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Short-term incorporation of organic manures and biofertilizers influences biochemical and microbial characteristics of soils under an annual crop [Turmeric (*Curcuma longa* L.)]

R. Dinesh *, V. Srinivasan, S. Hamza, A. Manjusha

Division of Crop Production and Post Harvest Technology, Indian Institute of Spices Research (IISR), P.O. Box 1701, Marikunnu P.O., Calicut 673 012, Kerala, India

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ABSTRACT

The study was conducted to determine whether short-term incorporation of organic manures and biofertilizers influence biochemical and microbial variables reflecting soil quality. For the study, soils were collected from a field experiment conducted on turmeric (*Curcuma longa* L.) involving organic nutrient management (ONM), chemical nutrient management (CNM) and integrated nutrient management (INM). The findings revealed that application of organic manures and biofertilizers (ONM and INM) positively influenced microbial biomass C, N mineralization, soil respiration and enzymes activities. Contrarily, greater metabolic quotient levels in CNM indicated a stressed soil microbial community. Principal component analysis indicated the strong relationship between microbial activity and the availability of labile and easily mineralizable organic matter. The findings imply that even short-term incorporation of organic manures and biofertilizers promoted soil microbial and enzyme activities and these parameters are sensitive enough to detect changes in soil quality due to short-term incorporation of biological fertilizers.

1. Introduction

Low inputs of organic materials, excessive use of mineral fertilizers and more frequent tillage have contributed to a general reduction in soil organic matter (SOM) content, with a consequent decline in the quality of agricultural soils. This negative effect of agricultural practices could be reversed by the correct utilization of manures and/or crop residues within cropping systems, either alone or in combination with mineral fertilizers (Mandal et al., 2007). But any increase in SOM content due to organic matter addition may be slow. However, whilst the amount of C stored in soil is a good indicator of soil quality, it does not necessarily reflect the complexity of the organic compounds present and the influence that these may have on the microbiological processes controlling nutrient availability.

To overcome these limitations, different authors have proposed several soil indicators to study the effects of organic manure applications on soil C accumulation and C and N turnover (Gil-Sotres et al., 2005). Some are based on soil physical and chemical properties, but the majority focuses on biochemical properties that reflect the size and activity of microbial processes. This is because biologically mediated processes in soils play a key role in the mineralization of organic C and in nutrient cycling. Moreover, changes in the size and activity of the soil microbial biomass occur more rapidly in response to changes in environmental conditions, land use and management than most physical and chemical parameters (Sparling, 1992).

Also, the biochemical properties are more sensitive to environmental stress, play a major role in degradation, and provide rapid and accurate information on soil quality (García et al., 2000). While biochemical properties of the soil can be studied at various levels, 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, soil respiration etc.), and the activities of extra-cellular hydrolytic enzymes involved in the C, N, S and P cycles in soil. These soil biochemical and microbiological parameters are considered as potential indicators of management impacts on soil quality (Gil-Sotres et al., 2005) especially under different agricultural management practices because soil microbial biomass and enzyme activities respond much more quickly to the changes in soil management practices as compared to total soil organic matter (García-Ruiz et al., 2008).

The response of these soil biochemical and microbial variables to organic and conventional amendments is often studied in the long-term (Ferreras et al., 2006; Monaco et al., 2008). Differently, Gil-Sotres et al. (2005) have indicated the possibility of using these

* Corresponding author. Tel.: +91 0495 2731410; fax: +91 0495 2730294.
E-mail address: rdinesh2005@gmail.com (R. Dinesh).

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biochemical and microbial properties to assess the short-term impact of agricultural management.

We report here data on biochemical and microbial properties, under short-term field conditions, in response to various nutrient management regimes in an annual crop (turmeric – *Curcuma longa* L.). Turmeric, being an exhaustive crop, requires heavy manuring for higher yields. Hence, the use of biofertilizers like *Azospirillum lipoferum*) and phosphobacteria (*Bacillus megaterium* var. *phosphaticum*) and organic manures like farmyard manure, vermicompost and neem cake offer an economically attractive and ecologically sound means of reducing external inputs and improving the quality of soil under turmeric. These organic manures and biofertilizers offer themselves as alternative to chemical fertilizers and are being increasingly used in present day agriculture. While earlier studies on the effects of organic manure and biofertilizers either alone or in combination with inorganic fertilizers on the growth and productivity of turmeric are available, data on their effects on soil biochemical and microbial properties is severely lacking.

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 and microbial variables reflecting soils quality and to determine the inter-relationships between these variables in soils under turmeric. The CNM involved exclusive use of chemical fertilizers (60–50–120 kg ha^{-1} NPK applied as urea, rock phosphate and muriate of potash), INM involved use of chemical fertilizers (60–50–120 kg ha^{-1} NPK applied as urea, rock phosphate and muriate of potash) in combination with organic manures (farmyard manure and neem cake) and ONM involved exclusive use of organic manures (FYM, neem cake, ash and vermicompost) and biofertilizers (*A. lipoferum* and *B. megaterium* var. *phosphaticum*). We hypothesized that under field conditions, even short-term incorporation of organic manures in combination with biofertilizers or chemical fertilizers would influence substrate levels, thereby altering soil quality under turmeric.

2. 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

The field experiment was initiated in May 2007 with turmeric as the test crop. The site chosen for the study was flat and had not been under cultivation for the past several years.

2.2.1. Land preparation

Due to the high intensity rainfall lasting over seven months, turmeric is generally grown under rain fed conditions on raised beds in Kerala, India. For preparation of the beds, the land was cleared of weeds and the soil was tilled with a tractor mounted disk harrow, puddled to a fine tilth and levelled using a soil leveller. Raised beds of size 3 × 1 × 0.15 m ($l \times b \times h$) were made manually using a garden spade. A spacing of 40 cm was allowed between the beds. Small shallow pits for planting were then made on the beds at a spacing of 30 × 20 cm. The seed-rhizome (20–30 g) of turmeric (variety: Prathiba) 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 adopted for the study consisted of the following:

i. *Organic nutrient management (ONM):* 20 kg FYM + 1.0 kg neem cake (NC) + 0.5 kg ash + 2.0 kg vermicompost (VC, applied at 45 day after planting (DAP)) + Azospirillum (10^8 Colony forming units (CFU) g^{-1} soil) + Phosphobacteria (10^8 CFU g^{-1} soil), all applied to one bed.
ii. *Chemical nutrient management (CNM): 60–50–120* 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 DAP) and MOP in two splits (45th and 90th DAP).
iii. *Integrated nutrient management (INM): 60–50–120* kg ha^{-1} NPK applied exactly as in CNM + 10 kg FYM bed^{-1} + 1.0 kg NC bed^{-1}.
iv. *Control*: Beds in which no fertilizers, whatsoever, were applied.

The nutrient composition of FYM, VC, NC and ash are given in Table 1. Azospirllum (*A. lipoferum*) and phosphobacteria (*B. megaterium* var. *phosphaticum*) were applied at rates equivalent to 10^8 CFU g^{-1} soil. These biofertilizers were thoroughly mixed with FYM. During application, ash, FYM, NC and VC were spread evenly on the beds and incorporated manually into the soil using a garden hoe.

Intercultural operations like regular weeding and plant protection measures were followed as per schedule in all the treatments. The crop was harvested manually at 240 DAP. The experiment had four replications laid out in a randomized block design.

2.3. Soil sampling

Soil samples were taken immediately after harvest (at 240 DAP, January 2008) 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 their moisture content and stored at 4 °C for not more than one week before analyses. 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, 1982), mineral N by steam distillation (Mulvaney, 1996), Bray P using the dilute acid–fluoride extractant (Kuo, 1996) and exchangeable K in the NH_4OAc extract (Helmke and Sparks, 1996) was estimated using an atomic absorption spectrophotometer (Varian AA 240FS). Soil pH was measured in 1:2.5 soil:water suspension.

2.5. Soil biochemical/microbiological analyses

Nitrogen mineralization capacity 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. The NH_4–N and total inorganic N were

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 turmeric.

	CNM[a]	INM[b]	ONM [c]	Control
pH (1:2.5 H_2O)	5.47a	4.94a	4.55a	5.29a
SOC (g kg^{-1})	16.9c	19.4ab	21.7a	16.3cd
Mineral N (mg kg^{-1})	121c	138a	135ab	115cd
Bray P (mg kg^{-1})	18.3bc	18.7a	18.5ab	11.6d
Exchangeable K (mg kg^{-1})	219c	242b	267a	166d
Dissolved organic C (μg g^{-1})	356c	451b	484a	241d
Dissolved organic N (μg g^{-1})	37c	58a	51ab	27d

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.

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 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}) using k_{EC} of 0.45 (Jenkinson et al., 2004). Soil respiration (SR) was measured as the CO_2 evolved from moist soil, adjusted to 55% water holding capacity, and pre-incubated for seven days at 20 °C in the dark. The CO_2 production was then measured for the next seven days using NaOH traps and titration with HCl. The metabolic quotient (qCO_2) was calculated as follows: (μg CO_2–C evolved in 7 days g^{-1} soil)/(μg biomass C g^{-1} soil)/7 days) × 1000 = mg CO_2–C g^{-1} biomass C per day (Salamanca et al., 2002).

2.6. Soil enzyme activities

Dehydrogenase [DHA, Enzyme Commission (EC) number 1.1.1.] activity was estimated using 2,3,5-triphenyltetrazolium chloride as the substrate (Casida et al., 1964). Protease (EC 3.4.4) hydrolyzing benzoyl argininamide (BAA-protease) was determined using α-benzoyl-*N*-argininamide as the substrate (Gil-Sotres et al., 1992), acid phosphatase (EC 3.1.3.2) activity using *p*-nitrophenyl phosphate as the substrate (Tabatabai and Bremner, 1969), ß-glucosidase (EC 3.2.1.21) activity using *p*-nitrophenyl-β-d-glucopyranoside as the substrate (Eivazi and Tabatabai, 1988) and arylsulphatase (EC 3.1.6.1) activity using *p*-nitrophenyl sulphate as the substrate (Tabatabai and Bremner, 1970).

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 analysis of variance. Where the *F* values were significant, post hoc comparisons of means were made using the least significance difference (LSD) test. Principal component analysis (PCA) was performed for reflection of any intrinsic pattern in the multidimensional data swarm. PCA often reveals previously unsuspected associations among variables and thereby allows interpretation that would not be possible otherwise (Johnson and Wichern, 1982). A VARIMAX rotation was performed to enhance interpretability of the uncorrelated components (Flury and Riedwyl, 1988). Only principal components with eigen values of more than one (>1) and that explain > 10% of the total variance were retained.

3. Results and discussion

The data on soil physico-chemical parameters is given in Table 2. In general, soil pH was acidic (range 4.55–5.47) and did not vary significantly among the treatments. However, the levels of SOC and mineral N varied markedly between the treatments. Greater levels of SOC, mineral N, DOC, DON, Bray P and exchangeable K were registered by either ONM or INM. Compared to CNM, SOC and mineral N levels in ONM were greater by 22% and 10%, respectively. Similarly, SOC and mineral N levels in INM was greater by 13% and 12%, respectively compared to the CNM. Bray P level was greatest in INM, exchangeable K and DOC in ONM and DON in the INM treatment. DOC level in ONM was greater by 25% and DON level in INM was greater by 36% compared to CNM.

3.1. Soil microbial biomass – C (C_{MIC})

Microbial biomass is among the most labile pools of organic matter and it serves as an important reservoir of plant nutrients and can therefore, have important implications for nutrient bioavailability (Melero et al., 2006). In this study, appreciable variations in C_{MIC} levels were observed among the treatments, with maximum level in ONM and INM (Table 3). In fact, C_{MIC} levels in ONM and INM were greater by 31% and 29%, respectively, compared to CNM. The supply of readily metabolisable C in the organic manures is likely to have been the most influential factor contributing to the C_{MIC} increases measured (Tejada et al., 2006). The positive effect on microbial biomass observed in the soils amended with organic manures is due to a direct (microbial growth in these by products, Pascual et al., 1998) and indirect (improvement of plant growth) effect. Incorporation of organic manures, therefore, provided a steady supply of substrates to support the microbial community thus confirming the observation that the levels of microbial biomass might be strongly related to the steady-state substrate availability in soils. This was well reflected by the existence of a strong correlation ($p < 0.01$; $n = 16$) between C_{MIC} and related parameters like SOC ($r = 0.79$), DOC ($r = 0.82$), DON ($r = 0.70$) etc.

3.2. Soil respiration (SR)

Similar to C_{MIC} levels, SR in INM and ONM was greater by 16% relative to CNM and by 20% compared to the control (Table 3). Enhanced respiration rate in INM and ONM is indicative of higher soil microbial activity (Melero et al., 2006) and can be attributed to greater levels of SOC which has been found to account for 75%

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

	CNM [a]	INM [a]	ONM [a]	Control
Microbial biomass C ($\mu g\ g^{-1}$)	353c	496ab	513a	342cd
CO_2 evolution ($\mu g\ CO_2$–C $g^{-1}\ day^{-1}$)	21b	25a	25a	20bc
qCO_2 (mg CO_2–C (g biomass C)$^{-1}$ day^{-1})	60a	50c	49cd	58ab
Microbial biomass C:SOC (%)	2.08cd	2.56a	2.36ab	2.10bc
Total inorganic N mineralized (mg N kg^{-1} per 10 days)	56b	102a	107a	23c

In each row, means followed by the same letter are not significantly different at $P < 0.05$.
[a] Expanded form of abbreviations given in Table 2.

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

	CNM[a]	INM[a]	ONM[a]	Control
Dehydrogenase (nmol TPF g^{-1} soil h^{-1})	181c	247ab	256a	173cd
Acid phosphatase (μmol *p*-nitrophenol $g^{-1}\ h^{-1}$)	10.6c	14.7ab	15.3a	6.8d
Arylsulphatase (μmol *p*-nitrophenol $g^{-1}\ h^{-1}$)	0.58a	0.54ab	0.51bc	0.36d
ß-glucosidase (μmol *p*-nitrophenol $g^{-1}\ h^{-1}$)	3.51c	4.87ab	4.96a	2.73cd
BAA-protease (μmol NH_3–N $g^{-1}\ h^{-1}$)	6.46c	7.71a	7.13ab	6.14cd

In each row, means followed by the same letter are not significantly different at $P < 0.05$.
[a] Expanded form of abbreviations given in Table 2.

and 81% of the variations in CO_2 production in the non-pre-incubated and pre-incubated soils, respectively (Wang et al., 2003). They also suggested that soil respiration is dependent on the replenishment of the labile substrate from the bulk organic C pool. Our results, therefore, indicated that in the soil amended with organic manures and biofertilizers the organic substrates are mineralized more rapidly and that the greater microbial biomass derived from these treatments would have been able to degrade a greater quantity of substrates (Tejada et al., 2006).

3.3. Total N mineralized

Potentially mineralizable N is frequently used as a reliable indicator of the potential N supplying capacity of a soil (Russell et al., 2006). In our study, manure application created conditions that promoted an increase in the easily mineralizable inorganic-N pool, which was predominantly ammoniacal. The total inorganic N mineralized was 45–48% higher in INM and ONM compared to CNM (Table 3) due to greater organic matter levels because N mineralization is a microbial process that is influenced both by the quantity and quality of soil organic matter. Apparently, these soils accumulated greater level of dissolved organic matter especially the labile fraction, which directly regulates N mineralization and nitrification and is the initial substrate for these N cycling pathways (Jones et al., 2004).

3.4. Dehydrogenase (DHA)

The oxyreductase enzyme (DHA) is an indicator of microbiological activity and has been used as a valid biomarker of soil quality under different agricultural management practices (García-Ruiz et al., 2008). In our study, DHA activity in ONM and INM was greater by 29% and 27% compared to CNM (Table 4). This is because the organic amendments may contain intra- and extra-cellular enzymes and also stimulate microbial activity in the soil (Liang et al., 2005). Also, the higher DHA activity in soils treated with biological fertilizers suggested the availability of a higher quantity of biodegradable substrates and hence, an improvement in microbial activity.

In particular, a significant correlation ($P < 0.01$; $n = 16$) was found between DHA and DOC ($r = 0.81$), suggesting a relationship between the availability of labile and easily mineralizable organic matter and the activity of microbial populations. Such positive correlations between water soluble C and microbial activity (usually expressed as DHA) have been found previously by earlier workers (Caravaca et al., 2002; Madejón et al., 2009). In addition, DHA activity was positively correlated ($P < 0.01$, $n = 16$) with SOC ($r = 0.74$) and SR ($r = 0.79$) suggesting that addition of mineralizable organic residues provided substrates for this enzyme and enhanced microbial growth.

3.5. Soil hydrolytic enzyme activities

Similar to DHA, all the hydrolytic enzymes were activated to different degrees in the treated beds (Table 4). However, not all the treatments affected the enzyme activities to the same degree. For instance the activities of acid phosphatase and ß-glucosidase were greater in ONM, arylsulphatase activity in CNM and BAA-protease activity in INM.

Proteases are considered to be greatly dependent on microbial activity (Caravaca et al., 2002), indicating that the reduction of metabolism in the control and CNM treatments affected the biological transformation of N. Differently, greater ß-glucosidase activity in INM and ONM suggested an enrichment in fresh organic materials of a cellulolytic nature, which acts as substrate for these enzymes. Our results using hydrolytic enzymes suggest that soil functionality (in this context the capacity to cleave organic compounds) was also enhanced due to incorporation of organic manures and biofertilizers.

3.6. C_{MIC}:SOC ratio and metabolic quotient (qCO_2)

From the results it is evident that decreased levels of biologically available substrates and organic matter led to simultaneous decrease in microbial activity in the control. This was well reflected by the ratio of C_{MIC}:SOC (Table 3), which was greatest in INM (2.56%) and ONM (2.36%) and least in CNM (2.08%). The ratio of C_{MIC}:OC reflects the availability of substrate to the soil microflora and lower C_{MIC}:SOC ratios in CNM and control is apparently due to lower availability and/or degradability of organic substrates and, therefore, decreased microbial development and C turnover. Contrarily, relatively greater C_{MIC}:SOC ratios in ONM and INM indicated less recalcitrant soil organic matter (Turner et al., 2002).

Table 5
Loadings of physico-chemical, biochemical and microbial properties on the factors identified by principal components analysis. The soil parameters are grouped according to the maximum fittings to principal components (correlation coefficients > 0.50[b]; $n = 16$).

Variable	Principal components [a]		
	PC1	PC2	PC3
pH	n.s.[c]	n.s.	n.s.
Organic C	**0.57**[c]	**0.69**	n.s.
Mineral N	**0.84**	n.s.	n.s.
Bray P	n.s.	n.s.	**0.87**
Exchangeable K	n.s.	n.s.	**0.86**
DOC	**0.76**	**0.64**	n.s.
DON	**0.82**	n.s.	n.s.
C_{MIC}	**0.83**	0.23	n.s.
Soil respiration	n.s.	**0.76**	n.s.
qCO_2	n.s.	**−0.83**	n.s.
DHA	**0.84**	n.s.	n.s.
Acid phosphatase	n.s.	**0.81**	n.s.
Arylsulphatase	n.s.	n.s.	n.s.
ß-glucosidase	**0.60**	**0.72**	n.s.
BAA-protease	**0.80**	n.s.	n.s.
Explained variance (%)	36.7	31.7	14.6

[a] Only principal components with eigen values > 1 and those explaining > 10% of the total variance were retained.
[b] Correlations with absolute values higher than 0.50 are in bold.
[c] n.s. – loadings lower than 0.50.

The qCO_2 levels were greater under control and CNM than under INM and ONM (Table 3). In fact, the levels in CNM were greater by 18% compared to the INM and ONM. The qCO_2 provides a measure of the specific metabolic activity and has been proposed as a bioindicator for substrate quality and environmental stress and reflects the efficiency of the use of SOC by microorganisms (Knoepp et al., 2000). Greater qCO_2 levels in CNM and control indicated decreased substrate use efficiency i.e. more substrate is catabolized to CO_2 and less substrate is incorporated into the microbial biomass, which suggested that the conversion of total carbon into microbial carbon is less efficient as reported by Frazão et al. (2010) in soils of varying land use. Contrarily, the decrease of qCO_2 in the INM and ONM suggested less adverse environmental conditions and relatively higher use efficiency of the organic resources than in the control.

3.7. Inter-relationships between various soil properties

To study the relationships among the soil properties, principal component analysis (PCA) was employed. The analysis revealed that 83% of the variance was explained by three factors (Table 5). The first (PC1), which accounted for 36.7% of the total variance, was defined by mineral N, DON and the measured biochemical parameters like C_{MIC}, DHA, and BAA-protease. This reflects the size and activity of the microbial biomass and possibly reflected the strong relationship between the availability of labile and easily mineralizable organic matter and the activity of microbial population. The positive part of the second factor (PC2) explaining 31.7% of the variance was defined by soil respiration, acid phosphatase and ß-glucosidase. This indicated the strong relationship between microbial activity and P cycle in soils and also suggested that in soils relying solely on chemical fertilizers the potential to mineralize organic matter, and so the activity of the C-cycle, is reduced. The negative loading of qCO_2 in this factor suggests a decrease in substrate use efficiency in beds with low organic matter especially the CNM and control treatments. The third factor (PC3) with 14.6% of the variance was defined by Bray P and exchangeable K. This reflected the logical dependence of soil microorganisms on available P and K in the soil. The fact that DOC and soil C contents are included with high loadings in more than one factor indicates the effect of the different nutrient management regimes on the composition of SOM and the typical interactions among the properties involved in the C, N, P and S cycles.

4. Conclusion

Our results showed that short-term incorporation of organic manures and biofertilizers either alone or in combination with inorganic fertilizers promoted soil quality. Apparently, microbial activity was limited by the reduced supply of organic substrates in the chemical and control treatments. Therefore, a fertilization strategy that involves organic and biofertilizers either alone or in combination with inorganic fertilizers is crucial for nutrient exhaustive crops like turmeric. The study also implies that biochemical parameters could be successfully used to detect changes in soil quality in response to short-term incorporation of biological fertilizers in annual arable crops.

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References

Caravaca, F., Masciandaro, G., Ceccanti, B., 2002. Land use in relation to soil chemical and biochemical properties in a semiarid Mediterranean environment. Soil Till. Res. 68, 23–30.
Casida Jr., L.E., Klein, D.A., Santoro, R., 1964. Soil dehydrogenase activity. Soil Sci. 98, 371–378.
Eivazi, F., Tabatabai, M.A., 1988. Glucosidases and galactosidases in soils. Soil. Biol. Biochem. 20, 601–606.
Ferreras, L., Gomez, E., Toresani, S., Firpo, I., Rotondo, R., 2006. Effect of organic amendments on some physical, chemical and biological properties in a horticultural soil. Bioresour. Technol. 97, 635–640.
Flury, B., Riedwyl, H., 1988. Multivariate Statistics. A Practical Approach. Chapman and Hall, London.
Frazão, L.A., Piccolo, M.C., Feigl, B.J., Cerri, C.C., Cerri, C.E.P., 2010. Inorganic nitrogen, microbial biomass and microbial activity of a sandy Brazilian Cerrado soil under different land uses. Agric. Ecosyst. Environ. 135, 161–167.
García, C., Hernandez, T., Pascual, J.A., Moreno, J.L., Ros, M., 2000. Microbial activity in soils of SE Spain exposed to degradation processes. Strategies for their rehabilitation. In: García, C., Hernandez, T. (Eds.), Research and Perspectives of Soil Enzymology in Spain. Consejo Superìor de Investìgacìones Cìentificas, Madrid, pp. 93–143.
García-Ruiz, R., Ochoa, V., Belén Hinojosa, M., Carreira, J.A., 2008. Suitability of enzyme activities for the monitoring of soil quality improvement in organic agricultural systems. Soil Biol. Biochem. 40, 2137–2145.
Gil-Sotres, F., Trasar-Cepeda, M.C., Ciardi, C., Ceccanti, B., Leirós, M.C., 1992. Biochemical characterization of biological activity in very young mine soils. Biol. Fert. Soils 13, 25–30.
Gil-Sotres, F., Trasar-Cepeda, C., Leirós, M.C., Seoane, S., 2005. Different approaches to evaluating soil quality using biochemical properties. Agric. Ecosyst. Environ. 37, 877–887.
Helmke, P.A., Sparks, D.L., 1996. Lithium, potassium, rubidium, and caesium. In: Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnston, C.T., Sumner, M.E. (Eds.), Methods of Soil Analysis, Part 3, Chemical Methods. SSSA, Madison, WI, pp. 551–574.
Jenkinson, D.S., Brookes, P.C., Powlson, D.S., 2004. Measuring soil microbial biomass. Soil Biol. Biochem. 36, 5–7.
Johnson, R.A., Wichern, D.W., 1982. Applied Multivariate Statistical Analysis Inc.. Prentice-Hall, NJ, USA.
Jones, D.L., Shannon, D., Murphy, D., Farrar, J., 2004. Role of dissolved organic nitrogen in soil N cycling in grassland soils. Soil Biol. Biochem. 36, 749–756.
Knoepp, J.D., Coleman, D.C., Crossley Jr., D.A., Clark, J.S., 2000. Biological indices of soil quality: an ecosystem case study of their use. Forest Ecol. Manage. 138, 357–368.
Kuo, S., 1996. Phosphorus. In: Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnston, C.T., Sumner, M.E. (Eds.), Methods of Soil Analysis, Part 3, Chemical Methods. SSSA, Madison, WI, pp. 869–919.
Leirós, M.C., Trasar-Cepeda, C., Seoane, S., Gil-Sotres, F., 2000. Biochemical properties of acid soils under climax vegetation (Atlantic oakwood) in an area of the European temperate-humid zone (Galicia, NW Spain): general parameters. Soil Biol. Biochem. 32, 733–745.
Liang, Y., Nikolic, M., Peng, Y., Chen, W., Jiang, Y., 2005. Organic manure stimulates biological activity and barley growth in soil subject to secondary salinization. Soil Biol. Biochem. 37, 1185–1195.

Madejón, E., Murillo, J.M., Moreno, F., López, M.V., Arrue, J.L., Alvaro-Fuentes, J., Cantero, C., 2009. Effect of long-term conservation tillage on soil biochemical properties in Mediterranean Spanish areas. Soil Till. Res. 105, 55–62.

Mandal, A., Patra, A.K., Singh, D., Swarup, A., Masto, R.E., 2007. Effect of long-term application of manure and fertilizer on biological and biochemical activities in soil during crop development stages. Bioresour. Technol. 98, 3585–3592.

Melero, S., Porras, J.C.R., Herencia, J.F., Madejón, E., 2006. Chemical and biochemical properties in a silty loam soil under conventional and organic management. Soil Till. Res. 90, 162–170.

Monaco, S., Hatch, D.J., Sacco, D., Bertora, C., Grignani, C., 2008. Changes in chemical and biochemical soil properties induced by 11-yr repeated additions of different organic materials in maize-based forage systems. Soil Biol. Biochem. 40, 608–615.

Mulvaney, R.L., 1996. Nitrogen – Inorganic forms. In: Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnston, C.T., Sumner, M.E. (Eds.), Methods of Soil Analysis, Part 3, Chemical Methods. SSSA, Madison, WI, pp. 1123–1184.

Nelson, D.W., Sommers, L.E., 1982. Total carbon, organic carbon and organic matter. In: Page, A.L., Miller, R.H., Keeney, D.R. (Eds.), Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. ASA, SSSA, Madison, WI, pp. 539–594.

Pascual, J.A., Hernandez, T., Garcia, C., Ayuso, M., 1998. Enzymatic activities in an arid soil amended with urban organic wastes: laboratory experiment. Bioresour. Technol. 64, 131–138.

Russell, C.A., Dunn, B.W., Batten, G.D., Williams, R.L., Angus, J.F., 2006. Soil tests to predict optimum fertilizer nitrogen rate for rice. Field Crop Res. 97, 286–301.

Salamanca, E.F., Raubuch, N., Joergensen, R.G., 2002. Relationships between soil microbial indices in secondary tropical forest soils. Appl. Soil Ecol. 21, 211–219.

Smolander, A., Kitunen, V., 2002. Soil microbial activities and characteristics of dissolved organic C and N in relation to tree species. Soil Biol. Biochem. 34, 651–660.

Sparling, G.P., 1992. Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. Aust. J. Soil Res. 39, 195–207.

Tabatabai, M.A., Bremner, J.M., 1969. Use of *p*-nitrophenyl phosphate for assay of soil phosphatase activity. Soil Biol. Biochem. 1, 301–307.

Tabatabai, M.A., Bremner, J.M., 1970. Arylsulfatase activity of soils. Soil Sci. Soc. Am. Proc. 34, 225–229.

Tejada, M., Garcia, C., Gonzalez, J.L., Hernandez, M.T., 2006. Use of organic amendment as a strategy for saline soil remediation: Influence on the physical, chemical and biological properties of soil. Soil Biol. Biochem. 38, 1413–1421.

Turner, B.L., Hopkins, D.W., Haygarth, P.M., Ostle, N., 2002. ß-glucosidase activity in pasture soils. Appl. Soil Ecol. 20, 157–162.

Vance, E.D., Brookes, P.C., Jenkinson, D.S., 1987. An extraction method for measuring soil microbial biomass C. Soil Biol. Biochem. 19, 703–707.

Wang, W.J., Dalal, R.C., Moody, P.W., Smith, C.J., 2003. Relationships of soil respiration to microbial biomass, substrate availability and clay content. Soil Biol. Biochem. 35, 273–284.