical sources of NPK + organic manures and ONM consisted of exclusive use of organic manures and biofertilizers.

2. Materials and methods

2.1. Location details

The field experiment was conducted in the Experimental Farm of the Indian Institute of Spices Research at Peruvannamuzhi (11°35′0″ N 75°49′0″E), Calicut, Kerala, India. The mean annual precipitation is 4374.0 mm spread over 7 months from May to November. The dry season lasts from December to April. The site experiences tropical monsoon climate characterized by persistent high temperatures (Max—35 °C) which normally do not go below 18 °C even in the coolest months. The soil of the study site is clay loam Ustic Humitropept. The initial properties of the soil are pH—5.12; organic C—14.2 g kg^{-1}; mineral N—105 mg kg^{-1}; Bray P—13.4 mg kg^{-1}; exchangeable K—164 mg kg^{-1}.

2.2. Experiment details

2.2.1. Land preparation

Due to the high intensity rainfall lasting over seven months, ginger is generally grown under rainfed conditions on raised beds in Kerala, India. For preparation of the beds, the land was cleared of weeds, the predominant ones being *Ageratum conyzoides* L., *Tridax procumbens* L., *Scoparia dulcis* L. and *Alternanthera sessilis* (L.) R. Br. Ex DC. The soil was then tilled with a tractor mounted disk harrow, puddled to a fine tilth and leveled using a soil leveler. Raised beds of size 3 × 1 × 0.15 m (l × b × h) were made manually using a garden spade. A spacing of 40 cm was allowed between the beds for drainage. Small shallow pits for planting were then made on the beds at a spacing of 20 × 25 cm with a plant population of 40 bed^{-1}. The seed–rhizome (20–30 g) with at least two sprouted eyebuds was placed 3.5–5.0 cm deep in the pits and the soil pressed over it.

2.2.2. Nutrient management regimes

The nutrient management regimes mentioned below are those adopted by the ICAR network program on organic farming in ginger. The nutrient management consisted of the following regimes:

i. Organic nutrient management (ONM): 20 kg farmyard manure (FYM) + 1.0 kg neem cake (NC) + 0.5 kg ash + 2.0 kg vermicompost (VC, applied at 45 DAP) + *A. lipoferum* (10^8 colony forming units (CFU) g^{-1} soil) + *P. megaterium* (10^8 CFU g^{-1} soil), all applied to one bed.
ii. Chemical nutrient management (CNM): 75–50–50 kg ha^{-1} NPK applied as urea, rock phosphate (RP) and muriate of potash (MOP) respectively. RP was applied as basal, urea in two splits (45th and 90th day after planting (DAP)) and MOP in two splits (45th and 90th DAP).
iii. Integrated nutrient management (INM): 37.5–50–50 kg ha^{-1} NPK applied exactly as above + 10 kg FYM bed^{-1}.

The nutrient composition of FYM, VC, NC and ash is given in Table 1. *A lipoferum* and *B. megaterium* were applied at rates equivalent to 10^8 CFU g^{-1} soil. Prior to application, the biofertilizers were thoroughly mixed with FYM. The other organic sources *viz*., FYM, NC, VC and ash were spread evenly on the beds and incorporated manually into the soil using a garden hoe. The study also consisted of an absolute control where no nutrients, whatsoever, were applied. The experiment had five replications laid out in a randomized block design. Intercultural operations like regular weeding and plant protection measures were followed as per schedule. The crop was harvested manually at 240 DAP.

2.3. Soil sampling

Soil samples were taken immediately after harvest and after clearing the litter layer. The soils samples (four per bed) were taken from the inner two-thirds of each bed, bulked to obtain a composite sample, cleared of any organic debris and transferred for storage in sealed plastic bags. Once in the laboratory, the soils were sieved (<2 mm), analyzed for moisture content and stored at 4 °C. Subsamples for the determination of SOC and mineral N were sieved to pass a 0.5 mm mesh.

2.4. Soil physico-chemical properties

Soil organic C (SOC) was determined by the Walkley–Black method (Nelson and Sommers, 1996), mineral N by steam distillation (Mulvaney, 1996), Bray P using the dilute acid-fluoride extractant (Olsen and Sommers, 1982) and exchangeable K in the NH_4OAc extract was estimated using an atomic absorption spectrophotometer (Varian AA 240FS). Soil pH was measured in 1:2.5 soil:water suspension.

Table 1
Relevant characteristics of the organic manures used in the study.

	OC	N	P	K	Ca	Mg	S	Fe	Mn	Zn
	g/kg									
Farmyard manure	90.5	6.0	2.0	4.0	13.0	3.9	1.2	5.73	0.518	0.040
Neem cake	270.7	18.0	2.4	17.0	5.0	2.2	1.0	3.05	0.227	0.017
Vermicompost	94.0	10.0	3.0	3.0	33.0	11.0	0.8	3.86	0.268	0.427
Ash	ND[a]	2.0	54.0	121.0	68.0	18.0	1.0	7.0	0.749	0.144

[a] ND—not determined.

Table 2
Soil pH, soil organic C (SOC), levels of major nutrients (N, P, K), dissolved organic-C (DOC) and -N (DON) in soils under various nutrient management regimes of ginger.

	CNM[a]	INM[b]	ONM[c]	Control
pH (1:2.5 H_2O)	5.34a	4.54a	4.35a	5.19a
SOC (g kg^{-1})	12.0b	16.3a	17.4a	11.0b
Mineral N (mg kg^{-1})	131a	123a	100b	79c
Bray P (mg kg^{-1})	18.0a	18.0a	17.0a	11.0a
Exchangeable K (mg kg^{-1})	216a	242a	251a	176b
Dissolved organic C (μg g^{-1})	232c	319b	344a	192d
Dissolved organic N (μg g^{-1})	60a	48b	45bc	32d

In each row, means followed by the same letter are not significantly different at $P<0.05$.
[a] CNM—chemical nutrient management.
[b] INM—integrated nutrient management.
[c] ONM—organic nutrient management.

2.5. Soil biochemical/microbiological analyses

Net N mineralization was determined by extracting 10 g soil with 50 mL of 2 M KCl for 30 min before and after incubation for 10 days at 30 °C (Paz-Ferreiro et al., 2009). The NH_4^+–N and total inorganic N were determined by steam distillation (Mulvaney, 1996). The difference between the values obtained before and after incubation indicates N mineralization capacity. Steam distillation for the determination of inorganic N (NH_4^+–N and NO_3^-–N) was done using an N analyzer (Kjeltech 2100, Foss).

Dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) were determined by the method described by Smolander and Kitunen (2002). The fumigation–extraction method (Vance et al., 1987) was used to determine soil microbial biomass-C (C_{MIC}), -N (N_{MIC}) and -P (P_{MIC}) using k_{EC} of 0.45 (Wu et al., 1990), k_{EN} of 0.54 (Joergensen and Mueller, 1996) and k_{EP} of 0.40 (Brookes et al., 1982), respectively. Soil respiration (SR) was measured as the CO_2 evolved from moist soil, adjusted to 55% water holding capacity, and pre-incubated for 7 days at 20 °C in the dark. The CO_2 production was then measured for the next 7 days using NaOH traps and titration with HCl. The metabolic quotient (qCO_2) was calculated as SR per unit of C_{MIC} as described by Salamanca et al. (2002).

2.6. Soil enzyme activities

Dehydrogenase (DH) activity was estimated using 2,3,5-triphenyltetrazolium chloride (TTC) as the substrate (Casida et al., 1964), urease (UR) using urea as the substrate (Kandeler and Gerber, 1988), acid phosphatase (Ac-P) using *p*-nitrophenyl phosphate as the substrate (Tabatabai and Bremner, 1969), β-glucosidase (βG) using *p*-nitrophenyl-β-d-glucopyranoside as the substrate (Eivazi and Tabatabai, 1998) and arylsulphatase (AS) using *p*-nitrophenyl sulfate as the substrate (Tabatabai and Bremner, 1970). The amount of *p*-nitrophenol released in all these cases was estimated spectrophotometrically.

2.7. Statistics

All values reported are expressed on an oven-dried soil basis (105 °C). The significance of treatment effects was determined by one-way ANOVA. Where the F values were significant, post hoc comparisons of means were made using the Least Significance Test (LSD) at the 0.05 probability level. The relationship between two parameters was measured using Pearson's correlations. All statistical analyses were performed using SPSS v. 11.0 for Windows.

3. Results

3.1. Soil pH, mineral N, Bray P and exchangeable K

Soil pH, Bray P and exchangeable K were not significantly influenced by the nutrient management regimes (Table 2). However, mineral N varied markedly between the treatments and was greater by 31% in CNM compared to ONM and only marginally greater than INM.

3.2. Soil organic C (SOC), dissolved organic-C (DOC) and -N (DON)

The concentrations of SOC and labile organic substrates (DOC and DON) were significantly influenced by the nutrient management regimes (Table 2). Mean SOC levels ranged between 11.0 and 17.4 g kg^{-1} across treatments. The levels of SOC were greater in ONM and INM treatments indicating a 45% and 36% increase respectively compared to CNM. The SOC levels in CNM and control were almost identical. Mean DOC levels ranged from 192 to 344 μg g^{-1}, registering a marked increase of 48% in ONM and 36% in INM compared to CNM. Conversely, chemical fertilization either singly (CNM) or in combination with FYM (INM) positively influenced DON levels. DON levels ranged from 32 to 60 μg g^{-1} across treatments, and were greater by 25–33% in CNM compared to INM and ONM. Among the treatments, the control treatment registered the lowest levels of SOC, DOC and DON. The ratio of DOC:DON was consistent with the levels of DOC across treatments (Table 2). It reduced from a high of 7.6 in ONM to a low of 3.9 in CNM.

3.3. Soil microbial biomass-C (C_{MIC}), -N (N_{MIC}) and -P (P_{MIC})

Mean values of C_{MIC} ranged from 186 to 473 μg g^{-1}, N_{MIC} from 20–38 μg g^{-1} and P_{MIC} from 8 to 22 μg g^{-1}, indicating appreciable variations among the treatments (Table 3). The greatest C_{MIC} and

Table 3
Biochemical/microbial properties of soils under various nutrient management regimes of ginger.

	CNM[a]	INM[b]	ONM[c]	Control
Microbial biomass C, C_{MIC} (μg g^{-1})	227c	316b	473a	186d
Microbial biomass N, N_{MIC} (μg g^{-1})	38a	32b	24c	20d
Microbial biomass P, P_{MIC} (μg g^{-1})	13b	22a	21a	08c
Soil respiration, SR (μg CO_2–C g^{-1} day^{-1})	24b	29a	32a	23b
Total inorganic N mineralized, N_{MIN} (mg N kg^{-1} per 10 days)	80b	110a	102ab	53c

In each row, means followed by the same letter are not significantly different at $P<0.05$.
[a] CNM—chemical nutrient management.
[b] INM—integrated nutrient management.
[c] ONM—organic nutrient management

P_{MIC} levels were registered in the treatments with organic manures (ONM and INM). Exclusive use of chemical fertilizers (CNM) led to a significant reduction in C_{MIC}, which was on an average 52% and 28% lower compared to ONM and INM respectively. Further, C_{MIC} level in INM was lower by 33% compared to ONM. Similarly, P_{MIC} levels in CNM were lower by 38–41% compared to ONM and INM, while it was almost identical in the treatments involving organic manures (ONM and INM). In contrast, chemical fertilization significantly increased N_{MIC} levels, which was on an average 58% greater in CNM and 33% greater in INM compared to ONM. The control registered the lowest levels of C_{MIC}, N_{MIC} and P_{MIC}. The ratios of C_{MIC}:N_{MIC} and C_{MIC}:SOC (Q_{MIC}) are given in Table 5. The ratio of C_{MIC}:SOC (Q_{MIC}) ranged between 1.73 and 2.73%, being lower in treatments involving chemical fertilizers (CNM and INM) compared to ONM. The lowest Q_{MIC} rate was, however, obtained in the control. Chemical fertilization also reduced the C_{MIC}:N_{MIC} ratio, which ranged from 6.1 to 20.2 across treatments. Wider C_{MIC}:N_{MIC} ratio was registered in ONM, while INM and control registered almost similar C_{MIC}:N_{MIC} ratios.

3.4. Soil respiration (SR) and metabolic quotient (qCO_2) and net N mineralized (N_{MIN})

SR (CO_2 efflux) ranged from 23 to 32 μg CO_2–C g^{-1} day^{-1} across treatments and was clearly greatest in ONM and INM followed by CNM and lastly by control (Table 3). On an average, SR in ONM was greater by 33% compared to CNM and by 10% compared to INM. Similarly, the SR in INM was on an average greater by 21% compared to CNM. The control recorded the least SR among the treatments. The metabolic quotient, qCO_2 (CO_2 flux per unit of C_{MIC}) ranged from 68 to 124 mg CO_2–C (g biomass C)$^{-1}$ day^{-1} and contrary to SR, mean qCO_2 level was significantly lower in treatments with organic manures (ONM and INM) and showed marked enhancement in CNM and control (Table 3). Among the fertilized treatments, qCO_2 level was in the order CNM > INM > ONM. The results indicated an average reduction to the tune of 25–45% in ONM treatment compared to the other treatments and mean qCO_2 in CNM was greater by 57% compared to ONM and by 18% compared to INM. N_{MIN} ranged between 53 and 110 mg N kg^{-1} per 10 days across treatments and was greatest in INM and ONM followed by CNM and control (Table 3). N_{MIN} rates varied little among ONM and INM, but were greater by 28% and 38% respectively compared to CNM.

3.5. Enzyme activities

The oxi-reductase enzyme, dehydrogenase (DH) and hydrolytic enzymes involved in C (β-glucosidase, βG), N (urease, UR), P (acid-phosphatase, Ac-P) and S (aryl-sulphatase, AS) cycles in soil were activated to different degrees by the treatments (Table 4). However, not all the treatments affected the enzyme activities to the same degree. For instance, the activities of DH, Ac-P and βG were in the order ONM > INM > CNM, while the activities of UR and AS were in the order CNM > INM > ONM. DH activity in ONM was greater by 53% compared to CNM and by 26% compared to INM. Similarly, Ac-P and βG activities in ONM were greater by 53% and 71% respectively compared to CNM. Ac-P activities in CNM and INM were almost identical, while βG was greater by 54% in INM relative to CNM. UR activity in CNM was greater by 32% and 28% compared to ONM and INM respectively. AS activity differed little between CNM and INM, but was greater by 19% compared to ONM.

Table 5
Ratios of various biochemical/microbial properties of soils under various nutrient management regimes of ginger.

	CNM	INM	ONM	Control
Metabolic quotient, qCO_2 (mg CO_2–C (g biomass C)$^{-1}$ day^{-1})	107b	91c	68d	124a
DOC:DON	3.9d	6.6ab	7.6a	6.0bc
C_{MIC}:N_{MIC}	6.10c	9.96b	20.23a	9.21b
C_{MIC}:SOC, Q_{MIC} (%)	1.88ab	1.96bc	2.73d	1.73a

4. Discussion

The nutrient management regimes markedly influenced the levels of SOC and dissolved organic substrates (DOC and DON), soil microbial properties and enzyme activities, albeit at varying degrees. C_{MIC} accumulated at lower levels in CNM. This is most likely due to N fertilizer (urea) used in split doses (at 45 and 90 DAP). A fertilization treatment effect upon soil microbial biomass is not new (Rifai et al., 2010) and lower levels of soil microbial biomass that are attributable to inorganic N fertilization have been reported by many (Fang et al., 2009; Wallenstein et al., 2006; Wang et al., 2008). Wallenstein et al. (2006) reported that chemical N addition lowered C_{MIC} by an average of 40–59% and that C_{MIC} had negative relationships with total N inputs in both mineral soils and organic soils. A meta-analysis of microbial biomass in ecosystem studies also found that C_{MIC} was lower by an average of 15% under inorganic N fertilization (Treseder, 2008). Results from our study indicated that soil C_{MIC} and P_{MIC} were relatively lower in CNM. A number of hypotheses on why chemical N fertilization produces reductions in soil microbial biomass have been put forth. One potential mechanism suggested by Sarathchandra et al. (2001) was that fertilization reduced SOC, which is the energy source for soil microorganisms. In our study, we did find that SOC and DOC levels in the CNM treatment were markedly lower than the levels in the ONM and INM treatments. In fact, the SOC level due to chemical fertilization was almost identical to the control. Therefore, the supply of readily metabolisable C by the organic manures is likely to have been the most influential factor contributing to the C_{MIC} and P_{MIC} increases measured (Tejada et al., 2006) in ONM and INM treatments. This confirmed that the levels of C_{MIC} is strongly related to the steady-state substrate availability in soils as reflected by the existence of strong correlations ($p<0.01$; $n=20$) between C_{MIC} and related parameters like SOC ($r=0.88$) and DOC ($r=0.84$). Also, P_{MIC} showed strong correlations ($p<0.01$; $n=20$) with SOC ($r=0.87$) and DOC ($r=0.88$).

Table 4
Enzyme activities in soils under various nutrient management regimes of ginger.

	CNM[a]	INM[b]	ONM[c]	Control
Dehydrogenase (nmol TPF g^{-1} soil h^{-1})	151c	184b	231a	109d
Acid phosphatase (μmol *p*-nitrophenol g^{-1} h^{-1})	9.0b	8.9b	13.8a	7.0c
Arylsulphatase (μmol *p*-nitrophenol g^{-1} h^{-1})	0.51a	0.50a	0.43b	0.27c
β-glucosidase (μmol *p*-nitrophenol g^{-1} h^{-1})	3.14c	4.83b	5.37a	2.70d
Urease (μmol NH_3–N g^{-1} h^{-1})	8.30a	6.50b	5.04b	3.36c

In each row, means followed by the same letter are not significantly different at $P<0.05$.
[a] CNM—chemical nutrient management.
[b] INM—integrated nutrient management.
[c] ONM—organic nutrient management.

Interestingly, C_{MIC} levels in INM treatment did not decrease even though it involved chemical fertilization albeit at 50% of the N applied in the CNM treatment. This suggested that differences in microbial response to inorganic N additions are explained by variations in the type, timing, and rates of N fertilizer application (Gallardo and Schlesinger, 1994). Inorganic N application at a lower rate and more importantly application of FYM offset the negative effects of chemical fertilization on C_{MIC} in INM treatment. This is in conformity with the results of Liu et al. (2009) who found that organic amendments with low amount of chemical fertilizer enhanced C_{MIC}, N_{MIC} and P_{MIC} more than recommended amount of chemical fertilization only and an unfertilized control. Similarly, Monaco et al. (2008) reported that repeated applications of the different organic materials, in addition to urea-N fertilizers, increased not only SOC content, but also C_{MIC} when compared with soil that received no fertilizer N and soil that received urea alone. In this study, besides chemical N fertilization, P and K application was done through chemical sources. However, the influence of other inorganic nutrients apart from N on soil microbial biomass has largely been regarded as inconsequential (Allen and Schlesinger, 2004).

Contrary to C_{MIC} and P_{MIC}, N_{MIC} accumulated at markedly greater level in CNM treatment. Apparently, N availability increased after N application and consequently microbes immobilized N, which led to an increase in N_{MIC}. This is in agreement with the observations of Wang et al. (2008). Positive correlation between N_{MIC} and DON ($r=0.84$; $p<0.05$; $n=20$) suggested that chemical fertilization enhanced DON level in the soil. Such effects of fertilization on DON have previously been shown and DON concentrations have been observed to be doubled by N fertilization (McDowell et al., 2004). Similar to DOC, DON is also used as a substrate by soil microbes. However, we obtained weak correlations between DON and DOC ($r=0.37$; $p<0.05$; $n=20$). This subsequently decreased the DOC:DON ratio in CNM treatment which was in agreement with Neff et al. (2000) who found that inorganic N fertilization increased DON fluxes by 50% and decreased DOC:DON ratios in N poor Hawaiian soils. Similar to DOC, the availability of labile C in the soil can also be evaluated by Q_{MIC} (Anderson and Domsch, 1990), which is the percentage of C_{MIC} to SOC and is used as a stability indicator for quick recognition of an environmental change (Anderson, 2003). Besides, it indicates the substrate availability to the soil microbes, values below 2% being a signal of SOM depletion (Anderson, 2003). In our study, mean Q_{MIC} ranged from 1.73 to 2.74% across treatments. Greater Q_{MIC} in the ONM treatment resulted from the diversity of organic matter input and/or through a more efficient microbial community. However, since Q_{MIC} represents a fraction of total organic matter content, it is the latter that assumes significance while interpreting N mineralization rates (Malchair and Carnol, 2009). For instance, lower labile C availability (lower Q_{MIC}) in INM treatment was offset by higher SOC content, resulting in almost similar N_{MIN} rates under ONM and INM treatments. Besides, the reduction of Q_{MIC} in the CNM treatment was associated with a steep decline in soil C_{MIC}:N_{MIC} ratio, which reflected microbes under stress due to C deficiency but an abundance of N. This suggested that microbes in CNM treatment took up N beyond their current metabolic requirements (i.e. 'luxury consumption'). Besides, it is also possible that N addition caused a shift in microbial community with a high C:N ratio (i.e. fungi) to those with a low C:N ratio (i.e. bacteria; Paul and Clark, 1989). Moreover, enhanced Q_{MIC} in ONM treatment reflected the availability of large amount of organic substrates for microbial growth (Anderson, 2003).

Our results also showed a clear effect of nutrient management regimes on net N_{MIN} rates suggesting that increased soil microbial pool is often associated with high net N_{MIN} rates (Dinesh et al., 2010; Rivest et al., 2010). Higher N_{MIN} rates in INM and ONM treatments suggested that in addition to the nutrients returned by organic manure decomposition, high allochthonous C-supply may provide favorable conditions for soil microorganisms, resulting in high microbial biomass values and fast nutrient turnover. N_{MIN} was lower under CNM but markedly higher under INM suggesting that organic manure application in conjunction with chemical fertilization enhanced net N_{MIN} rate. Differently, N_{MIN} rates in ONM treatment represent late stage decomposition, when organic manures with diverse initial chemistries has been transformed into chemically more uniform soil organic matter, as stated by the decay filter hypothesis (Melillo et al., 1989). At this decomposition stage, main controlling factors reported are climate (temperature, moisture), soil texture, total N pool and new sources of labile C (Malchair and Carnol, 2009; Prescott, 2005). Except for labile C (DOC), none of these factors differed among our treatments suggesting that higher N_{MIN} rates under ONM and INM were due to the high SOC content although Q_{MIC} was different between these two treatments. The positive correlation between N_{MIC} and N_{MIN} ($r=0.63$; $P<0.05$; $n=20$) might be explained by the role played by microbial extracellular enzymes in the depolymerization of N-containing polymers (Schimel and Bennett, 2004). This is also supported by positive correlations reported between N_{MIC} and N_{MIN} with UR activity ($r=0.76$ and $r=0.65$ respectively; $p<0.05$; $n=20$).

In our study, SR rates in ONM and INM treatments were marginally significantly higher than those in the CNM. Lower levels of SR due to chemical fertilization have been found in earlier studies when N fertilizer was added (Bowden et al., 2004; Thirukkumaran and Parkinson, 2000). Contrarily, enhanced SR in INM and ONM treatments is due to higher soil microbial activity (Dinesh et al., 2010; Melero et al., 2006) attributable to greater levels of SOC which has been found to account for 75% and 81% of the variations in CO_2 production in the non-preincubated and pre-incubated soils, respectively (Wang et al., 2003). Therefore, in our study it is possible that lower SR in CNM resulted from the suppression of the decomposition of native SOC (Ding et al., 2010) due to decrease in microbial biomass and activity (Lee and Jose, 2003). Wang et al. (2003) suggested that SR is dependent on the replenishment of the labile substrate from the bulk organic C pool which confirmed that there was less labile C in the CNM treatment. We did see changes in the DOC pool that would suggest changes in labile C. It is, therefore, possible that this explained the difference in SR rates across treatments. Hence, in our study, lower SR in CNM and control is apparently due to the lower substrate quality (lower Q_{MIC}), resulting in a lower C use efficiency (higher metabolic quotient, qCO_2). In contrast, under ONM, increased C availability via a broader range of substrates (FYM, VC, NC, ash) and good yield efficiency (high Q_{MIC}, low qCO_2) increased SR.

The qCO_2 (SR per unit of microbial biomass) reflects the maintenance energy requirement of soil microbes; level above 2 g C–CO_2 - h^{-1} kg C_{MIC}^{-1} being the critical threshold for the base line performance of microbial communities (Anderson, 2003). Lower qCO_2 values under ONM observed in our study are in conformity with the observations of numerous workers (Lagomarsino et al., 2009; Melero et al., 2006; Scheller and Joergensen, 2008). Greater qCO_2 levels in CNM treatment indicated decreased substrate use efficiency i.e. more substrate is diverted toward catabolic at the expense of anabolic processes (Anderson and Domsch, 1990), which would mean that the conversion of total carbon into microbial carbon is less efficient. Anderson and Domsch (2010) suggested that high qCO_2 reflects a high maintenance carbon demand, and if the soil system cannot replenish the carbon which is lost through respiration, microbial biomass must decline.

Consistent with the results on microbial biomass, we observed marked variations in soil enzyme activities due to nutrient management regimes, although the responses of DH, UR, Ac-P, βG and AS were different. The increases in activities of DH, Ac-P and βG provided further evidence of better conditions for soil microbial biomass in ONM and INM treatments. CNM enhanced the activity of UR and to some extent AS indicating the positive effects of N fertilization on these enzymes. Previous studies have shown that fertilization with N increased UR and Ac-P activities (Allison et al., 2006; Graham and Haynes, 2005). However, in our study we observed lower Ac-P activity in CNM and INM treatments relative to ONM. This may be partly explained by the high P fixing capacity of our soils (Srinivasan et al., 2000) and partly by the negative effects of P application at

50 kg ha^{-1}. The stronger effects of ONM and INM treatments on DH suggested the availability of a higher quantity of biodegradable substrates and hence, an improvement in microbial activity (Dinesh et al., 2010; García-Orenes et al., 2010). The rather poor influence of inorganic fertilization especially N on DH activity is consistent with the results of Kautz et al. (2004). They showed that mineral N fertilization had weaker effects on DH activity as compared to organic manuring and concluded that mineral N additions are rapidly dispersed into the soil organic matter, the plant biomass, or are lost by leachates without effecting soil biological properties. Conversely, marked reductions in DH activity due to high N fertilization rates (Shen et al., 2010) and significant increase in activity due to optimum and balanced applications of nutrients (Ebhin Masto et al., 2006) have been observed. The study also revealed similar results for βG and is similar to the results of Liu et al. (2010) who reported that the activities of βG in treatments with organic manures were significantly higher compared to mineral fertilizers treatments and unamended control. Lower values of βG in the CNM treatment indicated that the potential to mineralise organic matter, and so the activity of the C-cycle is reduced (Caravaca et al., 2002).

5. Conclusion

The responses of microbial biomass, enzyme activities and dissolved organic matter in soils under rainfed ginger showed that the short-term effects of nutrient management regimes are dramatic and pervasive. Chemical fertilization (CNM) registered lower levels of C_{MIC}, P_{MIC}, SR, net N mineralization, DOC, DH, Ac-P and βG activities but enhanced the levels of N_{MIC}, DON, UR activity and qCO_2. Conversely, organic manuring (ONM) registered significantly greater levels of C_{MIC}, P_{MIC}, SR, N_{MIN} and activities of DH, Ac-P and βG owing to the additive effects of both organic manures and biofertilizers. Combined application of chemical fertilizers and FYM (INM) offset the negative effects of chemical fertilization on microbial activity as evidenced by the greater levels of C_{MIC}, P_{MIC}, N_{MIN}, Ac-P and βG and lower level of qCO_2 relative to CNM. This indicated that nutrient management regimes affected these parameters differently possibly due to changes in microenvironments for microbes, organic C input and substrate availability across treatments. The contrasting nutrient management regimes did produce differences in biochemical and microbial parameters in soils under rainfed ginger. The biochemical indicators allowed us to measure changes in soil quality even in the short-term which indicated that management practices specific to rainfed ginger such as bed making and exclusive chemical fertilization could reduce SOC levels. Conversely, exclusive organic farming of ginger would not be feasible under high-productive rainfed agriculture. It is, therefore, important to strike a balance between organic, biological and chemical sources of fertilizers to optimize a nutrient management regime that favors SOM and soil quality build up under rainfed ginger.

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