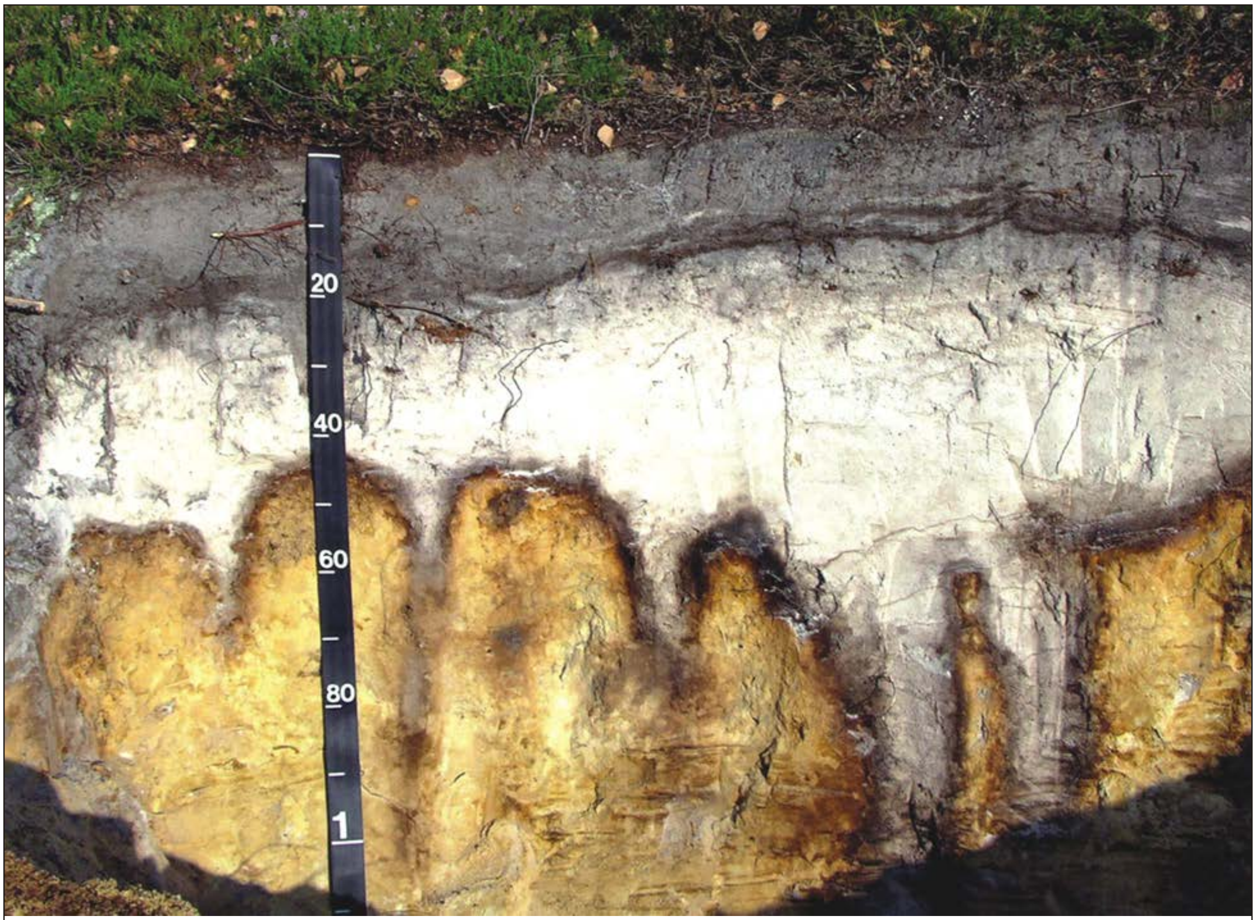

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Carbon-Nitrogen Stocks and Structural Stability of a Tropical Loamy Sand Soil as Influenced by *Tithonia diversifolia* (L.) and Other Fertilizers

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ABSTRACT

This study investigated the residual effects of *Tithonia diversifolia* (wild Mexican Sunflower) incorporated as green manure and also composted with poultry manure and other organic-based and inorganic fertilizers on C-N storage and structural stability (SI) of a loamy sand soil in South-western Nigeria. Treatments applied include fresh *Tithonia diversifolia* (GM), Poultry Manure (PM), *Tithonia diversifolia* composted with PM (CP), Organo-Mineral Fertilizers (OMF), Neem fertilizer (NF), NPK (20-10-10) and control (C) while soil samples were collected at different depths (0-15, 15-30 and 30-45 cm). Results show that OC were stored most in OMF plots while total nitrogen was occluded most by green manure. The overall trend was OMF>PM>GM>CP>C>NF>NPK irrespective of sampling depth. The SI varied between 11.59-18.63% at 0-15 cm soil depth, 4.26-9.13% at 15-30 cm depth and 4.39-9.19% at 30-45 cm depth, while highest SI values were obtained in plots amended with only PM. The SI values for the surface soils were >9% considered to indicate sufficient accumulation of soil carbon to maintain structural stability. In conclusion, *Tithonia diversifolia* when incorporated fresh into soil or applied as compost and OMF are good sources of amendments to improve soil quality than inorganic fertilizers alone.

Key words: C-N sequestration, stability-index, wild Mexican sunflower, manures, erodible tropical alfisol

INTRODUCTION

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 Carbon Dioxide (CO_2) release into the atmosphere (Adesodun and Odejimi, 2010). 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). Consequently, concerns about global climate change mediated by increased atmospheric concentrations of Greenhouse Gases (GHGs) such as CO_2, methane (CH_4) and nitrous oxide (N_2O), have prompted interest in soil carbon sequestration as a strategy to ameliorate CO_2 emission.

Current practices for management of Soil Organic Matter (SOM), its labile forms and plant residues can be essential for maintaining soil quality and sustainability due to the recovery of soil structure after detrimental impacts (Balashov *et al*., 2010). The common recommended management practices leading to improve soil C sequestration under integrated nutrient management include the use of manures, compost, crop residues and biosolids, mulch farming, conservation tillage, agro-forestry, diverse cropping systems and cover crops (Lal, 2004; Brar *et al*., 2013). All these practices have the potential to alter C storage capacity of agricultural soil (Halvorson *et al*., 2002; Russell *et al*., 2005; Brar *et al*., 2013). Mexican sunflower (*Tithonia diversifolia*) used in this experiment for making the compost and also applied as green manure is an annual broadleaf weed introduced into West Africa as an ornamental plant but has become a weed problem in croplands, wastelands and roadsides. This weed is gaining prominence in Nigeria and most farmers are finding it difficult to manage its infestation on their croplands. The life cycle and growth habits of this weed, particularly its luxuriant growth on nutrient poor soil and roadsides, makes it a plant whose menace as weed must be controlled and at the same time assess its potentials as manure. Therefore, this study estimated the C-N sequestration and stability of a tropical Alfisol amended with *Tithonia diversifolia* compared with other organic and inorganic amendments.

MATERIALS AND METHODS

Experimental site and soil sampling: The experiment was sited at the Teaching and Research Farm of the Federal University of Agriculture, Abeokuta, southwestern Nigeria (Lat. 7.12°N and Long. 3.23°E) located within the transition zone of the sub-humid forest to the south and the derived savannah to the northwest (Keay, 1959). The soil at this research site is well-drained loamy sand on the surface with gravelly sandy clay loam on the sub-surface derived from basement complex and classified as Oxic Paleustalf (FDALR., 1990). Selected physical and chemical properties of this site are given in Table 1.

Table 1: Selected properties of the study site

Parameters	Values
Sand (2000-50 μm) (g kg^{-1})	864
Silt (50-2 μm) (g kg^{-1})	36
Clay (<2 μm) (g kg^{-1})	100
Texture	Loamy sand
Bulk density (g cm^{-3})	1.12
pH (H_2O)	7.1
OC (g kg^{-1})	13
Total N (g kg^{-1})	1.4
Av.P (mg kg^{-1})	0.12
C:N	9.29
Ca (cmol kg^{-1})	3.34
Mg (cmol kg^{-1})	2.4
K (cmol kg^{-1})	12
Na (cmol kg^{-1})	6.2

Table 2: Chemical properties of the organic-based fertilizers used for the experiment

Fertilizers	N (%)	P (%)	K (%)	OC (%)
PM	2.0	0.65	5.7	8.84
OMF	3.5	1.00	1.2	8.98
CP	2.6	0.36	3.5	8.81
NF	3.8	1.33	6.4	8.95
GM	3.5	0.35	5.9	8.17

N: Nitrogen, P: Phosphorus, K: Potassium, OC: Organic carbon, PM.: Poultry manure, OMF: Sunshine Organo-Mineral, CP: Compost, NF: Neem based-organic fertilizer, GM: *Tithonia diversifolia*

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 monthly temperature range varies between 28 and 32°C. A total land area of 35×26 m (910 m^2) divided into 28 plots of 5×4 m (20 m^2) with 1 m intra plot space and 2 m inter row gang way was used for this study. The treatments on these plots were: (1) Control (C), i.e., no amendments, (2) Green Manure (GM), i.e., fresh *Tithonia diversifolia* incorporated into the soil and allowed to decompose naturally, (3) Poultry Manure Only (PM), (4) Compost (CP), i.e., *Tithonia diversifolia* composted PM, (5) Neem (*Azadirata indica*)-based organic fertilizer (NF), (6) Sunshine Organo-Mineral Fertilizer (OMF) and (7) inorganic (NPK 20-10-10) fertilizer. These were arranged in Randomized Complete Block Design (RCBD), replicated four times and planted with maize (*Zea mays* L.). Neem and OMF are commercial organic fertilizers available in Nigeria. The organic-based fertilizers were applied at 10 mg ha^{-1} and NPK at 120 kg N in two split in the year 2009 and repeated in 2010. The NPK and OMF were applied 2 weeks after planting while other organic-based fertilizers were applied two weeks before planting. Analyses of the organic materials are presented in Table 2.

Soil sample were collected from the 28 experimental plots at 0-15, 15-30, 30-45 cm soil depths in the year 2011 to evaluate the residual effect of the amendments on some soil physical properties. These soil samples were air-dried and pre-sieved at room temperature to pass through 2 mm sieve before laboratory analysis.

Soil organic carbon and total nitrogen: The Organic Carbon (OC) concentration of the soil samples at various depth was determined by acid dichromate wet oxidation procedure as presented by Nelson and Sommers (1996) while total nitrogen was by micro-kjeldahl method (Bremner, 1996).

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

$$ES = BD \times EC \times a \times 10^{-6} \quad (1)$$

where, ES is elemental stock (kg m^{-2}), BD is bulk density (g cm^{-3}), EC is elemental concentration (mg g^{-1}) and a is area multiplier (15 cm depth×10,000 cm^2 = 150,000 cm^3 m^{-2}). Soil bulk density was determined according to the method of Blake and Hartge (1986).

Structural stability: Structural stability of this soil as influenced by the organic-based and inorganic fertilizers applied was estimated by the model of Pieri (1992). Organic carbon levels required to maintain soil structure are thus estimated as (Reynolds *et al.*, 2007):

$$SI = \frac{1.72\ OC(wt.\%)}{(Clay+Silt)\ (wt.\%)} \times 100 \qquad (2)$$

where, SI (%) is a soil structural "stability index" and (Clay+Silt) is the soil's clay and silt content. Reynolds *et al.* (2007) stated that SI = 5% indicates structurally degraded soil due to extensive loss of organic carbon; 5%<SI = 7% indicates high risk of structural degradation due to insufficient organic carbon, 7%<SI = 9% indicates low risk of soil structural degradation and >9% indicates sufficient soil organic carbon to maintain structural stability.

Data analysis: Data was analyzed using the general analysis of variance procedure of GenStat Release 10.3DE (GenStat, 2011) and significance was reported at 5% probability level.

RESULTS AND DISCUSSION

Organic carbon and total nitrogen stocks (kg m^{-2}): The Organic Carbon (OC) and Total Nitrogen (TN) stocks within the top 45 cm of the soil (Table 3 and 4), relative to the treatments were calculated from bulk densities presented in Table 5 and the elemental concentrations using Eq. 1. Results show that at soil surface (0-15 cm), the highest OC stocks were obtained in plots amended with OMF (4.38 kg m^{-2}) followed by PM (3.65 kg m^{-2}) while for total nitrogen it was GM (0.44 kg m^{-2}) and NPK (0.41 kg m^{-2}). At 15-30 cm depth, higher accumulation of OC was observed

Table 3: Organic carbon stock (kg m^{-2}) relative to soil amendments at various depths

	Depth (cm)		
Treatments	0-15	15-30	30-45
C	3.31	2.94	2.11
CP	3.60	2.35	1.80
GM	3.46	2.01	2.23
NF	2.94	2.96	1.71
OMF	4.38	2.17	1.69
PM	3.65	2.62	1.93
NPK	2.78	2.70	1.98
LSD ($p \leq 0.05$)	Treatment = 0.74	Depth = 0.48	Treatment×Depth = 1.28

C: Control, CP: Compost, GM: Green manure, NF: Neem fertilizer, OMF: Organo-mineral fertilizer, PM: Poultry manure, NPK: Inorganic fertilizer

Table 4: Total nitrogen stock (kg m^{-2}) relative to soil amendments at various depths

	Depth (cm)		
Treatments	0-15	15-30	30-45
C	0.35	0.30	0.23
CP	0.32	0.26	0.22
GM	0.44	0.32	0.21
NF	0.35	0.36	0.19
OMF	0.34	0.20	0.25
PM	0.35	0.27	0.18
NPK	0.41	0.24	0.18
LSD ($p \leq 0.05$)	Treatment = 0.08	Depth = 0.05	Treatment×Depth = 0.13

C: Control, CP: Compost, GM: Green manure, NF: Neem fertilizer, OMF: Organo-mineral fertilizer, PM: Poultry manure, NPK: Inorganic fertilizer

Table 5: Soil structural stability and bulk density as influenced by the amendments

	Structural index (%)			Bulk density (g cm^{-3})		
	Depth (cm)			Depth (cm)		
Treatments	0-15	15-30	30-45	0-15	15-30	30-45
C	5.60	5.62	6.75	1.22	1.28	1.48
CP	14.48	6.26	6.88	1.08	1.18	1.35
GM	13.68	9.13	5.59	1.23	1.18	1.65
NF	13.77	4.26	5.45	1.03	1.01	1.69
OMF	17.45	4.34	4.39	1.19	1.24	1.63
PM	18.63	7.31	7.55	1.12	1.09	1.28
NPK	11.59	8.35	6.48	1.06	1.03	1.65
LSD ($p \leq 0.05$)	Treatment = 2.43			Treatment = 0.16		
	Depth = 1.59			Depth = 0.10		
	Treatment×Depth = 4.21			Treatment×Depth = 0.27		

C: Control, CP: Compost, GM: Green manure, NF: Neem fertilizer, OMF: Organo-mineral fertilizer, PM: Poultry manure, NPK: Inorganic fertilizer

in plots amended with NF (2.96 kg m^{-2}) while it was green manure (2.23 kg m^{-2}) at 30-45 cm soil depth. Preferential accumulation of total nitrogen over the control at sub-surface soil depths was in plots amended with NF (0.36 kg m^{-2}) for 15-30 cm depth and OMF (0.25 kg m^{-2}) at 30-45 cm depth. As observed in this study, highest OC and TN storage were obtained in plots amended with organo-mineral fertilizer followed by poultry manure. Preferential accumulation of OC and TN within the macroaggregates following application of composted-manure was earlier reported by Adesodun and Odejimi (2010).

Structural stability and bulk density: The mean structural Stability Index (SI) estimated from organic carbon levels and combined silt and clay percentage varied from 5.60-18.63% (Table 5) at different depths. Plots amended with Poultry Manure (PM) produced the highest stability index (18.63%) at 0-15 cm soil depth while the least structural stability was observed in control plots irrespective of soil depth. Application of the organic-based and inorganic (NPK) fertilizers increased the SI at the soil surface over the sub-surface depths when compared with the control (Table 5). The overall trend at soil surface (0-15 cm) followed: Poultry manure>organo-mineral fertilizer>compost>Neem fertilizer>green manure>inorganic fertilizer (NPK)>control. Application of organic and inorganic fertilizers generally lowered the bulk density at soil surface (0-15 cm) and 15-30 cm depths to the level considered to be optimum for crop production Specifically, treatment with Neem organic fertilizer (NF) significantly ($p = 0.05$) lowered the bulk density (1.03 g cm^{-3}) compared with control value (1.22 g cm^{-3}) at near surface depth (Table 5) which was followed by NPK (1.06 g cm^{-3}) and compost (1.08 g cm^{-3}). While soil physical quality is relevant and important for the entire crop rooting zone, the top 10 cm of soil is particularly important because it controls many critical agronomic and environmental processes (Reynolds *et al*., 2007). Generally, the SI values obtained for the surface soils were greater than 9% considered to indicate sufficient soil carbon to maintain structural stability. The results therefore showed that treatment with organic fertilizers were able to significantly ($p = 0.05$) increase the organic carbon level and also enhanced structural stability of this highly erodible tropical loamy sand soil better than application of inorganic (NPK) fertilizer.

Table 6: Estimated carbon and nitrogen sequestered (kg m^{-2}) within surface and sub-soil

Treatments	Depth (cm)		
	0-15	15-30	30-45
Organic carbon			
CP	0.290	-0.59	-0.31
GM	0.150	-0.92	0.13
NF	-0.370	0.03	-0.40
OMF	1.080	-0.76	-0.42
PM	0.340	-0.32	-0.18
NPK	-0.530	-0.20	-0.13
Total nitrogen			
CP	-0.030	-0.04	-0.01
GM	0.090	0.02	-0.02
NF	-0.002	0.06	-0.04
OMF	-0.003	-0.10	0.02
PM	0.006	-0.03	-0.05
NPK	0.060	-0.06	-0.05
LSD ($p\leq 0.05$)			
Organic carbon: Treatment×Depth = 1.68			
Total nitrogen: Treatment×Depth = 0.16			

CP: Compost, GM: Green manure, NF: Neem fertilizer, OMF: Organo-mineral fertilizer, PM: Poultry manure, NPK: Inorganic fertilizer. Values: Difference between OC and TN stock values for the amendments and control in Table 3 and 4, where control represented the baseline values

Soil dry bulk density is often used as an index of soil's mechanical resistance to root growth (Reynolds *et al*., 2007). The overall trend in this study showed that application of organic and inorganic fertilizers produced bulk density values at top soil (0-30 cm) that were within 0.90-1.20 g cm^{-3} considered by Olness *et al*. (1998), Drewry *et al*. (2001), Reynolds *et al*. (2003), Drewry and Paton (2005) and Reynolds *et al*. (2007) to be optimum for field crop production.

Estimation of carbon and nitrogen sequestration: The potentials of fresh *Tithonia diversifolia* (wild Mexican Sunflower) applied as green manure and other organic fertilizers to enhance carbon and nitrogen sequestration, when compared with inorganic (NPK) fertilizer was evaluated by the method of (Tan and Lal, 2005). In this study, OC and TN stocks for the amended plots presented in Table 3 and 4 were used to estimate the C-N sequestration where values for the control plots were taken as baseline. In the procedure of Tan and Lal (2005), positive value represents sequestration, while negative value which indicated less OC and TN than control levels was considered as C and N source contribution to the greenhouse effect.

Results in Table 6 showed that the average C sequestration as influenced by the organic and inorganic fertilizers at surface soil (0-15 cm) was highest in plots amended with OMF (1.08 kg C m^{-2}), followed by poultry manure (0.34 kg C m^{-2}), compost (0.29 kg C m^{-2}) and green manure (0.15 kg C m^{-2}). Whereas, there were losses of 0.53 kg C m^{-2} in plots amended with NPK fertilizer and 0.37 kg C m^{-2} NF plots. At near-surface (15-30 cm) and subsurface (30-45 cm) depth, 0.03 kg m^{-2} and 0.13 kg m^{-2} carbon were sequestered in plots treated with NF and GM, respectively. However, there were carbon losses with application of other amendments at lower depths. Nitrogen (TN) sequestration was enhanced with the application of GM (0.09 kg C m^{-2}), PM

(0.006 kg C m^{-2}) and NPK (0.06 kg C m^{-2}) at soil surface (0-15 cm) while N-sequestration was improved by GM (0.02 kg C m^{-2}) and NF (0.06 kg C m^{-2}) at 15-30 cm depth. Application of OMF sequestered more TN at 30-45 cm soil depth, while other amendment led to nitrogen loss to the atmosphere.

Overall implication of this study showed that the highest capacity to sequester carbon within the surface of this soil was enhanced with application of organo-mineral fertilizer, followed by poultry manure and compost. Treatment with green manure, poultry manure and NPK better sequestered nitrogen. Adesodun and Odejimi (2010) in a soil amended with different rates of pig-composted manure reported that C-N sequestration was better at 10 mg ha^{-1} for the soil with similar textural characteristics (i.e., loamy sand).

CONCLUSION

This study showed that at near-soil surface (0-15 cm), highest OC storage were obtained in plots amended with organo-mineral fertilizer followed by poultry manure while for total nitrogen it was green manure, i.e., fresh *Tithonia diversifolia* incorporated into the soil and NPK-inorganic fertilizer. Also application of the organic fertilizers were able to significantly ($p = 0.05$) enhance the structural stability of this highly erodible tropical soil better than inorganic fertilizer, following: Poultry Manure(PM)>Organo-Mineral Fertilizer(OMF)>compost>Neem fertilizer>Green Manure(GM)>inorganic fertilizer (NPK)>control. Therefore, application of OMF, PM and fresh *Tithonia diversifolia,* i.e., Green Manure (GM), stored organic carbon and nitrogen better and also improved the structural stability of this fragile tropical soil than inorganic fertilizer. It is therefore, concluded that *Tithonia diversifolia* (wild Mexican Sunflower) which has become a weed menace in West Africa if incorporated fresh into the soil as green manure or as compost is a good source of amendment to improve the soil quality.

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