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Soil structure indices under different tillage systems of sandy loam soil in Hadejia, Jigawa state, Nigeria

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Abstract. *Soil structural indices have a significant effect on the nutrients retention and crop yield. Studies on soil structure indices in the semi-arid zone are minimal despite their importance in controlling water and water transmission, root elongation and erosion. A study was conducted in the area of Hadejia to evaluate the influence of tillage systems (TS) and sampling depths on some selected soil structure indices. The TS were four (4); conventional tillage (CT), reduced tillage (RT), zero tillage (ZT) and chisel plough (CP), while the sampling depths were two - 0-15cm and 15-30cm. Randomised complete block design (RCBD) was used in factorial arrangement. The result showed that the soil is sandy loam in texture irrespective of the TS. Lower dispersion ratio (DR) was observed in ZT with greater aggregate silt + clay (ASC) and water stability index (WSI) which differed significantly (p<0.01) from one another. Pearson's correlation and simple linear regression analysis revealed a significant (p<0.01) positive and negative relationships between organic matter (OM) content of the soil with ASC, WSI and DR, respectively. Negative correlation of OM with DR stressed the significance of OM in decreasing DR of the soil which further explains lower DR by ZT because of greater OM content (p<0.05). Sodium (Na), sodium absorption ratio (SAR) and exchangeable sodium percentage (ESP) were in the order of RT>ZT>CT>CP with RT having the highest that differed significantly (p<0.05) from other TS. Lower values in CT and CP could be a result of leaching due to the lower surface residues relative to conservational tillage systems. Conclusively, the best tillage systems to improved soil structural indices are conservation tillage (ZT and RT) systems, particularly ZT.*

Keywords: soil structure, conservation tillage, dispersion ratio, organic matter, water stability index, zero tillage

Introduction

Soil structure can be defined in terms of form and stability (Kay et al., 1988). Soil structural form refers to the heterogeneous arrangement of solid and void space that exists at a given time, whereas the stability of soil structure is its ability to retain this arrangement when exposed to different stresses (Angers and Carter, 1996). Soil structure contributes significantly to the supply of water and air to the plant roots, roots elongation, nutrient availability and macro fauna activity (Milton da Veiga et al., 2009). Greater water stable aggregates had been observed in reduced and zero tillage systems as compared to the conventional system (Barzeger et al., 2004). This increase in aggregate stability in conservation tillage systems had been attributed to increased organic carbon content and less mechanical disturbance by tillage implements (Mbagwu and Bazzoffi, 1989; Barzeger et al., 2004; Golchin and Asgari, 2008). Knowledge of structural stability of soil for agricultural uses is achieved through determination of its aggregate stability (Osuji and Onweremadu, 2007). Decline in structural stability leads to an increase of soil erodibility (Ngandeu et al., 2016). Several researches showed that lower mean weight diameter (MWD) leads to greater risk of soil erosion, while the higher mean weight diameter gives the soil aggregates resistance to detachability and hence, lower erodibility (Igwe and Ejiofor, 2005). Aggregate size and stability was lower in the land under cultivation compared to forest and fallow (Tangtrakampong and Vityakan, 2002). Thus, aggregate stability influences a wide range of physical and biogeochemical processes in the natural and agricultural environments. Hortensius and Welling (1996) include it in the international standardization of soil quality measurements. Goldberg et al. (1990) reported that wet aggregate stability (macro-aggregate stability) and dispersible clay (micro-aggregate stability) are related to similar soil variables. Barzegar et al. (1994) and Levy and Torrento (1995), however, noted an adverse effect of sodicity (SAR) on macro-aggregate stability, showing that sodicity decreased the amount of macro-aggregates (>250µm) and consequently increased the amount of micro-aggregates (<250µm). Low electrolyte concentrations and high SAR values produce clay dispersion and swelling and consequently the loss of soil structure. Sodium causes swelling and/or dispersion of clay particles, and slaking of unstable aggregates (Crescimanno et al., 1995).

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Goldberg et al. (1990) and Nadler et al. (1996) suggest that the effect of organic matter on soil structure is a function of the size scale of the soil particles examined. In clay soils aggregate, organic matter acts over the particle charge (Goldberg et al., 1990), whereas in coarse sand-sized aggregates, organic matter acts as a binding agent, through roots and hyphae (Tisdall and Oades, 1982). Other works have found no correlation between OM and WSA (Carter et al., 1994), suggesting that some components of the organic carbon pool are more actively involved in stabilizing aggregates than others (Perfect and Kay, 1990).

Tillage breaks down the aggregates to smoothing the surface and exposing organic matter (OM) to microbial attack and consequently, OM is lost (Roberson et al., 1991). Intensive tillage practices can also cause excessive soil compaction and poor structure, especially under conditions of high soil moisture (Carter et al., 1994). Higher demand of tractors and other implements leads to higher compaction extending to deeper zones. As a result, plough-pans and subsoil compaction are produced (Soane et al., 1982). Oades (1993) concluded that cultivation destroys the continuity of biopores by cutting them off at plough depth and as such they will not transmit free water. The reduction (2-3 times) of EC in zero tillage soils contributed to increase the sensitivity of the farmed soils to dispersion (Naidu et al., 1996). Amézketa et al. (1995) observed that the most intensive system in terms of tillage had the lowest macro-aggregate stability while comparing four tillage systems. Watts et al. (1996) found that aggregates obtained after tillage had higher amounts of dispersed clay than those before the tillage. Zero tillage had an important stabilizing effect on macro-aggregation compared to other tillage treatments; Angers et al. (1993) found that aggregates under ZT were less subject to slaking. Conservation tillage methods reduced soil erosion (Wollenhaupt et al., 1995). Consequently, conservation tillage has gained interest as a method for reducing soil degradation and conserving soil moisture.

Several authors evidenced that macro-aggregate stability is improved in the presence of roots (Habib et al., 1990; Pojasok and Kay, 1990). Arshad and Coen (1992) proposed aggregate stability as one of the soil physical properties that can serve as an indicator of soil quality. The severity of wind erosion depends on the aggregate size distribution of the soil surface (Kemper and Rosenau, 1986). The hypothesis tested was that different tillage systems would influence the structural stability of the soil differently. The objective of the study was to ascertain the tillage influence on some soil structure indices.

Material and methods

Experimental site

The study was carried out at four different locations (I – CT: 12.46° 06[1]N, 10.04° 08[1]E; II – RT: 12.46° 01[1]N, 10.04° 09[1]E; III – ZT: 12.47° 03[1]N, 10.04° 07[1]E and IV – CP: 12.46° 04[1]N, 10.04° 03[1]E) of a Sudan savannah zone of Hadejia area of Jigawa state. The ecological zone is characterised by erratic and intense rainfall within short period of time, which subjects the area to wind erosion during the longer dryer period of the year. The area has a rainfall and temperature range of 550-700mm and 24-38°C, respectively. The sampling sites had a history of four different tillage systems that have been in practice for about 5 years. The crops grown in the area are rainfed arable crops such as legumes and cereals.

Experimental design and treatments

Randomised Complete Block Design (RCBD) was employed in a factorial arrangement which involved tillage systems (TS) as the first factor and sampling depth (D) as the second factor, with three replications each. The four tillage systems were; Conventional tillage (CT: ox-ploughed by animal to a depth of about 15-20cm), reduced tillage (RT: using one to two manual hoeing), Zero tillage (ZT: no tillage activity is performed) and Chisel plough (CP: tillage by chisel plough up to 30cm depth using a tractor). The sampling depths were 0-15cm and 15-30cm.

Soil sampling

Soil sampling was done in the month of November 2018 immediately after harvest. Core samplers of 5x5cm of length and diameter dimension, respectively, were used at the two different depths of the sampling for each tillage system, making a total of 24 soil core samples. The sample cores were trimmed, top and bottom openings covered, labelled and sealed in plastic bags and transported to the laboratory for further preparation.

Soil analysis

Particle size analysis was conducted using Bouyoucos hydrometer method (Gee and Bauder, 1986). The USDA textural triangle was used to determine the textural class of the soil samples.

Dispersion ratio (DR) was determined following Middleton (1930) procedure as;

$$DR = (X / Y).100, \% \quad (1)$$

Where X is the percent silt + clay in water-dispersed sample and Y is the percent silt + clay in calgon-dispersed sample.

Aggregate silt-plus-clay (ASC %), which is defined as the difference between silt + clay in calgon-dispersed and that in water-dispersed soil samples was also determined following Middleton (1930) procedure.

Water-stability index (WSI, %) was determined using a formula (Malquori and Cecconi, 1962) as follows:

$$WSI = \{1 – (X / Y).100\}, \% \quad (2)$$

Where X is the proportion of aggregates that passed a 200µm sieve in 5min after shaking at the rate of 60 oscillations per minute at room temperature and Y is the proportion that passed after 60min under the same conditions.

Chemical properties of the soil were determined following Page et al. (1982). Organic carbon (OC) by wet oxidation method and to obtain OM, the organic carbon values were multiplied by a constant factor of 1.724 (Jones, 2001). Sodium (Na) was determined using flame photometer, while SAR and ESP were obtained by the following formulae:

$$SAR = \{Na / \sqrt{(Ca + Mg)/2}\} \quad (3)$$

$$ESP = (Na / CEC).100, \% \quad (4)$$

Data analysis

Minitab 16, was used for the correlation and simple linear regression analysis as well as the normality test of the parameters determined, which was conducted using Anderson-Darling at p=0.05. The normality test showed that the data were normal in distribution. All data collected were tested using Statistical Analyses System (SAS Institute Inc., 2011). ANOVA (Analysis of Variance) and Proc GLM were used to determine the significant treatment effect on the measured properties with the significant difference of 1 and 5% levels. Tukey (HSD) test for mean separation was used to detect significant difference between the means.

Results and discussion

Table 1 shows the particle size distribution (PSD) of the soil under different tillage systems at different depths. No significant difference (p>0.05) was observed in the different TS across different depth of sampling with all having sandy loam textural classes. Higher sand with lower silt content was obtained in the ZT system, which could be due to aggregate stability of the soil under the system because of the minimal soil disturbances relative to other TS. Oades (1993) stated that cultivation is detrimental to biopores continuity by cutting them off at plough depth. Higher silt content was recorded by conventional TS (CT and CP) with 11% each at both depths (0-15 and 15-30cm) relative to 8%, 9% and 6%, 7% of RT and ZT systems, respectively. The general trend was that, proportion of sand decreases with increase in depth while clay content increases with depth in all the TS which agrees with Sauwa et al. (2013).

Table 1. Particle size distribution of the soil under different tillage systems at different depths

Tillage systems	Sand, %	Silt, %	Clay, %	Textural class
		0-15cm		
CT	74	11	15	Sandy Loam
RT	75	8	17	Sandy Loam
ZT	80	6	14	Sandy Loam
CP	77	11	12	Sandy Loam
		15-30cm		
CT	71	11	14	Sandy Loam
RT	72	9	19	Sandy Loam
ZT	77	7	16	Sandy Loam
CP	73	11	16	Sandy Loam

*CT-conventional tillage, RT- reduced tillage, ZT- zero tillage, CP-chisel plough

Figure 1 shows the interaction between tillage systems and depth on: (a) dispersion ratio (DR), (b) Aggregate silt + clay (ASC) and (c) water stability index (WSI). In terms of DR (Figure 1a), there was no significant difference between CT, RT and CP which recorded higher DR of 80.4 and 85.5%, 82.2 and 85.4% and 81 and 81.4%, respectively at 0-15 and 15-30cm depths. However, they differed significantly (p<0.05) from ZT which had the lower DR of 73.7 and 79.6% at 0-15 and 15-30cm depths, respectively. Lower DR value by ZT is an indication of higher structural stability by the system relative to other TS. The trend is, DR increases with depth irrespective of TS. Significant negative correlation was obtained between DR and organic matter (OM) content at both 0-15cm (-0.87**) and 15-30cm (-0.67*), respectively (Table 2). The relationship showed that TS with higher OM content will have lower DR and as such the greater the structural stability. The result is in agreement with Mbagwu and Bazzoffi (1989) and Sauwa et al. (2013) who reported a significant negative correlation between DR and OC. The regression equation relating DR and OM content of the soil at 0-15cm and 15-30cm depths is presented in equations 5 and 6 which show that for every unit increase in OM content of the soil DR decreases by 51.46 and 38.6% at 0-15 and 15-30cm depths, respectively. There was no significant correlation between DR and Na content of the soil (Table 2), but a non-significant linear relationship indicated that for every unit increase in Na content, DR increased by 2.8 (equation 7) and 8.1% (equation 8) at both 0-15 and 15-30cm depths, respectively. Adverse effect of sodicity (SAR) on macro-aggregate stability was noted by Barzegar et al. (1994) and Levy and Torrento (1995), indicating that sodicity decreased the amount of macro-aggregates (>250µm) and consequently increased the amount of micro-aggregates (<250µm). High SAR values produce clay dispersion and swelling and consequently the loss of soil structure.

$$DR = 89.6 - 51.46\ OM,\ R^2 = 0.66 \quad (5)$$

$$DR = 89.8 - 38.60\ OM,\ R^2 = 0.61 \quad (6)$$

$$DR = 77.60 + 2.86\ Na,\ R^2 = 0.37 \quad (7)$$

$$DR = 78.05 + 8.10\ Na,\ R^2 = 0.41 \quad (8)$$

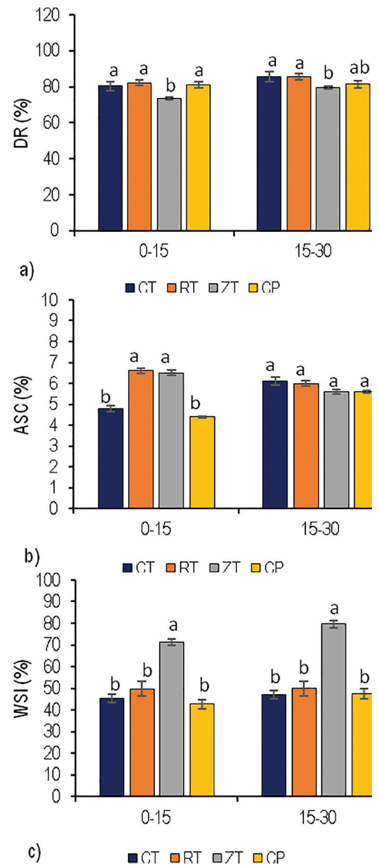

Figure 1. Means (±standard error) for (a) DR, (b) ASC and (c) WSI as influenced by different tillage systems and sampling depth (Means with same letters within the same month are not significantly different from one another at 5% level of significance)

Table 2. Pearson correlation coefficients between some measure parameters at the two different depths

	WSI	ASC	DR	ESP	Na	SAR	OM	HC
0-15 cm depth								
ASC	0.81**							
DR	-0.4ns	-0.2ns						
ESP	-0.22ns	-0.01ns	0.67*					
Na	0.69*	0.82**	0.1ns	0.34ns				
SAR	0.56ns	0.7*	0.17ns	0.3ns	0.89***			
OM	0.81**	0.007ns	-0.87**	-0.74**	-0.24ns	-0.35ns		
HC	0.94***	0.86***	-0.37ns	-0.25ns	0.69*	0.57*	0.35ns	
BD	-0.34ns	-0.49ns	-0.32ns	-0.003ns	-0.45ns	-0.42ns	0.19ns	-0.29ns
15-30 cm depth								
ASC	-0.35ns							
DR	-0.29ns	0.74**						
Na	0.67*	0.27ns	0.21ns					
ESP	0.13ns	0.61*	0.46ns	0.73**				
SAR	0.63*	0.27ns	0.14ns	0.98***	0.79**			
OM	0.65*	-0.55ns	-0.64*	-0.49ns	-0.64*	-0.48ns		
HC	0.86***	-0.41ns	-0.41ns	0.65*	0.22ns	0.67*	-0.04ns	
BD	-0.44ns	-0.28ns	-0.4ns	-0.58*	-0.38ns	-0.51ns	0.52ns	-0.26ns

Na- sodium content, SAR- sodium absorption ratio, ESP- exchangeable sodium percentage, DR- dispersion ration, ASC- aggregate silt+clay, OM- organic matter, HC- saturated hydraulic conductivity, BD- bulk density; *significant at 5%, **significant at 1%, ***significant at 0.1% and ns- not significant at ≤5%.

In terms of ASC (Figure 1b), significant difference ($p<0.01$) was observed between the TS across the two depths of the sampling. Conservation systems had the higher ASC values which differed significantly ($p<0.05$) from conventional tillage (CT and CP) systems at 0-15cm depth only but there was no significant difference at 15-30cm depth. The result agrees with Sauwa et al. (2013) who reported no significant difference between TS across different depths of sampling. At 0-15cm conservation TS (RT and ZT) had 28.7% increases in ASC (%) more than conventional TS (CT and CP). Higher values by conservation TS could be due to minimum to no disturbance in the soil that allows the pore continuity and structural development of the soil. This explains the lack of significance obtained at 15-30cm, because aggregate stability decreases with depth irrespective of the tillage system which agrees with findings of Mbagwu and Bazzoffi (1989) and Sauwa et al. (2013). ASC correlates positively with Na (0.82**) and Ksat (0.86**) at 0-15cm depth only (Table 2). Simple linear regression equations between ASC and OM content (equation 9 and 10) of the soil indicated that for every unit increase in OM content ASC decreased by 3.5 and 3.03% at 0-15 and 15-30cm depths, respectively.

$$ASC = 6.33 - 3.55\ OM,\ R^2 = 0.33 \quad (9)$$

$$ASC = 6.36 - 3.03\ OM,\ R^2 = 0.31 \quad (10)$$

Significant difference ($p<0.01$) was observed between the TS across the depth of sampling (Figure 1c) on WSI. The WSI was in the order of ZT>RT>CT>CP. ZT system had 36.4 and 40% higher WSI relative to other TS which differed significantly from them at both depths. Conservation TS (RT and ZT) had the higher WSI values at both 0-15 and 15-30cm depths, relative to the conventional tillage systems. Greater WSI in ZT was an indication of greater soil structural stability. Similar results were obtained by Mbagwu and Bazzoffi (1989) and Tadeschi (2000). The WSI of the soil correlated positively with ASC, Na, OM and Ksat at 0-15cm depth and with SAR, Na, OM and Ksat at 15-30cm depth (Table 2). The regression equation linking WSI and OM content in the soil at both 0-15 and 15-30cm depths are given by equations 11 and 12 below:

$$WSI = 29 + 112\ OM,\ R^2 = 0.97 \quad (11)$$

$$WSI = 33 + 129\ OM,\ R^2 = 0.97 \quad (12)$$

The above equations show that WSI increased by 112 and 129% for every unit increase in OM content of the soil. Similar findings were made by Tadeschi (2000).

The interaction between TS and sampling depths on organic matter content was not significant ($p>0.05$) but the main effect of TS was significant ($p<0.01$) on the OM content as shown in Figure 2. Higher OM content was recorded by ZT system with 0.58% which differed significantly from CT, RT and CP with 0.41, 0.34 and 0.36% each, respectively. ZT system had an increment of 29.3, 41.3 and 38% OM content over CT, RT and CP systems, respectively. Higher OM content under ZT system was due to the minimum disturbance of the soil and crop residues incorporation. Tillage breaks down the aggregates to smoothing the surface and exposing organic matter to microbial attack there by rendering the soil void of OM as reported by (Roberson et al., 1991). OM could serve as both particle charge and as binding agent through roots and hyphae depending on the aggregate sizes of the soil (Tisdall and Oades, 1982; Goldberg et al., 1990).

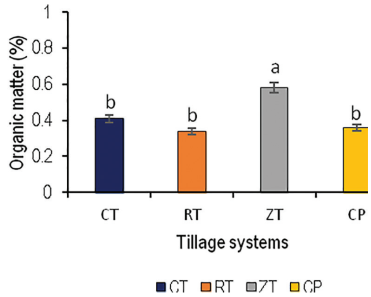

Figure 2. Means (±standard error) of organic matter content as influenced by different tillage systems (Means with same letters within the same month are not significantly different from one another at 5% level of significance)

Figure 3 shows the interaction between TS and sampling depth on: a) Na, b) SAR and c) ESP. The interaction was significant (p<0.01) at both 0-15 and 15-30cm depths. Higher Na content was recorded by RT system with 0.74 and 0.77 mg kg^{-1} while the lowest was observed in CP with 0.52 and 0.46 mg kg^{-1} at 0-15 and 15-30cm depths, respectively. The same trend was also observed in terms of SAR and ESP with the highest under RT and the lowest by CP which differed significantly (p<0.01) from other TS at both depths. Higher values of the parameters in the RT were due to the greater percentage of Na content in the TS relative to other systems, since Na is the determining factor for the parameters. Significant positive correlation was obtained between Na with SAR and ESP (Table 2). Higher Na accumulation in the RT could be due to the organic and inorganic fertilizer application in the farm. Higher SAR and ESP by RT could also be attributed to the lower CEC and Ca and Mg content (Data not shown) of the system relative to other TS. The lower proportion of Na by CP relative to other TS could be due to the leaching effects and lower organic matter content because of the intensive tillage. Crescimanno et al. (1995) noted that sodium causes clay particles to swell and/or disperse and slaking of unstable aggregates. There was no significant increase or decrease of the parameters with depth (Figure 3).

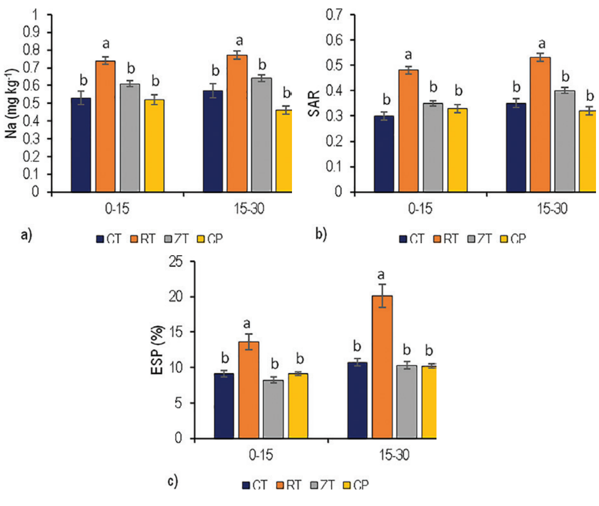

Figure 3. Means (±standard error) for (a) Na, (b) SAR and (c) ESP as influenced by different tillage systems and sampling depth (Means with same letters within the same month are not significantly different from one another at 5% level of significance)

Conclusion

The research showed that conservation tillage system (particularly zero tillage - ZT) recorded higher structural stability aggregates over the commonly practiced conventional tillage (CT and CP). ZT had higher aggregate silt-plus-clay (ASC) and water-stability index (WSI), organic matter (OM) with lower dispersion ratio (DR), which is an indication of a greater structural stability. Significant positive correlations between OM content with ASC and WSI and negative correlation between OM and DR indicated that minimum soil disturbance and incorporation of organic residues that leads to higher OM under conservation tillage systems lead to their better structural stability indices relative to conventional tillage systems. Conclusively, ZT had greater structural stability indices with lower Na, SAR and ESP which affect the soil structure negatively and as such it is the best tillage system for a sandy loam soil of Hadejia.

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