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Soil Organic Carbon and Crop Yield under Different Soil Amendments and Cropping Systems in the Semi-deciduous Forest Zone of Ghana

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ABSTRACT

A field experiment to evaluate Soil Organic Carbon (SOC) and maize grain yield under different soil amendments and cropping systems was conducted in 2006 and 2007 at the Soil Research Institute, Kwadaso, Kumasi. The experiment was a split plot with three replications. The main plot factor (cropping systems) consisted of continuous maize, maize/soybean intercropping and maize cowpea rotation systems, the sub-plot (amendments) comprised of Poultry Manure (PM) at 4 t ha^{-1}, poultry manure+chemical fertilizer (PM+CF) at 2 t ha^{-1} (PM)+45-30-30 kg ha^{-1} (NPK 15-15-15), Chemical Fertilizer (CF) at 90-60-60 kg ha^{-1} NPK 15-15-15 and a control (no amendment). Soil samples were taken at 21 and 84 days after amendment (DAA). Generally, PM+CF produced the highest range of SOC (1.14-1.37%). The least (0.98-1.28%) was recorded on the control plots. Plots amended with chemical fertilizer alone or in combination with poultry manure out-yielded the control in maize grain yield. Positive correlations between SOC at 84 DAA and maize grain yield were recorded in the major (r = 0.70*) and minor (r = 0.89**) rainy seasons of 2006 which established crop yield a function of SOC at harvest. Land equivalent ratios of sole maize (maize grown under continuous maize system) and maize intercropped with soybean were <1 which suggested more efficient utilization of land resources with sole maize cropping than intercropping maize with soybean.

Key words: Organic carbon, soil fertility, cropping systems, amendments

INTRODUCTION

The role of Soil Organic Carbon (SOC) in crop production cannot be overemphasized. It governs structural stability and cation exchange capacity of soils either directly through its chemical structure and surface properties, or indirectly as a source of energy and nutrients for soil biota (Zech *et al*., 1997). According to Schoenau and Campbell (1996) soil organic matter content has a large impact on soil quality and nutrient cycling. These effects are especially important in cultivated tropical soils, where soil organic matter is frequently related to soil fertility and productivity (Fritzsche *et al*., 2002). However, most tropical soils are characterized by low organic carbon content due to its decline over cropping seasons. The decline in SOC under cropping systems can be minimized if relevant information is available on the impact of different nutrient management systems on SOC not only in the long term but in the short term as well. Given the widespread prevalence of nutrient stresses worldwide, a thorough understanding of acquisition and dynamics of nutrients at the level of the cropping system is essential (Arihara, 2000). The soil organic matter is a repository of plant nutrients such as N, P, S, etc.

Earlier studies considered the dynamics of SOC under one or two cropping systems in temperate climates, results of which may be of limited importance in tropical climate. The knowledge of soil fertility variation in different cropping systems provides a strong foundation for sustainable agricultural production (Ranamukhaarachchi *et al.*, 2005). Soil organic carbon shows variation with soil type (topography, soil texture) climate and management. Hence, there is the need to evaluate SOC on different soils under different nutrient management strategies and cropping systems to enhance crop yield. The objective of this study therefore was to evaluate SOC under organic and inorganic amendments and under different cropping systems on a Ferric Acrisol in a tropical climate.

MATERIALS AND METHODS

The study was carried out at the experimental research site of the Central Agricultural Station, Kwadaso, Kumasi (06°.39' and 06°.43' N, 01°.39' and 01°.42' W of the Greenwich meridian). The annual precipitation is about 1500 mm while monthly temperatures range from 24-28°C. The soil of the study area was Asuansi series classified by Adu (1992) as Ferric Acrisol according to FAO (1990) and Typic Haplustult according to USDA (1998).

The field experiment was conducted in three consecutive cropping seasons (i.e. 2006 major, 2006 minor and 2007 major seasons) on the same piece of land of area 595 m^2. The size of each plot was 3×4 m. The experiment was a split plot in a Randomized Complete Block Design (RCBD) with three replications. The main plot factor was cropping system and consisted of Continuous Maize (CM), Maize/Soybean (M/S) intercropping and Maize/Cowpea (M/C) rotation. The sub-plot factor consisted of three different soil amendments and a control. The amendments were Poultry Manure (PM), Chemical Fertilizer (CF) (NPK 15-15-15) and Poultry Manure+Chemical Fertilizer (PM+CF). The PM and CF were applied at the rates of 4 t ha^{-1} and 90-60-60 kg ha^{-1}, respectively whilst PM+CF was applied at 2 t ha^{-1} (PM)+45-30-30 kg ha^{-1} (NPK). The control plots received no amendment. The amendments were applied to the cropping systems as a whole. The test crops were maize (Dorke SR), cowpea (Soronko) and soybean (Ahoto) cultivars.

Ten plants were selected at random from each plot excluding the border rows. Soil samples were taken near the base of each plant at a depth of 0-15 cm (Moore *et al.*, 2000) using an auger. The ten auger soil samples were thoroughly mixed and sub-sampled to obtain a representative sample for each plot. The representative samples were subjected to analysis after air-drying and passing through a 2 mm sieve. In all, two samplings were made during each season at 3 and 12 weeks after application of amendments. However, in order to assess the nutrient status of the soil before cropping, the soil was initially characterized and the physico-chemical properties determined. The initial characterization of the soil in 2006 showed a pH of 6.7 in 1:2.5 suspension of soil and water. The soil's textural class (sandy loam) was determined by the hydrometer method (Boyoucos, 1962). The SOC, N, P and K contents of the soil were determined using standard protocols in the laboratory of the Soil Research Institute, Kwadaso, Kumasi. Initial soil organic carbon was low (1.36%). Total N content of the site was 0.07%. Available P and exchangeable K contents were 45.13 mg kg^{-1} soil and 0.38 cmol kg^{-1} soil, respectively.

Data collected were subjected to analysis of variance (ANOVA) using the Genstat statistical package (GenStat, 2007). Treatment means were separated using the Least Significant Difference (LSD) method at 5% level of probability. Regression and correlation analyses were carried out to determine the nature and magnitude of relationships between maize grain yield and soil organic carbon at harvest.

RESULTS

Results: Table 1a-c show SOC under the amendments and cropping systems on a Ferric Acrisol. During the 2006 major rainy season, the SOC showed an increase (4.1%) at 84 DAA over the level recorded at 21 DAA in the control plot (Table 1a). Conversely, plots under PM, PM+CF and CF showed increases of 1.4, 6.6 and 2.2%, respectively. At the level of cropping systems, CM and M/S systems recorded decline whilst M/C systems showed a marginal increase at 84 DAA (Table 1a). SOC values recorded in 2006 minor rainy season (Table 1b) at 84 DAA were relatively higher than

Table 1a: Soil organic C under treatments in 2006 major rainy season

	Soil organic C (%)	
Treatments	21 DAA	84 DAA
Amendment		
Ctrl	0.98	1.02
PM	1.25	1.07
PM+CF	1.22	1.14
CF	1.08	1.06
LSD (0.05)	0.19	NS
Cropping system		
CM	1.20	1.17
M/S	1.09	0.95
M/C	1.09	1.10
LSD (0.05)	NS	NS

DAA: Days after amendment, 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 1b: Soil organic C under treatments in 2006 minor rainy season

	Soil organic C (%)	
Treatments	21 DAA	84 DAA
Amendment		
Ctrl	1.10	1.04
PM	1.17	1.17
PM+CF	1.14	1.17
CF	1.12	1.10
LSD (0.05)	NS	NS
Cropping system		
CM	1.26	1.26
M/S	1.05	1.06
M/C	1.09	1.04
LSD (0.05)	0.17	NS

DAA: Days after amendment, 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 1c: Soil organic C under treatments in 2007 major rainy season

	Soil organic C (%)	
Treatments	21 DAA	84 DAA
Amendment		
Ctrl	1.06	1.28
PM	1.21	1.33
PM+CF	1.25	1.37
CF	1.09	1.21
LSD (0.05)	0.17	0.11
Cropping system		
CM	1.25	1.37
M/S	1.06	1.22
M/C	1.14	1.30
LSD (0.05)	NS	NS

DAA: Days after amendment, 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 $p<0.05$

values recorded at 84 DAA in the previous season (2006 major rainy season). Differences in SOC among amendments were not significant ($p>0.05$) at both 21 and 84 DAA in 2006 minor season.

Values recorded in 2007 major rainy season (Table 1c) were generally higher than values recorded in both seasons of 2006 indicating a buildup of SOC over the period. In all seasons of the study, CM system generally recorded the highest SOC whilst the least was recorded under M/S system. The differences were however significant only at 21 DAA in 2006 minor rainy season (Table 1b).

Maize grain yield: Generally, maize grain yield declined in the 2006 minor rainy season (Table 2) compared to values recorded in both 2006 and 2007-major seasons. Application of CF and PM+CF increased maize grain yield relative to the control from the 2006-minor to the 2007 major rainy season of cropping. All the amendments gave yields that were significantly higher than the control in the three cropping seasons. Irrespective of the type of amendment applied, there was a decline in maize grain yield of 51% from the first to the second cropping cycle. In 2007 major rainy season, yield increment of 265.5% was obtained over that of the previous minor season (2006). Plots under CM cropping system significantly out-yielded ($p<0.05$) the M/S system. Similarly, plots under M/C cultivation gave yield that was significantly ($p<0.05$) higher than that of M/S cropping system (Table 2). Yield produced under the two cropping systems (CM and M/C) were about twice that recorded in M/S cropping system during the first year of study. However, maize grain yields produced under CM and M/C cropping systems were statistically the same.

Figure 2 shows the Land Equivalent Ratios (LERs) of sole or intercropped maize during the seasonal cycles. The lowest ratio (0.43) was obtained in 2006 minor rainy season whilst the highest (0.75) was recorded in the 2007 major rainy season.

Cowpea and soybean grain yields: In both seasons of the first year of study, the highest soybean grain yield was obtained on the control plots (Table 3). The least was recorded for plots under PM+CF amendment in 2006 major rainy season. The control yielded about 3-4 times the level of yield in plots amended with PM+CF and CF in the 2006 minor rainy season. The second year however, recorded the highest yield on plots under PM amendment and the least on CTRL and

Table 2: Maize grain yield as affected by amendments and cropping systems

	Maize grain yield (kg ha^{-1})		
Treatment	(2006) Major rainy season	(2006) Minor rainy season	(2007) Major rainy season
Amendment			
Ctrl	1611	0875	2913
PM	2103	1085	3858
PM+CF	2459	1165	4070
CF	2546	1085	4601
LSD (0.05)	274.9	1320.7	3830.1
Cropping system			
CM	2546	1472	4210
M/S	1642	0633	3139
M/C	2351	-	4232
LSD (0.05)	335.4	0103.8	6730.0

Ctrl: Control, PM: Poultry manure, PM+CF: Poultry manure+chemical fertilizer, CF: Chemical fertilizer, CM: Continuous maize, M/S: Maize/soybean intercrop, M/C: Maize/ cowpea rotation

Table 3: Soybean grain yield under different amendments

	Soybean grain yield (kg ha^{-1})		
Amendment	2006 Major rainy season	2006 Minor rainy season	2007 Major rainy season
Ctrl	387	133	293
PM	288	120	481
PM+CF	160	40	293
CF	288	32	347
LSD (0.050)	90.1	190.8	127.6

Ctrl: Control, PM: Poultry manure, PM+CF: Poultry manure+chemical fertilizer, CF: Chemical fertilizer

Table 4: Cowpea grain yield under amendments in 2006 minor season

Amendment	Yield (kg ha^{-1})
Ctrl	438
PM	684
PM+CF	449
CF	930
LSD (0.05)	188.6

CTRL: Control, PM: Poultry manure, PM+CF: Poultry manure+chemical fertilizer, CF: Chemical fertilizer

PM+CF plots. There was a decline in the yield of soybean from the 1st season to the 2nd season by 72%. Statistically, amendments influenced soybean grain yield more in both seasons of the first year than in the second year.

The highest cowpea grain yield (930 kg ha^{-1}) (Table 4) was recorded under CF amendment whilst the least (438 kg ha^{-1}) was obtained on control plots. Application of chemical fertilizer doubled the yield compared to that of the control. Significant differences ($p<0.05$) were observed between amendments.

DISCUSSION

SOC under amendments and cropping systems: Soil organic carbon recorded in both years of study ranged from 0.98-1.37% (1.69-2.36% SOM) which is low (Ranamukhaarachchi *et al.*, 2005).

According to Metson (1961), a productive soil should have an organic matter content of at least 4% (2.32% SOC). The generally low organic carbon recorded during the period of study was due to the low inherent soil fertility, high soil temperature and aeration favouring faster microbial activity (breakdown). Application of amendments during the two years of experimentation could not raise the organic carbon content in the respective amended plots to the optimum (2.32%).

However, plots under PM+CF amendment recorded significant increase in SOC in 2007 major rainy season (Table 1c). This suggests that Ghanaian soils which are often characterized by low SOC could be improved to some extent in the short term by complementary application of chemical fertilizer and poultry manure (Logah *et al*., 2011).

Peterson *et al*. (I998) indicated that cropping intensification increased crop residue production and organic carbon storage in the soil. The data from this study (Table 1b) showed higher levels of SOC in CM than in M/S and M/C cropping systems, with significant ($p<0.05$) differences between CM and M/S systems at the 21 DAA in the 2006 minor rainy season. Havlin *et al*. (1990) reported less organic carbon contents in soils from crop rotations that involved soybean and related this to the lower amounts of crop residues left after soybean as compared to those left after maize harvest. Clear comparisons revealed that organic carbon was, generally, lowest in plots under continuous soybean, followed by maize-soybean rotation and highest in continuous maize and maize-oat-meadow rotation systems, with no significant difference between the latter two systems (Moore *et al*., 2000).

Maize grain yield under amendments and cropping systems: Maize grain yields obtained during the major seasons were generally higher than those in minor season (Table 2) due to poor rainfall distribution in the minor cropping season. Generally, there was a decline in maize grain yield by 51% from the 2006 major rainy season to the 2006 minor rainy season. In 2007-major season, yield increment of 265.5% was obtained over that of the previous minor rainy season (2006). However, Chemical Fertilizer alone (CF) or in combination with poultry manure (PM+CF) significantly out-yielded the control in both years of study. This observation corroborates with the finding of Kapkiyai *et al*. (1998) that maize grain yields were significantly affected by manure and fertilizer application.

Among the amendments in both years, the application of PM+CF significantly increased grain yield of maize due to the positive effect of integrated nutrient management on yield of maize. Maize grain yields under CM cropping system were higher than those under M/S cropping system. Specifically, yields under M/S cropping systems were about one-half the yields achieved in CM cropping system (Table 2). This difference suggests that there was inter-species competition between the maize and soybean components of the M/S system for resources. Greater nutrient uptake by intercropping has been shown by several workers (Dalal, 1974; Adu-Gyamfi *et al*., 1997; Sakala, 1998). The lower yield obtained under the M/S cropping system (Table 2) contrasts the findings of Francis *et al*. (1986) that total corn yield in strip intercropping of corn and soybean was between 10 and 40% higher than corn in monocrop fields. The observation however, agrees with a report by Ennin *et al*. (2002) that intercropping maize and soybean reduced maize grain yields. Maize grain yields produced under CM and M/C cropping systems were statistically not different (Table 2). This contrasts a report by Adetunji (1996) that maize grain yields were significantly increased when cowpea was rotated with maize as compared with continuous maize.

Positive correlations between final soil organic carbon contents and maize grain yields were recorded during the seasonal cycles in 2006 (Fig. 1a, b). Kapkiyai *et al*. (1998) found positive

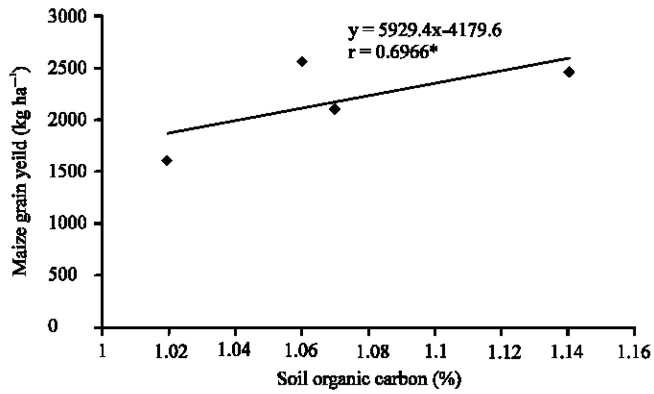

Fig. 1a: Relationship between soil organic carbon at 84 DAA and maize grain yield in 2006-major season on a Ferric Acrisol, Kwadaso. *Significant at $p<0.05$

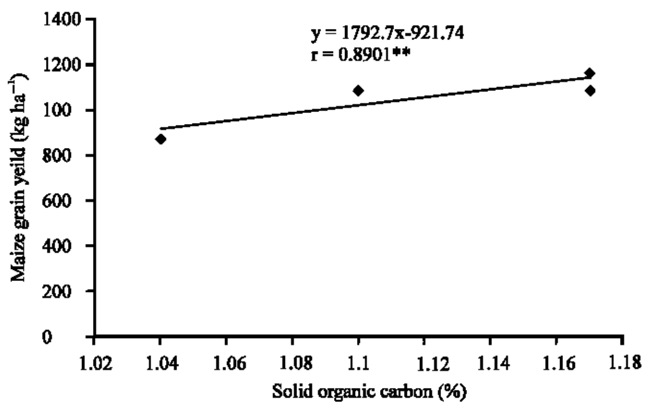

Fig. 1b: Relationship between soil organic carbon at 84 DAA and maize grain yield in 2006-minor season on a Ferric Acrisol, Kwadaso. **Significant at $p<0.01$

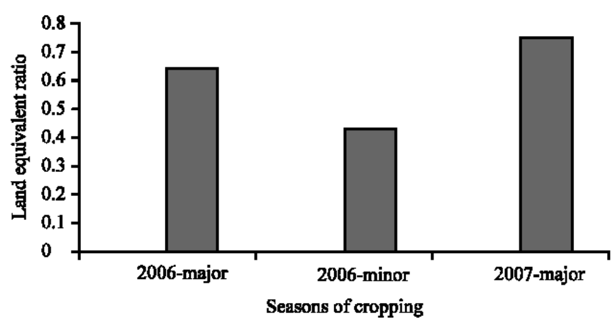

Fig. 2: Land Equivalent Ratio (LER) of maize under CM and M/S systems

correlation between the final soil organic content under cattle manure and fertilizer amendments with crop yield. In India, Kanchikerimath and Singh (2001) reported linear correlations between 26 year average yields of crops and the final soil organic carbon in experimental plots.

The LERs throughout the study were less than unity (Fig. 2). This was caused by lower grain yield of maize intercrops than sole crops. Results obtained in this study strongly suggested that there was more efficient utilization of land resources with sole maize cropping than planting maize as intercrop with soybean.

Effect of amendments on soybean and cowpea grain yields: It is not clear why the control recorded the highest soybean grain yield (Table 3). This observation was consistent throughout both seasons in 2006. It can therefore, be inferred from results of this study that amendments application under maize-soybean intercrop system may not necessarily lead to yield increase of soybean. The effect of amendments on the grain yield of soybean cultivated as an intercrop has not been reported in literature. There was a decline in the yield of soybean from the 1st season to the 2nd season by 72%. Statistically, amendments influenced soybean grain yield more in both seasons of the first year than in the second year (Table 3).

Among the amendments, application of chemical fertilizer produced the highest yield of cowpea (930 kg ha^{-1}) (Table 4). The least (438 kg ha^{-1}) was recorded on control plots. Application of chemical fertilizer doubled the yield compared to that of the control. Olofintoye (1986) similarly observed increased grain yield of cowpea by virtue of fertilizer application. In a pot experiment by Stewart and Reed (1969), yield and plant growth of cowpea increased with increasing fertilizer application. Significant differences in cowpea grain yield ($p<0.05$) were observed between amendments in this study (Table 4).

CONCLUSION

The study indicated that soil organic carbon content under cropping systems could be increased within the short-term with complementary application of poultry manure and chemical fertilizer in low fertility soils. The study has established that maize grain yield is a function of final soil organic carbon content at harvest. Sole maize cropping could lead to better agronomic use of land resources than planting maize as intercrop with soybean in cropping systems. Sole applications of poultry manure and chemical fertilizer for cowpea production could lead to appreciable yield increase of cowpea.

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