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Carbon-nitrogen sequestration potentials and structural stability of a tropical Alfisol as influenced by pig-composted manure

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A b s t r a c t. The organic carbon (OC) and total nitrogen (N) stocks (kg m^{-2}) within the aggregates were estimated from the elemental concentrations and bulk density values. Soil aggregation by water-stable aggregates (*WSA*) showed significant ($p \leq 0.05$) increase in the proportion of macroaggregates > 0.50 mm than aggregates < 0.50 mm with addition of the compost. Mean-weight diameter (*MWD*) was significantly higher in uncultivated forestland than cultivated land, whereas addition of compost to the cultivated land improved the stability of this soil over the control. The OC stocks (kg m^{-2}) within the aggregates of cultivated land amended with pig-composted manure followed the pattern observed for the forestland *ie* OC was preferentially sequestered within the macroaggregates (> 0.25 mm) than microaggregate fraction (< 0.25 mm); while the distribution of N was relatively uniform within the aggregates. Application of the compost to the cultivated plots significantly improved total N stocks (kg m^{-2}) over that observed for the forestland. The results also revealed that application of pig-composted manure improved the structural stability better at 10 Mg ha^{-1} than 5 and 15 Mg ha^{-1} rates. The C-N sequestration in cultivated land was also higher than the baseline forestland with addition of 10 Mg ha^{-1} manure over other rates. Overall, this study showed that application of compost at 10 Mg ha^{-1} is adequate to improve the stability and enhanced C-N storage within this fragile tropical soil.

K e y w o r d s: greenhouse effect, sequestration, aggregate stability, compost, tillage

INTRODUCTION

Management practices influence carbon and nutrient dynamics in agricultural ecosystems. The major reason for the high degradation of most tropical soils is due to decline in their organic carbon contents; and the rate of such decline is often influenced by cultivation, soil type, and dominant mineralogy (Mbagwu and Piccolo, 1998), type and length of tillage (Balashov *et al.*, 2010; Balesdent *et al.*, 1988; Cambardella and Elliot, 1992; Dalai and Mayer, 1987). The rate of soil organic carbon (SOC) loss upon conversion of natural ecosystem to agricultural use is more drastic in the tropics than temperate regions (Lal, 2001; Stalenga and Kawalec, 2008).

Soil organic matter (SOM) consists of series of fractions from very active to stable pools; and there is a similarity in the dynamics of C and N among the labile SOM pools (Adesodun *et al*., 2005). Therefore, the amount of SOC and total N that exists in any given soil is determined by the balance between rate of OC input and output (CO_2) release into the atmosphere. Human activities in the last two centuries have elevated to an unprecedented levels the atmospheric concentration of CO_2, CH_4, N_2O and other greenhouse gases, and this has led to large scale alterations in the global climate (Houghton *et al*., 2001). Concerns about the rising atmospheric CO_2 levels have prompted considerable interest in recent years regarding the sink potentials of soil organic carbon. While CH_4 dynamics are closely linked to livestock production practices and wetland agriculture such as rice production, CO_2 dynamics are related to energy use cycles and to soil management; while N_2O dynamics are related to soil-nitrogen management (fertilizer-nitrogen).

Soil C sequestration through changes in land use and management is one of the important strategies to mitigate the global greenhouse effect. Important land uses and practices with the potential to sequester SOC include conversion of cropland to pastoral and forest lands, conventional tillage to conservation tillage or no-tillage, and no manure use to regular addition of manure. However, food security needs for the world teeming population make conversion of cropland to forestland unsustainable. Therefore, increased food demands call for management of croplands to ensure food security and at the same time enhanced SOC sink within the soil to minimized atmospheric emission of CO_2.

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In this study, the SOC and total N values of adjacent forestland were considered as the baseline. Abid and Lal (2008) noted that using the current forestland as baseline in comparison with that in cultivated land is a good indicator of either the C source contribution to greenhouse effect by deforestation or the potential of SOC sequestration through reforestation of cultivated land. Therefore, this study estimated the C-N sequestration potentials and stability of a light-textured tropical Alfisol amended with different rates of pig-composted manure.

MATERIALS AND METHODS

Soil samples for this study were collected in 2008 at 0-20 cm depth from organic agriculture experimental farm located within the University of Agriculture, Abeokuta, Ogun-State (7.12° N and 3.23° E) with the aid of spade to maintain the soil relatively in its natural aggregates. The rainfall distribution for this area is bimodal with wet season from March to October and dry season from November to February. The mean annual rainfall is about 1400 mm with the maximum in July. The mean annual minimum and maximum temperature are 22.2 and 33.3°C, respectively. The total land area of the site is 0.30 ha with 24 experimental plots (6x10 m). The amendments on these plots were pig-composted manure applied at 0, 5, 10 and 15 Mg ha^{-1}, and planted with two varieties of maize *Zea mays ie* TZESR-W (improved variety) and OHORI (local variety). These treatments were applied in the year 2005, 2006 and in 2007 while residual effect of these treatments was monitored in the year 2008. Soil samples were also collected from adjacent uncultivated forest re-growth land to serve as base-line. Initial routine analysis of soil of this site was carried out in 2005 before the organic amendment was applied; and the results of this analysis are presented in Table 1.

The distribution of aggregates was estimated by the wet-sieving technique described in detail by Kemper and Rosenau (1986). In this procedure, 50 g of the < 5.66 mm aggregates were placed on the topmost of a nest of sieve of diameters 2, 1, 0.5 and 0.25 mm. The samples were pre-soaked in distilled water for 10 min before oscillating vertically in water 20 times (along 5 cm amplitude) at the rate of 15 stokes mm^{-1} for 2 min. The resultant aggregates on each sieve were dried at 105°C for 24 h and weighed. The mass of < 0.25 mm fraction was obtained by difference between the initial sample weight and the sum of sample weights collected on the 2, 1, 0.5 and 0.25 mm sieve nest.

The percent water-stable aggregates (%*WSA*) on each of the following size ranges, 5.66-2.0, 2.0-1.0, 1.0-0.50, 0.50-0.25 and < 0.25 mm were then determined. Thus:

$$\%WSA = (M_{a+s} - M_s/M_t - M_s)\ 100, \qquad (1)$$

where: M_{a+s} is the mass of the resistant aggregates plus stone (g), M_s the mass of the stone fraction alone, and M_t the total mass of the sieved soil (g).

The method of Van Bavel (1950) as modified by Kemper and Rosenau (1986) was used to determine the mean weight diameter of wet-stable aggregates. Thus:

$$MDW = \sum_{i=1}^{n} X_i W_i, \qquad (2)$$

where: *MWD* is the mean weight diameter of wet-stable aggregates (mm), X_i the mean diameter of each size fraction (mm) and W_i the proportion of the total sample weight (*WSA*) in the corresponding size fraction, after deducting the weight of stone (upon dispersion and passing through the same sieve) as indicated above, and *n* is the number of size fractions. Higher values of *MWD* indicate the dominance of the less erodible, large aggregates of the soil (Piccolo *et al.*, 1997).

Soil organic carbon and total nitrogen concentrations within the aggregate fractions of 5.66-2.0, 2.0-1.0, 1.0-0.50, 0.50-0.25 and < 0.25 mm of the cultivated and uncultivated (forest) land were measured. The organic carbon (OC) was determined by acid dichromate wet oxidation procedure as presented by Nelson and Sommers (1996); while total nitrogen was by micro-Kjeldahl method (Bremmer, 1996).

Organic carbon and total N stocks (kg m^{-2}) of the upper 20 cm were calculated using elemental concentration and bulk density equation described by Steffens *et al.* (2008) as:

$$ES = BD\ EC\ a\ 10^{-6}, \qquad (3)$$

where: *ES* – elemental stock (kg m^{-2}), *BD* – bulk density (g cm^{-3}), *EC* – elemental concentration (mg g^{-1}), and *a* – area multiplier (20 cm depth 10 000 cm^2 = 200 000 cm^3 m^{-2}).

Data was analyzed using the general analysis of variance procedure of GenStat Release 7.2 DE (2007), and significance was reported at 5% probability level.

Table 1. Selected properties of the study site

Parameter	Units	Cultivated land	Adjacent forestland
Sand (2000-50 μm)	g kg^{-1}	752	772
Silt (50-2 μm)	g kg^{-1}	80	40
Clay (<2 μm)	g kg^{-1}	168	188
Texture	-	Loamy sand	Loamy sand
pH (H_2O)		6.43	6.44
OC	g kg^{-1}	42	50
Total N	g kg^{-1}	7.0	8.8
C:N	-	6.00	5.70
Ca	cmol kg^{-1}	0.52	0.46
Mg	cmol kg^{-1}	0.73	0.15
K	cmol kg^{-1}	0.60	0.73
Na	cmol kg^{-1}	1.17	1.11

RESULTS AND DISCUSSION

Soil aggregation represented by percent water-stable aggregates (%*WSA*) and mean-weight diameter (*MWD*) for cultivated plots previously planted with improved (TZESR-W) and local (OHORI) varieties of maize (*Zea mays*), and amended with different rates of pig-composted manure are presented in Table 2. Observation from these previously cultivated plots were compared with the trend obtained in adjacent forest re-growth land thereafter referred to as forestland. The general trend indicated significant ($p \leq 0.05$) increase in the proportion of large macroaggregates (>0.50 mm) compared with the small macroaggregates (0.50-0.25 mm) and the microaggregate (<0.25 mm) fractions in both previously cultivated land amended with compost and adjacent baseline forestland. This showed that application of pig-composted manure improved the soil aggregation. In plots planted with TZESR-W (improved) maize variety, the proportion of 5.66-2.0 mm aggregate fraction was significantly higher in plots amended with 10 Mg ha^{-1} pig-composted manure than the control. Higher improvement was also observed at this rate (10 Mg ha^{-1}) of compost for 5.66-2.0 and 0.50-0.25 mm aggregate fractions in plots planted with local (OHORI) maize variety. These observations are in agreement with Hati *et al*. (2006) who noted that treatment where more organic matter was added either through farm yard manure or plant residues maintained higher fractions of larger aggregates but lower fraction of micro-aggregates.

The stability of intact water-stable aggregates (*WSA*) as determined by the mean-weight-diameter (*MWD*) was significantly ($p \leq 0.05$) higher for the adjacent forestland (2.069 mm) than values obtained in the cultivated plots (Table 2). While there were no significant differences in the aggregate stability of soils of the cultivated plots, there was increase in *MWD* with addition of pig-composted manure than the control. The overall trend for *MWD* relative to the land use followed forestland > cultivated land planted with TZESR-W (improved maize variety) > cultivated land planted with local (OHORI) maize variety. This observed trend could be due to higher residue and root action especially in uncultivated or fallow system, as also reported by Filho *et al*. (2002), and higher residues from improved maize varieties which normally influence formation and stabilization of soil aggregation.

Generally, this study revealed that addition of 10 Mg ha^{-1} pig-composted manure to this fragile tropical soil improved the aggregation better. Also, the results presented in Table 2 indicated that addition of manure above 10 Mg ha^{-1} did not significantly influenced the aggregation and stability of this soil.

Organic carbon (OC) and total nitrogen (N) stocks within water-stable aggregates (*WSA*) of the top 20 cm of the cultivated land amended with pig-composted manure and the adjacent uncultivated forestland were calculated from bulk densities and the elemental concentrations using Eq. (3). The distribution of carbon stocks within the *WSA* (Table 3) showed that OC was preferentially sequestered in the macroaggregate fractions (>0.25 mm) than in the microaggregates (< 0.25 mm) with addition of the compost irrespective of application rates. The highest OC stocks were obtained in plots amended with 10 Mg ha^{-1} manure. For example, 68.68 and 66.91 kg m^{-2} OC were occluded within 5.66-2.0 mm aggregate fraction and 48.62 and 52.61 kg m^{-2} were obtained in microaggregate (< 0.25 mm) fraction of plots planted with improved and local maize varieties respectively. Generally, OC stocks within the soil aggregates of cultivated land followed the pattern observed for the baseline forestland which showed significant ($p \leq 0.05$) higher

Table 2. Aggregate size distribution (%*WSA*), stability (*MWD*) and bulk density (g cm^{-3}) of the soil as influenced by different land use

Land use	Compost rate (Mg ha^{-1})	Aggregate size (mm)					*MWD* (mm)	*BD* (g cm^{-3})
		5.66-2.00	2.00-1.00	1.00-0.50	0.50-0.25	< 0.25		
C1 (TZESR-W[a])	0	27.11	26.01	28.03	9.10	9.75	1.713	1.31
	5	28.82	26.59	34.43	7.29	2.87	1.792	1.28
	10	32.59	26.88	24.70	9.91	5.92	1.857	1.25
	15	27.34	28.35	31.30	8.08	4.93	1.744	1.26
C2 (OHORI[b])	0	26.31	31.22	26.40	8.94	7.13	1.707	1.37
	5	27.07	25.54	32.39	8.78	6.22	1.735	1.45
	10	28.96	30.56	27.65	9.33	3.59	1.796	1.30
	15	26.93	32.12	27.43	9.21	4.31	1.760	1.27
Forestland	NA	31.34	28.23	25.24	11.07	4.12	2.069	1.21
LSD ($P < 0.05$):	Aggregate size = 4.66 Mean weight diameter (*MWD*) = 0.18 Bulk density (*BD*) = 0.197							

C1, C2 – cultivated land amended with pig-composted manure; NA – not applicable; [a]improved maize variety; [b]local maize variety.

T a b l e 3. Aggregate size distribution (%*WSA*), stability (*MWD*) and bulk density (g cm^{-3}) of the soil as influenced by different land use

Land use	Compost rate (Mg ha^{-1})	Aggregate size (mm)				
		5.66-2.00	2.00-1.00	1.00-0.50	0.50-0.25	< 0.25
C1 (TZESR-W[a])	0	56.77	45.59	11.44	45.50	38.43
	5	64.77	64.51	50.26	43.52	37.38
	10	69.68	68.64	53.65	42.90	48.62
	15	62.39	67.50	47.52	60.90	46.82
C2 (OHORI[b])	0	58.36	50.60	53.16	37.54	37.17
	5	65.83	79.75	49.88	37.12	45.92
	10	66.91	72.02	72.37	35.27	52.61
	15	61.04	62.57	63.33	36.66	37.00
Forestland	NA	58.80	58.92	37.44	32.40	24.00
LSD (P < 0.05): Treatments x aggregate size = 11.42						

Explanations as in Table 2.

T a b l e 4. Total nitrogen stock (kg m^{-2}) within the aggregates of soil amended with compost compared with uncultivated forestland

Land use	Compost rate (Mg ha^{-1})	Aggregate size (mm)				
		5.66-2.00	2.00-1.00	1.00-0.50	0.50-0.25	< 0.25
C1 (TZESR-W[a])	0	2.73	2.82	2.91	2.96	2.74
	5	2.99	2.92	2.94	2.94	2.87
	10	2.96	3.06	3.07	3.13	2.99
	15	2.98	3.02	3.05	3.00	2.85
C2 (OHORI[b])	0	2.88	2.43	2.90	2.78	2.79
	5	3.09	3.06	2.91	3.03	2.98
	10	3.07	2.79	2.96	3.09	2.91
	15	2.74	2.74	2.74	2.73	2.70
Forestland	NA	1.83	1.84	1.85	1.94	1.70
LSD (P < 0.05): Treatments x aggregate size = 0.26						

Explanations as in Table 2.

OC within the larger aggregates fractions than the smaller aggregates. This study further showed higher accumulation of OC within the aggregates of soil amended with pig-composted manure over the baseline forest soils (Table 3). Application of the compost to cultivated land also improved total nitrogen stocks (kg m^{-2}) within the soil aggregates over the values obtained from the adjacent forestland area (Table 4). However, overall distributions of the total nitrogen were relatively uniform within the aggregate fractions.

The preferential accumulation of OC within the macro-aggregates of this soil following application of composted-manure was earlier reported by Adesodun *et al*. (2005, 2007), Christensen (1986) and Dormaar (1983), Mbagwu and Piccolo (1990). While these workers observed similarity in the distribution pattern of OC and N concentrations within *WSA*, total N stocks (kg m^{-2}) reported in this study did not follow this trend but was uniform within the aggregate fractions. However, application of pig-composted manure generally led to higher sequestration of C and N within the water-stable aggregates of this soil.

The potentials of pig-composted manure applied to the cultivated land to enhance carbon and nitrogen sequestration was estimated using the OC and N stocks from the adjacent forestland as baseline. Evaluation procedure of Tan and Lal (2005) was adopted *ie* positive difference between the OC and total N stocks for the cultivated land amended with

T a b l e 5. Estimated carbon and nitrogen sequestration values[a] for top 20 cm depth derived from Tables 3 and 4

Land use	Compost rate (Mg ha^{-1})	Aggregate size (mm)					Mean
		5.66-2.00	2.00-1.00	1.00-0.50	0.50-0.25	< 0.25	
				Organic carbon			
C1 (TZESR-W[a])	0	-2.0	-13.3	-26.0	13.1	14.4	-2.76
	5	6.0	5.6	12.8	11.1	13.4	9.78
	10	10.9	9.7	16.2	10.5	24.6	14.38
	15	3.6	8.6	10.1	28.5	22.8	14.72
C2 (OHORI[b])	0	-0.4	-8.3	15.7	5.1	13.2	5.06
	5	7.0	20.8	12.4	4.7	21.9	13.36
	10	8.1	13.1	34.9	2.9	28.6	17.52
	15	2.2	3.6	25.9	4.3	13.0	9.80
				Total nitrogen			
C1 (TZESR-W[a])	0	0.91	0.99	1.06	1.02	1.04	1.01
	5	1.16	1.08	1.09	1.00	1.16	1.10
	10	1.31	1.22	1.22	1.19	1.29	1.21
	15	1.16	1.18	1.21	1.06	1.15	1.15
C2 (OHORI[b])	0	1.05	0.59	1.06	0.83	1.08	0.92
	5	1.27	1.22	1.06	1.08	1.27	1.18
	10	1.24	0.96	1.12	1.15	1.21	1.14
	15	0.92	0.91	0.90	0.78	1.00	0.90
LSD ($P < 0.05$): Treatments x aggregate size = 0.26							

[a] Values = Difference between OC and N stock values (Tables 3 and 4) for baseline forestland and cultivated land amended with compost. In cultivated land, positive values = sequestration; negative values = C and N contribution to greenhouse effect; [b] improved maize variety; [c]local maize variety. Other explanations as in Table 2.

pigcomposted manure and the baseline forestland values represent C and N sequestration. Therefore, OC and total N stocks levels for the cultivated land less than that of the baseline forestland were considered as C and N source contribution to the greenhouse effect.

Results in Table 5 showed that the average C sequestration capacity in land previously cultivated with improved (TZESR-W) maize variety were higher in plots amended with 10 Mg ha^{-1} compost (14.38 kg C m^{-2}) and in plots amended with 15 Mg ha^{-1} manure (14.72 kg C m^{-2}); while there was loss of 2.76 kg C m^{-2} from the control. Average carbon sequestration in land planted with local maize (OHORI) variety were 163.4, 246.3, and 93.7% higher than the control with addition of 5, 10 and 15 Mg ha^{-1} pig-composted manure respectively (Table 5). The trend within the *WSA* revealed that more OC were occluded within the macroaggregates 2.0-0.25 mm and the microaggregate fraction than the larger macroaggregate (5.66-2.0 mm) fraction. Whereas loss of OC, possibly to the atmosphere was observed in the control plots where no compost was applied. The implication of these observations was that carbon sequestration was enhanced with the application of pig-composted manure. Overall, the highest capacity to sequester OC by the manure was observed at the application rate of 10 Mg ha^{-1}.

Nitrogen sequestration (Table 5) was also enhanced over the control with addition of pig-composted manure to this fragile tropical alfisol. The overall trend of N sequestration was similar to that observed for OC showing that C-N sequestration was better at 10 Mg ha^{-1} rate of this composted manure. This indicated that application of this manure above 10 Mg ha^{-1} did not significantly enhanced C-N sequestration in this soil.

CONCLUSIONS

1. The potentials of pig-composted manure to enhance C-N sequestration and improve soil aggregate stability revealed significant increase in the proportion of aggregates > 0.50 mm than < 0.50 mm.

2. Higher soil stability as determined by mean-weight diameter (*MWD*) were observed at the rate of 10 Mg ha^{-1} compost than 0, 5 and 15 Mg ha^{-1} compost, and in plots previously planted with improved (TZESR-W) maize variety than the local (OHORI) variety.

3. Elemental stocks (kg m^{-2}) of OC and N in cultivated land amended with 10 Mg ha^{-1} compost showed higher accumulation of these elements within the larger soil aggregates fractions (> 2.0 mm) than the baseline forestland.

4. Generally, this study indicated that application of manure at 10 Mg ha^{-1} was adequate to enhance C-N sequestration and improve the stability of this fragile tropical soil.

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