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The effects of tillage systems on soil physical properties and water conservation in a sandy loam soil in Eastern Kenya

J. M. Miriti[1]*, G. Kironchi[2], A. O. Esilaba[3], C. K. K. Gachene [2], L. K. Heng[4] and D. M. Mwangi[2]

[1]Kenya Agricultural Research Institute (KARI), ARC Muguga South Centre, P.O. 30148-00100 Nairobi, Kenya.
[2]Faculty of Agriculture, University of Nairobi, P.O. Box 30197-00100 Nairobi, Kenya.
[3]Kenya Agricultural Research Institute (KARI) Headquarters, P.O. Box 57811-00200 Nairobi, Kenya.
[4]International Atomic Energy Agency (IAEA), Soil and Water Management and Crop Nutrition Section, Wagrammer Strasse 5, P.O. Box 100, 1400 Vienna, Austria.

Soil water conservation through tillage is widely accepted as one of the appropriate ways of addressing soil moisture constraints in rainfed agriculture. A field experiment was conducted for 6 seasons (2007 to 2009) to evaluate the effects of 3 tillage practices namely ox-plough (OP), subsoiling-ripping (SR) and tied-ridge (TR) on soil physical and hydro-physical properties of a sandy loam soil. Soil surface roughness, bulk density (BD), total porosity, crust strength, saturated hydraulic conductivity, steady infiltration rates and soil water storage were evaluated. Results showed that, mean inter-row BD (1.51 Mg m^{-3}) and crust strength (3.05 MPa) with SR tillage were 7 and 15% greater (P ≤ 0.05) than with OP, respectively. Inter-row infiltration rates for OP (7.9 cm h^{-1}) were more than two fold greater than for SR (3.6 cm h^{-1}) and TR (3.3 cm h^{-1}). Soil surface roughness with TR was significantly greater than with OP and SR tillage systems. Soil water storage for TR (222 mm) exceeded (P ≤ 0.05) that for OP and SR by 30 mm (16%) and 32 mm (17%), respectively. This study concluded that, ripping soil along planting line that are prone to surface crusting without disturbing the soil between crop rows was not effective as a conservation tillage method.

Key words: Tillage, soil physical properties, soil water conservation, sandy loam soil, infiltration rate.

INTRODUCTION

Agricultural production in the arid and semi-arid areas of Kenya is highly dependent on rainfall because water for irrigation is scarce or farmers cannot afford the technology. In order to have successful rainfed crop production in these areas, rain water conservation is essential (Barron et al., 2003). The success of on-farm soil water conservation however depends upon many soil factors such as soil bulk density (BD), porosity, soil surface sealing and crusting, surface roughness, hardpans, hydraulic conductivity, and infiltration rates as

they determine the hydrological properties of soil (Strudley et al., 2008). Soil compaction causes low porosity, reduced infiltration, increased penetration resistance and limited root growth. Soil surface roughness (configuration) influences wind and water erosion by decreasing soil detachment and transport caused by erosion (Cogo et al., 1983). Soil surface roughness can however change considerably with rain, wind and soil cultivation events (Guzha, 2004). Crusting is a soil surface characteristic that provides information

*Corresponding author. E-mail: jmmiriti@yahoo.co.uk. Tel: +254722865683. Fax: +254 20 4183344.

Table 1. Seasonal rainfall during the study period.

Season	Rainfall (mm)	Rainy days
Long rains of 2007	44	7
Long rains of 2008	125	18
Long rains of 2009	54	10
Short rains of 2007	203	30
Short rains of 2008	222	18
Short rains of 2009	200	29

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 (Gicheru et al., 2004; Shivonje et al., 2005).

Large areas of semi-arid areas of Kenya are covered by sandy soils which are prone to crusting and compaction leading to low rain water use efficiency (Biamah et al., 1993). It has been suggested that, tillage can improve the physical and hydro-physical properties of the soils and consequently increase rainwater harvesting and crop yields (Gachene and Kimaru, 2003, Rockstrom et al., 2009, Strudley et al., 2008). Ox-plough (OP) tillage using mouldboard plough followed by hand weeding with a hoe is a common tillage method used by farmers in semi arid areas of Kenya. This tillage system has been reported to encourage crust and hardpan formation (Biamah et al., 1993; Gitau 2004). In such soils, deep tillage in form of subsoiling-ripping (SR) has been recommended to improve soil hydraulic conditions (Rockström and Lars-Ove, 1999; Soltanabadi et al., 2008). It has also been reported that, tillage practices that increase soil surface roughness such as tied ridging and ripping can increase soil water storage and availability to crop because they are able to capture rainfall and increase the time for infiltration to take place resulting in better crop yields (Guzha, 2004). The challenge faced by farmers when using tied ridging in Kenya is the high labour required because this tillage system is not mechanized. According to Rockström et al. (2009) and Stevens (2000), SR is an attractive tillage system that farmers can use to harvest and conserve rainwater because less time is required in the tillage operations. Temesgen (2007) however noted that subsoiling a sandy loam soil along crop rows with minimum soil disturbance between rows resulted in reduced yields when compared to ploughing because of increased runoff.

Soils of Kenya are diverse and there is need to determine the appropriateness of different water conservation tillage systems. Currently, there is very little information available on appropriateness of subsoiling and ripping tillage technologies on the crust prone soils widely cultivated by farmers in the dry areas. Previous studies on ripping in Kenya reported by Rockström et al. (2009) was focused on crop yields and did not study its effects on soil properties and soil moisture conservation. The objective of this study was therefore, to determine

the comparative effectiveness of SR, tied-ridge (TR) and OP tillage systems in improving soil hydraulic properties and soil water conditions in sandy loam soils in semi-arid eastern Kenya.

MATERIALS AND METHODS

Site characteristics and treatments

The field experiment was conducted at Kampi ya Mawe (1°50'S, 37°40'E, elevation 1155 m) in the experimental field of Kenya Agricultural Research Institute. Average annual rainfall is 600 mm with two peaks in April/May and in October/December (Jaetzold et al., 2006). The first and second rainy seasons were referred to as long rainy season and short rainy season, respectively. The field experiment was conducted for 6 rainy seasons: three long and three short rainy seasons between 2007 and 2009. Seasonal rainfall received at the site during the study period is given in Table 1. The soil is classified as chromic Luvisol (FAO-UNESCO, 1994) formed on undifferentiated basement system rock (gneisses). The soil surface 0 to 14 cm layer texture is sandy loam (80% sand, 7% silt, and 13% clay) with low organic carbon (0.61%) content (Table 2). The land slope at the study site was 0 to 2%.

The treatments consisted of 3 tillage practices: TR, SR and OP. SR tillage (about 24 cm depth) was done along the planting line (90 cm interval) with an ox driven soil subsoiler to break the hardpan. The subsoiler and ripper used were fabricated at the University of Nairobi in the Department of Environmental and Biosystems Engineering (Figure 1).

Tied ridges in TR tillage were made manually as this tillage method is not yet mechanized. Cross ties (small ridges joining big ridges) were made at 1 m intervals to prevent water movement along the furrow and create small check dams for rainwater harvesting. In each plot, there were 35 check dams. For the OP tillage treatment, the entire plot was ploughed (about 14 cm depth) using an oxen drawn mouldboard plough as practiced by farmers in the area. In each tillage method, 3 cropping systems namely sole maize (3.7 plants m^{-2}), sole cowpea (5.5 plants m^{-2}) and maize/cowpea intercrop (planted in the same row but in alternate hill) were compared; in a randomized split-plot design with tillage practices as the main plots and cropping systems as the sub-plots. When comparing the tillage systems, OP tillage treatment was used as control while sole maize was the control when comparing cropping systems. No crop rotation was done during the study. Each treatment was replicated 3 times. A ridge was constructed around the experimental block to prevent water run-on.

Data collection and analysis

At different stages of crop cycle, undisturbed soil cores were taken between and within crop rows for determination of soil saturated hydraulic conductivity, bulk porosity density and porosity changes. This was achieved by driving stainless steel cylinder (100 cm^3, approximately 4.0 cm in length, diameter 5.6 cm) in the soil using a hammer. The samples were then carefully trimmed both sides to the size of the cylinder and then taken to the laboratory for soil physical properties analysis. The saturated hydraulic conductivity of the soil was determined using the constant head method described by Klute and Dirksen (1982). After this determination, the soil cores were put in an oven and dried at 105°C to a constant weight. BD of the soil was calculated as the mass of dry soil divided by the core ring volume. Total soil porosity was calculated from BD as:

$$\text{Porosity (\%)} = \left(1 - \frac{BD}{PD}\right) \times 100$$

(1)

Table 2. Soil characteristics at the Kampi ya Mawe experimental site.

Soil horizon	Depth (cm)	Sand (%)	Clay (%)	Silt (%)	BD (Mg m^{-3})	pH	Organic Carbon (%)
Ap	0-14	80	13	7	1.48	6.04	0.61
AB	14-27	63	29	8	1.54	5.32	0.50
Bu$_1$	27-50	48	39	13	1.44	5.78	0.57
Bu$_2$	50-83	47	37	16	1.33	5.28	0.58
BC	83-94	57	23	20	1.57	5.47	0.70
C	90-106+	61	32	7	1.59	5.32	0.72
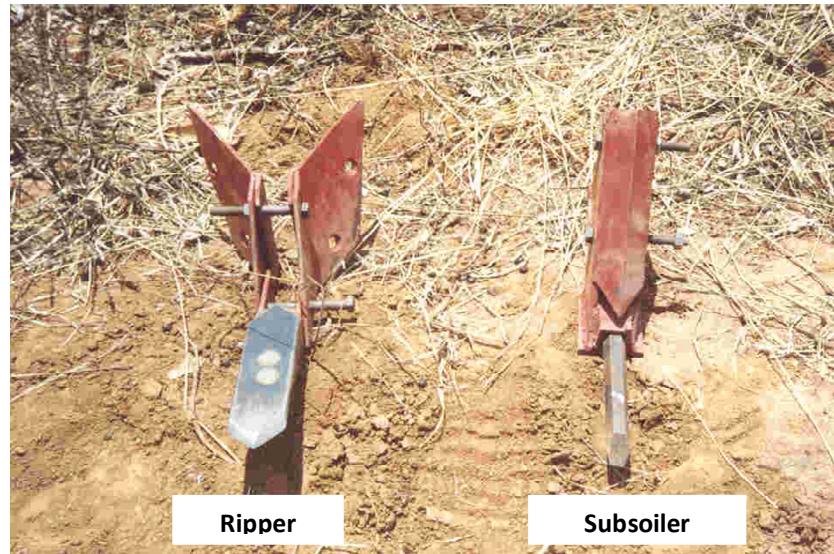
Figure 1. The ripper and subsoiler used in the study.

Where BD is the soil BD (Mg m^{-3}) and PD is average particle density (2.65 Mg m^{-3}).

Soil surface roughness was measured immediately after the tillage operations and within the crop season. Readings were taken from 3 randomly selected positions in each plot. A pin-meter similar to that described by Moreno et al. (2008) was used to measure surface roughness (Figure 2). The instrument consisted of a graduated flat metal board on which a 130 × 90 cm frame with 20 needles that slide up and down was fitted. The spacing from one pin to the other was 20 cm. Each needle was fitted with a small foot to prevent it from penetrating the soil.

During the height measurement, the whole device was placed horizontally and the needles were then allowed to slide down until their feet freely touched the soil surface and then locked in position. The height of each of the needles above the top of the frame was recorded after taking the readings on the graduated board. The needles were then pulled up, locked and the instrument moved to the next measuring position. Measurements were replicated in 3 positions per plot and the following the formula was used to calculate surface roughness:

$$\text{Surface roughness (\%)} = LOG\,(STDEV)\times100$$

(2)

Where LOG is the logarithm, STDEV is the standard deviation of the pin height measurements. Penetration resistance was measured at the soil surface using a hand-held cone penetrometer (Stiboka penetrograph, Eijkelkamp Agrisearch Equipment,

Netherlands). The penetration resistance was measured within and between crop rows at 13, 26, 56, and 101 days after sowing (DAS) during short rains cropping season of 2009. Ten soil crust strength measurements were taken at randomly selected positions in sole maize plot. The penetrometer springs and cone sizes were adjusted depending on the soil strength. The penetration resistance which represents the crust strength was calculated as:

$$CR = I \times \left(\frac{C_s}{A\,C} \right)$$

(3)

Where CR is the resistance (N cm^{-2}), I is the impression on the scale (cm), Cs is the spring constant (N cm^{-1}), AC is the area of the cone (cm^2).

Field infiltration rates were measured using a disc permeameter as described by Perroux and White (1988). Measurements were taken at planting, mid season, and at harvest. A 20 cm diameter steel ring was gently forced, approximately 5 mm into the soil surface, taking care not to disturb the soil and after organic material at soil surface was removed. A spirit level was placed over the ring to ensure the ring was horizontal. The clear polycarbonate disc was placed on the ring and adjusted until a 5 mm gap between the soil surface and the bottom of the disc was achieved. The valve was opened to allow water to flow from the side tube filling the gap between the soil surface and the disc. As water entered the soil, the time taken for a 5 cm depth of water drop in the graduated big tube was recorded. Water in the big tube was refilled immediately after

Figure 2. The pin meter used in the study

80 cm of water entered the soil. Infiltration test was then continued until the time taken by 5 cm of water in big tube to enter the soil was constant. Infiltration rate and cumulative infiltrations were then calculated from the recorded data. Soil water in the profile (0 to 110 cm) was monitored using a neutron probe (CPN 503-DR Campbell Pacific Nuclear, Martinez, CA). The measurements were done weekly during the crop cycle at 15, 30 45, 60 80, and 100 cm soil depths from aluminum access tubes installed in the plot along the middle crop row.

The data was subjected to analysis of variance (ANOVA) using the Genstat (2007) software package. Significant treatment differences were obtained using Fisher's Protected LSD test. Effects were considered significant in all statistical analysis for P values ≤ 0.05.

RESULTS

Soil bulk density (BD) and total porosity

Soil surface (0 to 10 cm) BD and total porosity data measured between the crop rows (inter-row) is presented in Table 3. BD and porosity were significantly affected by the tillage methods. The BD after sowing was greatest in SR (1.47 Mg m^{-3}), followed by TR (1.41 Mg m^{-3}) and lowest in OP tillage (1.34 Mg m^{-3}) which indicated that, OP significantly (P ≤ 0.05) reduced inter-row BD by 5% (0.13 Mg m^{-3}) compared to untilled soil in SR plots. Initial total porosity was greatest for OP (49%) and least for SR (44%) with significant (P ≤ 0.05) differences among the tillage systems.

There was a temporal increase in inter-row BD and a decrease of soil porosity as the season progressed. The greatest increase in BD 10% (from 1.34 Mg m^{-3} to 1.48 Mg m^{-3}) was recorded in the OP plots while BD changes in SR and TR plots were 6% (from 1.47 Mg m^{-3} to 1.56 Mg m^{-3}) and 5% (from 1.41 Mg m^{-3} to 1.48 Mg m^{-3})

respectively, by the end of season. Total porosity also declined in similar proportions. BD and total porosity within rows was not significantly different among the tillage methods.

Saturated hydraulic conductivity and infiltration

Soil surface (0 to 10 cm) saturated hydraulic conductivity (Ks) measured between crop rows (inter-row) is presented in Table 3. The Ks in TR (0.81 cm h^{-1}) was significantly (P ≤ 0.05) lower than in OP (6.24 cm h^{-1}) and SR (4.33 cm h^{-1}) plots after sowing. The Ks data shows that, though there was a significant tillage differences in Ks at sowing, the Ks at 30 DAS and at harvest was smaller and not significantly different among tillage systems. The overall reduction in Ks ranged from 5.61 to 0.38 cm h^{-1} and the greatest decline was in OP followed by SR and least in TR plots. The Ks values within crop rows were not significantly different (P ≤ 0.05) among tillage treatments during the crop cycle but they double the Ks observed in the inter-row.

Soil surface (0 to 5 cm) steady infiltration rates measured using a disc permeameter is given in Table 4. The highest inter-row infiltration rate was observed in the OP tillage (7.9 cm h^{-1}) and was two fold greater than the infiltration rate observed in SR and TR tillage systems. SR resulted in the least infiltration rates (27.4 cm h^{-1}) within crop rows compared to OP but the difference was not significant. The infiltration within the rows in the ridges was not measured because water was being lost through the sides of the ridge during the process of measurement. When averaged across OP and SR tillage systems, the infiltration rates within crop rows was 32.2 cm h^{-1}, significantly greater than the inter-row

Table 3. Effect of tillage treatments on inter-row row soil surface (0 to 10 cm) BD, porosity and saturated hydraulic conductivity at sowing, 30 DAS and at harvest during the short rainy season of 2009.

Tillage	Bulk density (Mg m^{-3})				Porosity (%)				Hydraulic conductivity (cm h^{-1})			
	Sowing	30 DAS	Harvest	Mean	Sowing	30 DAS	Harvest	Mean	Sowing	30 DAS	Harvest	Mean
Ox-plough	1.34	1.39	1.48	1.40	49.43	47.55	44.15	47.04	6.24	1.37	0.63	2.75
Subsoiling-ripping	1.47	1.49	1.56	1.51	44.53	43.77	41.13	43.14	4.33	1.07	0.97	2.12
Tied-ridge	1.41	1.45	1.48	1.45	46.79	45.28	44.15	45.41	0.81	0.80	0.43	0.68
Mean	1.41	1.44	1.51		46.92	45.53	43.14		3.79	1.08	0.68	
LSD (0.05)	0.02[†]	0.01[‡]	NS[§]		1.32[†]	1.59[‡]	NS[§]		1.51[†]	0.84[‡]	1.67[§]	

[†] = for comparing tillage means within a soil property, [‡] = for comparing date means within a soil property, [§] = for comparing the interaction, NS = not significant.

infiltrations rates (5.75 cm h^{-1}).

Soil crust strength

Soil crust strength is an important soil physical characteristic that provides information on ability to allow water movement into the soil. The temporal variations in soil crust strength with the tillage treatments during the long rain season of 2009 are shown in Figure 3. The inter-row crust strength responded to tillage and the crust strength for OP (0.15 MPa) was 213 and 166% significantly lower than for SR (0.47 MPa) and TR (0.40 MPa) respectively, 13 DAS. The crust strength increased with time in all tillage systems. When averaged across the tillage systems, crust strength at the end of the season was 4.8 MPa compared to crust strength (0.34 MPa) soon after tillage. OP maintained the least crust strength throughout the entire crop season. The low crust strength measured on 13 and 26 DAS in the TR plots was because of the loose soil deposited at the ridge basin during weeding and ridge reconstruction. In general, the crust strength recorded along crop rows was higher by a factor of 6 compared to the inter-row crust strength.

Tillage did not have a significant effect on the crust strength along crop rows.

Soil surface roughness

Soil surface roughness is an unevenness of the soil surface. Temporal variations in soil surface roughness with the tillage treatments during are shown in Figure 4. Surface roughness was significantly different among the tillage methods and the effect of tillage was largest soon after cultivation and the effect decreased as the season progressed. The soil surface roughness was consistently highest in TR (64 to 79%) tillage and lowest in OP (6 to 50%). Surface roughness soon after tillage was 79, 58, and 50 for TR, SR and OP, respectively. At the time of harvesting, surface roughness had declined to 64, 20 and 6% in TR, SR and OP plots respectively, indicating that the greatest decline was with OP, followed by SR and then TR tillage.

Soil water storage

Seasonal rainfall at the site ranged from 44 to 222

mm per season during the study period (Table 1). The short rains of 2008 was the wettest season (222 mm), followed by short rainy season of 2007 (203 mm), short rains season of 2009 (200 mm), long rains season of 2008 (125 mm), long rains season of 2009 (54 mm) and finally the long rains season of 2007 (44 mm). There were crop failures during the long rains seasons of 2007 and 2009 failed due to low rainfall and hence the 2 seasons are not discussed in this paper.

Soil profile (0 to 110 cm) water content averaged over 4 seasons (long rainy season of 2008 and short rainy seasons of 2007, 2008, and 2009) responded significantly to tillage, cropping systems, and tillage × cropping systems interactions (Figure 5). When averaged across seasons and cropping systems, the highest soil water storage was observed under TR (222 mm) and exceeded (P ≤ 0.05) that for OP and SR by 30 mm (16%) and 32 mm (17%), respectively. There was no significant soil water content difference between SR and OP tillage systems. The soil water content under cowpea sole crop and maize/cowpea intercrop cropping systems were similar but significantly less than the soil water content under sole maize cropping system, when averaged across tillage systems

Table 4. Effect of tillage treatments on steady infiltration rates between the crop rows (inter-row) and within rows during the short rains of 2009.

Tillage	Inter-row	Within row
Ox-plough	7.9	37.0
Subsoiling-ripping	3.6	27.4
Tied-ridge	3.3	-
Mean	5	32.2
LSD (0.05)	1.7	NS

NS = not significant
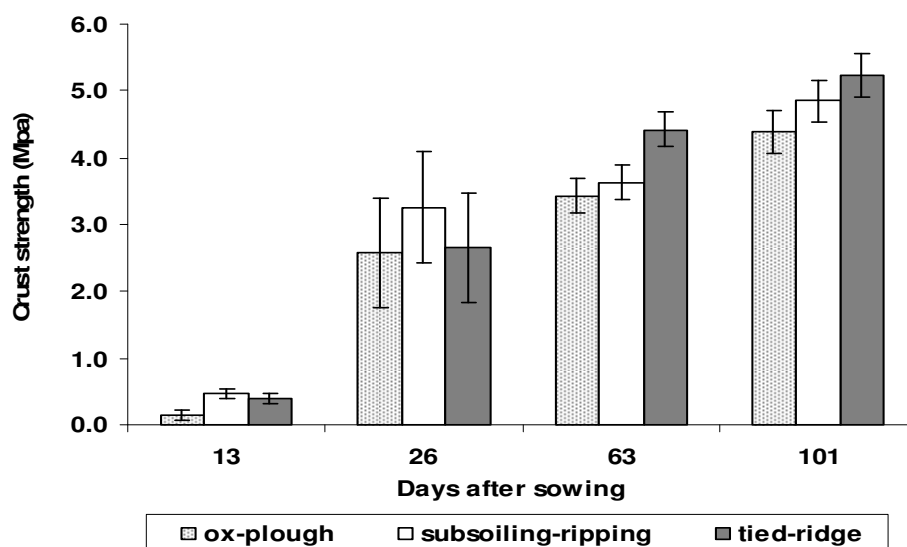
Figure 3. Effect of tillage on inter-row soil crust strength during short rains of 2009 season. Bars=LSD$_{0.05}$.

over the 4 seasons. The tillage × cropping systems interactions indicated that, maximum soil water content (225 mm) was recorded in sole maize grown under TR and minimum soil water content (179 mm) in sole bean grown under SR tillage system.

DISCUSSION

Soil bulk density and total porosity

The low BD and high porosity values observed in OP plots is attributed to soil disturbance during ploughing. The high initial BD in SR compared to OP is because the compacted inter-rows which were not tilled during land preparation. Though the inter-row BD after sowing was different (P ≤ 0.05) among tillage systems, it was statistically the same at the end of the season in all tillage treatments. Similar observations were reported by Šimanskaitė (2008). The temporal increase in BD during

the crop season could be due to a combination of rain drop impact and soil compaction due to repeated human traffic during weeding, data collection and other crop management activities. The exposure of the hardpan during the construction of ridges caused the observed high inter-row BD in TR plots. BD within rows was not different among tillage methods but TR maintained the lowest BD than OP and SR because of the relatively lose soil on the ridge.

Soil crust strength

Ploughing caused a breakdown of soil surface sealing resulting in weak crust strength in OP, and by not ploughing the inter-rows in SR tillage resulted in soil surface sealing and strong crust. These results are in agreement with Gicheru et al. (2004) who observed that bare minimum tillage where the weeds were controlled by herbicides had a stronger crust strength at the soil
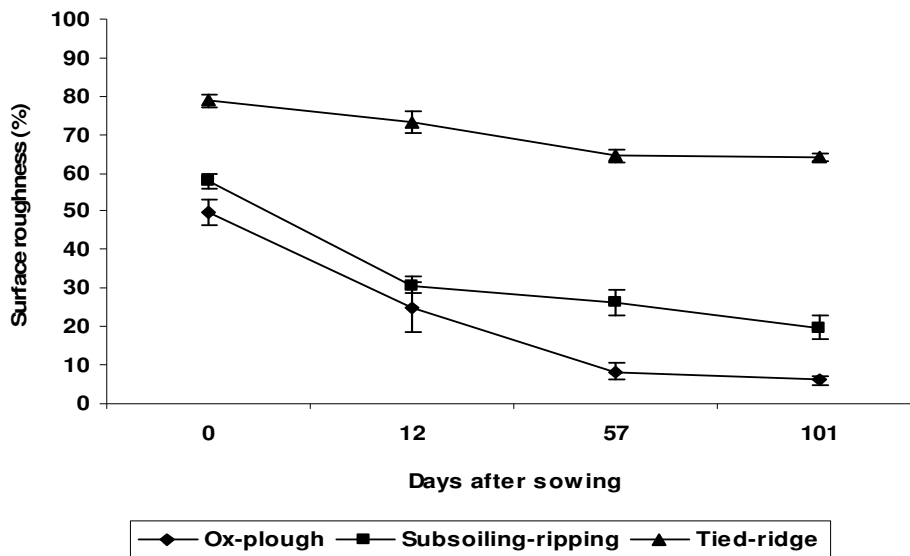
Figure 4. Soil surface roughness decline as affected by tillage during short rains of 2009 season. Bars=LSD$_{0.05}$
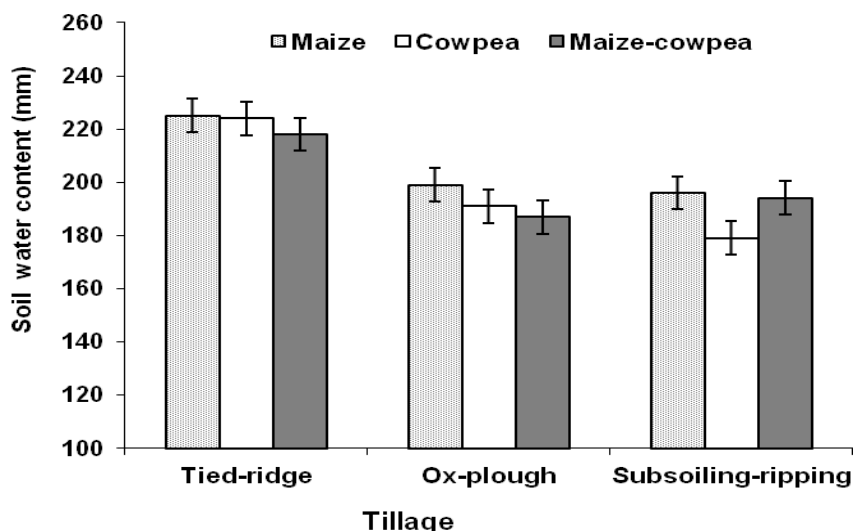

Figure 5. Soil profile (0 to 110 cm) water storage as affected by tillage and cropping systems (averaged for 4 seasons). Error bars =LSD$_{0.05}$.

surface (0 to 5 cm) than in treatments where the crust were disturbed by hand hoe weeding. Crust strengths at the base of the ridge basins were higher than under OP because of the exposure of hard subsoil during the making of the ridges. The crust strength between crops rows was always higher than within crop rows due to compaction through trampling. The general increase in crust strength with time within crop rows is attributable to natural formation of crust under raindrop impact since there was minimal human interference.

Saturated hydraulic conductivity and steady infiltration rate

Previous studies show that high BD, strong soil crust and low total porosity have a negative influence on Ks and infiltration rates (Bhattacharyya et al., 2006, Gicheru et al., 2004). In our study, the low inter-row Ks and infiltration rates observed in SR and TR plots is a reflection of the high BD and crust strength, and low total porosity in the inter-row spaces. The temporal decline in

inter-row Ks during the crop cycle is consistent with the findings of Mwendera and Feyen (1993). They attributed the Ks decline to the increase in soil compaction and total porosity decline. The insignificant changes in Ks observed in TR are due to the exposed hardpan.

In this study, we observed that SR did not result in higher in-row infiltration rates when compared to the OP tillage system. There are two possible explanations to this unexpected result. One of them is that, there was downward movement of fine soil particles into the soil profile during the rains leading to the clogging and sealing of the macro pores in the ripped furrows. Clogging of macro-pores causes a discontinuity of water transmitting pores (Kooistra et al., 1984; Römkens et al., 1990). Low infiltration rates in SR tillage could also have been caused by slow lateral water movement in SR treatments because downward and outward of water during infiltration depend on the capacity of soil to transmit water both vertically and laterally (Michael, 1978). Ploughing the entire plot in the OP treatments, resulted in increased total porosity in the whole plot which probably encouraged faster water lateral movement in the plots while lateral water movement in SR tillage was restricted by the low total porosity in the unploughed sections between crop rows. These results are supported by the Guzha (2004) who reported that tilled soil gave significantly higher infiltration rates than untilled soil. The infiltration rates within crop rows were greater than the inter-row infiltrations rates due to the observed stronger crust strength and lower total porosity in the inter-row spaces.

Soil surface roughness

The high surface roughness observed in the TR is due to the raised ridges and basins created during tie ridging; while the surface roughness in SR was greater than in OP tillage because of the ripped deep furrows. The rapid reduction in surface roughness particularly in OP is a reflection of unstable soil which looses the clods formed after tillage due to raindrop impact, erosion and human interference during data collection and weeding. Lal (1997) reported that tilled sandy soils are susceptible to soil erosion after ploughing as soil aggregates are broken down leading to loss of soil structure. The clay content of the study soil at the plough layer was less than 13% implying that the soil had unstable structure. TR maintained the greatest surface roughness than the other tillage systems because the ridges were reconstructed every time weeding was done. The high surface roughness observed in TR would ensure that substantial rainfall is trapped and conserved in the soil profile.

Soil water storage

The variations in tillage effects on soil hydro-physical properties (BD, porosity, crust strength, infiltrations, and surface roughness) led to the observed differences in soil water storage among the tillage systems. The highest soil water content recorded in TR treatments is due to increased depression water storage induced by the high surface roughness in the tillage system. According to Hansen et al. (1999), depression storage of tilled soil increases with increasing surface roughness. This was apparent in the field soon after the rains when we observed higher depression storage (water pools) in TR than in the other tillage treatments. The capacity for TR to capture and store rainfall would ensure more water will be available to crop in TR tillage than the other tillage systems (Guzha, 2004). SR tended to produce less soil water content than OP because of the low steady infiltration rates associated with the high BD and soil crust strength and low total porosity conditions developed between the crop rows under SR tillage system.

Temesgen (2007) observed that, runoff in treatments with subsoiling and furrowing along planting rows (without disturbing the soil in between) exceeded runoff in ploughed treatments which he ascribed to the high BD (low porosity) in the un-ploughed inter-row spaces. Soil water retention under SR tillage systems would probably have been improved by mulching as it protects soil structure from destruction by the raindrop impact thus, maintaining good soil porosity for infiltration (Gicheru et al., 2004). The mulching option was however not feasible at the study site because the crop residue is mainly for livestock feed.

Soil water content in cowpea sole crop was always less ($P \leq 0.05$) than maize sole crop treatments, suggesting that cowpea utilized more soil moisture than maize. The observation that cowpea sole crop and maize/cowpea intercrop treatments tended to give similar soil water content implies that both treatments had similar water consumption.

Conclusion

The results confirmed that sandy loam soils are prone to crust formation and compaction which lead to unfavorable soil hydro-physical properties. Ox-plough tillage resulted in significant improvement in soil surface hydraulic conditions. Subsoiling-ripping tillage system conserved lesser soil water compared to OP tillage system (control) because of the unfavorable soil surface hydraulic conditions (high BD and soil crust strength, and low total porosity) that developed between the crop rows under the SR tillage. The significantly higher soil water conserved under TR tillage was attributed mainly to high soil surface roughness which enhanced depression water storage. Based on these results, the conclusion is that the subsoiling and ripping tillage method used in this study was inferior to the conventional OP tillage method in conserving soil moisture in the sandy loam soils. The results presented in this study, therefore, clearly

demonstrated that maintenance of good soil porosity, infiltration and surface roughness is critical when selecting tillage systems for increased soil water conservation.

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