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Full Length Research Paper

Chemical quality indicators of an entisol under different tillage practices in Maiduguri, Nigeria

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Abstract

The impact of tillage on soil quality indicators is useful in the assessment of dynamic soil properties and processes that are useful for evaluating the sustainability of soil and crop management practices. The influence of three tillage systems: no-tillage (NT), reduce tillage (RT) and conventional tillage (CT) on chemical quality indicators after about 12 years of management was evaluated on an Entisol in Maiduguri, north eastern Nigeria. Soil pH, cation exchange capacity (CEC), organic carbon (OC), total N, available P and exchangeable Na, K, Ca and Mg were determined on soil samples collected at depth of 0-15 and 15-30 cm. An accumulation of soil OC occurred primarily in the top (0-15 cm) soil layer with values of 0.296, 0.262 and 0.196 % for NT, RT and CT treatments respectively. Total N, C:N ratio, Mg, K, CEC, and ESP were significantly ($p \leq 0.05$) influenced by tillage practices particularly at surface (0-15 cm) soil layer. The NT treatment recorded highest values of most chemical parameters (including OC, CEC, TN, Mg and K) followed by the RT treatment, while the CT treatment recorded the least. Soil salinity (EC) and sodicity (SAR) attributes, soil pH and other chemical properties of the soil (including Ca, Na, EXA and BS) were not affected by tillage methods. From the study it could be concluded that, adoption of conservation tillage systems (NT and RT) promotes agricultural sustainability and environmental quality for the soil studied compared to the conventional system (CT).

Keywords: Soil quality, conservation tillage, conventional system, chemical quality indicators, sustainable agriculture.

INTRODUCTION

Soil degradation has become a global environmental problem militating against sustainable agriculture and environmental quality. This degradation is the result of negative changes in soil physical, chemical and/or biological properties, among which the primary causes include excessive cultivation or the use of improper tillage methods (Zeliha and Ismail, 2009). The resultant impact of soil degradation on sustainable agriculture due to improper tillage methods has motivated farmers and researchers to investigate and employ more sustainable management systems that focus on improving soil quality or health (Golchin and Asgari, 2008).

Soil quality is considered a key element of sustainable agriculture and commonly defined as 'the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, to maintain and enhance water and air quality, and to support human health and habilitation (Doran *et al*.,1996). Measurement of soil quality indicators defined as those soil properties and processes that are sensitive to changes in soil function (Andrews *et al*., 2004) had been suggested as a tool for evaluating sustainability of soil and crop management practices (Hussain *et al*., 1999). The objective of this study was to evaluate the effect of different tillage practices on soil chemical quality indicators for sustainable agriculture and environmental quality.

MATERIALS AND METHOD

The study was carried out in Maiduguri, Semi-arid north

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east Nigeria. Climate of Maiduguri is semi arid with long-term mean annual rainfall (1961-1990) of 553 mm. Rainfall distribution is unimodal, starting on average in Mid-June and lasting until the end of September (Grema and Hess, 1994). Five sites were used for the study. The sites were selected based on their land use history. Soil of the study area is Sandy loam (from textural class determination). GPR equipment (12 channels GPS ETREX, courtesy GARMIN Corporation 1999-2002) was used in determining coordinates of the sites. The experiment was carried out using randomize complete block design (RCBD) with three tillage treatments and five replications. Statistix 8.0 (version 2005) analytical software was used in analyzing data obtained. Three tillage treatments namely *no-tillage* (NT) (without tillage), *reduce tillage* (RT) (Tillage practices in the cultivated fields involving hand hoe cultivation per season) and *conventional tillage* (CT) (Tillage practices in the cultivated fields involving 1-2 tractor harrow passes) were evaluated on each site. The locations and land use history of the selected sites are as follows:

SITE1: University of Maiduguri Teaching and Research Farm (11˚54'N,13˚5'E).

At this site, a soil uncultivated (left fallowed) for a period of 12 years was sampled. The dominant plant species in this area are *Andropogon gayanum*, *Cenchrus biflorus*, and scattered *Azadirachta indica* trees. Adjacent to this field, a conventionally tilled plot continuously sown to groundnut and millet for about 12 years and a reduced-till plot continuously sown to groundnut and cowpea for a period of 12 years were also sampled. Tillage practices in the cultivated fields involved 1-2 tractor harrow passes and hand hoe cultivation per season for conventional tillage (CT) and reduced tillage (RT) treatments respectively. Further, NPK and Phosphatic fertilizers are commonly applied by farmers in all the fields because of the cereals (millet) and legumes (cowpea and groundnut) cultivated.

SITE 2: Livestock Farm, University of Maiduguri (11˚47.6'N, 13˚12.5'E). In this site, an uncultivated land (left fallow) for a period of 12 years and an adjacent conventionally tilled plot continuously sown to Maize and Cowpea for about 12 years were sampled. A nearby reduced- till plot sown to Groundnut and Cowpea for a period of 12 years was also sampled. The Dominant plant species in this area are *Senna* obtusfolia, *Achyranthes asper* L., and scattered *Balanities aegyptiaca* trees. Tillage practices performed in the cultivated fields were same as those in site 1.

SITE3: Kwayam Village, off University of Maiduguri (11˚ 47.9'N,13˚12.6'E).

At this site, uncultivated land (left fallow) for 12 years and an adjacent reduced- till plot sown to Millet and Cowpea for about 12 years were sampled. Adjacent to the reduced- till plot, a conventionally tilled plot continuously sown to Maize and Cowpea for 12 years was also sampled. The dominant plant species in this area are *Cenchrus biflorus*, *Imperata cylindrical*, and scattered *Piliostigma reticulatum and Faidherbia albida* trees. Tillage practices in the cultivated plots were same as those in site 1.

SITE 4: Old Malumbrari Primary School, Maiduguri (11˚47'N, 13˚12.7'E).

In site 4, a soil uncultivated (left fallow) for about 12 years and a conventionally tilled plot adjacent to the uncultivated plot continuously sown to Groundnut and Cowpea for about 12 years were sampled. Adjacent to the conventional plot, a reduced- till plot continuously sown to Groundnut and Cowpea for 12 years was also sampled. The Dominant plant species in this area are *Senna obtusfolia*, *Achyranthes asper* L., *Zizuphus mauritiana* and *Balanities aegyptiaca* trees. The same tillage practices were carried out as in sit e 1.

SITE 5: University of Maiduguri Commercial Farm (11˚47.61'N,13˚13.04'E). At this site, a field uncultivated (left fallow) for a period of 12 years was sampled. Adjacent to this plot, conventionally tilled plot continuously sown to Millet and Cowpea for about 12 years and a reduced- till plot continuously sown to Millet and Cowpea for 12 years were also sampled. The dominant plant species in this area are *Cenchrus biflorus*, *Achyranthes asper* L., *Senna obtusfolia*, and scattered *Balanities aegyptiaca* trees. The same tillage practices for the cultivated plots in site 1 were also carried out in this site.

The five selected sites were located within close proximity of one another and within each selected site; three (3) treatment plots (NT, RT, and CT) were located at about 40-60 m of one another and had similar slope, aspect and parent material. The soils of the area have been classified as Sandy Loam Typic Ustipsamment (Rayar, 1984). At the end of the growing season of 2010 (November) soil samples were collected in the three (3) treatments plot at the depth of (0-15 and 15-30 cm) which serve as replicates and composited for the determination of chemical properties. Giving a total of six (6) composite samples. The composite samples were air dried, sieved through 2 mm sieve for analysis. The chemical properties of the soil were analyzed according to the methods of Page *et al.* (1982). Soil pH was determined on 1:2.5 soil/water suspension with a glass electrode pH meter, while organic carbon (OC) was determined by wet oxidation method, total nitrogen by micro-kjeldahl digestion procedure. Available Phosphorus (P) was determined by Bray-1 method, exchangeable cation] were extracted using neutral ammonium acetate, Ca and Mg determined by EDTA titration method, while Na and K were determined by flame photometry. The electrical conductivity (EC) was determined using the conductivity meter while the cation exchange capacity (CEC) was determined by summing the exchangeable bases. Sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP), percentage base saturation (BS) and

Table 1. Effect of tillage systems on soil chemical properties at surface 0-15 cm and subsurface 15-30 cm soil depth

Treatments	OC (%)	TN (%)	C:N	P ($mgkg^1$)	Ca	Mg	Na	K	CEC	EXA	ECEC	SAR	ESP (%)	EC dSm^{-1}	BS (%)	pH (H_2o 1:2.5)
					……………………..cmol kg^{-1} ……………………....											
0-15cm																
NT	0.296	0.142	2.24	1.88	3.20	2.58	0.24	0.42	6.44	0.80	7.24	0.143	3.82	0.039	89.59	6.71
RT	0.262	0.128	2.01	2.66	2.82	2.38	0.23	0.30	5.74	0.68	6.42	0.143	4.05	0.037	89.90	6.54
CT	0.196	0.104	1.84	2.04	2.88	1.54	0.25	0.29	4.96	0.92	5.88	0.168	5.06	0.036	85.12	6.36
LSD(0.05)	0.077	0.035	0.344	Ns	Ns	0.649	Ns	0.121	1.147	Ns	Ns	Ns	1.127	Ns	Ns	Ns
15-30cm																
NT	0.176	0.094	1.85	1.71	3.54	2.32	0.26	0.36	6.48	0.60	7.08	0.150	3.96	0.028	91.44	6.38
RT	0.164	0.082	1.95	2.17	3.14	2.40	0.26	0.26	6.06	0.36	6.42	0.154	4.25	0.029	94.38	6.10
CT	0.130	0.076	1.69	1.57	3.14	1.88	0.27	0.18	5.47	0.54	6.01	0.172	5.10	0.033	90.81	5.38
LSD(0.05)	Ns	Ns	Ns	Ns	Ns	Ns	Ns	0.166	1.006	Ns	1.030	Ns	1.019	Ns	Ns	Ns

[1] NT – no tillage, RT – reduce tillage, CT – conventional tillage
[2] NS - not significant at p≤ 0.05
[3] OC – Organic Carbon, TN-total nitrogen, C:N – Carbon nitrogen ratio, Ca – Calcium, Mg – Magnesium, Na – Sodium, K – Potassium, pH – Soil pH, EXA – exchangeable acidity, SAR – Sodium adsorption ratio, ESP – exchangeable sodium percentage, EC – electrical conductivity, BS – Base saturation

effective cation exchange capacity (ECEC) were determined using the following relations.
$ESP = Na / CEC \times 100$, $SAR = Na \div \sqrt{Ca + Mg/2}$, $BS = CEC/ECEC \times 100$, $ECEC = CEC + EXA$.

RESULTS AND DISCUSSION

Soil organic carbon (OC), a key indicator of soil quality was significantly ($p \leq 0.05$) affected by tillage systems. Soil OC accumulation occurred at the surface (0-15 cm) soil layer and was inversely related to soil disturbance (Table 1). This increase in soil OC plays important role in soil quality due to improvement in infiltration, crop available soil water (Bruce et al.,1995), as well as soil aggregation (Osuji and Onweremadu, 2007). Increased OC storage in soils had also been reported to aid regulation of the atmospheric green house gases concentration (Smith et al., 2008) thereby improving air quality. Similar results were obtained by Motta et al. (2000). Furthermore, the superficial accumulation of OC occurred under adverse conditions of climate (Hunt et al., 1996) and low clay content of the soil (Campbell et al., 1996). The results showed that the use of conservation tillage system (NT and RT) can sustain soil OC under high temperatures (Reeves,1997). Total nitrogen (TN) and carbon nitrogen ratio (C:N ratio) mirrowed the variation in soil OC (Table 1) particularly at surface soil layer. Good correlation between TN, C:N ratio and OC at surface (0-15 cm) soil layer was observed (Table 2). Although higher C:N ratio is an indication of decline humus quality and its nutrient reserve capacity (Lal, 1997), it is also an indication of stability of soil carbon and nitrogen to decomposition (Mills and Fey,2003) thereby decreasing loss of soil nitrogen as nitrates through leaching and volatilization (Theron,

Table 2. Correlation matrix table for selected soil chemical properties at surface 0-15 cm soil depth

	OC	TN	P	Ca	Mg	Na	K	CEC	ECEC	C:N
OC	1.0000									
TN	0.8419***	1.0000								
P	-0.5121*	-0.5032*	1.0000							
Ca	0.4396ns	0.5327*	-0.2625ns	1.0000						
Mg	0.7802***	0.4853 ns	-0.0694ns	0.1600ns	1.0000					
Na	0.3361ns	0.0165ns	0.0670ns	0.3924ns	0.3739ns	1.0000				
K	0.7474***	0.5981**	-0.3277 ns	0.4158 ns	0.6136**	0.2103ns	1.0000			
CEC	0.8424***	0.6556**	-0.2044 ns	0.6534**	0.8488***	0.5105*	0.7327***	1.0000		
ECEC	0.7935***	0.6099**	-0.2334 ns	0.7418***	0.7198***	0.4777ns	0.7581***	0.9539***	1.0000	
C:N	0.8687***	0.5071*	-0.3789 ns	0.1891ns	0.8344***	0.495ns	0.7026***	0.7600***	0.7126**	1.0000

[1] * - Significant at 5%, ** - significant at 1%, *** - significant at 0.1%.
[2] OC – Organic Carbon, TN-total nitrogen, C:N – Carbon nitrogen ratio, Ca – Calcium, Mg – Magnesium, Na – Sodium, K – Potassium, CEC – Cation exchange capacity, ECEC – effective cation exchange capacity, C:N – Carbon nitrogen ratio.

1951). Therefore, the results suggest that adoption of conservation tillage systems (NT and RT) may enhance the soil's ability to supply a greater portion of crop nitrogen (Weinhold and Halvarson, 1999). Contrary to the findings of (Edwards et al., 1992, Agbede, 2007) no tillage did not result in phosphorus (P) accumulation in the upper most soil layer. The cultivated plots (RT and CT) had higher P values relative to the NT treatment although the differences were not significant (Table 1). Motta et al. (2000) maintained that, combined low P adsorption capacity and high levels of extractable P (possibly due to high OC of NT treatment) can contribute to P mobility in soils. Similarly, surface accumulation of OC had been reported to decrease P adsorption capacity (Guertal et al., 1991). The results therefore indicate that, both CT and RT systems are as effective as no-tillage (NT) in supplying crop available P. Another key indicator of soil quality, soil pH was not affected by tillage systems, implying that both NT and RT treatments are as effective as the CT treatment in maintaining pH at acceptable levels. Similar results were obtained by Ismail et al. (1994), although they observed slight decrease in pH with no-tillage. Further, cation exchange capacity (CEC), exchangeable magnesium (Mg) and potassium (K), effective cation exchange capacity (ECEC) and exchangeable sodium percentage (ESP) of the soil were also influenced by tillage systems. The conservation tillage systems (NT and RT) having significantly ($p \leq 0.05$) higher values of most parameters compared to the CT treatment (Table 1). Good correlation between CEC, Mg, K, ECEC and OC content of the soil at (0-15 cm) soil depth was observed (Table 2). The regression equations relating these parameters and OC content of the soil are:

CEC= 2.996 + 10.816OC, r^2=0.70; ECEC= 3.403 + 12.383OC, r^2=0.62; Mg= 0.404 + 7.011OC, r^2= 0.60 and K= 0.117 + 0.886OC, r^2= 0.55.

The above equations showed good relationship of the parameters in question and OC content of the soil, with greatest relationship observed in ECEC of the soil. This result implies that cation loss can be prevented by adopting conservation tillage practices (NT and RT) as they promote OC accumulation which in turn, increases cation concentrations. Furthermore, soil salinity (EC) and sodicity (SAR) attributes and other chemical properties of the soil (including Ca, Na, EXA, and BS) were not affected by tillage systems (Table 1). It is not clear why some chemical properties of the soil increased with depth, it could however be related to the non significant effect of tillage systems on soil OC at sub surface (15-30 cm) layer, which might have generated varied responses. In general, however, values of most chemical properties of the soil decreased with depth (Table 1).

CONCLUSIONS

Tillage systems affected chemical indicators of soil quality. Surface accumulation of soil OC and TN occurred within the surface (0-15 cm) soil layer and were inversely related to soil disturbance (NT > RT > CT), regardless of the adverse conditions of climate (in the study area) and coarse soil texture. In addition, C:N ratio, exchangeable Mg, K, ECEC, CEC and ESP of the soil were all affected by tillage systems especially at surface soil layer. The conservation tillage systems (NT and RT) having higher values of most chemical parameters relative to the conventional (CT) system. In contrast to soil OC and TN, available P, soil pH, EC, SAR, Na, BS Ca and EXA were not affected by tillage systems. Soil OC was found to be the most important chemical property determining chemical quality of the soil. The results revealed that, adoption of conservation tillage systems (NT and RT) promotes long-term agricultural sustainability and environmental quality for managing coarse textured soils of north eastern Nigeria.

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