



Original Research Article

Short term impact of tillage and fertility management on *Lixisol* structural degradation

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Soil degradation is recognized as a serious constraint to crop production in sub-Saharan Africa. A study was conducted in Nadiou, located in the South Sudan zone of Burkina Faso to assess the impact of no-till, tied ridging; ripping and conventional tillage combined with soil fertility management options on *Lixisol* structural stability after two years of treatments imposition. The fertility management options were control, 2.5 Mg ha⁻¹ of compost every year, 100 kg ha⁻¹ of NPK + 50 kg ha⁻¹ of Urea, mulching (100 % crop residues applied) and 2.5 Mg ha⁻¹ of compost + 100 kg ha⁻¹ of NPK + 50 kg ha⁻¹ of Urea. The results showed that soil structural stability index (StI) tended to decrease under ripping, tied ridging and conventional tillage practices after two years. The application of organic amendments by improving soil organic carbon storage, tend to improve soil structural stability.

Key words: Fertility management, *lixisol*, structural stability, tillage

INTRODUCTION

It is widely recognized that land degradation is reducing the productive capacities of cropland, rangeland and woodland while demand for food, fiber, fuel, freshwater, fodder, household energy and income are increasing. This is particularly alarming in Africa, where land is the key asset of the rural poor (FAO, 2009). Whether the problem is expressed as soil or forest loss, reduced water availability, or poor yields on tired soil, such impoverishment of the land is being driven by inefficient or unsustainable land management practices and inappropriate or competing land uses (FAO, 2011).

Increasingly intensive soil use for cultivation and livestock production, expansion of open fields, and burning of grass and bush savannah are resulting in significant loss of vegetation cover (Serme et al. 2015). The effects can be seen in greater runoff and increased soil erosion by wind and water, loss of soil organic carbon, crusting and desiccation of soils, and related declines in groundwater

and surface water levels (Zida, 2011). Soil nutrients are excessively depleted by soil transport and leaching.

Expansion of cultivated areas, increasingly deeper tillage, and loss of vegetation cover owing to deforestation and overgrazing have led to accelerated loss of soil organic matter. This process is further accelerated by hot bush fires over extensive areas. Large amounts of gases that contribute to climate change, such as CO₂ and methane, are released (Lompo, 2012). The restoration of degraded soils and ecosystems and adoption of recommended land management practices are viable options for reducing CO₂ in the atmosphere. Degraded soils in dry-lands often have less than 1% of soil organic carbon (SOC), whereas through good land management the soil organic carbon can be significantly increased (to 2-3%) (Sedogo, 1993). Improved combination of tillage practices and soil fertility management can reduce soil degradation in the sub-Saharan zone in Africa.

Table 1. Physico-chemical characteristics of the soil at the research site

Soil depth (cm)	0-10	10-20
Organic carbon (%)	1.06	0.89
pH (1:2.5 H ₂ O)	6.00	5.70
Total nitrogen (%)	0.06	0.04
Total phosphorus (mg kg ⁻¹)	312.17	246.67
Total potassium (mg kg ⁻¹)	665.17	911.03
Exchangeable bases (cmol kg⁻¹)		
Calcium (Ca ⁺²)	4.59	3.03
Magnesium (Mg ⁺²)	0.96	0.75
Potassium (K ⁺)	0.15	0.13
Sodium (Na ⁺)	0.10	0.09
Cation Exchange Capacity (CEC) (cmol kg ⁻¹)	6.24	7.60
Sum of Anions (S) (cmol kg ⁻¹)	5.80	4.00
Saturation rate (S/CEC) (%)	92.67	56.33
Bulk density (cm ³ g ⁻¹)	1.64	1.62
Sand (%)	66.30	65.00
Silt (%)	26.90	26.10
Clay (%)	6.80	8.90

The objective of this study was to evaluate the impact of tillage and fertility management options on soil structural degradation tendency after two years.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at Nadion (11°7'60" North and 2°13'0" East), located at about 175 km south of Ouagadougou. Nadion is in the south Sudan zone of Burkina Faso where the annual rainfall is more than 1000 mm. In general, the rainfall is irregular and poorly distributed in the entire region. This situation is not very favorable for the achievement of high agricultural productivity. The main soil in this area is Lixisoil with 66.4% of sand, 26.9% of silt and 6.8 of clay. Tables 1 and Table 2 show the nutrients content of the research site and mineral composition of the compost and the straw material used for mulching.

Experimental design

The experiment design was a randomized complete block with a split plot treatment arrangement in three replications. The main plots were water conservation practices with four options: 1. No-till (direct planting); 2. Minimum till (ripping); 3. Tied ridging; the ridges were tied one month after sowing; 4. Conventional tillage (plowing using animal traction with soil inversion to 15 cm depth).

The sub plots had five options as amendment practices as follows:

1. Control –no fertilizer, no compost and no crop residues;
2. 2.5 tons per ha of compost every year;
3. (37-23-14) kg/ha applied in the form 100 kg of NPK/ha (14-23-14) and 50 kg of Urea ha⁻¹ (46%N);
4. 100% crop residues retained (for the first year 2 tons

ha⁻¹ of crop residues was applied);

5. 2.5 tons per ha of compost x 100 kg of NPK ha⁻¹ (14-23-14) and 50 kg of Urea ha⁻¹ (46%N)

Soil organic carbon (SOC) analysis

The modified Walkley and Black procedure as described by Nelson and Summers (1982) was used in the determination of organic carbon. One gram of soil sample was weighed into an Erlenmeyer flask. A reference sample and a blank were included. Ten millilitres of 1.0 N (0.1667 M) potassium dichromate was added to the sample and the blank. Concentrated sulphuric acid (20 mL) was carefully added to the soil from a measuring cylinder, swirled and allowed to stand for 30 minutes in a fume cupboard. Distilled water (250 mL) and 10 mL concentrated orthophosphoric acid were added and allowed to cool. A diphenylamine indicator (1 mL) was then added and titrated with 1.0 M ferrous sulphate solution.

The organic carbon content was calculated from equation:

$$\text{Carbon (\%)} = \frac{(m.e. K_2Cr_2O_7 - m.e. FeSO_4) \times (1.32) \times 0.003 \times 100}{wt}$$

Where:

- m.e = normality of solution x mL of solution used
- 0.003 = m.e. wt of C in grams (12/4000)
- 1.32= correction factor
- wt= weight of oven-dried sample in gram

Particle size analysis

The particle size distribution was measured using the modified procedure described by Dewis and Freitas (1970). The sand fraction was determined by a nest of appropriate sieves (1.0, 0.5, 0.25, 0.1 mm) while silt and clay content

Table 1. Chemical characteristics of compost and sorghum straw

Organic materials	Organic Carbon (%)	Total N (%)	C/N	Total P (g kg ⁻¹)	Total K (g kg ⁻¹)
Compost	19.05	1.01	18.82	2.85	12.1
Straw	53.83	0.39	135.41	2.92	15.9

Table 3. Effects of tillage practices on soil organic carbon content at 0 - 10 cm depth

Tillage Practices	SOC in 2012		SOC in 2013	
	(%)			
No-till	1.14		1.14	
Minimum till (ripping)	1.09		1.08	
Tied ridging	1.25		1.20	
Conventional tillage	1.03		0.90	
F probability	0.60		0.50	
LSD	0.40		0.30	

Table 4. Effects of fertility management options on soil organic carbon content

Fertility management options	SOC (%) in 2012		SOC (%) in 2013	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Control	1.10	0.77	1.09	0.72
Compost	1.21	0.93	1.22	0.93
NPK + Urea	1.11	0.74	1.04	0.74
Mulching	0.97	0.73	0.97	0.74
Compost + NPK + Urea	1.22	0.86	1.24	0.86
F probability	0.06	0.22	0.05	0.24
LSD	0.19	0.19	0.20	0.17

was determined by the hydrometer method.

Soil stability index

Particle size distribution and soil organic carbon (SOC) content were used to calculate the structural stability index (StI) as suggested by Pieri (1992), which expresses the risk for soil structural degradation associated with SOC depletion:

$$StI = \frac{1.72 \times SOC}{clay + silt} \times 100$$

where, SOC is the soil organic carbon content (%) and clay + silt is the combined clay and silt content of the soil (%).

StI < 5% indicates a structurally degraded soil; 5 % < StI > 7 % indicates a high risk of soil structural degradation; 7 % < StI > 9 % indicates a low risk of soil structural degradation; and StI > 9 % indicates sufficient SOC to maintain the structural stability.

Statistical analyses

Mixed models analysis was conducted using pro Genstat package (version 9.2) for soil structure degradation index. The standard error of the difference of means (Sed) was used to separate significant treatment means at 5%

probability. Soil organic content was subjected to analysis of variance (ANOVA) and the treatment means separated using the least significant difference (LSD) method at 5 % probability.

RESULTS

Effect of tillage and soil amendment on soil organic carbon content

Tillage practices did not significantly affect ($P > 0.05$) soil organic carbon content (SOC) during the two years of experimentation (Table 3). Soil organic carbon content declined under conventional tillage practice after the two year period. The decrease in SOC content from 2012 to 2013 under conventional tillage practice was up to 13 %. Similarly, soil organic carbon content decreased in 2013 over values recorded in 2012 under tied ridging. Soil organic carbon content under zero tillage remained the same in 2013 as it was observed in 2012.

Table 4 shows the effects of fertility management options on soil organic carbon content both at 0 - 10 cm and 10 - 20 cm depths during the two years of experimentation. Soil organic carbon content did not change considerably after the two years but decreased with depth. As expected, the topsoil (0 - 10 cm) was richer in organic carbon than the

Table 5. Mixed model analysis of soil of Pieri soil structural stability index

Fixed term	Wald statistic	d.f.	Wald/d.f.	chi pr
Tillage	3.28	3	1.09	0.351
Fertility	2.75	4	0.69	0.601
Tillage x Fertility	15.68	12	1.31	0.206
Tillage Practices	StI	Fertility management	StI	
Zero tillage	4.8	Control	4.4	
Ripping	4.7	Compost	4.9	
Tied Ridging	4.7	NPK + Urea	4.8	
Conventional tillage	4.4	Mulch	4.2	
		Compost+NPK+Urea	5.1	
SED	0.8	SED	0.5	

sub soil (10 - 20 cm). The soil organic carbon content ranged from 0.97 % to 1.22 % for 0 - 10 cm depth and 0.72 % to 0.93 % for 10 - 20 cm depth. In both years of the study, the fertility management options significantly affected the SOC content of the top soil (0 - 10 cm depth) but not the subsoil. The organic carbon contents of the soil with no compost and no mineral fertilizer amendment (i.e. the control) were similar to organic carbon content at the onset of the study. The highest values of SOC were obtained under compost + mineral fertilizer treatment followed by the compost treatment. The lowest value was obtained under mulching treatment in both years. Contrary to expectation, the control plots were high in SOC than in mulched plots. The SOC values recorded at both depths during the study were generally low.

Effects of tillage practices and fertility management options on soil structural stability

As illustrated from (Table 5), the impact of the soil tillage and amendments on soil structural stability was assessed by Pieri's (1992) soil structure degradation index (StI). The greater the value of StI, the better the aggregate stability with values < 5 signifying degraded soil structure. The mean values of StI under the tillage practices (Table 5) ranged from 4.4 to 4.8 in decreasing order of Zero tillage > Ripping = Tied-ridging > Conventional tillage.

The mean StI under soil amendments (Table 5) varied from 4.2 and 5.1 in the order of Compost + NPK + Urea > compost > NPK + Urea > Control > Mulch.

DISCUSSION

The soil organic carbon content recorded was low. According to Metson (1961), a productive soil should have an organic carbon content of 2.3 %. According to Greenland (1994), low organic carbon can result in reduction in crop response to fertilizers. Sedogo (1981) previously observed that low organic matter content of sub-Saharan Africa's soils reduces crop response to fertilizer application. Even though it is recognized that soil organic carbon is not a sensitive parameter of a soil quality as it varied slowly

(Ouattara, 1994), the results indicated an increase in soil organic carbon content under compost and compost + NPK + urea amendments over the control at a shallow depth (0 - 10 cm). This observation is in line with results of other studies showing the addition of exogenous organic matter like compost resulting in an enhancement of soil organic carbon storage in addition to improvement of many functions related to the presence of organic matter (Lashermes et al., 2009, Okae-Anti et al., 2013). In tropical soils, the impact of organic amendment on long-term carbon storage might be rather small (Mandal et al., 2007). However, many studies noted their beneficial effects on nutrient cycling (Ngo et al., 2012; Kaur et al., 2005). The organic carbon content of the control was similar to the soil organic carbon content at the onset of the study.

In this study, tillage practices did not affect the soil organic carbon content though the highest values were recorded under no-till practice. This may be due to the short - term nature of the experiment (2 years). Other studies have previously highlighted the improvement in soil organic carbon content under no tillage practice after several years (Ouattara, 1994; Mazzoncini et al. 2011; Dimassi et al. 2014; Villarino et al. 2014). According to Jenkinson (1990), most of SOM in agricultural soils is degradation resistant and turns over much more slowly. The labile fraction which plays a prominent role in soil nutrient dynamics and which may function as a temporal nutrient reservoir (Ouattara, 1994), declines with cultivation (Cambardella and Elliott, 1994), and when a fallow period is included in the rotation system (Biederbeck et al., 1994).

The major concern with tillage arises when it becomes intensive and continuous by which the natural soil structure is destroyed to significantly alter soil functions and cause erosion (Blanco and Lal, 2008). As observed in this study, the generally low structure stability of the experimental soil, using that of the Zero tillage as the base value, was further reduced by conventional tillage. This may be due to the generally observed rapid decomposition of organic matter and loss of carbon under conventional tillage as well as the selective removal of soil fines particles, particularly clay and silt by both wind and water erosion over the two seasons (Quansah and Baffoe-Bonnie, 1981

and Ouattara, 1994). Importance and positive role of organic matter and clay in soil structure formation and aggregate stability are well documented by Ouattara (1994) and Le Bissonnais (1996). As indicated in subsequent sections, although the differences in organic matter content under the various tillage treatments were not significant, the conventional tillage consistently recorded the lowest level of soil organic carbon.

On the other hand, all soil amendments incorporating compost as a constituent tended to increase stability index. This may be ascribed to the higher soil organic carbon under the compost treatments than the other soil amendments as indicated in the results section.

CONCLUSION

Soil structural stability index (StI) tended to decrease under ripping, tied ridging and conventional tillage practices after two years. The application of organic amendments by improving soil organic carbon storage, tend to improve soil structural stability. Continuous monitoring of bulk density, porosity and aggregate stability under future tillage of the soil and application of soil amendments would be necessary to avert the adverse impact of tillage and choice of appropriate land management practices for sustained crops growth and yield in the south Sudan agro-ecological zone.

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Competing interests

The authors declare that they have no competing interests.

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