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The effects of moisture content at tillage on soil strength in maize production

Kabiru Alani Shittu^{a,*}, Durodoluwa Joseph Oyedele^a, Kayode Moses Babatunde^b^a Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria^b The Oke-Ogun Polytechnic, Saki, Oyo State, Nigeria

1. Introduction

An adequate and balanced supply of moisture is essential for plant growth. Moisture is constantly being taken up by plants together with nutrients and is lost by transpiration. Inadequate moisture coupled with transpiration decreased plant growth rate and the final crop yield [1]. Water serves four general roles in plants: it is the major constituent of the physiologically active tissue; as a reagent in photosynthetic and hydrolytic processes; as a solvent for salts, sugars and other solutes and it is essential for the maintenance of turgidity necessary for cell enlargement and growth [2]. In agricultural systems, soil and crop management practices (crop rotation, residue management, the intensity and frequency of tillage) produce long-term effects on soil quality which may be detrimental or beneficial to our environment. For instance, tillage can degrade soil quality by mechanically destroying soil aggregates and exposing protected soil organic to microbial attack [3]. Compaction and tensile stresses during seedbed preparation drastically altered porosity and pore size distribution due to change in soil volume. However, tillage mixes residue with the soil, aiding decomposition of crop residue and native soil organic matter, thereby enhancing mineralization and release of nutrients [4]. Studies have shown that greater bulk density can be expected in some soil types with no-till compared to plough-till practices [5]. Crusting is a soil surface characteristic that provides information on soil strength or penetration resistance. Higher crust strength has been reported to reduce soil water storage due to the reduction of crust conductance and infiltration rates [6,7]. Tillage systems create an ideal seedbed condition for plant emergence, developments and un-impaired root growth [8]. It is an essential management technique that helps to control weeds and input that also affects soil physical characteristics. However, changes in soil properties differ among management practices [9].

To efficiently handle the demand in agricultural food production, soil physical properties must be managed adequately. The main concern of soil physics in crop productivity is to preserve suitable proportions between solid, liquid and gaseous phases [10]. It was reported that soil physical properties affected by soil tillage treatments, could influence the yields of crops [11]. For

instance, soil compaction causes low porosity, reduced infiltration, increase penetration resistance and limit root growth. Soil surface roughness (configuration) influences wind and water erosion by decreasing soil detachment and transport caused by erosion [12]. Low soil moisture content can make the cohesive force between particles of soil to be very strong and a lot of energy is to overcome this during tillage. However, with the higher soil moisture content, the effectiveness of tillage equipment in the field is reduced [13]. In a study at North Dakota, U.S.A, it was concluded that inconsistencies observed in relative grain yield differences among tillage treatments over a period of years were partly associated with inconsistent differences in soil properties produced by given tillage treatments from one year to another [14]. The authors concluded that the observed inconsistencies were likely to be associated with the presence of soil water at the time of tillage distribution and differences in soil temperature.

The major contributing factor to the increasing rate of soil degradation in African countries is due to tillage being carried out at inappropriate soil moisture contents. Tillage induced soil compaction is becoming a growing ecological concern because of the steady increase in the weight of machineries used in agriculture. Moreover, soil properties are not considered in purchasing these equipment. This problem is exacerbated by carrying out tillage operations under unfavourable moisture conditions. In Nigeria, no conscious effort has been made to evaluate the appropriate soil moisture conditions for the tillage of benchmark agricultural soils. This study is therefore expected to determine maize yield and soil properties changes resulting from tillage operations carried out at different soil moisture conditions. It is with the view to establishing the optimum range of moisture contents for the cultivation of the selected Alfisol in Ile-Ife area, Nigeria.

2. Materials and methods

2.1. The study area

The field experiment was conducted at Obafemi Awolowo University Teaching and Research Farm (O.A.U.T. & R.F.), Ile-Ife, Nigeria. The coordinates of the location ranged from latitude 7° 33.308'N to 7° 33.267'N and longitude 4° 33.466'E to 4° 33.446'E. Average annual rainfall is about 1400 mm which is bimodally distributed with peaks in June and September. Average daily

* Corresponding author.

E-mail address: kabirualani05@gmail.com (K.A. Shittu).

insolation is $19.2 \text{ MJ m}^{-2} \text{ d}^{-1}$ while average monthly value for humidity, maximum temperature, minimum temperature, sunshine hour, potential evapotranspiration (PET), wind speed were 73.8%, 30.7 °C, 27 °C, 6.6 h, 4.36 mm d^{-1} and 114.6 km d^{-1} , respectively [15]

The soils at the experimental site were derived from coarse grained granite and gneisses and classified as Iwo series and as Alfisol [16]. The site was located on a 1–3% slope. The soil is well-drained with the surface texture varying from sandy loam to loamy sand.

2.2. Experimental layout

The experimental field which was 0.6 ha in size was laid out in a randomized complete block design. The treatment consisted of plots that were ploughed at moisture contents (g g^{-1}) of 13% (MC_4), 14% (MC_3), 16% (MC_2) and 19% (MC_1) and no-tillage plot. The no-tillage plots were sprayed with glyphosate herbicide to control weeds. The treatments (soil moisture contents) were monitored with the use of a TDR 300 (Specmeters, Pullman, USA) weekly. The experimental field was planted to maize in the early seasons of 2008 and repeated in early season 2009 (May–June)

2.3. Field study

Changes in field soil moisture content was monitored within crop rows weekly to a depth of 15 cm. Ten readings were taken randomly within each treatment plot. Saturated hydraulic conductivities were measured using a Guelph Permeameter. Three soil hydraulic conductivities measurements were taken fortnightly at randomly selected positions within each experimental plot for 3 months during the cropping season to the depth of 15 cm. A dynamic Cone Penetrometer (UK DCP 2.2) with 20 mm cone diameter and 60° angle was used to measure the soil strength. Ten soil crust strength measurement were taken at randomly selected positions fortnightly for 3 months during 2008 and 2009 cropping season. Penetrometer readings to 50 cm soil depth were taken at random from each experimental plot and the average computed. The hammer of the instrument was raised to height of 50 cm before release to make the cone penetrate into the soil. Several blows were made until the depth of 50 cm was reached. The depth of penetration following each blow was read on the meter rule and recorded. Soil samples were collected from each plot using a 71.30 cm^3 volume cylindrical steel core sampler for bulk density determination. The total dry shelled weight maize from each plot was determined after harvested.

2.4. Laboratory analysis

At 4 and 8 weeks after planting for each cropping season, undisturbed soil cores were taken within crop rows for determination of bulk density (BD). The soil cores were put in an oven and dried at

105 °C to a constant weight. Bulk density of the soil was calculated as the mass of dry soil divided by the core ring volume. Particle size analysis was determined by the modified Bouyoucos hydrometer method [17].

2.5. Statistical analysis

The data were subjected to correlation and analysis of variance (ANOVA). Significant treatments differences were obtained using Duncan's Multiple Range Test (DMRT) to determine the effect of moisture content at tillage on selected soil physical properties and maize crop yield. Effects were considered significant in all statistical analysis for P values <0.05

3. Results

3.1. Soil textural composition

The data on textural composition of the soil are presented in Table 1. Soil textural composition within 0–15 cm and 15–30 cm soil depth ranged from sandy loam to loamy sand. The textures of the soils were sufficiently homogenous, and hence may not contribute to variations in the experimental units.

3.2. Bulk density (BD), soil crust strength and saturated hydraulic conductivity

Soil surface (0–15 cm) BD data measured between the crop rows (inter-row) is presented in Table 2. This shows that soil BD was not significantly affected by the tillage methods during both years of cropping. Soil crust strength is an important soil physical characteristic that provides information on ability to allow water movement. The temporal variations in soil crust strength with different moisture content at tillage during cropping season are shown in Fig. 1. There were significant differences ($P \leq 0.05$) in the crust strength at 5, 15 and 40 cm soil depths among the treatments. The no-tillage plots (Control) had the highest crust strength (0–15 cm depth) value of $1.84 \times 10^{-3} \text{ MPa}$ ($P \leq 0.05$) while the plots tilled at 14% moisture content (MC_2) had the least value at 0–5 cm soil depth. The order of increase in soil penetrometer resistance was $C > \text{MC}_1 > \text{MC}_4 > \text{MC}_3 > \text{MC}_2$. The soil strength for MC_1 ($2.97 \times 10^{-3} \text{ MPa}$) at 10–15 cm soil depth, was 89.17% significantly higher than MC_3 ($1.57 \times 10^{-3} \text{ MPa}$) (Table 3).

The higher values of soil strength recorded for conventional tillage systems when compared with zero tillage system at this soil depth might be due to soil compaction because of continuous use of heavy machinery on the former. The crust strength for no tillage plot ($6.93 \times 10^{-3} \text{ MPa}$) was 87.59% significantly lower than MC_4 ($13.00 \times 10^{-3} \text{ MPa}$) at soil depth between 40 and 50 cm. The order of increase was $\text{MC}_4 > \text{MC}_2 > \text{MC}_3 > \text{MC}_1 > C$. The saturated hydraulic conductivity (Ks) at the soil surface (0–15 cm) showed

Table 1
Textural composition of surface and sub-surface soils.

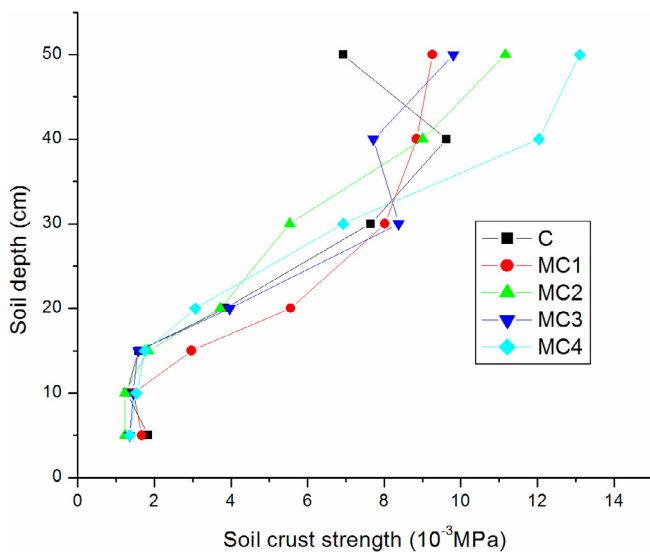
Treatments	0–15 cm				15–30 cm			
	Sand	Silt	Clay	Texture	Sand	Silt	Clay	Texture
	g/kg				g/kg			
C	700	210	90	S L	680	250	70	SL
MC_1	770	160	70	SL	740	220	40	LS
MC_2	750	180	70	SL	710	230	60	SL
MC_3	780	170	50	LS	770	200	30	LS
MC_4	780	140	80	LS	710	220	70	SL

S L = Sandy Loam, LS = Loamy Sand.

Where, C = control, MC_1 , MC_2 , MC_3 and MC_4 are 19, 16, 14 and 13% moisture contents respectively.

Table 2Bulk densities (g/cm^3) at 0–15 cm soil depth for the early seasons of 2008 and 2009.

Treatments	Bulk density (g/cm^3)			
	First cropping		Second cropping	
	Db ₁	Db ₂	Db ₃	Db ₄
C	1.45a	1.45a	1.22a	1.36a
MC ₁	1.52a	1.56a	1.36a	1.30a
MC ₂	1.48a	1.47a	1.16a	1.34a
MC ₃	1.59a	1.55a	1.37a	1.35a
MC ₄	1.56a	1.40a	1.30a	1.39a
Mean	1.52	1.49	1.28	1.35

Means along the same column followed by the same alphabets are not significantly different at ($P \leq 0.05$) according to Duncan's Multiple Range Test.Where, C = control, MC₁, MC₂, MC₃ and MC₄ are 19, 16, 14 and 13% moisture contents respectively. Db₁: Bulk density at 4th week in the first cropping season, Db₂: Bulk density at 8th week in the first cropping season. Db₃: Bulk density at 4th week in the second cropping season. Db₄: Bulk density at 8th week in the second cropping season.**Fig. 1.** Effects of moisture content on soil strength.**Table 3**Effect of moisture content at tillage on soil saturated hydraulic conductivity, Ks, (cm/h).

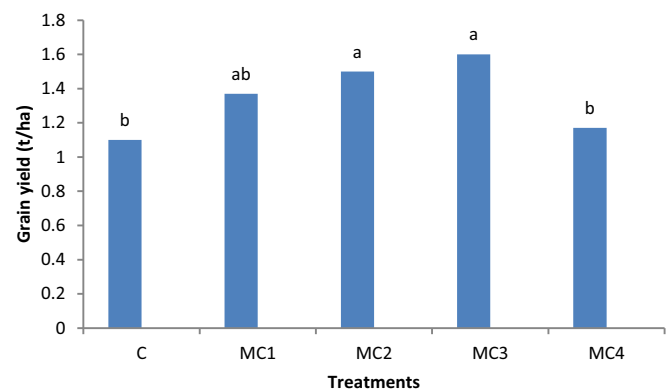
Treatments	First season	Second season	Mean
	(cm/h)		
C	21.60a	32.40a	28.80
MC ₁	18.00a	10.80a	15.48
MC ₂	10.80a	9.72a	5.40
MC ₃	3.60a	11.16a	7.20
MC ₄	21.61a	9.36a	15.84

Means within the same column followed by the same alphabets are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test.Where, C = control, MC₁, MC₂, MC₃ and MC₄ are 19, 16, 14 and 13% moisture contents respectively.

that values were not significantly different ($P \leq 0.05$) among the treatments considered in the two cropping seasons.

3.3. Grain yield of maize

There was a significant seasonal difference in the average grain yield of maize (Fig. 2). The highest yield of 1.6 t/ha ($p \leq 0.05$) was recorded on treatment MC₂ followed by MC₁ (1.5 t/ha) while no tillage had least value of 1.10 t/ha. The order of increase in the average grain yields for the two cropping seasons was MC₃ > MC₂ > MC₁ > MC₄ > C.

**Fig. 2.** Effect of moisture content at tillage on average grain yield of maize for the two cropping seasons.

3.4. Relationship among selected soil physical properties and maize grain yield

Table 4 shows the correlation matrix for selected soil properties. The cone index (which expresses the resistance of soil to root penetration and seedling emergence) at 10 cm soil depth was highly positively correlated with soil bulk density in the first cropping season ($r = 0.57$). Positive association between soil cone index at 0–5 cm and 5–10 cm soil depths suggested that soil strength increased as soil depth increased. Soil penetrometer resistance at both 0–5 cm and 5–10 cm soil depths are significantly negatively correlated with the yield in the first cropping season ($r = -0.64$ and $r = -0.51$, respectively). It may be stated that among the soil parameters considered about 41% and 26%, respectively of the decrease in the yield in this environment were solely due to mechanical impedance to root growth due to increased soil resistance.

4. Discussion

This study investigated the effects of four different moisture contents at tillage on soil strength. Textural composition within the soil depth studied was relatively uniform, hence can not constitute variation in the experimental units. The highest crust resistance recorded for control experiment (i.e. plot without tillage) at 0–5 cm soil depth can be due to a combination of rain drop impact, surface sealing, strong crust and soil compaction due to repeated human traffic during weed control. These results are in agreement with [6] who observed that bare minimum tillage where the weeds were controlled by herbicides had stronger crust strength at the surface (0–5 cm) than in the treatments where the crust were disturbed by farm machinery. The higher values of soil

Table 4

Correlation matrix for selected soil physical properties and maize grain yield.

	Db1	Db2	Db3	Db4	K_1st	K_2nd	Y1st	Y2nd	CL_5	CL_10
	(g/cm ³)				(cm/h)		(t/ha)		(MPa)	
Db1 (g/cm ³)	1.00									
Db2 (g/cm ³)	0.26	1.00								
Db3 (g/cm ³)	0.27	0.59**	1.00							
Db4 (g/cm ³)	0.10	0.27	0.22	1.00						
K_1st (cm/h)	0.43	0.01	0.16	0.07	1.00					
K_2nd (cm/h)	−0.24	0.24	0.14	−0.13	0.05	1.00				
Yd_1st (t/ha)	−0.01	−0.26 0.03	−0.40	0.10	0.33	1.00				
Yd_2nd (t/ha)	0.37	−0.19	−0.13−0.50**	0.21	−0.12	0.41	1.00			
CL_5 (MPa)	−0.26	0.31	0.07	0.39	−0.40	−0.27	−0.64**	−0.34	1.00	
CL_10 (MPa)	0.09	0.57**	0.29	0.26	−0.05	−0.11	−0.51**	−0.21	0.67**	1.00

* and ** significant at 0.05 and 0.01 level of probability.

Where, Y 1st: Yield of the first cropping season; Y 2nd: Yield of the second cropping season; CL_5: Crust resistance for 0–5 cm soil depth; CL_10: Crust resistance for 5–10 cm soil depth; K_1st: First saturated hydraulic conductivity in the first cropping season; K_2nd: Second saturated hydraulic conductivity in the second cropping season.

strength recorded for conventional tillage systems when compared with zero tillage system at 10–15 cm soil depth might be due to soil compaction as a result of heavy machinery continuously being used in the former. This is because of the weight of tractor is usually vectored below the ploughed layer [18]. The implication of this is possible mechanical impedance to root development and proliferation under MC₄ when compared to other treatments in line with the observations of [19,20]. This may be responsible or negative association between maize yield and soil cone index of the soil of soil penetration resistance.

It may be stated that among the soil parameters considered, about 41% and 26% respectively of the decrease in the yield in this environment were solely due to mechanical impedance to root growth. Similar findings were reported by [21–23].

5. Conclusion

The results confirmed that sandy loam or loamy sand soils are prone to crust formation and compaction which lead to unfavourable soil hydro-physical properties especially when the tillage is done at very low or very high moisture content. Tillage at MC₂ and MC₃ resulted in significant improvement in soil surface hydraulic conditions. Highest crust resistance recorded for control experiment compared to conventional tillage can hinder seedling emergence. The highest grain yield ($P \leq 0.05$) was recorded on treatments MC₃ and MC₂ as a result of favourable time at which the tillage were carried out. It can thus be suggested that tillage operations done at moisture content ranging from 14 to 16% produces optimum soil conditions and maize yield on the studied Alfisol.

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References

- [1] Alan W. Soils and environment. Soil conditions and crop production, 1993. p. 161.
- [2] Kamoni PT. Assessment of the land quality soil moisture availability and its effects on potential production by using a quantitative land evaluation approach. Wageningen: M.Sc. Agricultural University; 1985.
- [3] Follett RF, Schimel DS. Effect of tillage practices on microbial biomass dynamics. *Soil Sci Soc Am J* 1989;53:1091–6.
- [4] Gadjia AM, Doran JW, Kettler TA, Eienhoil BJ, Pikul JL, Cambardell CA. Soil quality evaluation of alternative and conventional management system in great plains. In: Las R, Kimble JM, Follett RF, Stewart BA, editors. Assessment method for carbon. Boca Raton, T.L. P: Lewis Publishers; 2001. p. 381–400.
- [5] Bruce RR, Langdale GW, Dillard AL. Tillage and crop effect on characteristics of a sandy surface soil. *Soil Sci Soc Am J* 1990;54:1744–7.
- [6] Gicheru PT, Gachene C, Mbuvi J, Mare E. Effects of soil management practices and tillage systems on soil surface soil water conservation and crust formation on a sandy loam in semi-arid Kenya. *Soil Tillage Res* 2004;75:173–84.
- [7] Shivorje FM, Okwach GE, Kironchi G. Soil crust formation as affected by slope gradient on clay soils of semi-arid Machakos District, Kenya. In: Mugendi DN, Kironchi G, Gicheru PT, Gachene CKK, Macharia PN, Mburu M, Mureithi JG, Maina F, editors. Capacity building for land resources management to meet the challenges of Soil Science Society of East Africa (SSSEA), 1st–5th December, 2003. Kenya: Eldoret; 2005. p. 123–36.
- [8] Licht MA, Al-Kaisi M. Strip-tillage effects on seedbed soil temperature and other soil physical properties. *Soil Tillage* 2005;80(1–2):233–49.
- [9] Elder JW, Lal R. Tillage effects on physical properties of agricultural organic soils of north central Ohio. *Soil Tillage* 2008;98(2):208–10.
- [10] Glinski J, Lipiec J. Soil physical conditions and plant roots. U.S.A.: CRC Press; 1990. p. 120.
- [11] Buschiazzo DE, Panigatti JL, Unger PW. Tillage effect on soil properties and crop production in the sub-humid and semi-arid Argentinean pampas. *Soil Tillage Res* 1998;49:105–16; Anazodo UGN, Onwualuand AP, Watts KC. Evaluation of alternative tillage system in the absence of herbicides for maize production in savanna loamy sand. *J Agric Eng Res* 1991;49:259–72.
- [12] Cogo NP, Moldenhauer WC, Foster GR. Effects of crop residue, tillage-induced roughness and runoff velocity on size distribution of eroded soil aggregates. *Soil Sci Soc Am J* 1983;47(5):1005–8.
- [13] Hojat A, Kaveh M. Effect of plowing depth and soil moisture content of reduced secondary tillage agricultural engineering international. *CIGRE J Manuscript* 2009.
- [14] Baurer A, Kucera HL. Effect of tillage on some soil physicochemical properties on annually cropping spring wheat yield. Agricultural Experiment Station, Northern Dakota State University. Bulletin 1978;80:506.
- [15] Akintola O. Rainfall distribution in Nigeria. Ibadan, Nigeria: Impact Publishers; 1986. p. 380.
- [16] Smyth AJ, Montgomery RF. Soil and land use in central Western Nigeria. Ibadan, Nigeria: Government Printers; 1962. p. 10–84.
- [17] Bouyoucos GJ. Hydrometer method improved for making particle size analysis of soils. *Agron J* 1962;27:738–74.
- [18] Anazodo UGN, Onwualuand AP, Watts KC. Evaluation of alternative tillage system in the absence of herbicides for maize production in savanna loamy sand. *J Agric Eng Res* 1991;49:259–72.
- [19] Barber SA. Effect of tillage practices on corn root distribution and morphology. *Agron J* 1971;63:724–6.
- [20] Adepetu JA, Sagay GA. Effect of tillage system and fertilizer application on root growth, nutrient uptake and yield of maize. *Nigeria J Agric Sci* 1981;3:37–43.
- [21] Gregory PI. Growth and functioning of plants roots. In: Wild A, editor. Russell's soil conditions and plant growth. Harlow, U.K.: Longman; 1988. p. 113–67.
- [22] Vepraskas MJ. Plant response mechanism to soil compaction. In: Wilkerson RE, editor. Plant environment interactions. New York: Marcel Dekker; 1988. p. 263–87.
- [23] Mckenzie DC. Measurement and management of compaction damage on vertisols under irrigated cotton [Ph.D. thesis]. Australia: Department of Agriculture, Chemistry and Soil Science, University of Sydney; 1996.