



INFLUENCE OF TILLAGE PRACTICES ON PHYSICAL PROPERTIES OF A SANDY LOAM IN SEMI-ARID REGION

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ABSTRACT

The contrasts observed in soil tillage research studies documented the need for more research in many regions of the world if the mechanics of tillage effects on soil physical properties is to be well understood. Thus, the effect of three tillage systems: no-tillage (NT), reduce tillage (RT) and conventional tillage (CT) on the physical properties of a sandy loam soil in Maiduguri, Nigeria was investigated after 9-15 years of management. During the growing season of 2010, triplicate undisturbed core samples (5.5 cm in diameter and 4 cm height) were obtained at two soil depths (0-15 cm and 15-30 cm), for determination of volumetric (θ_v) moisture content, bulk density (Bd), and total porosity (TP) of the soil at selected dates, while soil penetration resistance (PR) was determined using hand held digital penetrometer. Tillage systems significantly ($p \leq 0.05$) affected Bd and TP of the soil at two of the four sampling dates. The RT treatment recorded highest Bd and lowest TP at (0-15 cm) depth across most sampling dates, while at (15-30 cm) soil depth, the CT and RT treatments maintained higher Bd. Soil PR was significantly influenced by tillage systems only at the surface (0-15 cm) soil depth. The NT treatment recorded significantly ($p \leq 0.05$) higher PR while the RT treatment recorded the least. Further, significant ($p \leq 0.05$) tillage treatment effects on the θ_v content of the soil was observed at both surface (0-15 cm) and sub surface (15-30 cm) soil depths. The NT and RT treatments, on average, recorded higher values of θ_v relative to the CT treatment. Soil organic carbon (OC) and aggregate stability in water (MAW, ASC, DR and WSI) were found to correlate ($p < 0.05$) well with θ_v content of the soil for most sampling dates particularly a surface soil layer.

The study revealed that, the NT and RT treatments promotes better physical quality of the soil relative to the CT treatment. It is however recommended that, other reduced tillage systems such as animal traction and ridgetillage be tried to assess their efficacy of improving soil physical quality.

Key words: Tillage, Tillage systems, Soil Physical properties, Moisture storage, Physical quality

INTRODUCTION

Soil tillage is one of the fundamental agrotechnical operations in agriculture because of its influence on soil properties, environment and crop production in general (Husnjak *et al.*, 2002). This influence of tillage on soil properties and crop production had motivated numerous workers to investigate tillage effects on soil physical properties (Dao, 1993; Mielke *et al.*, 1984; Khan *et al.*, 2001; Jabro *et al.*, 2008), however, results obtained by these and other workers as indicated by the below literature seems contradictory.

For example, while Alegre *et al.* (1991) observed higher bulk density (Bd) in minimum till (MT) and no-till (NT) systems relative to the conventional tillage (CT) treatment, Logsdon and Cambardella (2000) reported no significant effect of tillage systems on the Bd of a fine loam soil. Increased water storage had also been associated with conservation tillage practices (Dao, 1993; Agbede, 2007), this increase in water storage of conservation tillage systems had been attributed to decreased evaporation (Dao, 1993), greater organic carbon contents (Agbede, 2007;

Golchin and Asgari, 2008) and greater aggregate strength (Milton da Viegas *et al.*, 2009). However, Jabro *et al.* (2008) reported no significant effect of tillage systems on water storage of a sandy loam soil after 22 years of tillage implementation. Further, while Jabro *et al.* (2008) reported significantly higher penetration resistance (PR) in conservation tillage practices relative to the conventional system, Mielke *et al.* (1984) observed no significant effect of tillage systems on soil PR after longer period of tillage imposition. These contrasts observed had been related to several things including soil type (Azooz and Arshad, 1996), kind of tillage practiced, soil moisture conditions before tillage, and climatic characteristics especially the pattern and magnitude of precipitation (Mapa *et al.*, 1986).

From the foregoing, the need for more research on tillage effects upon soil physical properties in many regions of the world became pertinent, if the mechanics of tillage effects on soil physical properties are to be well understood. The aim of this study was therefore to evaluate the effects of different tillage practices on some physical properties of the soil.

MATERIALS AND METHODS

The Study Area

The study was carried out in Maiduguri, north 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 the 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 (Table 1a and b). GPR equipment (12 channel GPS etrex, courtesy GARMIN Corporation 1999-2002) was used in determining coordinates of the sites.

Treatments and Experimental Design

The experiment was established as randomized complete block design (RCBD) with three tillage treatments and five replications. Three tillage treatments namely; *no tillage* (NT), *reduce tillage* (RT) and *conventional tillage* (CT) were evaluated on each site.

The CT treatment in the five selected sites involved 1-2 tractor harrow passes per season (year), and the commonly grown crops in this treatment (CT) are groundnut, cowpea, millet or maize. While the RT treatment in all selected sites involved 1-2 hand hoe cultivation per season (year), and the commonly grown crops in this treatment (RT) are groundnut, cowpea or millet. The NT treatment in all selected sites comprises of uncultivated lands left fallowed under natural vegetation. In addition, the CT and RT treatments are either opposite or adjacent to the uncultivated (NT) plots. All treatments (CT, RT and NT) in the selected sites were under management for a period of about 9-15 years. NPK and phosphate fertilizers are the commonly applied fertilizers by farmers in the cultivated plots (CT and RT). The commonly found plant species and locations of the five selected sites are as follows:

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

The dominant plant species in this area are *Andropogon gayanum*, *Cenchrus biflorus*, and scattered *Azadirachta indica* trees.

SITE 2: Livestock Farm, University of Maiduguri (11°47.6'N, 13°12.5'E). In this site, the commonly found plant species are *Senna obtusifolia*, *Achyranthes asper* L., and scattered *Balanites aegyptica* trees.

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

This site is characterized by scattered *Piliostigma reticulatum* and *Faidherbia albida* trees likewise *Cenchrus biflorus* and *Imperata cylindrica* as dominant vegetation.

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

In site 4, the commonly found plant species are *Senna obtusifolia*, *Achyranthes asper* L., *Zizuphus mauritiana* and *Balanites aegyptica* trees.

SITE 5: University of Maiduguri Commercial Farm (11°47.61'N,13°13.04'E).

At this site, the dominant plant species found are *Cenchrus biflorus*, *Achyranthes asper* L., *Senna obtusifolia*, and scattered *Balanites aegyptica* trees.

The five selected sites were within close proximity (40-80 m) of one another, and within each selected site, treatment plots are located within 40-60 m of one another and had similar terrain and parent material (Aeolian sand). During the growing season of 2010, triplicate undisturbed core samples (5.5 cm in diameter and 4 cm height) were obtained at four selected dates for the determination of bulk density (Bd), total porosity (TP) and volumetric moisture content (Θ_v) of the soil, while penetration resistance of the soil was determined using hand held digital penetrometer (D 1558-84 ASTM standard of needle head 0.6 cm). The bulk density was determined using the core method as described by Blake and Hartage (1986), while gravimetric moisture content (Θ_g) was determined by direct method as described by Hillel (1971). The Θ_g was then converted to Θ_v using the following relation :

$$\Theta_v = \Theta_g \times Bd$$

Where Bd = bulk density

The soil physical properties were determined at two soil depths (0-15 and 15-30 cm) to capture cultivation zone around the experimental area. The two soil depths were determined using measuring tape and one profile was dug in each treatment plot to observe profile characteristics.

Aggregate properties and organic carbon determination

Macro aggregates of wet (MAW) and macro aggregates of dry (MAD) aggregates were determined after determination of mean weight diameter (MWD) of wet and dry aggregates as described by Kemper (1965) and Kemper and Chepil (1965) respectively. While aggregate silt-plus clay (ASC %), water stability index (WSI %), dispersion ratio (DR %) and organic carbon (OC) contents of soil samples were determined as follows:

Aggregate silt-plus clay (ASC %): This is defined as the difference between silt + clay in calgon dispersed and that in water – dispersed soil samples (Middleton, 1930).

Water stability index (WSI %): This was computed as $100 (1 - A/B)$. Where A is percentage of aggregates which passed a 0.20 mm sieve in 5 minutes after shaking at the rate of 60 oscillations per minute at room temperature and B is the percentage that passed after 60 minutes under the same conditions (Malquori and Cecconi, 1962).

Dispersion ratio was computed as $DR = (A/B) \times 100$. Where A = Percent silt + clay in water – dispersed sample, and B = Percent silt + clay in calgon-dispersed sample (Middleton, 1930). *Organic carbon (OC)* : The organic carbon content of soil samples was determined by wet oxidation method of Walkley and Black (1934).

Statistical Analysis

Statistical analysis system (SAS) version 2005 analytical software was used in analyzing data obtained. The results obtained were analyzed using analysis of variance (ANOVA) statistics and means were separated using least significant difference (LSD) test at 5 % level of probability.

RESULTS AND DISCUSSION

Particle size distribution (Texture)

Tillage treatments effects on textural composition (% sand, silt and clay) of the soil are presented in Table 1a and b. Tillage treatments had no significant effect on the % sand, silt and clay contents of the soil at surface (0-15 cm) soil depth (Table 1a). However, at the sub surface (15-30 cm) soil depth, tillage practices significantly ($p \leq 0.05$) influenced textural composition of the soil. The NT and RT treatments had higher sand contents (67.8 and 67.3 respectively) relative to the CT treatment (64.3). Similarly, tillage treatments effect on clay content of the soil at the sub surface soil depth was also significant. The RT treatment gave the highest clay content (14.85) followed by the CT (13.35), then NT treatment (12.35) Table 1b. No significant treatments effect on the silt content of the soil at both the surface and sub surface soil depths was observed. The result agrees with findings of Mbagwu and Bazzoffi (1989) who reported that cultivation encourages movement of finer soil particle (clay) within the soil profile. Generally, values of sand contents of the soil decreased with depth, while those of clay content increased with depth irrespective of tillage treatment (Table 1a and b).

Soil bulk density (Bd) and total porosity (TP)

Result of soil Bd and TP measurement for the various treatments at various sampling dates are presented in Table 2. No consistent trend in Bd and TP of the soil was observed with time at the surface (0-15cm) soil layer during crop growing season. However, at the subsurface (15-30 cm) soil layer, the CT treatment showed a trend of increasing Bd as the raining season progressed. Generally, Bd of the soil increased with increasing soil depth irrespective of tillage method (Table 2). In addition, Bd and TP of the soil were significantly ($p \leq 0.05$) influenced by tillage systems only during two of the four sampling dates.

In general, the CT treatment had the least Bd and the highest TP at the surface soil layer compared to either the NT or RT treatments during all the measurement dates. This could be attributed to the loosening effect of tillage equipment used for the CT treatment (Barzegar *et al.*, 2004). The trend reversed at the sub surface soil layer with the CT and RT treatments having relatively higher values of Bd and lower values of TP compared to the NT treatment irrespective of measurement date (Table 2). The higher Bd recorded in the sub surface soil layer of the CT treatment could be attributed to the effect of tractor wheel traffic as observed by previous workers (Mielke *et al.*, 1984; Heddadj and Gascuel-Odoux, 1999). Excavation of profiles displayed a fairly dense layer at about 20 – 40 cm of all the CT

treatments further supporting densification of soil matrix at the sub surface soil layer by the CT treatment. The results revealed that the CT and NT treatments offer significant advantage over the RT treatment in ensuring good aeration status of the soil, and ease of root penetration (particularly shortly after tillage imposition). However, studies have shown that for the CT treatment, these conditions diminished rapidly due to aggregate disruption by rain drop impact (Moran *et al.*, 1988) and soil consolidation after pulverization (Suwardji and Eberbach, 1998). Values of Bd observed in this study generally seems high and are relatively approaching critical Bd value (1.90 g/cm^3) considered as root limiting in coarse textured soils (Marshall and Tokunaga, 2006). Therefore, practices that reduce soil Bd such as crop residue mulch incorporation should be encouraged.

Penetration resistance (PR)

Tillage treatment effects on soil PR (kPa) are presented in Fig.1. Tillage systems significantly ($p \leq 0.05$) affected the soil PR only at the surface (0-15 cm) soil layer. The NT treatment recorded significantly ($p \leq 0.05$) higher PR value (238.6 kPa) at the surface soil layer relative to the RT (173 kPa) and CT (187.5 kPa) treatments (Fig.1). However, the RT treatment recorded lowest PR at both surface (173 kPa) and sub surface 15-30 cm (95.90 kPa) soil layers compared to the NT and CT treatments (Fig.1). The trend in PR among treatments reported in this study is quite unexpected because results of previous studies conducted on similar soils showed the existence of a direct positive correlation between Bd and PR (Khan *et al.*, 2001; Jabro *et al.*, 2008) indicating that higher values of Bd are associated with higher values of PR. However, this ambiguity could be associated with soil moisture (gravimetric) content at time of sampling which had been reported to decrease soil PR (Ghuman and Lal, 1984). The average moisture content for the NT, RT and CT treatments at the time of sampling were 0.35, 0.55, 0.34 and 1.21, 1.41 and 1.20 (% g/g) for the surface and sub surface soil layers respectively. Further, soil PR values observed are generally low irrespective of tillage method and quite far from the critical PR value (2000 kPa) reported to be detrimental to root penetration in soils (Dec *et al.*, 2011). In general, the results of Bd, TP and PR of the soil showed evidence of compaction by NT and RT treatments at surface soil layer, while the CT treatment showed compaction at the sub surface layer.

Soil moisture content

Moisture content of the soil was significantly ($p \leq 0.05$) influenced by tillage systems. The results of effect of tillage systems on the volumetric moisture content (θ_v) of the soil for the various sampling dates are presented in Table 3. No consistent trend in θ_v content of the soil was observed as the raining season progressed.

However, the NT and RT treatments consistently retained more moisture at both surface (0-15 cm) and sub surface (15-30 cm) soil layers relative to the CT treatment during most sampling dates (Table 3).

In addition, the NT and RT treatments on average, recorded significantly ($p \leq 0.05$) higher Θ_v contents at both surface and sub surface soil layers compared to the CT treatment across most of the sampling dates (Table 3). The Θ_v contents of the soil significantly ($p < 0.05$) correlated positively with organic carbon (OC) content and aggregate stability indices (ASC, MAW, MAD and WSI) of the soil at surface (0-15 cm) soil layer, while DR of the soil correlated negatively (Table 4a). However, at the sub surface soil depth, some of these parameters correlated ($p < 0.05$) with Θ_v content of the soil only for the first and the last sampling dates (Table 4b). MAW and ASC significantly correlated positively, while DR of the soil negatively correlated significantly with Θ_v content of the soil (Table 4b). It is not clear why most of the parameters did not correlate significantly with Θ_v content of the soil at the sub surface soil depth, this could however be related to decreased organic carbon content with depth as observed in a companion report on chemical quality of the soil (Sauwa *et al.*, 2012) which might have generated varied responses. The results are however in line with findings of Agbede (2007) and Golchin and Asgari (2008) who reported that, OC/organic matter contents of soils exerts great influence on soil moisture content.

The regression equations relating OC and

Θ_v content of the soil at surface (0-15 cm) are presented as follows:

$$\begin{aligned} \Theta_v &= 7.92 + 29.06 \text{ OC}; r^2 = 0.75 \text{ for } 27/07/2010 \dots\dots\dots 1 \\ \Theta_v &= 8.58 + 25.02 \text{ OC}; r^2 = 0.58 \text{ for } 12/08/2010 \dots\dots\dots 2 \\ \Theta_v &= 9.73 + 12.85 \text{ OC}; r^2 = 0.52 \text{ for } 28/08/2010 \dots\dots\dots 3 \\ \Theta_v &= 7.07 + 16.30 \text{ OC}; r^2 = 0.76 \text{ for } 12/09/2010 \dots\dots\dots 4 \end{aligned}$$

The above equations showed fair relationship of OC and Θ_v content of the soil, with best relationship observed for the first sampling date (27/07/2010). Previous workers had related greater moisture contents of NT and/or RT treatments to their greater organic carbon contents (Agbede, 2007; Golchin and Asgari, 2008). Likewise, Milton da veiga *et al.* (2009) reported greater soil moisture contents of tillage treatments due to greater aggregate stability in water. Therefore, the greater moisture content of the NT and RT relative to the CT treatment could be attributed to greater OC content and aggregate strength of these treatments compared to the CT treatment. The results obtained in this study are in agreement with findings of (Khakural *et al.*, 1992; Agbede, 2007) who reported greater moisture contents in conservation tillage practices relative to the conventional system.

Table 1a. Percentage sand, silt and clay contents of the soil as affected by tillage systems for 0-15 soil depth

Treatments	(% sand)	(% silt)	(% clay)	Textural class
0-15 cm				
NT				
1	72.1	18.2	9.7	Sandy loam
2	67.1	20.7	12.2	Sandy loam
3	69.6	20.7	9.7	Sandy loam
4	69.6	18.2	12.2	Sandy loam
5	69.6	20.7	9.7	Sandy loam
Mean	69.6	19.7	10.7	
RT				
1	69.6	18.2	12.2	Sandy loam
2	72.1	20.7	7.2	Sandy loam
3	69.6	20.7	9.7	Sandy loam
4	69.6	18.2	12.2	Sandy loam
5	67.1	20.7	12.2	Sandy loam
Mean	69.6	19.7	10.7	
CT				
1	72.1	15.7	12.2	Sandy loam
2	72.1	18.2	9.7	Sandy loam
3	69.6	18.2	12.2	Sandy loam
4	67.1	23.2	9.7	Sandy loam
5	69.6	18.2	12.2	Sandy loam
Mean	70.1	18.7	11.3	
LSD (0.05)	NS	NS	NS	

¹NS- not significant at $p \leq 0.05$ level of probability

² 1....5- replications

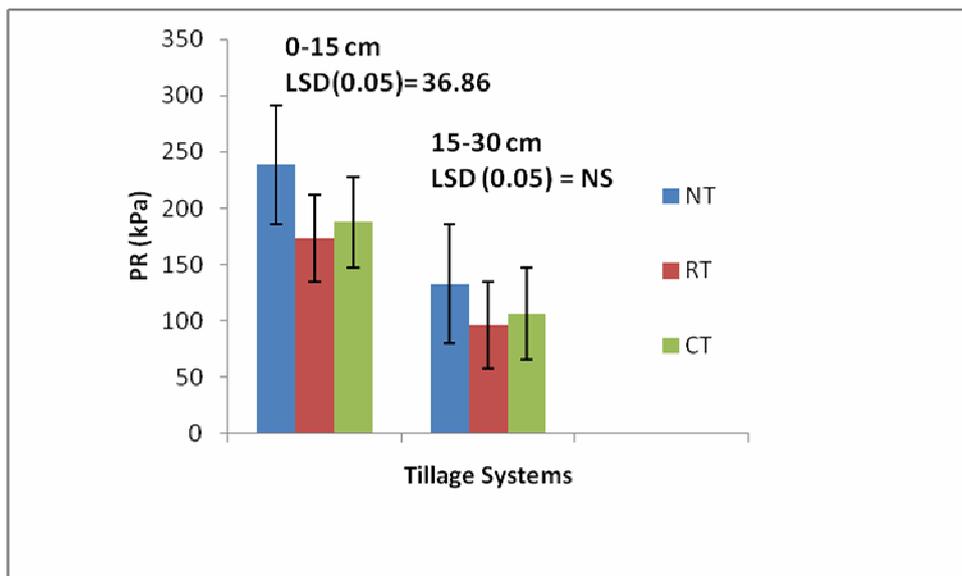


Figure 1: Effect of tillage systems on mean penetration resistance (PR) of the soil (kPa) at 0-15 and 15-30 cm soil depths (bars indicate standard error)

Table 1b: Percentage sand, silt and clay contents of the soil as affected by tillage systems for 15-30 cm soil depth

Treatments	(% sand)	(% silt)	(% clay)	Textural class
15-30 cm				
NT				
1	70.3	14.35	15.35	Sandy loam
2	65.3	24.35	10.35	Sandy loam
3	67.8	19.35	12.85	Sandy loam
4	67.8	19.35	12.85	Sandy loam
5	67.8	19.35	12.85	Sandy loam
Mean	67.8	19.35	12.35	
RT				
1	70.3	14.35	15.35	Sandy loam
2	67.8	19.35	12.85	Sandy loam
3	65.3	24.35	10.35	Sandy loam
4	67.8	16.85	15.35	Sandy loam
5	65.3	16.85	17.85	Sandy loam
Mean	67.3	18.35	14.85	
CT				
1	62.8	24.35	12.85	Sandy loam
2	65.3	24.35	10.35	Sandy loam
3	62.8	24.35	12.85	Sandy loam
4	65.3	19.35	15.35	Sandy loam
5	65.3	16.85	17.85	Sandy loam
Mean	64.3	21.85	13.35	
LSD	2.66	NS	2.15	

¹NS- not significant at $p \leq 0.05$ level of probability

² 1....5- replication

Table 2: Mean bulk density (Bd) and total porosity (TP) of the soil as affected by tillage systems at 0-15 and 15-30 cm soil depths

Treatment	Sampling Dates			
	27/07/2010	12/08/2010	28/08/2010	12/09/2010
0 – 15cm	Bd (g/cm⁻³)			
NT	1.62	1.64	1.63	1.68
RT	1.68	1.64	1.63	1.67
CT	1.60	1.62	1.62	1.66
LSD(0.05)	0.0275	NS	NS	NS
15 – 30cm	TP (%)			
NT	1.63	1.63	1.65	1.69
RT	1.74	1.66	1.68	1.70
CT	1.66	1.65	1.68	1.75
LSD(0.05)	0.0623	NS	NS	0.050
0 – 15cm	TP (%)			
NT	38.70	38.05	38.50	36.46
RT	36.50	38.20	38.42	36.74
CT	39.45	38.77	38.96	37.34
LSD(0.05)	1.055	NS	NS	NS
15 – 30cm	TP (%)			
NT	38.57	38.57	37.64	36.28
RT	34.35	37.35	36.44	35.84
CT	37.35	37.82	36.46	33.90
LSD(0.05)	2.363	NS	NS	1.918

¹NS – not significant at $p \leq 0.05$, ²NT

Table 3: Mean volumetric moisture content (Θv) of the soil as affected by tillage systems at 0-15 and 15-30 cm soil depths

Treatment	Sampling Dates			
	27/07/2010	12/08/2010	28/08/2010	12/09/2010
0 – 15cm	Θv (%)			
NT	15.24	15.60	13.03	11.74
RT	14.76	14.15	14.26	11.11
CT	12.65	12.28	11.61	10.66
LSD(0.05)	2.468	2.642	1.871	NS
15 – 30cm	Θv (%)			
NT	16.39	15.59	12.33	11.90
RT	16.50	16.60	14.53	12.39
CT	14.91	15.39	13.10	9.02
LSD(0.05)	NS	1.104	0.860	1.123

¹ NS – not significant at $p \leq 0.05$, ²NT-no-till, RT-reducetill, CT-conventional tillage.
- no-till, RT-reduce till, CT-conventional tillage

Table 4a: Pearson correlation coefficients (r) between organic carbon, aggregate stability indices and volumetric moisture content (Θv) of the soil at 0-15 cm soil depth

Parameters	Sampling Dates			
	27/07/2010	12/08/2010	28/08/2010	12/09/2010
	0 – 15 cm			
	(Θv)	(Θv)	(Θv)	(Θv)
OC	0.86***	0.76**	0.72**	0.87***
MAW	0.80***	0.89***	0.68**	0.52*
MAD	0.42 ^{ns}	0.44 ^{ns}	0.72**	0.19 ^{ns}
ASC	0.51 ^{ns}	0.62*	0.58*	0.59*
DR	-0.66**	-0.71**	-0.47	-0.54*
WSI	0.58*	0.58*	0.55*	0.65**

1-OC-organic carbon, MAW- wet macro aggregate, MAD- dry macro aggregate, ASC- aggregated silt + clay, DR- dispersion ratio, WSI- water stability index, Θv- volumetric moisture content (%)

2- *, **, ***, means significant at 5%, 1% and 0.1% level of probability

3- degree of freedom (df) of treatments in all analyses made are : tillage (2), blocks (4), error (8) and total (14)

Table 4b: Pearson correlation coefficients (r) between organic carbon, aggregate stability indices and volumetric moisture content (Θ_v) of the soil at 15- 30 cm soil depth

Parameters	Sampling Dates			
	27/07/2010	12/08/2010	28/08/2010	12/09/2010
	15 - 30 cm			
	(Θ_v)	(Θ_v)	(Θ_v)	(Θ_v)
OC	0.22 ^{ns}	- 0.08 ^{ns}	0.06 ^{ns}	0.37 ^{ns}
MAW	0.48 ^{ns}	0.19 ^{ns}	- 0.08 ^{ns}	0.51 [*]
MAD	0.17 ^{ns}	0.42 ^{ns}	0.18 ^{ns}	0.47 ^{ns}
ASC	0.58 [*]	- 0.04 ^{ns}	0.11 ^{ns}	0.43 ^{ns}
DR	- 0.50 [*]	0.16 ^{ns}	0.05 ^{ns}	- 0.55 [*]
WSI	0.20 ^{ns}	- 0.18 ^{ns}	0.27 ^{ns}	0.37 ^{ns}

1-OC-organic carbon, MAW- wet macro aggregate, MAD- dry macro aggregate, ASC- aggregated silt + clay, DR- dispersion ratio, WSI- water stability index, Θ_v - volumetric moisture content (%)

2- *, **, ***, means significant at 5%, 1% and 0.1% level of probability

3- degree of freedom (df) of treatments in all analyses made are : tillage (2), blocks (4), error (8) and total (14)

CONCLUSION

The study revealed that, tillage systems significantly ($p \leq 0.05$) affected physical properties of the soil with greatest influence observed on volumetric moisture content of the soil. The NT and RT treatments, on average, have best of soil physical conditions to

support crop production relative to the CT treatment, and should therefore be employed for sustainable crop production in the area. It is however recommended that, other reduced tillage systems such as animal traction and ridge tillage should be tried to assess their efficacy of improving soil physical quality.

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