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Effect of minimum tillage and mulching on maize (*Zea mays* L.) yield and water content of clayey and sandy soils

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Abstract

Rainfed smallholder agriculture in semi-arid areas of southern Africa is subject to numerous constraints. These include low rainfall with high spatial and temporal variability, and significant loss of soil water through evaporation. An experiment was established at Matopos Research Station, Zimbabwe, to determine the effect of mulching and minimum tillage on maize (*Zea mays* L.) yield and soil water content. The experiment was run for two years at two sites: clay (Matopos Research Station fields) and sand (Lucydale fields) soils, in a 7 × 3 factorial combination of mulch rates (0, 0.5, 1, 2, 4, 8 and 10 t ha^{-1}) and tillage methods (planting basins, ripper tine and conventional plough). Each treatment was replicated three times at each site in a split plot design. Maize residue was applied as mulch before tillage operations. Two maize varieties, a hybrid (SC 403) and an open pollinated variety (ZM 421), were planted. Maize yield and soil water content (0–30 and 30–60 cm depth) were measured under each treatment. On both soil types, neither mulching nor tillage method had a significant effect on maize grain yield. Tillage methods significantly influenced stover production with planting basins giving the highest stover yield (1.1 t ha^{-1}) on sandy soil and conventional ploughing giving 3.6 t ha^{-1} on clay soil during the first season. The three tillage methods had no significant effect on seasonal soil water content, although planting basins collected more rainwater during the first half of the cropping period. Mulching improved soil water content in both soil types with maximum benefits observed at 4 t ha^{-1} of mulch. We conclude that, in the short term, minimum tillage on its own, or in combination with mulching, performs as well as the farmers' traditional practices of overall ploughing.

Keywords: Conservation agriculture; Minimum tillage; Mulching; Planting basin; Semi-arid

1. Introduction

Ninety-five percent of the current population growth occurs in developing countries and a large proportion of these people rely on rainfed food production (Rockstrom et al., 2003). Fifty-eight percent of the world's food production comes from rainfed agriculture (Rosegrant et al., 2002). Irrigation development assistance from major international donors has been on the decline over the years as a result of high capital costs, water scarcities, limited benefits to the poor rural communities and negative environmental impacts (Postel, 1989). Thus, food production and rural livelihoods will continue to rely on rainfed agriculture in the foreseeable future. The continued development of rainfed agriculture is a potential key to increasing food production in the semi-arid areas of sub-Saharan Africa (Rosegrant et al., 2002). To achieve this, water productivity and crop yields have to be improved in rainfed farming systems. Analysis of on-farm water balances in Sub-Saharan Africa indicates that there is a great potential to improve crop and water productivity in the region. There is an opportunity to redirect unproductive green and blue water flows to productive green water (crop transpiration) (Rockstrom et al., 1999). In view of this, several studies have been conducted on water and soil management in semi-arid regions (Nyamudeza et al., 1992; Klaij and

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Vauchad, 1992; Chuma, 1993; Twomlow and Dhliwayo, 1999; Twomlow and Bruneau, 2000; Rockstrom et al., 2003; Barron, 2004). Water harvesting techniques have the potential to improve water supply to crops in rainfed cropping systems.

Rainfall in semi-arid areas of Zimbabwe occurs from November to March followed by a cool to warm period from May to October. Rainfall is erratic and highly variable both spatially and temporally. Variations in semi-arid rainfall patterns also include delayed onset and premature end of the rainy season. The rainfall often occurs as high intensity, short duration convective storms (Nonner, 1997) giving rise to severe soil erosion especially early in the cropping season when the ground is still bare. Intra-seasonal dry spells during the cropping season have become a common feature and their impact on crop production is often severe, especially if they coincide with critical stages of crop development (Oosterhout, 1996; Rockstrom et al., 2003). In the semi-arid areas severe crop yield reductions due to dry spells occur once or twice in every five years (Rockstrom et al., 2002). The long-term annual average rainfall in southern Zimbabwe is 590 mm (Ncube, 2007) with an estimated 70–85% of rainfall lost through soil evaporation, surface runoff and deep percolation (Rockstrom, 2000).

Conservation tillage (no till and reduced tillage) practices simultaneously conserve soil and water resources, reduce farm energy usage and increase or stabilise crop production. These practices lead to positive changes in the physical, chemical and biological properties of a soil (Bescansa et al., 2006). Soil physical properties that are influenced by conservation tillage include bulk density, infiltration and water retention (Osunbitan et al., 2004). Improved infiltration of rainwater into the soil potentially increases water availability to plants, reduces surface runoff and improves groundwater recharge (Lipic et al., 2005). Reduced soil cultivation decreases farm energy requirements and overall farming costs as less area has to be tilled (Monzon et al., 2006). This is crucial for the semi-arid areas of Zimbabwe where draught animals are weak at a time when land preparation has to commence.

Infiltration and soil evaporation are among the key processes that determine soil water availability to crops in semi-arid agriculture. The presence of crop residue mulch at the soil-atmosphere interface has a direct influence on infiltration of rainwater into the soil and evaporation from the soil. Mulch cover reduces surface runoff and holds rainwater at the soil surface thereby giving it more time to infiltrate into the soil. Trials conducted in the higher potential areas of Zimbabwe between 1988 and 1995 indicated that mulching significantly reduced surface runoff and hence soil loss (Erenstein, 2002). Mulch cover shields the soil from solar radiation thereby reducing evaporation from the soil. Soil biota increase in a mulched soil environment thereby improving nutrient cycling and organic matter build up over a period of several years (Holland, 2004).

This study was established to determine initial maize (*Zea mays* L.) yield and soil water responses to minimum tillage and mulching on clayey and sandy soils and identify optimum rates of mulch application for low potential areas of southern Zimbabwe. This paper focuses on the initial maize yield and soil water responses to the establishment of three tillage and seven residue/mulching treatments under two different rainy seasons.

2. Materials and methods

2.1. Experimental sites

The experiment was run at the International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Matopos Research Station, during 2004/05 and 2005/06 cropping seasons on two soil types, a clay and a granitic sand. The clay soil is located at the main Matopos experimental site (28°30.92′E, 20°23.32′S, 1344 m above sea level) and is classified as a shallow siallitic soil (4E.1) and Chromic–Leptic Cambisol according to the Zimbabwean and FAO systems, respectively (Moyo, 2001). The internal drainage of Matopos clay soil indicates saturation for short periods during the rainy season and external drainage is characterised by slow runoff (Moyo, 2001). The granitic sand is located at the Lucydale experimental site (28°24.46′E, 20°25.64′S, 1378 m above sea level) and is classified in the Zimbabwean system as moderately deep to deep well-drained fersiallitic soil (5G.2). This is classified as Eutric Arenosol (FAO, 1998). Internal drainage of Lucydale sand is rapid to very rapid and external drainage is characterised by slow runoff (Moyo, 2001). The chemical and physical properties of the two soil types are described in Table 1.

Matopos Research Station is located in Natural Farming Region IV, which is characterized by semi-arid climatic conditions with annual rainfall ranging between 450 and 650 mm. Rainfall season is unimodal and begins in November/December and ends in March/April. The long-term average rainfall for Matopos and Lucydale is 590 mm. The cropping season experiences periodic dry spells particularly in January. It is followed by a cool to warm dry season from May to September.

2.2. Experimental layout

The experiment was set up with a factorial treatment structure consisting of three tillage methods (conventional ploughing, ripping and planting basins) and seven rates of residue/mulch cover (0, 0.5, 1, 2, 4, 8 and 10 t ha^{-1}). Plots were pegged out in October of the first year, and then maintained in subsequent seasons. The treatments were arranged in a split-plot design with three replications at each site. The main plot factor was tillage (63×8 m) and seven mulch levels were randomly allocated in sub-plots (8×8 m) on each tillage treatment. Each plot was separated by a 1 m pathway to avoid movement of residue from

Table 1
Physical and chemical characteristics of Matopos and Lucydale soils, after Moyo (2001)

Soil property	Matopos				Lucydale			
Depth (cm)	0–6	6–16	16–40	40–60	0–12	12–24	24–35	35–57
Clay (%)	41	38	47	52	4	5	6	10
Silt (%)	20	23	17	17	4	5	4	3
Sand (%)	38	39	36	31	91	91	99	87
Gravel (%)	–	–	–	–	5	7	8	17
pH (CaCl_2)	7.5	7.6	7.7	7.8	5.0	4.9	4.8	5.5
O.C. (%)	0.46	0.80	0.37	0.48	0.00	0.00	0.04	0.00
Ca ($\text{Cmol}_c\text{kg}^{-1}$)	40.2	40.9	32.3	33.4	1.2	0.80	0.70	3.1
Mg ($\text{Cmol}_c\text{kg}^{-1}$)	14.8	15.4	16.6	19.7	0.40	1.00	0.70	2.2
K ($\text{Cmol}_c\text{kg}^{-1}$)	1.98	1.77	1.64	1.67	0.02	0.03	0.03	0.04
Effective depth (cm)	130				90			
Slope (%)	0.5–1 (nearly level, concave)				3 (straight)			

one plot to the next when tillage was undertaken. At Matopos research site a new block was established for the experiment in 2005/06 as cowpea was planted on the 2004/05 block as part of a rotation, which is not the focus of this paper. Cowpea results will not be reported in this paper. Unfortunately, due to logistical problems it was not possible to establish a new block at Lucydale in 2005/06. Residues at the location were not enough to make fresh applications. As a consequence in 2005/06 we looked at the residual impacts of the previous season's mulch levels. Digging of planting basins and ripping were carried out after applying mulch cover. Planting basins were dug at 0.6 m × 0.9 m spacing using a hand hoe and each basin measured 0.15 m (length) × 0.15 m (width) × 0.15 m (depth). Rip lines were opened at 0.9 m inter-row spacing using a ripper tine attached to the beam of a donkey-drawn mouldboard plough. The ripping depth achieved on both soils varied between 0.15 and 0.18 m. Cattle manure was applied in October each year at a rate of 3 t ha^{-1} in all plots under the three tillage treatments as basal soil fertility amendment. Manure was placed in the planting basins, dribbled along the ripline and broadcast under hand-dug planting basins, ripping and conventional tillage treatments, respectively. Conventional ploughing was done soon after the first effective rain (20–30 mm) in December each year using a donkey-drawn VS10 mouldboard plough. Planting furrows were then opened at inter-row spacing of 0.9 m. During the ploughing process most of the crop residue was incorporated into the soil.

Planting on both soils was achieved by mid-December in each season. At Matopos a hybrid maize variety, SC403, was planted in both seasons whereas at Lucydale an open pollinated variety, ZM421, was planted in 2004/05 season and SC403 in 2005/06. An open pollinated variety had to be planted at Lucydale in 2004/05 season in order to avoid contamination of breeding trials that were established nearby. Plant spacing was 0.9 m × 0.6 m with three kernels per-station for planting basins. In-row spacing was 0.3 m with two kernels per station for the ripping and conventional tillage treatments. Plants were thinned to two per basin in planting basin and one plant per station in the ripping and conventional tillage treatments two weeks after planting to achieve a population of 37,000 plants per hectare. Ammonium nitrate (34.5% N) was precision applied to all plots at 50 kg AN ha^{-1} as topdressing when the maize had reached the 6 leaf stage. The fertility regime reflects current fertility management practices that are being promoted to households with limited resources to invest (Ncube et al., 2006). Weeds were controlled by hand hoe as required in both seasons.

2.3. Data collection

At harvest grain and stover (above-ground biomass minus grain) yields were estimated from a net plot consisting of the five middle rows with a length of 6 m. The weights of cobs and stover from the netplot of each treatment were determined in the field before taking sub-samples for moisture correction. Grain and stover samples were dried at 60 °C for 48 h for moisture adjustment. The maize shelling percentage was determined for each treatment for converting cob weight into grain weight. Grain mass was converted to a per hectare basis at 12.5% moisture content as final grain yield.

Gravimetric soil water was determined by collecting soil samples fortnightly between basins, along riplines and rows in the planting basins, ripping and conventional tillage treatments, respectively. For bulk density determination, soil samples were collected by stainless steel cores of 50 mm internal diameter and 50 mm length. Soil samples for bulk density determination were collected before planting from outside the plots but within the same field. The soils were oven dried at 105 °C for 48 h before determining gravimetric water content. Bulk density and gravimetric water content for each soil layer were calculated using the procedure outlined by Anderson and Ingram (1993). Gravimetric water content was converted to volumetric water content for each respective depth using the measured bulk density for each soil layer. Soil water content in millimetres was determined by multiplying volumetric water content by thickness of each layer from which soil water was measured.

2.4. Statistical analysis

Analysis of Variance (Anova) was conducted using Genstat version 8.1 to determine the effect of tillage practice and mulching on maize yield and soil water content. Probability levels of 0.001, 0.01 and 0.05 were considered to determine level of significance between treatment means.

3. Results

3.1. Seasonal rainfall

The 2004/05 and 2005/06 cropping seasons were characterised by different rainfall patterns. Total seasonal rainfall for 2004/05 was less than half of that received in 2005/06 cropping period at Matopos and Lucydale (Figs. 1 and 2). During 2004/05 cropping period rainfall distribution was poor between mid-January and the beginning of March. Most of the rain for 2005/06 season fell in December and January. This coincided with the vegetative stage of the hybrid maize variety grown at both sites. More than 290 mm had been received at both sites by the time of planting in mid-December 2005. Planting in 2005/06 cropping season was delayed because of the incessant rains received in December.

3.2. Maize yield

3.2.1. Matopos site

In the two seasons of experimentation neither tillage nor residue/mulch level nor a combination of the two had any significant effect on maize grain yield and harvest index at the Matopos site. In fact, in both seasons of this experiment there were no discernible patterns of maize yield responses to residue/mulch level on the clay soil. However, tillage method significantly ($P = 0.015$) influenced maize stover production during the 2004/05 season, with planting basins giving the lowest yield (Table 2). This was in contrast to the 2005/06 season, where, although there was no statistical effects of tillage on either stover or grain production, the basins out performed conventional ploughing and the ripper.

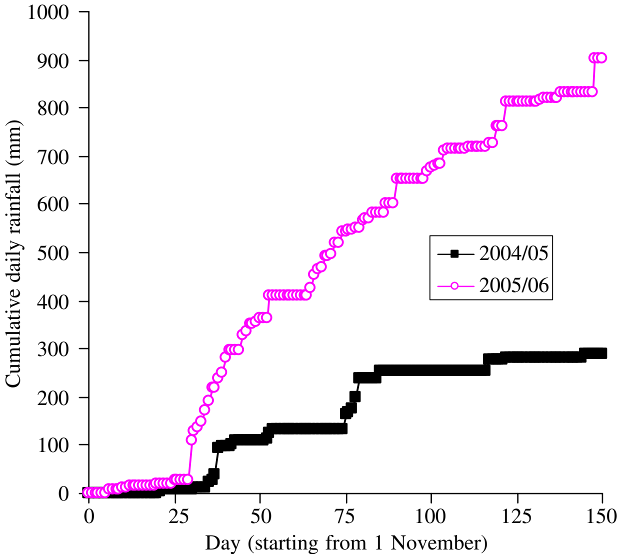

Fig. 1. Rainfall at Matopos between 1 November and 31 March during 2004/05 and 2005/06 cropping seasons.

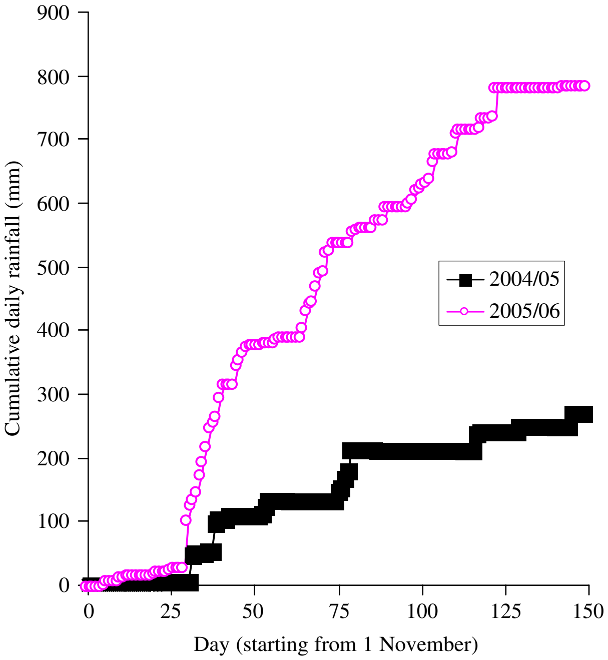

Fig. 2. Rainfall at Lucydale between 1 November and 31 March during 2004/05 and 2005/06 cropping seasons.

3.2.2. Lucydale site

In the first season of the experiment, the lower rainfall 2004/05 cropping season (Fig. 2), the planting basin tillage treatment out-yielded ripper and conventional tillage by 153 and 178 kg ha^{-1} respectively (Table 3). Maize crop under planting basin tillage produced significantly more ($P = 0.007$) total biomass than the other two tillage treatments. Somewhat surprisingly, mulch/residue levels had no significant impacts on maize responses in this below average rainfall season. During the 2005/06 season grain yield was weakly influenced ($P = 0.07$) by the tillage treatment. Maize stover production was not influenced by tillage treatment or the residual impacts of the previous seasons' residue/mulch levels. The three tillage methods had a significant effect ($P = 0.03$) on the harvest index of the hybrid maize variety grown in 2005/06 season (Table 3). Ripper and planting basins achieved similar harvest indices with conventional tillage giving a lower ($P < 0.05$) index.

3.3. Soil water content

3.3.1. Matopos site (2004/05 season)

Despite the below-normal rainfall, the three tillage methods had no significant influence on the average seasonal soil

Table 2
Maize yield (kg ha^{-1}) and harvest index responses to tillage treatments at Matopos during 2004/05 and 2005/06 cropping seasons

Tillage	2004/05 season			2005/06 season		
	Grain	Stover	Harvest index	Grain	Stover	Harvest index
Conventional plough	2616	3649	0.42	2721	6605	0.29
Ripper	2529	3596	0.42	2521	5012	0.28
Planting basin	2441	2808	0.48	3032	6958	0.29
s.e.d.	192	279	0.005	588	1189	0.009

Table 3
Maize yield (kg ha^{-1}) and harvest index responses to three tillage methods at Lucydale during 2004/05 and 2005/06 seasons

Tillage	2004/05 season			2005/06 season		
	Grain	Stover	Harvest index	Grain	Stover	Harvest index
Conventional plough	203	777	0.21	1262	3170	0.28
Ripper	238	834	0.22	1811	3723	0.33
Planting basin	381	1053	0.27	1523	3143	0.34
s.e.d.	91.7	70.7	0.074	464	1096	0.007

water content observed in the top 0.3 m, nor was there any significant interaction with residue/mulch rate (Fig. 3). However, average seasonal soil water content did vary significantly ($P < 0.001$) under the different residue/mulch rates (Fig. 3). Soil water content increased with increase in mulch cover irrespective of the tillage treatments. The low water contents observed under the plough treatment at the mulch rate of 2 t ha^{-1} have been attributed to sampling errors. As the cropping season progressed, soil water content remained significantly higher ($P < 0.001$) under 4, 8 and 10 t ha^{-1} mulch treatments.

3.3.2. Lucydale site (2004/05 season)

As observed on the clay soil, for the sandy soil, soil water content significantly increased ($P < 0.001$) with an increase in mulch cover in the top 0.3 m of this soil (Fig. 4). There were notable differences in soil water content in plots that had 2 and 4 t ha^{-1} mulch cover across the three tillage treatments. Further increase in mulch cover beyond 4 t ha^{-1} did not give additional benefits in soil water content under the three tillage treatments. The three tillage treatments had no significant ($P > 0.05$) effect on water content of the granitic sandy soil.

3.3.3. Matopos site (2005/06 season)

Neither tillage nor mulching treatments had any significant ($P > 0.05$) influence on soil water content measured in the top 0.60 m depth during this wetter-than-average season. Planting basins started with marginally higher soil

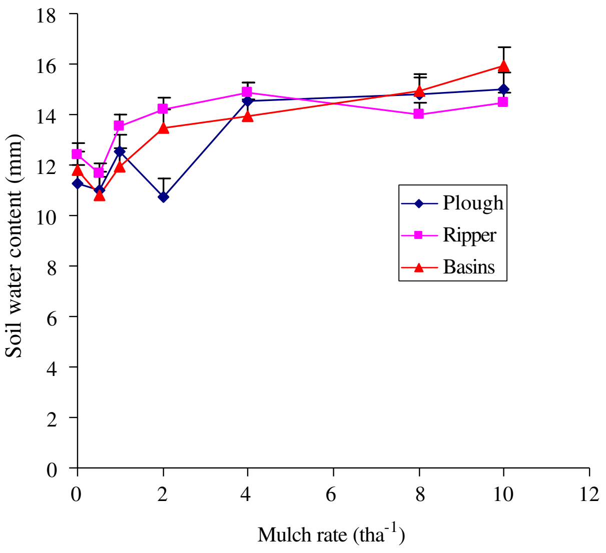

Fig. 3. Soil water content in the 0–0.30 m profile under different mulching treatments at Matopos during 2004/05 season. Bars indicate standard error.

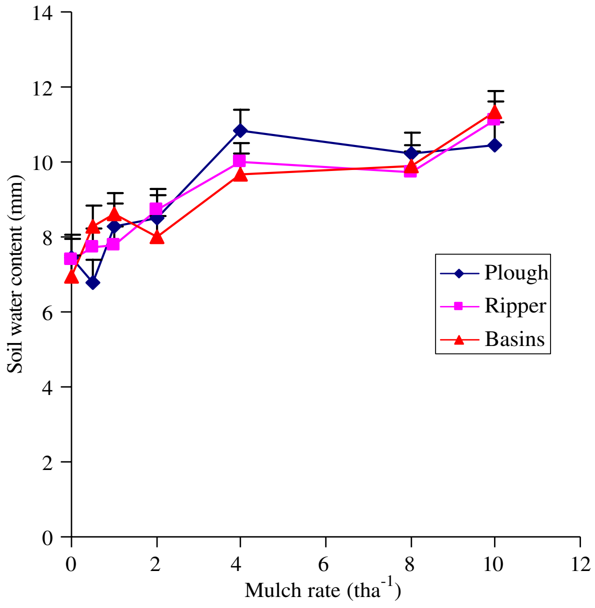

Fig. 4. Soil water content in the 0–0.30 m profile at Lucydale during 2004/05 cropping season. Bars indicate standard error.

water content in the top 0.60 m soil depth (Fig. 5), suggesting some initial water harvesting. However, soil water content in the top 0.60 m of the profile gradually declined as the season progressed (Fig. 5). Soil water content in the profile was significantly high between the day of planting and 20 days after planting. Thereafter, soil water content decreased significantly over time ($P < 0.001$), especially between 14 and 52 days after planting.

3.3.4. Lucydale site (2005/06 season)

Neither tillage method nor the residual effects of the previous seasons residue/mulch treatments had any significant influence on soil water content in the profile. For all tillage practices soil water content in the 0–0.60 m profile decreased rapidly between 83 and 97 days after planting (Fig. 6). The period between 41 and 69 days after planting also experienced soil water decline ($P < 0.001$) in the 0.60 m soil profile. The soil profile under conventional tillage experienced faster drying than planting basin and ripper tillage profiles from day 24 to day 69 after planting.

4. Discussion

The rainfall patterns of 2004/05 and 2005/06 farming seasons were quite different at both sites (Figs. 1 and 2). Total seasonal rainfall for 2004/05 was below the long-term average of 590 mm; Matopos recorded 320 mm and Lucydale received 291 mm between October and April. Poor distribution of rainfall during 2004/05 season negatively impacted maize growth at both Matopos and Lucydale sites. The higher crop stand under basin tillage was probably a result of more soil moisture availability than under ripper and conventional tillage. Soil water measurements showed that planting basins start off with marginally higher soil water, although this changed as the season progressed. The maize biomass yield was significantly suppressed under basin tillage on the clay soil during 2004/05 season. This may be due to the fact that it was the first time field staff had used the planting basin technique. Two plants in each planting basin competed for soil water especially during the dry spells that were experienced between January and March of 2004/05 season. Maize is usually more sensitive to soil moisture deficit between tasseling and silking stages of growth (Cakir, 2004). However, during the 2005/06 cropping period soil water was not limiting throughout all the sensitive stages of crop development, hence the higher crop yields observed at both sites (Tables 2 and 3).

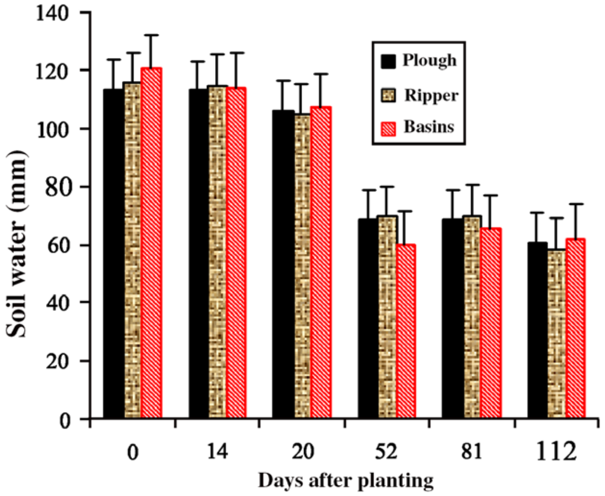

Fig. 5. Soil water content in the 0–0.30 m profile at Matopos during 2005/06 cropping season. Bars indicate standard error.

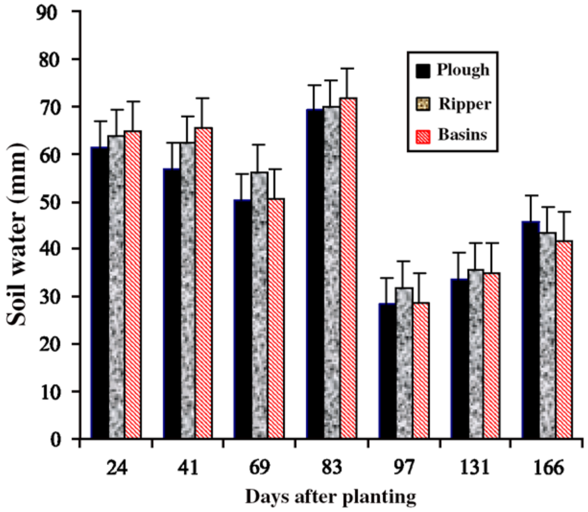

Fig. 6. Soil water content in the 0–0.60 m profile at Lucydale during 2005/06 cropping season. Bars indicate standard error.

During the second season, the harvest index from sandy soil site was influenced considerably by the tillage practice with planting basin and ripper tillage giving higher index than conventional ploughing (Table 3). This was probably a result of marginally better soil water and nutrient supply to crops under minimum tillage practices. The placement of basal manure in each planting basin and banding along the ripped furrow could have ensured a better availability of nutrients to plants compared to broadcasting of manure under conventional tillage practice. Studies conducted in Zimbabwe have shown that nutrients like N from manure become more available to crops in the second season (Nyamangara et al., 2003).

Total soil water content differed significantly between 2004/05 and 2005/06 cropping seasons at both Matopos and Lucydale experimental sites. In both seasons, soil water fluctuations were characterised by a gradual decline as the season progressed. In 2004/05 season there were sporadic periods of soil profile recharge in response to rainfall received. The soil profile refilled on day 74 after planting following a 28 mm rainfall event at Lucydale (Fig. 6). There was a sharp decline in soil water content between days 84 and 97 after planting in the sandy soil profile. This period coincided with the grain development stage of the maize crop. At this stage of development, demand for water by the crop can be substantial, leading to increased water extraction from the soil. A study by

Qin et al. (2006) showed that up to 80% of maize roots can be concentrated in the 0–30 cm layer under no-till systems. The sharp decline in soil water in sandy soil can also be attributed to drainage out of the sampling depth. During the 2005/06 cropping period, close to 50% of the long-term rainfall average for Matopos had been received by the time of planting in December 2005. The soil profile especially at Matopos was nearly saturated during the first half of the season. Crop demand for water was met even at the sandy soil site during the 2005/06 cropping period.

Mulching helped conserve soil water during 2004/05 cropping season at both Lucydale and Matopos experimental sites. Soil water content consistently increased with increase in surface cover across the three tillage practices (Figs. 3 and 4). Treatments that received 4, 8 and 10 t ha^{-1} mulch cover had the highest soil water content at the end of the cropping season. One of the major roles played by mulch cover during 2004/05 season was probably reducing soil evaporation. The season had long periods without rain especially after January 2005. Hatfield et al. (2001) reported a 34–50% reduction in soil water evaporation as a result of crop residue mulching. Under the heavy textured Matopos soil, water content did not increase significantly at mulching rates greater than 4 t ha^{-1} under ripper and conventional tillage practices whereas it continued to increase under planting basins treatment. However, with sand soil water benefits of mulching continued to increase insignificantly beyond 4 t ha^{-1} under ripper and basin tillage practices (Fig. 4). Understandably, during the 2005/06 season both fresh (Matopos) and residual (Lucydale) mulching had no notable effect on soil water across all tillage systems and soil types because of the continuous rainfall received. Surprisingly, despite the significant increases in soil water observed with increasing residue/mulch rates, this was not translated into significant impacts on maize yield in either season of the study.

5. Conclusion

On both soil types, neither mulching nor tillage method had a significant effect on maize grain yield, irrespective of rainfall received. The three tillage methods had no significant effect on seasonal soil water content, although planting basins harvested more rainwater during the first half of the cropping period. Mulching improved soil water content in both soil types with maximum benefits observed at 4 t ha^{-1} of mulch. We conclude that, in the short term, minimum tillage on its own, or in combination with mulching, performs as well as the farmers' traditional practices of overall ploughing. The lack of response to increased water content may be attributed to the soil fertility management regime followed in this study. Further work is required to look at the interactions between soil water conservation techniques and fertility management regimes.

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