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Impact of tillage types on compaction and physical properties of soils of Sebele farms in Botswana

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Abstract

The study was designed to evaluate the effects of tillage types including deep-ripping, conventional and zero tillage on compaction, using selected physical properties of agricultural soils.Particle size distribution, organic matter, bulk density, Atterberg limits, infiltration rate, and soil moisture content were determined to investigate the impacts of tillage induced compaction on soil properties.The study was carried out in three plots, each measuring 2 ha. Soil penetration resistance (PR) as an index of compaction was in-situ measured and was correlated with other soil properties. The results showed a positive correlation between PR and bulk density, soil moisture content, plastic limit and liquid limits. Although not statistically significant ($p < 0.05$), correlation coefficients of these relationships were 0.40, 0.47, 0.56, and 0.56, respectively, suggesting contribution of these properties to soil compaction. Zero tillage plot was more compacted with an average PR of 2.28 MPa, compared to conventional tillage which recorded an average of 1.45 MPa and deep-ripping tillage with an average PR of 1.13 MPa. Generally the results showed that tillage types have a significant ($p < 0.05$) impact on soil compaction and/or soil properties.

Keywords: *Compaction, moisture, soil physical properties, tillage types*

Introduction

Compaction of agricultural soils is a threat to soil productivity worldwide leading to soil desiccation and degradation manifested by poor crop production and detrimental environmental conditions. Soil compaction affects soil structure by destroying it. It also reduces soil porosity and water infiltration and air exchange and makes root penetration difficult and this leads to low crop yield (Wolkowski and Lowery, 2008). The vulnerability of soil to compaction is attributed to various factors. These are soil texture, moisture content and plasticity, vehicle weight and its speed, ground contact pressure and number of passes (Smith *et al*., 1997; Materechera, 2009). Compaction is becoming a threat in agriculture mainly due to the increasing weight of farm machinery (Materechera, 2009). Studies conducted in humid environments have indicated that soil compaction does not only lead to soil desiccation but leads to changes in soil physical and mechanical properties like soil structure, infiltration rate and bulk density (Ohu *et al*., 1993) as well.

Further, arid environments compaction due to tillage types may cause soil-hard setting especially in dry periods, making tillage difficult (Lal, 1995). Soil compaction effects on soil properties in arid and humid regions vary due to different soil properties like soil moisture content. In arid regions high temperatures lead to high evaporation rates resulting in decreased moisture content manifested by formation of a hard pan and/or compaction. As the soils get drier especially in areas characterized by clays the soil become more compact. Moreover, soil penetration resistance increases as soil water potential decreases (Kondo and Dias Junior,1999). Similarly compaction of soils is usually excessive when tillage is performed under wet conditions (Materechera *et al*., 2009).

In Botswana, deep-ripping and conventional tillage have been used widely for many decades mainly for agricultural production, and their impacts on soil remain a global concern as evidenced by numerous studies (Bennie and Burger, 1979; Ishaq *et al*., 2003; Mitchell and Wajberry, 2007; Materechera, 2009; Horn and Flesige, 2009). In comparative studies conducted in the study area, tilled fields were reported to be more prone to sub-soil compaction than non-tilled soils (Sekwakwa and Dikinya, 2012). In view of this, impact of tillage types on soil compaction is well documented especially in humid regions, but not much in arid regions. Thus the study aims to evaluate tillage types effects on compaction in semi-arid Sebele farms in Botswana by determining selected soil physical properties where; (a) deep-ripping, (b) conventional tillage and (c) zero tillage is being practised.

Materials and Methods

Study area

Sebele farms measures 16 hectares (ha) and is located at Latitude $24^0 34$'S and Longitude $25^0 57$'E. Conventional, deep ripping and zero tillage is practised and 2 ha plots of

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each tillage type was used for sampling. The study was conducted at Sebele farms (Block B and D, student garden and on virgin land). The farms are located approximately 10 km North east of the capital Gaborone along the A1 road leading to Francistown. The plots are generally fertilized with NPK fertilizers applied after every two ploughing seasons. However, the experiment was conducted on short term period after a fallow period of 4 years (with no further addition of fertilizers) following recent droughts. In each plot the same type of tillage is practised for three years and to date the farms are still used for ploughing and prior to collection of data the type of tillage that was practiced was in its third year of practice. Typical soils found in Sebele farms include Chromic Luvisols (Verbeek and Remmelzwaal, 1990) characterized by dark brown-toned, sandy loam and loamy sand. Crops that are normally grown there include lab, maize, sorghum and cowpeas. The climate is semi-arid with hot, wet summers and cool dry winters with an average rainfall of 500 mm.

Experimental design and sampling

To carry out a comparative assessment of tillage induced compaction using soil physical and mechanical properties, a total of 30 samples were collected at a depth of 0-45 cm. These samples were collected from various sites under different tillage treatments. Ten (10) samples were collected systematically from each tillage treatments namely; zero tillage (OT)-no soil disturbance, deep-ripping tillage (DRT) i.e. sub-soiling to a depth of about 45 cm, and conventional tillage (CT) where hand held machinery were used to till the soil. As for bulk density, a total of three samples were collected at each sampling point. Samples were collected at incremental depth of 15 cm (0-15, 15-30, 30-45 cm).Samples were collected when the soils were still under field moisture conditions i.e. after rainy season. In each tillage treatment, the distance between the sampling points was 20 m apart and 50 m between plant rows.

Soil measurements

Penetration resistance

Penetration resistance (PR) measurements were done in each tillage type from a depth of 5 to 50 cm. A total of three measurements were done at each point to get an average.A programmed digital Eijkelkamp penetrologger (cone base area of 1.0 cm^2 with an angle of 60^o) was used to measure penetration resistance at 5 cm incremental from 0 to 50 cm depth in every row of each tillage treatment. Measurements from each row were averaged to represent the PR of the row.The penetrologger cone was inserted into the soil evenly and as vertically as possible, at a constant average speed of about 2 cm s^{-1}. The penetrometer monitored the values digitally, and readings were taken once the maximum reading at a specified depth reached a constant value.

Soil particle size

To determine soil texture, the Bouyoucos Hydrometer method based on Stokes Law was applied (Van Reeuwijk, 2003).

Soil bulk density and soil moisture

To measure soil bulk density (BD), core method was used (Rowell, 1994). A cylindrical or core sampler of known volume (100 cm^3) was driven into the soil to collect soil samples. The samples were then oven-dried at 105 ^{0}C for 48 h to obtain dry mass. The BD was calculated as a ratio of mass of oven-dry soil to the volume of the core cylinder. Field moisture contents from the samples were also determined gravimetrically from samples collected at three depths being 0-15 cm, 15-30 cm and 30-45 cm. Further, to effectively evaluate the degree of soil compactness, we also calculated relative bulk density (RBD) as the ratio of soil BD to a reference bulk density. Critical bulk density (BDcrit) was calculated based on clay content using an empirical approach $BDcrit$ (g cm^{-3}) = 1.985 − 0.00857 clay (%) by Jones (1983) also cited in Dexter (2004) and Asgarzadeh *et al.* (2010).

Soil organic carbon

The wet-oxidation method, modified Walkley and Black Method (Schulte, 1995) was used to estimatesoil organic carbon (SOC) which was used to calculate the presence of organic matter in the soil.

Water infiltration

The double-ring in filtro meter method (Bouwer, 1986) was used to measure water infiltration into the soils in all three tillage types. A hammer was used to drive the cylinders into the soil to a depth of 30-50 mm with minimum disturbances to the soil. The diameter of the inner ring was 290 mm while the diameter of the outer was 520 mm. Water was added starting with the inner cylinder (with a hydraulic head of 50-75 mm above the soil surface). Water was then added to the outer cylinder with similar head. As the water levels drops, the reading and the time were noted. Measurements were taken at regular interval (5 min) until the water infiltration reached steady state i.e. intake reached a constant value i.e. after 90 min elapsed. A total of two measurements were done at each point to get an average.

Atterberg limits

Atterberg limits, mainly liquid limit and plastic limit were determined using the moisture tension method. The equilibrium moisture content of the soil samples was determined utilizing four pressure intensities. The pressure intensities used in the moisture tension method were: 6, 10, 12 and 18 psi. For each pressure intensity, four replicate tests were run. Linear regression models were hypothesized to study the relationships between the measured variables, liquid limit and plastic limit and independent variable, WC- (the symbol WC- will be used to represent the moisture content obtained under i psi pressure intensity). A separate model was evaluated for each of the four pressure intensities. Non-plastic soils were excluded from the study (Gadallah *et al*., 1973).

Statistical analysis

Collected data were analysed using analysis of variance (ANOVA) package on Microsoft Office Excel software. The least significant difference (LSD) was used to test the significant difference between the means of different soil properties from three different plots (at p = 0.05). Correlation between soil compaction and soil physical and mechanical properties was tested using soil PR as a composite index of compaction.

Results and Discussion

Compaction and moisture effects on penetration resistance

The mean values of penetration resistances for conventional, deep-ripping, zero tillage were1.13, 1.45 and 2.28 MPa, respectively, representing an increasing trend. The difference in these PR values was significant (p < 0.05). Generally soil penetration resistance (PR) increased with depth (Figure 1) as this was evidenced in all the three tillage types. For samples collected at 0-15 cm depth, PR value for conventional tillage was 0.75 MPa, whereas for zero tillage and deep ripping tillage was 2.33 MPa and 1.11 MPa, respectively. As depth increased, the moisture content decreased and the PR values increased, i.e. at 45 cm depth, deep-ripping tillage recorded 2.01 MPa, whereas conventional tillage recorded 1.42 MPa and zero tillage recorded 2.4 MPa. The high PR values down the profile corroborates with Materechera (2009) who stated that compaction increases with depth due to hard pan forming deep down the soil. The increase of PR down the profile is also attributed to low moisture content as you go down the profile (Figure 1). This was evidenced in this study as soils near the surface (0-15 cm) recorded high moisture content compared to soils sampled at 30-45 cm. Average moisture contents at 0-15 cm depth was 2.5% whereas at 30-45 cm it was 1.1%. Although the PR values were different, the trends were not different. The high PR values in zero tillage were attributable to minimal soil disturbance compared to other tillage types making the soil more compact. Donkor *et al*. (2002) reported thatfine-textured soils are easily compacted compared to texture characterised by larger particles. In this study textural class did not affect PR since there was no significant difference in particle size distribution (p < 0.05) of all the tillage types (Tables 1 and 2). Low compaction in deep-ripping and conventional tillage compared to zero tillage is also attributable to loosening of the soil although deep-ripping recorded higher PR (1.45 MPa) than conventional tillage (1.13 MPa).These two values were not significantly different (p < 0.05). This indicates that tillage types had little influence on soil compaction and this corroborates with other studies (Vaz and Hopmans, 2001).

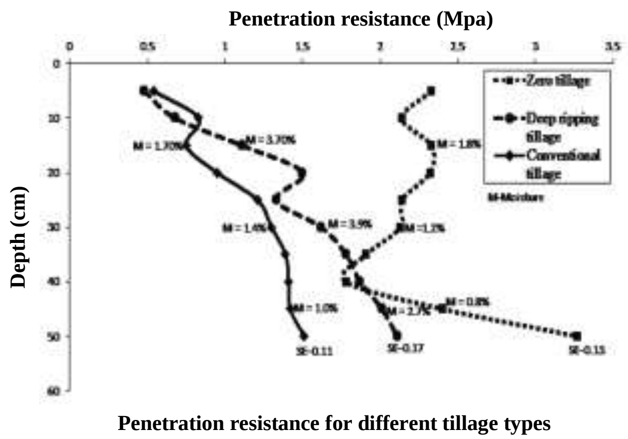

Figure 1: Penetration resistance values for different tillage types and moisture contents at various depths. The differences in PR values of all the three plots were non-significant (p < 0.05). SE denotes standard error

Correlation analysis was done to test the relationship and influence of each measured soil property had on PR as an indicator of compaction (Table 1).

Effects of particle size and organic matter on compaction

Table 2 shows a relatively high proportion of clay in zero tillage (16%) and conventional (15%) tillage types compared to zero tillage (12%) and a high percent of sand in zero tillage (82.6%) than in deep-ripping (77.2%) and conventional tillage (77.7%) although not significantly different (p<0.05). The main textural class in all the three tillage types was sandy loam and loamy sand. The loamy sands, because of their slightly cohesiveness (Rowell 1994) are susceptible to compaction. Similarly, finer texture (e.g. clay and silt), was reported to lead to compaction compared to coarser soil particles like sand (Ohu *et al*., 1993) because of the binding effect of clay particles (Yavuzcan *et al*., 2005). However, our results show that textural class did not influence PR since there was no significant difference ($p < 0.05$) in particle size distribution.

density is generally low and is attributable to loose soil structure causing immediate increase in the percentage of macrospores (So *et al*., 2009) which can benefit seedling establishment and crop growth (Sturz *et al*., 1997).

Table 1: Correlation coefficients between soil PR and measured soil properties for all three different tillage types (sampled at 0-45 cm depth)

	PR (MPa)	BD (g cm^{-3})	TP (%)	SMC (%)	PL	LL	IR (cm h^{-1})	OM (%)	% Clay	% Silt	% Sand
PR (MPa)	1										
BD(g cm^{-3})	0.40a	1									
TP (%)	–0.25	–0.34	1								
SMC (%)	0.47a	0.16	0.13	1							
PL	0.56a	0.19	0.13	0.61	1						
LL	0.56a	0.11	0.21	0.76	0.67	1					
IR(cm h^{-1})	0.53a	–0.10	0.15	0.13	0.14	0.10	1				
OM (%)	–0.15	0.08	0.30	0.25	0.38	0.54	–0.28	1			
% Clay	0.13 ns	–0.02	0.33	0.42	0.48	0.73	0.37	0.67	1		
% Silt	0.15ns	0.11	0.18	0.08	0.13	0.24	–0.01	0.31	0.24	1	
% Sand	–0.18ns	–0.05	0.33	0.34	0.41	0.64	–0.25	0.64	0.83	0.74	1

Correlations values with the same letters were significant ($p < 0.01$), ns-not significant ($p < 0.05$).
Where **PR**-soil penetration resistance, **BD**-bulk density, **TP**-Total porosity, **SMC**- Soil moisture content, **PL**-Plastic limit, **LL**-Liquid limit, **IR**-Infiltration rate, **OM**-Organic matter

Furthermore, zero tillage recorded higher organic matter content (2.23%) compared to conventional (1.35%) and deep-ripping tillage types (1.38%) Table 2. This might be due to plant residue mulches left on the soil surface in the zero tillage with least disturbance. Similar studies have found that zero or minimum tillage often increases soil organic matter content (Johnson, 1992). This is due to dead plants and litter (Brady and Weil, 2008). In contrast, soils low in organic matter tend to be easily compacted (Daum, 1996). This is further supported by Mamman *et al*. (2007) who stated that penetration resistance decreases with increase in organic matter level. In this study, this was not the case as reflected by high organic matter content (2.23%) and PR (2.28 MPa) in zero tillage and 1.35% organic matter and 1.13 MPa PR for conventional tillage. This shows that in this study organic matter did not influence soil compaction. This could be due to the reason that the soils were not severely compacted. Non-significant difference of organic matter content in deep-ripping and conventional tillage was primarily due to intense cultivation leading to loss of organic matter. This makes the soil to rebound against compaction and stabilizing soil structure (Cochrane and Aylmore, 1994; Thomas *et al*., 1996).

Effects of tillage induced compaction on soil bulk density

Soils under zero tillage and deep-ripping tillage recorded high bulk density values, therefore influencing compaction by leading to high PR values. This was supported by positive but weak correlation ($r^2 = 0.40$) between PR and bulk density. Compaction induced bulk

Figure 2 shows bulk density values for various tillage types. Deep-ripping tillage had slightly higher bulk density (1.49 g cm^3), followed by zero tillage (1.47 g cm^{-3}) and conventional tillage (1.38 g cm^{-3}). Although the values for bulk density were non-significantly different ($p < 0.05$), the results clearly show that both deep-ripping and zero tillage were relatively more compacted than conventional tillage as evidenced by high PR values and would probably restrict water and air movement (Sekwakwa and Dikinya, 2012). These findings are consistent with Wolkowski and Lowery (2008) who reported that conventional tillage type can lead to lower bulk densities which have consequent effects on the soil's ability to allow easy water and solute movement and soil aeration and in crop and land management practices. This is because compacted soils are associated with small pores of capillary size and therefore not penetrable by most roots. Generally the total porosity is relatively low when it ranges from 13 to 27% (Pengthamkeerati *et al*., 2011). In this study, porosities were relatively high; Zero tillage (30.5%), deep-ripping tillage (29.2%) and conventional tillage (30.6%) although these were not significantly different ($p < 0.05$). Consistently, Figure 2 and Table 3 also indicate that bulk density increased with an increase in PR as observed in all tillage types. The increase of bulk density with PR also corroborates with Balbuena *et al*. (2000) who indicated that high bulk density increases with PR.Similarly, Manyiwa and Dikinya (2013) also attributed high density to high clay content (binding effect) in the non-eroded soil thus making

Table 2: Particle size distribution and organic matter (Sampling depth was 0-45 cm), Value ± Standard Error.

Zero tillage					Deep-ripping tillage					Conventional tillage				
S	**%C ±SE**	**%Si ±SE**	**%S ±SE**	**%OM ±SE**	**S**	**%C ±SE**	**%Si ±SE**	**%S ±SE**	**%OM ±SE**	**S**	**%C ±SE**	**%Si ±SE**	**%S ±SE**	**% OM ±SE**
0T1	15 ± 0.48	6 ± 0.31	79 ± 0.55	2.12 ± 0.11	DR1	13 ± 0.33	4 ± 0.71	83 ± 0.65	1.07 ± 0.11	CT1	15 ± 0.37	10 ± 0.47	75 ± 0.63	1.01 ± 0.11
0T2	17 ± 0.48	6 ± 0.31	77 ± 0.55	2.33 ± 0.11	DR2	13 ± 0.33	6 ± 0.71	81 ± 0.65	1.31 ± 0.11	CT2	17 ± 0.37	7 ± 0.47	76 ± 0.63	1.24 ± 0.11
0T3	18 ± 0.48	7 ± 0.31	75± 0.55	2.56 ± 0.11	DR3	13 ± 0.33	4 ± 0.71	83 ± 0.65	1.04 ± 0.11	CT3	15 ± 0.37	6 ± 0.47	79 ± 0.63	1.11 ± 0.11
0T4	17 ± 0.48	8 ± 0.31	75± 0.55	2.41 ± 0.11	DR4	11 ± 0.33	2 ± 0.71	87 ± 0.65	1.63 ± 0.11	CT4	14 ± 0.37	9 ± 0.47	77 ± 0.63	1.32 ± 0.11
0T5	17 ± 0.48	8 ± 0.31	75± 0.55	2.01 ± 0.11	DR5	13 ± 0.33	4 ± 0.71	83 ± 0.65	1.09 ± 0.11	CT5	15 ± 0.37	8 ± 0.47	77 ± 0.63	1.41 ± 0.11
0T6	17 ± 0.48	6 ± 0.31	77 ±0.55	1.61 ± 0.11	DR6	11 ± 0.33	6 ± 0.71	83 ± 0.65	1.31 ± 0.11	CT6	14 ± 0.37	7 ± 0.47	79 ± 0.63	2.03 ± 0.11
0T7	15 ± 0.48	6 ± 0.31	79 ± 0.55	2.96 ± 0.11	DR7	11 ± 0.33	10 ± 0.71	79 ± 0.65	1.94 ± 0.11	CT7	17 ± 0.37	8 ± 0.47	75 ± 0.63	1.32 ± 0.11
0T8	15 ± 0.48	6 ± 0.31	79 ± 0.55	2.11 ± 0.11	DR8	11 ± 0.33	8 ± 0.71	81 ± 0.65	1.97 ± 0.11	CT8	15 ± 0.37	6 ± 0.47	79 ± 0.63	1.64 ± 0.11
0T9	13 ± 0.48	8 ± 0.31	79 ± 0.55	2.18 ± 0.11	DR9	11 ± 0.33	6 ± 0.71	83 ± 0.65	1.08 ± 0.11	CT9	14 ± 0.37	5 ± 0.47	81 ± 0.63	1.08 ± 0.11
0T10	15 ± 0.48	8 ± 0.31	77 ± 0.55	1.96 ± 0.11	DR10	11 ± 0.33	6 ± 0.71	83 ± 0.65	1.37 ± 0.11	CT10	14 ± 0.37	7 ± 0.47	79 ± 0.63	1.36 ± 0.11
$\bar{X}$	**16c**	**7c**	**77c**	**2.23a**		**12c**	**6c**	**82c**	**1.38b**	$\bar{X}$	**15c**	**7c**	**78c**	**1.35b**

Where %C, %Si, %S and OM denote fractions of clay, silt, sand and organic matter, respectively, and 0T, DRT, CT and S denote zero tillage, deep-ripping tillage, conventional tillage and sample, respectively. Mean values with the same letter are not significantly different (LSD, $p < 0.05$) from each other. USDA Textural Class: 0T-Sandy loam, DRT-Loamy sand, CT-Sandy Loam. (Mean textural classes used to classify soil according to USDA textural class) it less vulnerable to erosion. In this study, this was observed in deep-ripping tillage (BD of 1.49 g cm^{-3}) and high clay content (15.9%), but in conventional tillage and zero tillage bulk density and clay content were not directly proportional e.g. zero tillage recorded 1.47 g cm^{-3} and 16% clay while conventional tillage recorded 1.38 g cm^{-3} and 15% clay.

Table 3: Soil bulk density (BD), critical bulk density (BDcrit), relative bulk density (RBD) and penetration resistance (PR) values for three tillage types (sampled at 0-45 cm)

Treatment	BD (g cm^{-3})	BD_{crit} (g cm^{-3})	RBD = BD/BD_{crit} (-)	PR (MPa)
Zero Tillage	1.47a	1.85a	0.79a	2.28b
Deep-Ripping Tillage	1.49a	1.89a	0.78a	1.45a
Conventional Tillage	1.38b	1.86a	0.74a	1.13a

Values with the same letter in each column are not significantly different ($p < 0.05$) from each other.

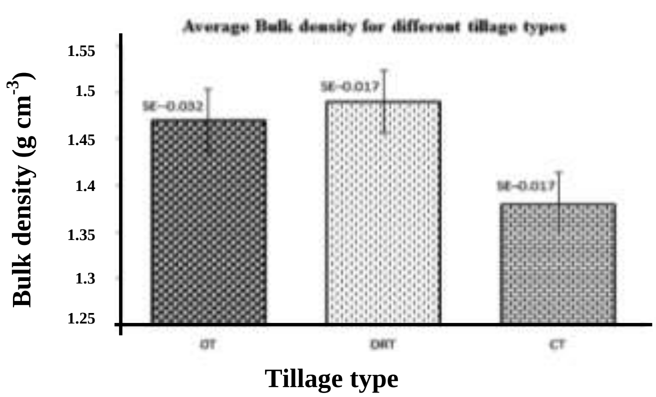

Figure 2: Average bulk density values for different tillage types, (non-significantly different), (LSD, $p < 0.05$). SE denotes standard error

However, to account for effectiveness of clay content contribution to compaction, we computed the critical bulk density (BD_{crit}) using an empirical approach by Jones (1983) cited in Dexter (2004) and Asgarzadeh *et al*. (2010). This is because BD_{crit} has a strong correlation with natural BD of the field soil where the plant roots are involved with environmental restrictions (Mosaddeghi *et al*., 2009). The results show that deep-ripping tillage recorded slightly higher BD_{crit} (1.89 g cm^{-3}) compared to conventional tillage (1.86 g cm^{-3}) and zero tillage (1.85g cm^{-3}). Furthermore, to effectively evaluate the degree of compactness, RBD was used. A closer look at the results shows an increase of PR with increment in RBD Table 3 and this was found to be consistent with other studies (Dexter, 2004; Asgarzadeh *et al*., 2010).

Soil moisture and water infiltration effects on compaction

Samples for soil moisture determinations were collected after rainy season (i.e. when samples were still under field moisture conditions). Figure 3a shows soil moisture content at field conditions under three different tillage types.Average soil moisture contents were 3.7, 1.5 and 1.6% for deep-ripping, conventional and zero tillage, respectively, and were significantly different ($p < 0.05$). The correlation between penetration resistance and soil moisture of samples analysed immediately after collection (Table 1) was interestingly positively correlated ($r^2 = 0.47$) although not statistically significant (Table 1). Quiroga *et al*. (1999) reported that soil compaction can be influenced by soil moisture since it allows the soil particles to stick together unlike dry soils. The high moisture content in deep-ripping tillage was due to the use of farm implements that go to a depth of about 45 cm compared to depth of 30 cm for conventional tillage. As farm implements churn and turn the soil it allows for better aeration and air and water movement (Quiroga *et al*., 1999). Increasing soil moisture content reduces the bearing capacity of the soil and this leads to an increase in PR with soil moisture content (Lipiec *et al*., 2002). In this study, this was only observed in deep-ripping tillage and conventional tillage. Significant difference between moisture contents ($p < 0.05$) were observed. Deep-ripping tillage recorded high moisture content of 3.9% and PR of 1.62 MPa at 30 cm depth and conventional tillage recorded low moisture content of 1.0% and PR of 1.51 MPa at 45 cm depth. This indicated that PR increases with soil depth and decrease in moisture content as shown in Figure 1. This was also the case with zero tillage since low moisture content (0.8%) and high PR (2.28 MPa) at 45 cm depth.. The low moisture content at 45 cm depth in zero tillage compared to other tillage types was attributed to no till effect which affects soil moisture by creating the mulching effect on the soil surface. Silva *et al*. (2000) also indicated that the dryness of the soil makes soil compaction to be easily noticeable leading to incompressible soil particles especially in semi-arid environments. This was evident in this study as zero tillage which was more compacted (2.28 MPa) compared to other tillage types, recorded low moisture content of 1.4%.

Interestingly, cumulative intake was high for conventional tillage followed by deep-ripping tillage and lastly zero tillage (Figure 3b) although these were not significantly different (p <0.05). Results also indicate there are high infiltration intakes at the beginning followed by relatively rapid decline for all tillage types. As expected, in all tillage types, infiltration intake decreased asymptotically with time till it reached steady infiltrability as corroborated by Mari and Changying (2007). This was due to combination of capillary and gravity forces (Sekwakwa and Dikinya, 2012). The lower intake values in deep-ripping imply that water enters the soils slowly as compared to the conventional tillage. This will lead to pooling of water (or water logging) on the surface and hence increased surface runoff and water erosion. Water logging can also cause nutrient deficiencies due to anaerobic conditions and reduction in biological activity and fertilizer use efficiencies (Wolf and Snyder, 2003) and consequently less plant available water.

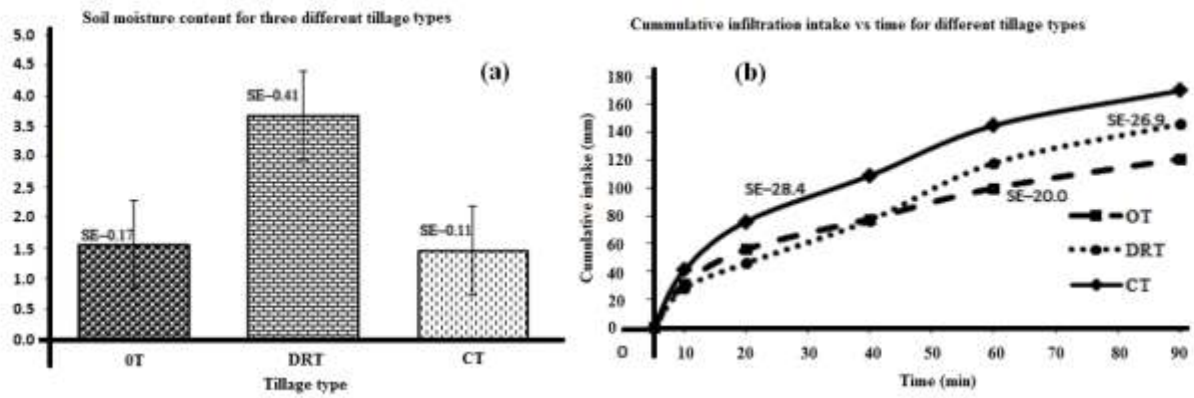

Figure 3: Soil moisture content (a) and cumulative infiltration (b) for different tillage types. Soil moisture and cumulative infiltration differences were significant (LSD, $p < 0.05$). SE denotes standard error

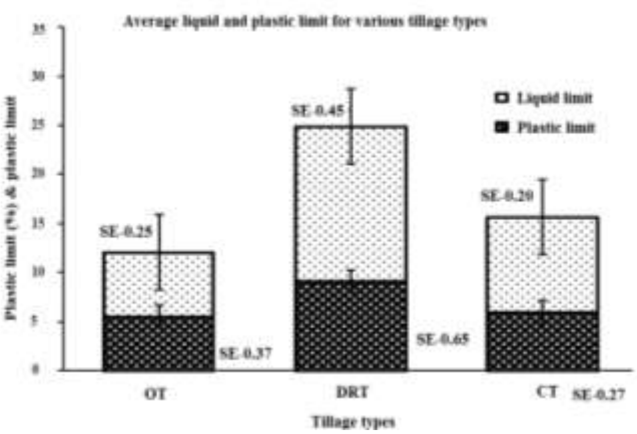

Figure 4: Plastic limit and liquid limit of three different tillage types. The differences in liquid limit were significant (LSD, $p < 0.05$) whereas for plastic limit, the differences were not significantly different (LSD, $p < 0.05$). SE denotes standard error

Atterberg limits

The Atterberg limits can influence compaction as demonstrated by high correlation of the soil compaction with the liquid limit (Sridharan and Nagaraj, 2005).The results indicate that PL (9.2%) and LL (15.7%) were high for deep-ripping tillage followed by conventional tillage with 5.9 and 9.7%, respectively. There was weak positive correlation between PL, LL and PR (r^2 =0.56) (see Table 1) indicating that LL moderately influences compaction. Whereas zero tillage had the lowest PL and LL values of 5.52 and 6.5%, respectively. The ANOVA also indicated that there was a significant difference between PL and LL ($p < 0.05$) in all tillage treatments. High compaction in zero tillage (2.28 MPa) is attributed to relatively higher percent of clay (16%). The finer clay particles cause the particles to easily bind together. This is supported by Sekwakwa and Dikinya (2012) who stated that cohesive soils are susceptible to compaction. Soils with high clay content normally have high liquid limit and plastic limit because of the binding potential of clay particles with instant retardation of detachment. While sand particles are easily merged together (because of no binding) hence they easily come together and lead to low plastic and liquid limit (Manyiwa and Dikinya, 2013).

According to Hamza and Anderson (2005), there is positive correlation between PR and PL and LL. In this study (Figure 4) this was only observed in deep-ripping and conventional tillage. Deep-ripping tillage recorded high PL (9.2) and LL of 15.7% and PR of 1.45 MPa whereas conventional tillage with relatively low LL (9.7) and PL (5.9%) compared to deep-ripping tillage had low PR (1.13MPa). The results were significantly different (p <0.05). This showed that PR increases with LL and PL, but in zero tillage this was not the case since it recorded low LL (6.5%) and PL of 5.5%. This was probably due to less soil disturbance.

Conclusion

The results of the study indicated that the soils in Sebele farms were moderately compacted, as shown by the results of penetration resistance. Zero tillage recorded high PR and was found to be more compact compared to deep-ripping and conventional tillage types. This indicated that the soils under zero tillage were relatively more compacted than other tillage types. There was significant difference between PR values of zero tillage and other tillage types. This indicated that tillage types have an influence on soil compaction.

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