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Short communication

Seasonal variations of soil microbial biomass under different nutrient management and cropping systems on a Ferric Acrisol in Ghana

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Abstract

A study was conducted for three consecutive cropping seasons at the Central Agricultural Station, Kwadaso, Kumasi in the semi – deciduous forest zone of Ghana to investigate the seasonal variations of soil microbial biomass carbon, nitrogen and phosphorus under different nutrient management and cropping systems. The field experiment was a split – plot in a randomized complete block design replicated thrice. Continuous maize cropping (CM), maize/cowpea rotation (M/C) and maize/soybean intercropping (M/S) systems were considered as main plot factors. Poultry manure (PM) at a rate of 4 Mg ha^{-1}, chemical fertilizer (CF) (NPK 15- 15- 15) at a rate of 90 - 60 - 60 kg ha^{-1}, complementary application of poultry manure and chemical fertilizer (PM + CF) at 2 Mg ha^{-1} PM + 45- 30 -30 kg ha^{-1} CF and a control (no amendment) constituted the sub-plot factors. Biomass C showed increases over the seasons under nutrient management systems (amendments) and cropping systems. Values recorded in 2006- major rainy season differed significantly ($P \leq 0.05$) from values recorded in the subsequent seasons. Unlike biomass C, biomass N recorded highest values in 2006 - minor rainy season. The lowest microbial P values were recorded in 2006 – minor rainy season which was characterized by P immobilization under all the amendments. Phosphorus was immobilized under cropping systems except in M/S system in the minor rainy season. Biomass carbon to nitrogen ratios (Cmic: Nmic) showed significant differences among amendments during all seasons of cropping and ranged from 3.9 – 35.0. Generally, cropping systems did not have siginificant effect on Cmic: Nmic ratios except in 2006- minor season when CM recorded the highest value of 15.2 with M/S system recording the least (11.9). Soil pH showed positive correlations with Cmic: Nmic ratios in the major rainy seasons but not in the minor season. The study has indicated that efficient seasonal nutrient management under cropping systems could result in buildup of microbial biomass C but may not necessarily lead to corresponding build up in biomass N and P.

Keywords: Cropping seasons, Immobilization, Soil fertility, Management practices.

Soil microbial biomass is an agent of transformation of added and native organic matter and acts as a labile reservoir of plant nutrients (Jenkinson and Ladd, 1981). It is also used as an early indicator of changes in soil properties resulting from soil management practices in agricultural ecosystems (Jordan et al., 1995). Although the soil microbial biomass C constitutes only 1 – 3 % of total soil C and the biomass N up to 5 % of total soil N, they are the most labile C and N pools in soils (Jenkinson and Ladd, 1981). Soil microbial biomass is a very important reservoir of phosphorus in the soil (Oberson et al., 1997). According to Morel et al. (1997), microbial population plays a central role in P cycling and availability. Dalal et al. (1991) indicated that microbial biomass is a labile source

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of C, N, P and S. Therefore, nutrient availability and productivity of agroecosystems mainly depend on the size and activity of the microbial biomass (Friedel et al., 1996). Microbial biomass can contribute substantial amounts of nutrients in the soil (Marumoto et al., 1982). Maintaining innate soil fertility in cropping systems is a prerequisite for sustainable crop production in both tropical and temperate climates. The general decline in the fertility status of agricultural soils has become a major concern in contemporary research. Since soil nutrient availability is a result of the interaction of soil physical, chemical, and biological factors, there is the need to examine how changes in soil microbial biomass can influence nutrient availability in cropping systems under different nutrient management strategies. Even though microbial biomass is important in the breakdown of soil organic matter (SOM) resulting in the availability of nutrients, little is known about its seasonal variation or changes with crop rotations and other agronomic practices such as intercropping (Ladd and Forster, 1988; Stern, 1993). In their study, Patra et al. (1990) reported microbial biomass to vary seasonally in European soils. In New Zealand, Ross (1987) observed negative relationship between microbial biomass and soil moisture content in soils under tussock grassland and introduced pasture. The study of Singh et al. (1989) indicated seasonal variation in microbial biomass in savanna and forests soils. There is however, dearth of published information on the seasonal variation of microbial biomass under different soil management and cropping systems in tropical climate. Available information on soil biomass P is scanty though it is known to affect availability and cycling of P in soils. Knowledge on the seasonal variations of microbial biomass under amendments and cropping systems will enhance soil fertility management under cropping systems, leading to increased productivity of the cropping systems. This study aimed at investigating the seasonal effect of different soil amendments and cropping systems on soil microbial biomass C, N, P on a ferric acrisol in the semi – deciduous forest zone of Ghana.

The study site geographically lies between latitudes 06^{o} 39' and 06^{o} 43' North and longitudes 01^{o}.39' and 01^{o}.42' West of the Greenwich meridian. The site has a bimodal rainfall distribution pattern with mean annual rainfall value of 1500 mm. The study was conducted on Asuansi soil series (Ferric Acrisol) of the textural class - sandy loam. Treatments consisted of three different soil amendments – poultry manure (4 Mg ha^{-1}), chemical fertilizer (90 – 60 – 60 kg ha^{-1} NPK 15 – 15- 15), poultry manure + chemical fertilizer (2 Mg ha^{-1} + 45 – 30 -30 kg ha^{-1}) and a control. These were assigned as subplot factors. Cropping systems such as continuous maize, maize/cowpea rotation, maize/soybean systems constituted the main plot factors. The crop varieties tested under the treatments were Dorke SR (maize), Soronko (cowpea) and Ahoto (soybean). The treatments were tested in a split plot experiment arranged in a randomized complete block design with three replications. Each experimental plot measured 3 x 4 m giving a total land area of 595 m^2. Soil samples were taken at 0 – 15 cm depth from the base of ten plants randomly selected from the middle rows of each plot. The ten soil samples were thoroughly mixed and sub- sampled to obtain a representative sample for each plot. The fresh soil samples were used for microbial biomass analysis. Microbial biomass C, N and P were determined by the chloroform fumigation and extraction method as described by Ladd and Amato (1989). Organic carbon, total nitrogen and available P were determined by the Walkley and Black, Kjeldahl, and Bray's method respectively. Collected experimental data was subjected to analysis of variance (ANOVA) using the GenStat statistical package (2007). Treatment means were compared using the least significant difference (LSD) method at P = 0.05.

The initial biomass carbon, nitrogen and phosphorus recorded ranged from 95.25 – 133.35 mg kg^{-1} soil, 12.46 – 17.26 mg kg^{-1} soil and 7.75 – 23.26 mg kg^{-1} soil, respectively (Table 1). The mean pH of the soil was 6.69. The fertility status of the soil was generally low (Tables 1 and 5).

Results indicated significant ($P < 0.05$) build up of biomass carbon under amendments and cropping systems over the seasons (Fig. 1 & 2). Under the different amendments, the lowest microbial C values were recorded in 2006- major rainy season, whilst the highest values were recorded in 2007 – major rainy season. The general build up of biomass C over the seasons was as a result of the increased level of soil organic carbon under the amendments and cropping systems throughout the period of study (Table 6). The increased level of the soil organic carbon was due to the cumulative effect of the

Table 1. Descriptive statistics of the initial soil properties taken at the study site

Soil property	Min	Max	Mean	SD	CV *
Microbial biomass C (mg kg^{-1} soil)	95.25	133.35	114.30	19.05	16.7
Microbial biomass N (mg kg^{-1} soil)	12.46	20.67	17.26	4.28	24.8
Microbial biomass P (mg kg^{-1} soil)	7.75	23.26	15.72	4.28	49.4
Soil pH	6.59	6.89	6.69	0.17	2.5
SOC (%)	1.08	1.42	1.36	0.42	30.9
Total N (%)	0.06	0.08	0.07	0.01	12.5
Available P (mg kg^{-1} soil)	45.21	51.11	45.13	4.69	10.4
Exchangeable cations (cmol kg^{-1} soil)					
K^+	0.33	0.43	0.38	0.05	13.4
Ca^{2+}	5.60	7.04	5.71	1.05	18.4
Mg^{2+}	0.25	0.87	0.50	0.27	53.4
Na^+	0.11	0.12	0.12	0.01	8.3
$Al^{3+} + H^+$	0.10	0.15	0.12	0.02	16.7
ECEC (cmol kg^{-1} soil)	6.39	8.61	6.83	0.79	11.6

* Coefficient of variation (CV) expressed in percentage, SD: standard deviation, SOC: soil organic carbon, values are means of three replications.

Table 2. Cmic:Nmic variations different under nutrient management and cropping systems

	Cmic: Nmic		
	2006 - Major	2006 - Minor	2007 - Major
Amendment			
CTRL	5.3	14.0	34.2
PM	8.6	15.3	35.0
PM + CF	6.5	20.5	33.1
CF	3.9	14.7	26.7
LSD (0.05)	1.0	3.8	4.7
Cropping systems			
CM	6.3	15.2	32.6
M/S	4.6	11.9	32.6
M/C	6.7	14.7	31.1
LSD (0.05)	NS	1.2	NS

CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer CF: chemical fertilizer, CM: Continuous maize, M/S: Maize/soybean, M/C: Maize – cowpea,
NS: not significant at $p < 0.05$.

Table 3. Regression equations, coefficients of correlation (r) of the relationship between soil pH (x) and Cmic:Nmic (y) during the seasons of study

Season	Regression equation	r
2006 - Major	$y = 2.53x - 9.73$	0.66
2006 - Minor	$y = 0.002x + 16.10$	0.70
2007 - Major	$y = 20.39x + 96.55$	0.75

Table 4. Rainfall recorded at experimental site during the experimental period

Season	Total rainfall (mm)	Average rainfall/ month
2006 - major	456.6	114.2
2006 - minor	469.5	117.4
2007 - major	762.1	190.5

Source: Soil Research Institute (2007)

Table 5. Soil total N under different nutrient management and cropping systems

Treatments	Soil total N (%)		
	2006-major	2006-minor	2007-major
Amendment			
CTRL	0.06	0.06	0.08
PM	0.07	0.08	0.10
PM + CF	0.08	0.08	0.11
CF	0.09	0.09	0.12
LSD (0.05)	0.01	0.02	0.02
Cropping systems			
CM	0.08	0.08	0.13
M/S	0.06	0.06	0.10
M/C	0.07	0.07	0.11
LSD (0.05)	NS	0.01	0.01

CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer,
CF: chemical fertilizer, CM: Continuous maize, M/S: Maize/soybean, M/C: Maize – cowpea,
NS: Not significant at 5%.

Table 6. Soil organic C under nutrient management and cropping systems

Treatments	Soil organic C (%)		
	2006-major	2006-minor	2007-major
Amendment			
CTRL	1.10	1.07	1.17
PM	1.16	1.17	1.27
PM + CF	1.18	1.16	1.31
CF	1.07	1.11	1.15
LSD (0.05)	NS	NS	0.12
Cropping systems			
CM	1.19	1.26	1.31
M/S	1.02	1.06	1.14
M/C	1.10	1.07	1.22
LSD (0.05)	NS	NS	0.14

CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer,
CF: chemical fertilizer, CM: Continuous maize, M/S: Maize/soybean, M/C: Maize – cowpea,
NS: Not significant at 5%. Source: (Logah et al., 2011).

amendments as well as crop residues left on the field at harvest during the previous seasons. The highly carbonaceous residues of 2006 served as energy source for microbial growth during the

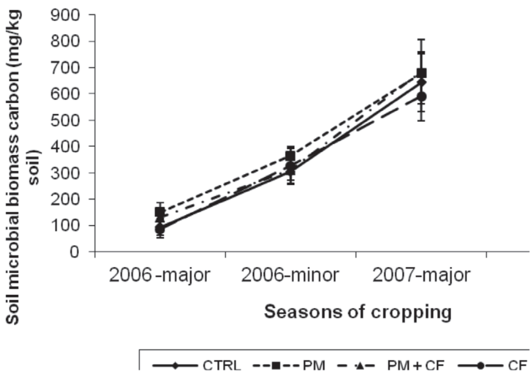

Figure 1. Variation of soil microbial biomass carbon under amendments over cropping seasons on a Ferric Acrisol, Kwadaso.

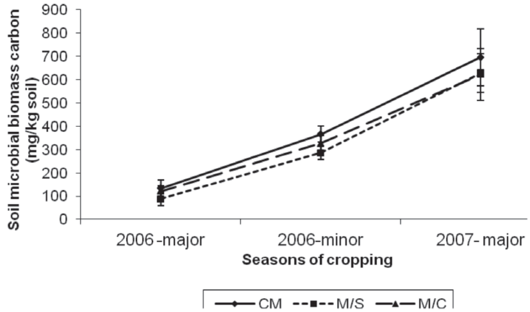

Figure 2. Seasonal variation of soil microbial biomass carbon under cropping systems on a Ferric Acrisol, Kwadaso.

subsequent season (2007) as reported by Logah et al. (2010). Efficient nutrient management in cropping systems could therefore, lead to buildup of biomass C over time (Logah et al., 2010). The observation could also be possibly due to variations in rainfall distribution pattern as observed during the study period (Table 4). Rainfall amount of 456.6 mm received in 2006 – major season rose to 762.1 mm in 2007 – major season. The results generally showed significant seasonal variations in microbial biomass especially C and P. While biomass C increased under amendments and cropping systems, throughout the study period, biomass P showed decline in 2006 – minor season over values recorded in 2006 – major season but showed increment in 2007 – major season. Biomass N increased from

2006 – major season to 2006 – minor season but generally showed a decline in 2007- major season (Figs. 3 & 4). However, differences in biomass N between the different cropping systems within each season were not significant at $P < 0.05$. Figs. 5 and 6 show seasonal variations of biomass P under amendments and cropping systems. In 2006 – major rainy season, there were observable differences ($P < 0.05$) in biomass P among the amendments. Microbial P values showed sharp decline in all amendments which were characterized by immobilization of P in 2006 – minor rainy season. The decline in 2006 – minor season was followed by an increase in 2007 major – rainy season. Cropping systems showed similar trends in microbial P as the amendments. There were significant differences among the cropping systems in 2006 – major season. There was a decline in recorded values in 2006 –minor season over values recorded in 2006 – major season. The decline was followed by a sharp increase in 2007 – major season (Fig. 6). Negative microbial P values were recorded in 2006 – minor season on plots under CM and M/C cropping systems. Cropping systems generally had no significant effect on biomass C and N over the seasons (Figs. 2 and 4). Moore et al. (2000) however, indicated that changes in microbial biomass C and N contents in response to cropping systems seem to be related to the amount and diversity of crop residues, the proportion of easily decomposable organic compounds to the soil, root density, microclimate and soil structure. In this study, cropping systems significantly affected microbial P only in 2006 – major season (Fig. 6). The negative microbial biomass P recorded under amendments and cropping systems in 2006 – minor

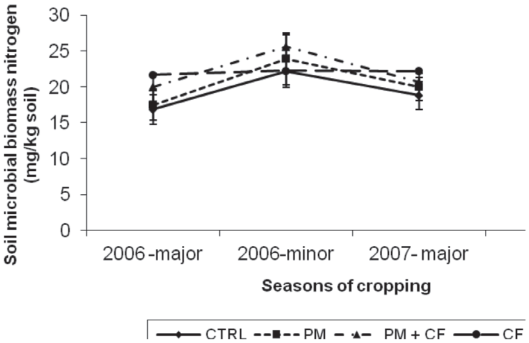

Figure 3. Seasonal variation of soil microbial biomass nitrogen under amendments over cropping seasons on a Ferric Acrisol, Kwadaso.

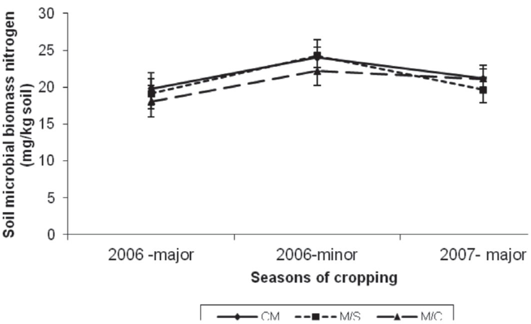

Figure 4. Seasonal variation of soil microbial biomass nitrogen under cropping systems on a Ferric Acrisol, Kwadaso.

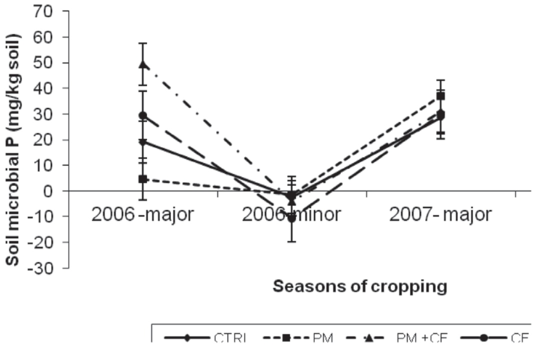

Figure 5. Seasonal variation of soil microbial biomass P under amendments on a Ferric Acrisol, Kwadaso.

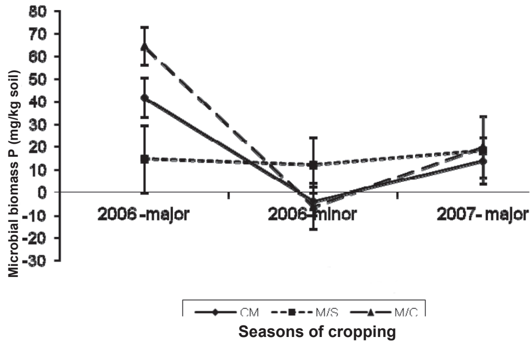

Figure 6. Seasonal variation of soil microbial biomass P under cropping systems on a Ferric Acrisol, Kwadaso.

rainy season was due to immobilization of P in microbial biomass. According to Barber (1995), phosphorus forms an integral part of the microbial cell nucleus and is required in the form of phosphate (PO_4^{3-}) radical to combine with adenosine diphosphate (ADP) for energy transfer within the cellular tissue. This possibly resulted in higher microbial affinity for P thereby causing immobilization (Logah et al., 2010). The Cmic: Nmic exhibited seasonal variations under both nutrient management and cropping systems (Table 2). Values recorded under amendments within the seasons ranged from 3.9 – 8.6, 14.0 – 20.5 and 26.7 – 35.0 in 2006 – major, 2006 – minor and 2007 – major seasons respectively. Chemical fertilizer amended plots recorded the least Cmic: Nmic values in all seasons of cropping except in 2006 - minor season where the control recorded the least (Table 2). Differences among the different nutrient management systems were significant ($P < 0.05$) in all seasons of study. Conversely, cropping systems showed differences in Cmic: Nmic only in 2006 – minor season. The ratio of Cmic: Nmic is often used to describe the structure and state of the microbial community. Lower ratios were found in 2006- major season than in the subsequent seasons. The differences found for these ratios between the two years are mainly due to the variations in biomass C (Cmic) values already discussed. The Cmic: Nmic ratio is affected by soil properties such as moisture content, pH and substrate availability (Moore et al., 2000). Joergensen (1995) reported C: N ratios of the microbial biomass varying from 5.2 in an arable land to 20.8 in a forest soil, with an average of 6.8 for 82 soils. Moore et al. (2000) found the Cmic: Nmic ratios of the soils from two different experimental sites to be 4.3 and 6.4 in 1996, and 7.6 and 11.4 in 1997. However, differences in these ratios are expected between microbial populations cultivated under laboratory conditions and those grown under natural conditions (Joergensen, 1995).

In conclusion, cropping systems generally had no significant effect on microbial biomass C and N in each season of cropping. Amendments significantly affected biomass P in 2006 – major season. Seasonal application of soil amendments could result in buildup of microbial biomass C under different cropping systems but may not necessarily lead to corresponding build up in biomass N and P. Soil pH highly influenced Cmic: Nmic ratios in the major rainy seasons of 2006 and 2007.

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