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Reduced tillage, mulching and rotational effects on maize (*Zea mays* L.), cowpea (*Vigna unguiculata* (Walp) L.) and sorghum (*Sorghum bicolor* L. (Moench)) yields under semi-arid conditions

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ABSTRACT

Proponents of conservation agriculture (CA) argue that the CA approach offers the greatest opportunity to increase the productivity in smallholder agro-ecosystems. This study was designed to assess (1) first year maize, cowpea and sorghum yield responses to a combination of reduced tillage and mulching and (2) maize yield responses to rotation with cowpea and sorghum in reduced tillage systems. Two conservation tillage methods (ripping and planting basins) combined factorially with seven mulch levels (0, 0.5, 1, 2, 4, 8 and 10 t ha^{-1}) were compared with conventional mouldboard ploughing. The experiment was run for four consecutive growing seasons allowing for a rotation of maize, cowpea, sorghum and maize in some fields used in the study. Crop yields were determined across all tillage and mulch combinations in each year.

Tillage system had no significant effect on maize yield while maize grain yield increased with increase in mulch cover in seasons that had below average rainfall. Mulching at 2–4 t ha^{-1} gave optimum yields in seasons with below average rainfall. Tillage system and mulching had no significant effect on cowpea yield when soil moisture was not limiting. However, the ripper and basin systems had 142 and 102% more cowpea grain than the conventional system in 2006/2007 because of differences in planting dates used in three systems and poor rainfall distribution. The conventional and ripper systems gave 26 and 38% more sorghum grain than the basin system. Rotating maize with cowpea and sorghum resulted in 114, 123 and 9% more grain than first year maize, maize–maize monocrop and maize–cowpea–maize in the conventional system. In the ripper system, maize–cowpea–sorghum–maize rotation gave 98, 153 and 39% more grain than first year maize, maize–maize monocrop and maize–cowpea–maize rotation. In the basin system, maize–cowpea–sorghum–maize rotation gave 274, 240 and 43% more grain than first year maize, maize–maize monocrop and maize–cowpea–maize rotation. However, long term studies under different soil, climatic and socio-economic conditions still need to be conducted to substantiate the observations made in the reported study.

1. Introduction

Improvement of household food security in the sub-Saharan Africa (SSA) region has been elusive due to a combination of factors related to low and variable rainfall, poor fertility of the highly weathered soils and inappropriate soil management practices (Sanchez, 2002; Cobo et al., 2009; Belane and Dakora, 2010). Productivity in smallholder systems of Africa is further hampered by the low adoption of improved technologies with potential to increase farming output, and poor input–output market system (Dar and Twomlow, 2006). Seasonal rainfall distribution dominates the climate related crop production constraints in rainfed agriculture (Harris, 1996; Wang et al., 2009) but in growing seasons with good rainfall distribution crop yields are limited by low soil fertility and poor agronomic practices (Sanchez, 2002). Most farming households fail to utilize the favourable soil water conditions resulting in food deficits even in seasons with good rainfall patterns (Ncube et al., 2009). In all seasons access to draught animal power, labour, seed and fertilizers often determine the timeliness of farming operations such as land preparation and planting on

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Table 1
Experimental fields used and crops grown in each field during the period of experimentation at Matopos Research Station, Zimbabwe.

Field number	Period under reduced tillage and mulching (#seasons)	Season(s) field was used	Cropping sequence
1	1	2007/08	Maize (M)
2	2	2006/07 and 2007/08	Maize–maize (MM)
3	3	2005/06, 2006/07 and 2007/08	Maize–cowpea–maize (MCM)
4	4	2004/05, 2005/06, 2006/07 and 2007/08	Maize–cowpea–sorghum–maize (MCSM)

smallholder farms. Delayed planting coupled with the use of no or low quantities of organic and inorganic soil fertility amendments leads to poor utilization of favourable rainfall conditions.

Reduced tillage either as manual or animal powered system, and mulching offer a viable opportunity to increase crop productivity in a long term sustainable manner (FAO, 2002; Hobbs, 2007; Govaerts et al., 2009; Kassam et al., 2009; Wall, 2009; Thierfelder and Wall, 2010). Reduced tillage techniques have been explored for improving soil water supply during the cropping period and stabilizing or increasing crop production. The reduced tillage techniques that have been developed include clean and mulch ripping, no-till tied ridging and zero tillage (Nyakatawa et al., 1996; Twomlow and Bruneau, 2000). The soil water and crop yield benefits derived from using reduced tillage under semi-arid conditions can be enhanced by using mulch cover in the cropping system. For the semi-arid areas mulching maybe a suitable agronomic practice for conserving soil and water, and controlling soil temperature regimes (Chakraborty et al., 2008). 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 (Erenstein, 2002) leading to improved soil water supply for crops. 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). Currently manual and animal powered reduced tillage systems such as planting basins, dibble stick and ripping are being widely promoted in the smallholder farming sector of southern Africa (Thierfelder and Wall, 2010; Twomlow et al., 2008a).

With the current CA paradigm emphasizing on full rotation or mixing of cereals and legumes in permanent/semi-permanent planting positions, can grain legumes such as cowpea (*Vigna unguiculata* (Walp) L.) and small grain cereals such as (*Sorghum bicolor* L. (Moench)) fit into the reduced tillage systems designed for maize (*Zea mays* L.) without compromising on yield? What are the maize, cowpea and sorghum yield responses to reduced tillage systems in the short term under semi-arid conditions where seasonal rainfall is highly variable? Planting basins (manual reduced tillage system) and animal powered ripping (animal traction system) could perform the same as conventional ploughing (CP) under similar soil and climatic conditions. The planting basin and animal powered ripper tillage systems were selected for this study because they are currently being promoted under the CA programmes aiming at improving productivity in smallholder agro-ecosystems of Zimbabwe (Twomlow et al., 2008b). The paper reports specifically on (1) first year maize yield (*Zea mays* L.) responses to a combination of reduced tillage and mulching (2) cowpea and sorghum responses to reduced tillage and mulching and (3) maize yield responses to rotation with cowpea and sorghum under reduced tillage and conventional ploughing systems.

2. Materials and methods

2.1. Description of experimental site

The experiment was conducted at Matopos Research Station (MRS) in southern Zimbabwe (28°30′E, 20°23′S, 1344 m above sea level). The soil at MRS is a red silty clay loam derived from basaltic greenstone and contains 0.26% organic carbon, 45% clay, 19% silt and 36% sand in the 0–0.44 m layer. According to Moyo (2001) the soil best approximates a Chromic-Leptic Cambisol according to the FAO classification. The mean soil pH ($CaCl_2$), exchangeable calcium, magnesium and potassium contents are 6.3, 10, 5.7 and 0.17 $C\,mol_c\,kg^{-1}$ in the 0–0.44 m layer. The long term average rainfall is 573 mm with most of it falling between November and April (Mupangwa et al., 2011). Minimum and maximum temperatures at MRS average 13 and 26 °C, and annual evapotranspiration ranges from 1600 to 2600 mm (FAO, 1998). Experimental fields used in the study were previously used for production of breeder's sorghum seed and received basal and topdressing inorganic fertilizer at recommended rates each season they were used.

2.2. Experimental design and layout

The experiment was established in October 2004 using one experimental field in its first year of no-till. The experiment was run for four seasons with a new experimental field being added each year and maintained in subsequent years. Table 1 gives the crop sequence used in each field each year between 2004/2005 and 2007/2008 seasons. The experiment consisted of three tillage methods (animal-drawn conventional ploughing and ripping, and hand-dug planting basins) as the main plot and seven mulch levels (0, 0.5, 1, 2, 4, 8 and 10 $t\,ha^{-1}$) arranged as split plots on each tillage method. To ensure that animal drawn tillage implements attained their optimum working speed and depth it was decided that the main plot factor would be tillage. The 63 m long plots ensured optimal tillage operations and usage of land allowed animals and equipment to turn. The main plots measured 63 m × 6 m and sub-plots were 8 m × 6 m. Experimental plots were separated by 1 m pathways to avoid movement of maize residue mulch from one plot to the next during tillage operations. Each tillage method × mulch treatment was replicated three times.

Planting basins were spaced at 0.9 m × 0.6 m and each planting basin measured 0.15 m (length) × 0.15 m (width) × 0.15 m (depth). Rip lines were spaced at 0.9 m inter-row and the ripping depth achieved with a single pass of the ripper varied between 0.15 and 0.18 m, dependent on antecedent soil conditions. Digging of basins and ripping were done before the onset of the rains as recommended for drier regions (Twomlow et al., 2008b, 2009). The planting basin and ripper tillage systems were designed for maize with a target population of 37 000 plants per-hectare under semi-arid conditions (Twomlow et al., 2008b). In the conventional system planting furrows were opened at 0.9 m and ploughing depth varied between 0.15 and 0.2 m. Conventional ploughing was done soon after receiving planting rains as practiced by smallholders in south-western Zimbabwe. Maize was sown at three seeds per station in the basin system, thinned to two after emergence, and one plant per station in the conventional and ripper systems at a 0.3 m in-row spacing. Cowpea and sorghum were sown at four plants per basin in the basin system and one plant per station in the conventional and ripper systems at a 0.2 m spacing, and all planting dates are given in Table 2. Maize and sorghum were included in

Table 2
Planting dates of different crops in the conventional and reduced tillage systems during four seasons of experimentation at MRS.

Season	Crop	Planting dates	
		Conventional ploughing	Reduced tillage systems
2005/2006	Cowpea	15/12/2005	15/12/2005
2006/2007	Maize	21/11/2006	21/11/2006
	Cowpea	8/12/2006	22/11/2006
	Sorghum	14/12/2006	14/12/2006
2007/2008	Maize	12/12/2007	12/12/2007

the experiment because they are the dominant cereals grown by smallholders in south-western Zimbabwe. Cowpea is one of the major grain legumes grown by smallholders as sole or intercrop with cereals in southern Zimbabwe (Ncube et al., 2007) and is recommended for inclusion in CA systems that are being promoted in southern Africa (Twomlow et al., 2008b). In the 2006/07 season the ripper and basin systems were planted earlier than conventional system because it was too wet to plough the clay loam soil after receiving 68 mm of rain 5 days prior to 21 November 2006.

In all seasons mulch levels of <3 t ha^{-1} were used because cereal stover yields of up to 3 t ha^{-1} are achievable on smallholder farms in southern Zimbabwe (Ncube et al., 2007; Twomlow et al., 2008a; Mashingaidze et al., 2009). Mulch levels of >3 t ha^{-1} were selected in order to assess if there is any yield benefit in increasing surface cover beyond 1–2 t ha^{-1} which normally gives the minimum 30% cover for CA systems (Trip and Barreto, 1993; Erenstein, 1997). In all years only maize residue was used as mulch and was applied annually before tillage operations in the CA treatments. In the conventional system ploughing was done with the first effective rain (30–50 mm for Matopos clay loam soil) and maize residue mulch was applied soon after the tillage operation. In subsequent seasons any remaining maize residue on the conventionally ploughed treatment were incorporated during the tillage operation. In all experimental fields maize residues were applied as mulch each year. In the first year of each experimental field, maize residue was imported from other fields and all plots except the control treatment in each tillage system in order to achieve the targeted mulch application rates. All cowpea residues were left in the field during the cowpea phase of the rotation while sorghum residue was removed from all plots by September. During winter all maize residues to be used for mulching in the next season was left in the plots. Based on earlier work by Ncube et al. (2007) it was determined that a typical household in southern Zimbabwe would apply manure at 3 t ha^{-1} if available. Cattle manure (averaging 40% C, 0.43% N, 0.21% P) was applied at 3 t ha^{-1} in ripper and basin systems soon after opening rip furrows and planting basins in the maize and sorghum phases while no fresh application of manure was made in the cowpea phase of the rotation. Manure was broadcast before the ploughing operation in the conventional system.

A semi-determinate and short duration (60–70 days) cowpea variety (86D 719) sourced from International Institute of Tropical Agriculture (IITA) (Ncube et al., 2009) was planted in 2005/2006 and 2006/2007 seasons. Medium duration (110–120 days) Macia sorghum variety sourced from a local seed company was planted in 2006/2007 season. In all four seasons a short duration (∼120 days) commercial maize hybrid SC 403 was used. Ammonium nitrate (34.5% N) was spot applied at the base of maize and sorghum plants at 20 kg N ha^{-1} as topdressing when crops had reached the six leaf stage. The N rate was selected based on results from earlier studies done by Ncube et al. (2007) and Twomlow et al. (2008a). In each season weeds were controlled manually using a hand hoe in all treatments as required in all seasons. During the dry season plots were kept weed free by hand weeding when necessary.

2.3. Data collection and statistical analysis

Daily rainfall was measured between planting and harvesting using a manual rain gauge installed at the experimental site. In every season plant counts in each treatment were done 2 weeks after crop emergence. At harvest maize, cowpea and sorghum grain and stover yields were estimated from a net plot consisting of five middle rows with a running length of 6 m. Grain and stover subsamples for each crop were taken to the laboratory and dried at 60 °C for 48 h for moisture adjustment. The maize shelling percentage was determined for each treatment so as to convert cob weight into grain and core weights. Cowpea pods and sorghum heads were threshed before weighing the grain from each treatment. Grain weight for each crop was converted to a per hectare basis at 12.5% moisture content as final grain yield.

All data were assessed for normality before being subjected to analysis of variance (ANOVA). Cowpea, maize and sorghum yield data were analyzed using split plot ANOVA. Tillage method and mulch level were used as factors in the analysis of cowpea, sorghum and first year effects of reduced tillage and mulching on maize yield in the split plot ANOVA. To assess rotational effects on maize yield tillage method, mulch level and crop sequence were used as factors in a split plot ANOVA with tillage as main factor, mulch as sub-plot and crop sequence as sub-sub-plot factor. Significant treatment mean differences were determined by *t*-tests at 5% significance level ($P < 0.05$). Regression analysis was conducted to assess the relationship between mulch levels applied and crop parameters measured each season.

3. Results and discussion

3.1. Seasonal rainfall

The 2005/2006 growing season was the wettest, receiving 45% more rainfall than the long term average for Matopos (Fig. 1). Rainfall was well distributed between November and March, and the highest daily rainfall event was 80 mm recorded on 30 November 2005. However, 2006/2007 and 2007/2008 growing seasons experienced 19 and 36% less rainfall than the long term average for Matopos. The highest 24 h rainfall event during 2006/2007 season was 52 mm and the same season experienced 16–20 day dry spells during the January to February period which coincided with the flowering and grain filling stages of cowpea, sorghum and maize crops. In 2007/2008 season rainfall was also poorly distributed and ended on 26 January 2008 when the maize crop was at flowering stage. The highest 24 h rainfall event was 46 mm received on 18 December 2007 and 26 January 2008 during the 2007/2008 season. The dry spells experienced during the peak rainfall period of 2006/2007 and 2007/2008 seasons resulted in significant yield reductions particularly of maize. Mid-season dry spells often occur in southern Zimbabwe and the probability of such weather pattern

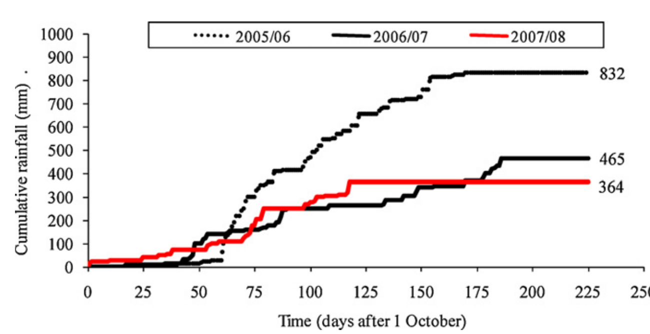

Fig. 1. Cumulative rainfall distribution at MRS during the period of experimentation.

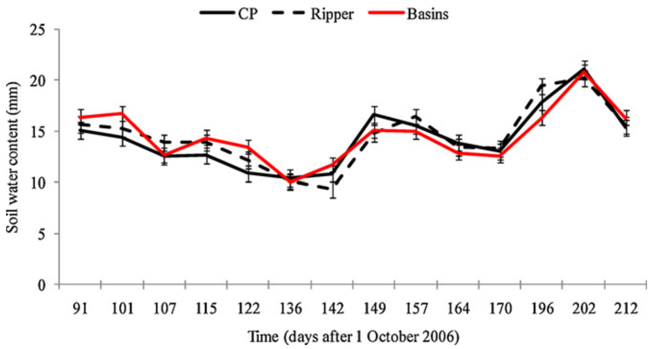

Fig. 2. Soil water changes in 0–0.25 m profile under conventional, ripper and basin systems across mulch levels applied during 2006/2007 cropping period at MRS. Vertical bars indicate standard error of means ($n = 3$).
Adapted from Mupangwa (2008).

increases rapidly during the January–March period (Mupangwa et al., 2011). Seasonal rainfall in 2006/2007 and 2007/2008 was less than 500 mm which is the lower limit for maximum production of medium maturity maize varieties (FAO, 1991). However, in 2006/2007 seasonal rainfall was just enough to meet the 450 mm water requirement for a 110–130 day sorghum variety (FAO, 1991).

3.2. First year maize responses to reduced tillage and mulching

In 2006/2007 season the tillage method and mulching interaction had no significant influence on grain yield ($P = 0.057$) but significantly affected crop establishment ($P < 0.001$) and stover production ($P = 0.046$) (Table 3). Generally the basin system had higher plant stand for most of the mulch treatments compared to conventional and ripper systems. In 2006/07 season basin system had higher soil water content early in the season compared to conventional and ripper systems (Fig. 2). This is consistent with on-farm results from southern Zimbabwe across different soil textural categories (Mupangwa et al., 2008). In 2006/2007 mulching increased grain yield and regression analysis indicated a significant ($P < 0.001$, $r = 0.59$) linear relationship between grain yield and mulch level applied regardless of the tillage system. In the conventional and ripper systems stover production increased ($P = 0.046$) with increase in mulch cover. However, the trend was reversed in the basin system where stover yield decreased with increase mulch cover except at 8 t ha^{-1} treatment, a trend which is consistent with the plant stand observed in the basin system. The increase in stover production with increase in mulch cover can be ascribed to the extension of the period when soil water was available to the maize crop under high mulch cover. Positive yield responses to mulching can be attributed to increased soil water in the plough layer (Mupangwa et al., 2007). Mulching conserves soil water by reducing soil evaporation as observed in previous studies (Zhai et al., 1990; Sauer et al., 1996; Erenstein, 2002).

In the 2007/2008 growing season, neither tillage method nor mulch cover, nor their interaction had any significant ($P > 0.05$) influence on crop establishment, maize grain and stover production (Table 4). The conventional and ripper systems had 41 and 52% more grain, and 18 and 20% more stover than the basin system across the mulch levels. Crop stand was similar in the conventional and basin systems but 19% higher in the ripper system compared to the other tillage treatments. Waterlogging in the basin plots during late December and early January resulted in the suppression of maize yields recorded at the end of 2007/2008 season. Waterlogging was more severe in basin plots with >4 t ha^{-1} mulch levels. There was no yield response to mulch despite the last rainfall event being recorded on 25 January 2008. This is consistent with results from Mashingaidze et al. (2009) which showed no maize and sorghum yield responses to mulching despite poorly distributed seasonal rainfall. The possible explanation is that the clay loam soil profile was saturated by the rains received in December 2007 and early January 2008 (Mupangwa, 2008), and there was enough soil water to take the maize crop to maturity regardless of mulch cover (Fig. 3). When exposed to soil water deficits maize roots also grow

Table 3
First year effects of reduced tillage and mulching on maize yield in 2006/2007 growing season at MRS, Zimbabwe ($n = 3$).

Tillage method	Mulch rate (t ha^{-1})	Plant stand (m^{-2})	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})
CP	0	0.8	676	1494
	0.5	1.1	1045	1543
	1	1.4	1712	3136
	2	1.4	1536	2420
	4	0.8	902	2086
	8	1.1	2018	2025
	10	1.4	1554	2099
	Mean	1.1	1349	2115
Ripper	0	2.6	1060	3086
	0.5	1.4	1148	1679
	1	1.8	919	3654
	2	1.3	1456	3790
	4	2.0	2030	4086
	8	1.5	1857	3444
	10	1.3	1751	4444
	Mean	1.7	1460	3455
Basins	0	2.5	735	4111
	0.5	2.6	973	4371
	1	1.9	1210	3876
	2	1.6	928	3642
	4	1.5	1570	3000
	8	2.2	2123	5025
	10	1.9	2129	3852
	Mean	2.0	1381	3982
SE (tillage)		0.317	150.8	460.1
SE (mulch)		0.126	142.4	326.7
SE (tillage × mulch)		0.376	273.7	697.2

SE: standard error of means.

Table 4
First year effects of tillage and mulching on maize yield in 2007/2008 season at MRS, Zimbabwe ($n = 3$).

Tillage method	Mulch rate (t ha^{-1})	Plant stand (m^{-2})	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})
CP	0	1.9	1504	1741
	0.5	1.7	1507	1321
	1	1.6	1129	1210
	2	1.5	664	815
	4	1.5	1218	1272
	8	1.4	1163	1284
	10	1.9	1878	1543
	Mean	1.6	1295	1312
Ripper	0	1.8	1257	1296
	0.5	2.2	2211	1790
	1	1.8	1194	1210
	2	1.8	1202	1198
	4	1.8	1162	1333
	8	2.0	1686	1679
	10	1.8	1100	1210
	Mean	1.9	1402	1388
Basins	0	1.6	1123	1296
	0.5	1.5	964	1173
	1	1.8	971	1185
	2	2.2	1009	1136
	4	1.7	1076	1271
	8	1.3	781	1037
	10	1.1	519	704
	Mean	1.6	920	1115
SE (tillage)		0.369	156.0	187.9
SE (mulch)		0.124	149.3	145.9
SE (tillage × mulch)		0.420	285.8	300.1

deeper and extract water from sub-soil layers (Otegui et al., 1995; Pandey et al., 2000) and this could have happened in our experiment. In all tillage systems maize residues were just enough to meet the minimum 30% mulch cover, highlighting the need for alternative sources of mulching materials for farmers practicing CA in southern Zimbabwe where livestock is a key resource for smallholders.

3.3. First year cowpea responses to reduced tillage and mulching

Cowpea responses to tillage method and mulching in 2005/2006 and 2006/2007 seasons are given in Tables 5 and 6. In the drier 2006/2007 season there was better cowpea establishment in the ripper tillage system. The poor stand in the planting basin system can be attributed to seed predation by rodents that were experienced at Matopos experimental fields. It was relatively easier for the rodents to identify planting positions under the planting basin system than ripper and conventional ploughing treatments. Some smallholder farmers have devised rodent traps such as 10 l bucket half-filled with water in an effort to curb seed predation. In Botswana seed predation was also observed at crop establishment particularly with small grains and chemical control was used (Harris, 1996). Tillage method and mulching interaction had no significant influence on grain ($P = 0.314$) and stover ($P = 0.106$) production during 2005/2006 season which had no soil water limitations. In 2006/2007 season the two-way tillage method and mulching interaction had no significant ($P = 0.218$) effect on grain yield but significantly ($P < 0.001$) influenced cowpea stover yield. Stover production increased with increase in mulch cover in the reduced tillage systems only (Table 6). This suggests that biomass accumulated under the different mulch conditions in the reduced tillage systems could not be translated into grain yield. The reduced tillage systems gave more ($P = 0.009$) grain compared to the conventional system in 2006/2007 season regardless of the mulch level used (Table 6). The ripper and basin systems had 142 and 102% more grain compared to the conventional system in 2006/2007. Delayed planting in conventional system exposed the cowpea crop to aphid (*Aphis craccivora* L.) attack and dry spells experienced during January and February 2007 and hence low yields were realized from the conventional system. Smallholders using reduced tillage systems on heavy textured soils stand a better chance of timely planting and getting higher crop yields compared to farmers using the traditional system. In 2006/2007 grain yield increased ($P = 0.030$) with increase in mulch cover up to 2 and 4 t ha^{-1} mulch treatments in all tillage systems (Table 6). The relationship between grain yield and mulch level applied was quadratic ($P < 0.001$, $r = 0.53$) and the lower grain yield achieved at 8 and 10 t ha^{-1} mulch cover in all tillage systems can be attributed to poor establishment observed in the experiment (Table 5). Cowpea grain yields achieved in reduced tillage systems in the two seasons and conventional system in 2005/2006 season were greater than the national yield average of 0.3 t ha^{-1} reported by Nhamo et al. (2003) but comparable to other research findings (Rusinamhodzi et al., 2006; Ncube et al., 2009; Belane and Dakora, 2010). The yield differences between our findings and the national average can be attributed to differences in rainfall patterns, varieties used, soil fertility of sites and general agronomic practices where the cowpea was grown.

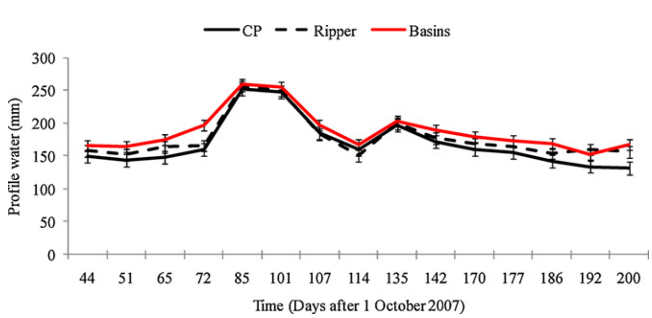

Fig. 3. Soil water changes in 0–0.6 m profile under conventional, ripper and basin systems across mulch levels during 2007/2008 cropping period at MRS. Vertical bars indicate standard error of means ($n = 3$).
Adapted from Mupangwa (2008).

Table 5
Cowpea responses to reduced tillage and mulching in 2005/2006 growing season at MRS, Zimbabwe ($n=3$).

Tillage method	Mulch rate (t ha^{-1})	Plant stand (m^{-2})	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})
CP	0	4.3	1286	5135
	0.5	4.5	835	5516
	1	4.6	1435	5623
	2	4.2	1333	6004
	4	5.0	1838	4526
	8	4.4	1254	6629
	10	4.6	1222	5166
	Mean	4.5	1315	5514
Ripper	0	4.6	1099	3745
	0.5	4.6	1301	4587
	1	4.5	1123	4444
	2	4.1	743	4006
	4	4.6	862	3117
	8	4.5	1430	4693
	10	4.3	980	4433
	Mean	4.5	1077	4146
Basins	0	6.5	1417	4978
	0.5	6.9	1180	4516
	1	6.9	1593	4978
	2	6.0	1217	4207
	4	6.3	1277	4456
	8	5.1	728	3176
	10	6.1	960	4148
	Mean	6.3	1196	4351
SE (tillage)		0.351	231.1	368.4
SE (mulch)		0.281	156.6	287.6
SE (tillage × mulch)		0.571	341.3	590.2

3.4. First year sorghum responses to reduced tillage and mulching

Sorghum responses to reduced tillage and mulching are given in Table 7. The two-way interaction had no significant effect on crop establishment ($P=0.883$), grain ($P=0.626$) and stover (0.433) production. However, the conventional and ripper systems had higher crop stand ($P=0.003$), grain ($P=0.014$) and stover ($P=0.018$) yields compared to the planting basin system across the mulch treatments. As experienced in the cowpea field at the beginning of 2006/2007 season plant stand was significantly reduced in the basin system by rodents. The conventional and ripper systems produced 26 and 38% more grain than the basin system across the mulch levels tested in this experiment. The conventional and ripper systems produced 39 and 42% more stover than the basin system across the seven mulch treatments.

Table 6
Cowpea responses to reduced tillage and mulching in 2006/2007 growing season at MRS, Zimbabwe ($n=3$).

Tillage method	Mulch rate (t ha^{-1})	Plant stand (m^{-2})	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})
CP	0	2.0	161	610
	0.5	2.2	129	589
	1	1.7	222	691
	2	2.8	226	876
	4	2.1	389	629
	8	1.9	147	762
	10	1.9	320	608
	Mean	2.1	228	681
Ripper	0	4.6	549	3547
	0.5	4.9	605	3893
	1	4.4	625	4000
	2	3.7	696	4933
	4	4.4	674	4640
	8	3.3	464	5147
	10	2.8	254	5040
	Mean	4.0	552	4457
Basins	0	3.7	412	3760
	0.5	2.9	460	3680
	1	3.3	367	4880
	2	2.9	640	4320
	4	3.1	389	5520
	8	2.1	473	5200
	10	2.3	487	5600
	Mean	2.9	461	4709
SE (tillage)		0.391	40.1	187.1
SE (mulch)		0.378	49.6	125.2
SE (tillage × mulch)		0.721	89.1	274.5

Table 7
Sorghum responses to reduced tillage and mulching in 2006/2007 growing season at MRS, Zimbabwe ($n = 3$).

Tillage method	Mulch rate (t ha^{-1})	Plant stand (m^{-2})	Grain yield (kg ha^{-1})	Stover yield (kg ha^{-1})
CP	0	2.2	2012	3975
	0.5	2.1	1894	3802
	1	2.0	1907	3941
	2	2.0	1805	4346
	4	2.2	2084	4000
	8	2.3	2193	4642
	10	1.9	2143	4741
	Mean	2.1	2005	4207
Ripper	0	2.0	1865	4086
	0.5	1.9	2007	3235
	1	1.9	2190	4765
	2	2.0	2294	4494
	4	1.9	2504	4123
	8	2.1	2310	4975
	10	2.0	2154	4333
	Mean	2.0	2189	4287
Basins	0	0.77	1390	2370
	0.5	0.87	1390	3210
	1	0.95	2043	2346
	2	0.97	1435	2790
	4	0.94	1340	3259
	8	1.2	1647	3827
	10	0.83	1879	3346
	Mean	0.93	1589	3021
SE (tillage)		0.108	79.3	197.1
SE (mulch)		0.069	131.0	231.0
SE (tillage × mulch)		0.155	224.6	419.6

Sorghum stover production increased ($P = 0.032$) with increase in mulch cover and the relationship between sorghum yield and mulch level applied was quadratic ($P = 0.028$, $r = 0.60$). Despite the low crop stand the basin system produced adequate sorghum residues to meet the minimum mulching requirements for CA systems. In southern Zimbabwe where sorghum is one of the major cereals grown by smallholders (Ncube et al., 2007) the less palatable sorghum residues can be used for mulching while maize residues are fed to livestock. Lack of grain yield response to mulching suggests that soil water conserved by mulch was just adequate to impact positively on stover production and not enough for the conversion of accumulated biomass into grain. Sorghum can survive dry conditions because of its ability to extract water from the subsoil (0.45–1.35 m depth) (Singh and Singh, 1995). When sorghum is exposed to soil water stress its roots grow deeper into the profile thereby increasing the volume of moist soil explored in search of water (Singh and Singh, 1995). Sorghum yields obtained in our study are comparable with results from some previous studies under semi-arid conditions (Postlethwaite and Coventry, 2003; Brhane et al., 2006; Ncube et al., 2007) but higher than the average yield (800 kg ha^{-1}) for Africa (FAO, 1998; Olembo et al., 2010).

3.5. *Effect of rotation on maize yield*

Tillage method, mulching and crop sequence interaction had no significant ($P = 0.900$) influence on maize grain yield recorded at the end of 2007/2008 season (Table 8). However, the two-way tillage method and crop sequence interaction influenced ($P = 0.001$) grain production during the 2007/2008 season. In each tillage system the MCSM rotation had higher grain yield than the other crop sequences across mulch treatments, illustrating the cumulative benefits of rotating maize with cowpea and sorghum, and the improved soil properties shown by changes in soil bulk density and total organic carbon (Tables 9 and 10). When averaged across mulch treatments, the MCSM rotation gave 114, 123 and 9% more grain than M, MM and MCM rotations in the conventional system. In the ripper system, MCSM rotation had 98, 153 and 39% more grain than the M, MM and MCM rotations. A similar trend was observed in the basin system where the MCSM rotation had 274, 240 and 43% more grain than the M, MM and MCM rotations. Differences in maize grain yield between the oldest field and the

Table 8
Effect of tillage, mulching and crop rotation on maize grain yield (kg ha^{-1}) at MRS, Zimbabwe in 2007/2008 season ($n = 3$).

Tillage method	Mulch level (t ha^{-1})	Crop sequence			
		M	MM	MCM	MCSM
CP	0	1504	1370	2971	2400
	0.5	1507	1367	2399	2791
	1	1129	1463	2527	2278
	2	664	1348	2867	1977
	4	1218	1021	2147	3569
	8	1163	997	2560	3525
	10	1878	1148	2408	2880
	Mean	1295	1245	2554	2774
Ripper	0	1257	998	2033	2579
	0.5	2211	1230	2819	3328
	1	1194	1037	2237	2409
	2	1202	1244	1852	3327
	4	1162	865	1697	2687
	8	1686	1163	1764	2393
	10	1100	1142	1547	2718
	Mean	1402	1097	1993	2777
Basins	0	1123	926	3139	3226
	0.5	964	1132	2619	3482
	1	971	880	2318	3728
	2	1009	1242	2469	3592
	4	1076	844	1688	2799
	8	781	1010	2438	3598
	10	519	1054	2195	3666
	Mean	920	1013	2409	3442
SE (tillage)				71.6	
SE (mulch)				109	
SE (crop sequence)				82.6	
SE (tillage × mulch × crop sequence)				379	

Table 9
Effect of tillage method, mulching and cropping sequence on soil bulk density of a red clay soil at Matopos Research Station.

Mulch (t ha^{-1})	Tillage and sampling location	Cropping sequence			
		M	MM	MCM	MCSM
0	Conventional plough	1.51	1.55	1.57	1.50
	Between riplines	1.45	1.51	1.52	1.52
	Within riplines	1.46	1.57	1.47	1.44
	Between basins	1.63	1.55	1.48	1.50
	Within basins	1.57	1.59	1.48	1.48
	Mean	1.55	1.55	1.50	1.49
4	Conventional plough	1.51	1.62	1.54	1.48
	Between riplines	1.48	1.54	1.54	1.45
	Within riplines	1.48	1.53	1.45	1.43
	Between basins	1.54	1.59	1.51	1.49
	Within basins	1.44	1.55	1.50	1.46
	Mean	1.49	1.57	1.51	1.46
10	Conventional plough	1.63	1.66	1.51	1.50
	Between riplines	1.46	1.54	1.52	1.46
	Within riplines	1.39	1.46	1.46	1.36
	Between basins	1.55	1.62	1.49	1.47
	Within basins	1.58	1.47	1.50	1.41
	Mean	1.52	1.55	1.49	1.44
$LSD_{0.05}$ (tillage × mulch × crop sequence)				0.096	
CV (%)				7.2	

Adapted from Mupangwa (2008).
LSD: least significant difference; CV: coefficient of variation.

three younger fields were greater in the basin system compared to the conventional and ripper systems.

Maize grain yields in ripper and basin systems after cowpea were comparable in some years with previous findings from the more humid agro-ecological regions under conventional and CA systems (Rusinamhodzi et al., 2006; Thierfelder and Wall, 2010). The higher maize productivity following the MCSM rotation can be attributed to the residual N contribution from cowpea grown in 2005/2006 season. Cowpea can contribute as little as 4 kg N ha^{-1} to as much as 92 kg N ha^{-1} to the following cereal crop dependent on soil and climatic conditions (Rusinamhodzi et al., 2006; Ncube et al., 2007; Adjei-Nsiah et al., 2008). The improved maize productivity observed in the reported study can also be attributed to improved soil conditions (Tables 9 and 10). An on-farm study by Belder et al. (2007) showed a significant decrease in soil bulk density with increase in years of implementing the basin system. Reduced soil bulk density observed in our experimental fields in 2007/2008 season (Table 9) could have allowed maize roots to explore the soil deeper for nutrients and water. Growth of plant roots into deeper soil layers can buffer crops against mid-season dry spells as roots are able to extract water from layers that are not significantly affected by soil evaporation during the growing season (Wang et al., 2009).

In all tillage systems the MCSM rotation had higher (P = 0.003) stover yield than the other crop sequences across the mulch treatments (Table 11). This further highlights improving productivity when rotation, organic and inorganic fertilizers are consistently used even in well managed conventional systems. In the conventional system the MCSM rotation had 132, 89 and 32% more stover compared to the M, MM and MCM rotations across the mulch treatments at the end of 2007/2008 season. The MCSM rotation gave 111, 93 and 48% more maize stover than M, MM and MCM rotations in the ripper system. In the basin system stover yield was 221, 159 and 48% higher in the MCSM rotation compared to M, MM and MCM rotations across the mulch levels. With the inclusion of crop rotation the basin system showed a greater potential for producing sufficient maize residues for the minimum 30% mulch cover recommended in CA systems compared to conventional and ripper systems after four seasons. Improved maize productivity in CA systems observed in the reported study is consistent with findings from other studies under sub-humid and semi-arid conditions (Thierfelder and Wall, 2010; Verhulst et al., 2011).

Table 10
Effect of tillage system and rotation on total soil organic carbon content (%) of a clay loam soil at Matopos Research Station.

Tillage method	Crop sequence			
	M	MM	MCM	MCSM
Conv. plough	0.67	0.71	0.90	1.00
Between riplines	0.97	0.92	0.91	0.90
Within riplines	0.98	0.90	0.92	0.95
Between basins	0.76	0.80	0.90	0.83
Within basins	0.93	0.90	1.13	1.06

Adapted from Mupangwa (2008).
$LSD_{0.05}$ = 0.19; CV = 21%.

Table 11
Effect of reduced tillage, mulching and crop rotation on maize stover yield (kg ha^{-1}) at MRS, Zimbabwe in 2007/2008 season (n = 3).

Tillage method	Mulch level (t ha^{-1})	Crop sequence			
		M	MM	MCM	MCSM
CP	0	1741	2000	2198	2321
	0.5	1321	1617	2111	2765
	1	1210	1593	2704	2975
	2	815	1519	2457	3049
	4	1272	1691	2099	3975
	8	1284	1309	2383	3247
	10	1543	1543	2222	2988
	Mean	1312	1610	2311	3046
Ripper	0	1296	1494	2148	2753
	0.5	1790	1617	2864	3407
	1	1210	1111	2049	3296
	2	1198	1988	1642	3370
	4	1333	1321	1617	2914
	8	1679	1691	2049	2395
	10	1210	1383	1469	2333
	Mean	1388	1515	1977	2924
Basins	0	1296	1556	2741	2901
	0.5	1173	1840	2395	4654
	1	1185	1173	2654	3543
	2	1136	1358	2370	3099
	4	1271	1235	1914	3148
	8	1037	1173	2321	3815
	10	704	1321	2556	3877
	Mean	1115	1379	2422	3577
SE (tillage)				32.5	
SE (mulch)				74.1	
SE (crop sequence)				74.9	
SE (tillage × mulch × crop sequence)				321.6	

4. Conclusion

The influence of the three tillage systems on maize production varied from season to season and was significantly influenced by seasonal rainfall pattern. The early season rainwater harvesting effect of basins offered an opportunity for better crop establishment in 2006/2007 season which had below average rainfall. Maize yields obtained from the reduced tillage systems were similar to the conventional system when soil water was not limiting and better in below average rainfall years. As observed in 2006/2007 season characterized by poor rainfall distribution, mulching improved maize yields. Although the highest maize yields were achieved at 8 t ha^{-1} mulch rate, there were no significant yield benefits derived from increasing mulch cover beyond 4 t ha^{-1}. Maize residues in excess of the minimum mulching requirements (30% surface cover) were achieved from the three tillage systems on a clay loam soil even in seasons with poor rainfall pattern. Smallholder farmers implementing CA can target using 2–4 t ha^{-1} mulch cover if crop residues are available. More research work is needed to address waterlogging in basin system. Future research could focus on exploring different basin sizes particularly smaller basins than the size used in the reported study.

The basin and ripper systems gave higher cowpea yields than a well managed conventional system in a drought year as observed in 2006/2007 season. However, rodent attack in the basin system poses a big challenge for successful cropping especially in seasons with below average rainfall. Future research could focus on chemical and physical rodent control options. Alternatively farmers without access to draught power can turn to manual reduced tillage options such as the jab-planter and dibble stick. Mulching improved cowpea yields in seasons that had poorly distributed rainfall with 2 and 4 t ha^{-1} giving similar yields. Higher mulch levels of 8 and 10 t ha^{-1}, which are unachievable under the current smallholder conditions, suppressed cowpea crop establishment, and subsequently lowered cowpea and sorghum yields, so they should not be recommended anyway. Our results indicated that the wide spacing used in the basin and ripper systems did not compromise the yields of cowpea and sorghum crops. Cowpea and sorghum can therefore be grown in the manual and animal powered reduced tillage systems that are being promoted in southern Africa.

Rotating cereals and legumes in both conventional and reduced tillage systems improved crop productivity with time as demonstrated by higher maize yields after MCSM crop rotation. A combination of reduced tillage, mulching and crop rotation increased grain and stover yields substantially and there was a greater potential for producing high biomass quantities with time in the basin system. Despite the yield benefits of mulching in dry years observed in our study long term studies under different soil, climatic and socio-economic conditions are still required to substantiate the crop responses shown in the reported study.

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