

Conservation Tillage for Soil Water Management in the Semi Arid Southern Zimbabwe

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Abstract

Planting basins and ripper tillage practices are major components of the recently introduced conservation agriculture package that is being extensively promoted for smallholder farming in Zimbabwe. Besides preparing land for crop planting, these two technologies also help in collecting and using rainwater more efficiently in semi-arid areas. The basin tillage is being targeted for households with limited or no access to draught animals while ripping is meant for smallholder farmers with some draught animal power. Trials were established at four farms in Gwanda and Insiza to determine soil water contributions and runoff water losses from plots under four different tillage treatments. The tillage treatments were hand-dug planting basins, ripping, conventional spring and double ploughing using animal-drawn implements. The initial intention was to measure soil water changes and runoff losses from cropped plots under the four tillage practices. However, due to total crop failure, only soil water and runoff were measured from bare plots between December 2006 and April 2007. Runoff losses were highest under conventional ploughing. Planting basins retained most of the rainwater that fell during each rainfall event. The amount of rainfall received at each farm significantly influenced the volume of runoff water measured. Runoff water volume increased with increase in the amount of rainfall received at each farm. Soil water content was consistently higher under basin tillage than the other three tillage treatments. Significant differences in soil water content were observed across the farms according to soil types from sand to loamy sand. The basin tillage method gives a better control of water losses from the farmers' fields. The planting basin tillage method has a greater potential for providing soil water to crops than ripper, double and single conventional ploughing practices.

Five keywords: Double ploughing, Planting basins, Ripping, Runoff, Soil water content.

Introduction

Smallholder agriculture in semi-arid areas is hampered by biophysical and climatic constraints among others. The predominant chemical and physical challenges with soils in smallholder farming areas of Zimbabwe include low organic matter, low pH and poor structure (Nyamangara and Mpofu, 1996; Twomlow et al., 2006). Marginal lands once used for grazing have been opened for cropping and this further increases the erosion risk of the poor structured soils (Whitlow, 1988). The spatial distribution of water in the soil is further restricted by the presence of a hard plough pan. In the wetter Agroecological Regions II and III of Zimbabwe Tsimba et al. (1999) observed a ploughpan at 10-15 cm depth within the soil profile across 23 farms. Poor land management which is rampant in semi-arid smallholder farming sector continues to threaten agricultural productivity in Zimbabwe.

Climatic challenges especially rainfall pose a major threat on household food security. In semi-arid areas rainfall is low, erratic and highly variable in space and time (Rockström 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). Rain falls as short duration, high intensity convective storms that can give rise to severe soil erosion and surface crusting (Nonner, 1997; Graef and Stahr, 2000). The raindrop impact on the soil surface promotes crusting which retards infiltration of rainwater into the soil (Mellis et al., 1996; Graef and Stahr, 2000). This in turn increases surface runoff and hence water loss from the field (Twomlow and Bruneau, 2000). Coupled with a high atmospheric evaporative demand of about 1.5-10 times the total annual rainfall (Barron, 2004), water is therefore one of the major limiting factors to semi-arid crop production.

Conservation tillage practices can potentially address the soil and water management constraints faced by smallholder farmers in semi-arid areas. In view of this, several studies have been conducted on water and soil management in semi-arid areas (Twomlow and Dhillwayo, 1999; Twomlow and Bruneau, 2000; Nyagumbo, 2002). Hand and animal powered techniques for soil and water management are being promoted in the semi-arid smallholder farming sector of southern Zimbabwe (Mupangwa et al., 2006). Conservation tillage techniques such as planting basins and tine ripping have brought a ray of hope to soil water management in semi-arid southern Zimbabwe. These tillage techniques can potentially address both soil water availability to crops and the soil physico-chemical limitations facing smallholder farmers. This study was designed to quantify (i) surface runoff losses from fields under each of the four tillage treatments and (ii) soil water contributions of planting basins, tine ripping, single and double conventional spring ploughing. Measurements of soil water and surface runoff were made on bare plots from December 2006 following maize crop failure due to drought.

Materials and methods

Site descriptions

The experiments were established in Insiza and Gwanda districts of Matebeleland South province, which forms part of the Mzingwane catchment. The climate of Insiza and Gwanda is characterised by a unimodal rainy season from November to March and a dry winter season from May to September. Rainfall is low (250-550mm) and variable, decreasing from the northeast to the southwest with a mean annual rainfall of 480 mm. The major soils are coarse-grained sands to loamy sands and are classified as 5G according to the Zimbabwe Soil Classification system. Vegetation consists of *Colophospermum mopane* as the dominant tree species with scattered associated tree species of *Commiphora* spp, *Combretum apiculatum* and *Adonsonia digitata*. The relief varies between undulating in Insiza district to flat in Gwanda district. The farming system of both districts consists of a combination of crop and livestock enterprises. The major cereals grown are maize, sorghum and pearl millet while the livestock enterprise comprises cattle, goats, donkeys and poultry. Legumes such as groundnut, bambaranut and cowpea are also grown as sole crops or intercrops with cereals.

Experimental set up

The experiment was established at four farms, two in Insiza district (Upper Mzingwane subcatchment) and two in Gwanda district (Lower Mzingwane subcatchment). Four tillage treatments namely planting basins, tine ripping (using Zimplow ripper), single and double ploughing were compared at each farm. Planting basins and tine ripping are technologies that are currently being promoted in smallholder farming areas of southern Zimbabwe. Double ploughing has been promoted by Department of Research and Extension (AREX) as way for conserving soil moisture after farmers have finished harvesting. Single ploughing is the current normal practice followed by smallholder farmers in Matebeleland South province. Digging of planting basins, tine ripping and the first ploughing of double ploughing treatment were done in October 2006. Single and the second ploughing of the double ploughing treatment were carried out after the first effective rains when farmers were planting (last week of November 2006).

Four plots measuring 30 m x 10 m each were pegged out at each farm. The recommended dimensions of each planting basin 15 cm (length) x 15 cm (width) x 15 cm (depth) and spacing of 90 cm x 60 cm (ICRISAT, 2006) were adopted in this study. Inter-row spacing for the riplines used was 90 cm. Depth of ripping averaged 18 cm across the four farms. Ploughing depth in both single and double ploughing treatments ranged between 15 cm and 18 cm across the four farms. Ripping and ploughing depths depended on the ability of each farmer's draught animals to pull the ripper or the plough during tillage operations. All host farmers used a span of four donkeys during the tillage operations in both districts.

Each of the 30 m x 10 m plot was subdivided into three 10 m x 10 m subplots and an access tube was sunk at the center of each subplot for soil water measurements. The depth of each access tube depended on the soil profile characteristics at each farm. However, the depth of tubes ranged between 60 and 80 cm across the four farms. Under planting basins tillage treatment, access tubes were sunk between basins in a row. In the ripper tillage treatment access tubes were sunk along the rip furrow. In the single and double ploughing treatments access tubes were sunk along the maize planting rows.

Under each tillage treatment, one of the 10 m x 10 m subplots was used for the determination of runoff losses. The borders of runoff plots were made from a heat resistant polythene plastic. The polythene plastic prevented water flow from other parts of the field onto the runoff plot. At the down slope side of each runoff plot a triangular surface measuring 10 m (base) x 1.7 m (height) was used to receive runoff water from the plot and lead it into 200 litre drum through a polythene plastic gutter.

Measurements

Bulk density was measured up to 60 cm depth using the procedure outlined by Anderson and Ingram (1993). Soil texture was determined at each site using the hydrometer method (Anderson and Ingram, 1993). At each farm daily rainfall was measured from October 2006 to April 2007 using a standard raingauge. Runoff water volume collected in each drum was measured after every runoff-generating rainfall event. The depth of water in each drum was measured by a staff gauge graduated to

the nearest centimetre. The drums were emptied after each rainfall event. Soil water was measured fortnightly using a Capacitance probe to a depth of 60-cm.

Statistical analysis

The runoff and soil water content data were analyzed using the method of residual maximum likelihood (REML) included in Genstat 6.1 statistical package. The REML method accounts for more than one source of variation and makes it possible to analyze data from unbalanced designs. The following models were used;

(a) Response: Surface runoff

Fixed model: Constant + Tillage + Farmer + Tillage. Farmer

Random model: District

(b) Response: Soil water content

Fixed model: Constant + Tillage + Depth + Tillage. Depth

Random model: Farmer + District

Results

Site characteristics

The soil profiles indicated a slight decrease in bulk density with depth at all farms (Table 1). Soil texture ranged from sandy (Mpofu farm) to sandy loam (Nyathi farm) while organic carbon content decreased with depth except at Ncube farm in Gwanda.

Rainfall patterns at the four farms

The cumulative rainfall observed at each farm between 1 October 2006 and 30 April 2007 is shown in Figure 2 below. All farms except one received more than 100 mm rainfall over the 28 December 2006 (day 89) to 1 January 2007 (day 93) period. The total rainfall received over that 5-day period ranged from 47 mm to 150 mm. In Insiza district the next rainfall event after 1 January 2007 occurred six weeks later with Mpofu and Nyathi farms recording 24 mm and 28 mm respectively. In Gwanda district the next rainfall event after 1 January 2007 (day 93) occurred eight weeks later with Sibanda and Ncube farms recording 26 mm and 49 mm respectively. Rainfall remained erratic up to the end of the cropping period.

Daily runoff from experimental plots

Six runoff-generating rainstorms were recorded at each farm in Insiza. Only three runoff-generating rainstorms were recorded at the Gwanda farms. Planting basins tillage treatment gave the lowest seasonal runoff losses across the three farms where the treatment was assessed (Figure 3). At the sandy soil site, Mpofu farm, single and double spring conventional ploughing gave similar water losses from the plots. A similar result between these two tillage treatments was also observed at Ncube farm in Gwanda district. The highest runoff water losses from planting basins and ripper treatments were observed at Nyathi farm while Sibanda farm recorded the lowest water losses.

The relationships between runoff generated under each rainfall event and rainfall recorded at of the Insiza farms are shown in Figure 4 and Figure 5. The relationship between daily runoff and rainfall under each tillage treatment was weak at the two farms (Table 2). Daily runoff was 7 % of rainfall received at the sandy soil Mpofu farm under single and double spring ploughing. A similar trend between runoff and rainfall was observed at Nyathi farm under single and double spring ploughing treatments. Planting basins treatment had an average of 4 % of the recorded rainfall as runoff across the two farms.

Soil water content

Despite the below average rainfall observed across the study sites soil water regimes did respond to each rainfall event. At Mpofu and Nyathi farms with sandy and sandy loam soils, planting basins treatment consistently gave the highest ($P < 0.05$) soil water content throughout the four-month study period (Fig. 6 and Fig. 7). In Gwanda at Sibanda farm (loamy sand) planting basins and double ploughing (DP) treatments had similar soil water content in April 2007 (Fig.8). At Mpofu farm soil water content under the single conventional ploughing (CP) treatment was marginally lower than planting basins treatment but higher than ripper and double ploughing treatments in January. Single conventional ploughing treatment had the lowest soil water content from February to April 2007 at Nyathi, Sibanda and Ncube farms. At Ncube farm the highest soil water content was observed under the ripper tillage treatment (Fig. 9). There was noticeable crusting at all experimental plots at Ncube and Nyathi farms especially after the heavy rains received at the beginning of January and end of March.

Discussion

The rainfall pattern was very erratic throughout the season and long dry spells were observed across all experimental sites (Fig. 2). The dry periods are shown by horizontal sections of each line for the four farms (Fig. 2). The long dry spells observed during the 2006/07 farming season are a common feature especially during drought years in semi-arid areas. The rainstorms of 70 and 50 mm recorded at Nyathi and Ncube farms at the turn of the year resulted in noticeable soil crusting at all experimental plots. Heavy rainstorms of 49 and 50 mm were further observed at Ncube farm in February and March. Heavy or high intensity rainstorms may cause serious surface sealing and crusting on conventionally ploughed soils (Bouman, 2007).

The loosening of soil during ploughing coupled with surface crusting could have promoted high runoff losses measured under single and double conventional tillage treatments. The heavy rainfall events observed could have promoted soil surface sealing and crusting, and reduced infiltration (Al-Qinna and Abu-Awwad, 2001) thereby increasing surface runoff from ploughing and ripping tillage treatments. As the season progressed surface roughness decreased in all four tillage treatments but the decline was least in planting basin experimental plots.

The four tillage treatments harvested different quantities of rainwater with planting basins having consistently higher soil water content at three of the four farms. The tillage treatments affected soil surface microtopography to varying degrees. The grid

of 0.9 m x 0.6 m spaced planting basins created a higher surface roughness compared to the other tillage treatments resulting in superior rainwater harvesting and better promotion of infiltration. As observed by Guzha (2004) the higher the surface roughness the greater the potential for depression water storage. As the season progressed the planting basin structure did not collapse completely as the basins were filled with soil. This allowed continued harvesting of rainwater up to the last rainfall event of the season in April. Results from a study by Guzha (2004) revealed that surface roughness decreases exponentially with increase in cumulative rainfall.

Although the single conventional ploughing treatment started off with higher soil water content at some farms in January, the treatment ended up having the least quantity to soil water by the end of season. This initial high soil water content under ploughing can be attributed to increased porosity of the soil following loosening during tillage operation. Initially ploughing reduces bulk density, increases porosity and infiltration capacity of the surface soil layer (Das and Chopra, 1988; Sasal *et al.*, 2006; van der Meer, 2000). However, as the season progresses compaction begins in the surface soil layer resulting in a reduction in soil porosity. Consequently infiltration capacity of the surface soil layer decreases as a result of reduced pore space (Shinde *et al.*, 1982). Ploughing may promote better soil water storage during rainy periods but can also accelerate soil evaporation during dry periods (Debaeke and Aboudrare, 2004). Furrows created by tine ripping were easily filled with soil as the season progressed and this resulted in reduced rainwater harvesting ability of the tillage treatment.

Conclusion

Results from this study have shown that planting basin tillage method gives a better control of water losses from the farmers' fields. Despite the below average rainfall received during the study period planting basin tillage method has a greater potential for capturing rainwater and promoting infiltration than ripper, double and single conventional ploughing techniques.

References

- Al-Qinna, M. I., Abu-Awwad, A. M., 2001. Wetting patterns under trickle source in Arid and Semi-Arid soils with surface crust. *J. Agric. Eng. Res.* 80 (3): 301-305
- Anderson, J.M., Ingram, J.S.I., 1993. *Tropical Soil Biology and Fertility. A Handbook of Methods.* 2nd Edition. C.A.B. International, Wallingford, UK, 221pp
- Barron, J., 2004. Dry spell mitigation to upgrade semi-arid rainfed agriculture: Water harvesting and soil nutrient management for smallholder maize cultivation in Machakos, Kenya. Ph.D. thesis in Natural Resources Management. Department of Systems Ecology, Stockholm University, Sweden
- Bouman, A. B. M., 2007. A conceptual framework for the improvement of crop water productivity at different spatial scales. *Agric. Systems* 93: 43-60
- Das, D. K., Chopra U. K., 1988. Soil water movement, balance and its use by crops as influenced by soil physical conditions. pp231-254. In: Somani L. L. (ed.). *Soil physical conditions and crop growth*, Monograph. Geo-Environ Academia and Divyajyoti Prakashan, Shatri Nagar, India. 254pp.
- Debaeke, P., Aboudrare, A., 2004. Adaptation of crop management to water-limited environments. *Eur. J. Agron.* 21: 433-446

- Graef, F., Stahr, K., 2000. Incidence of soil surface crust types in semi-arid Niger. *Soil and Tillage Research* 55: 213-218
- Guzha, A. C., 2004. Effect of tillage on soil microrelief, surface depression storage and soil water storage. *Soil and Tillage Research* 76: 105-114
- Kirchman, H., Thorvaldson, G., 2000. Challenging targets for future agriculture. *Eur. J. Agron.* 12: 145-161
- Mellis, D.A., Bruneau, P.M.C., Twomlow, S.J., Morgan, R.P.C., 1996. Field assessment of crusting on tilled sandy clay loam. *Soil Use and Management* 12: 72-75
- Mupangwa, W., Love, D., Twomlow, S.J., 2006. Soil-water conservation and rainwater harvesting strategies in the semi-arid Mzingwane Catchment, Limpopo Basin, Zimbabwe. *Physics and Chemistry of the Earth* 31, 893-900.
- Ncube, B. 2007. Understanding cropping systems in semi-arid environments of Zimbabwe: options for soil fertility management. Ph.D. Thesis, Wageningen University, Wageningen, The Netherlands. 155pp.
- Nonner, J., 1997. Principles of Hydrogeology. IHE Lecture Note. IHE. Delft, The Netherlands
- Nyagumbo, I., 2002. The effect of three tillage systems on seasonal water budgets and drainage of two Zimbabwean soils under maize. Ph.D. thesis (unpublished), University of Zimbabwe. 251pp
- Nyamangara, J., Mpofu, S. E., 1996: Soil pH and lime requirement for high potential communal areas of Zimbabwe. *Journal of Applied Science in Southern Africa* 2, 77-81
- Rockstrom, J., Barron, J., Fox, P., 2002. Rainwater management for increased productivity among smallholder farmers in drought prone environments. *Phys. Chem. Earth.* 27: 949-959.
- Sasal, M. C., Andriulo, A. E., Taboada, M. A., 2006. Soil porosity characteristics and water movement under zero tillage in silty soils in Argentinean Pampas. *Soil and Tillage Research* 87: 9-18
- Shinde, S. S., Magar, S. S., Kale, S. P., 1982. Effect of soil physical conditions and initial soil moisture content on infiltration into black soil. *J. Indian Soc. Soil Sci.* 30: 441-446
- Tsimba, R., Hussein, J., Ndlovu, L. R., 1999. Relationships between depth of tillage and soil physical characteristics of sites farmed by smallholders in Mutoko and Chinyika in Zimbabwe. On: <http://www.fao.org/ag/ags/agse/3ero/namibia1/c11.htm>. Visited on 2 July 2007.
- Twomlow, S.J., Dhliwayo, H., 1999. Semi-arid maize yield responses to conservation tillage and weeding. Brighton Crop Protection Conference – Weeds, November 1999. Farnham, Surrey, UK : BCPC.
- Twomlow, S.J., Bruneau, P.M.C., 2000. The influence of tillage on semi-arid soil-water regimes in Zimbabwe. *Geoderma* 95, 33-51.
- Twomlow, S. J., Steyn, J. T., du Preez, C. C., 2006. Dryland farming in southern Africa. Chapter 19. In: *Dryland Agriculture 2nd Edition*. Agronomy Monograph No. 23 . American Society of Agronomy, Madison, Wisconsin. 769-836
- Van der Meer, F.W., 2000. Modelling tropical soil water regimes in semi-arid environments. Ph.D. thesis (unpublished), Loughborough University. 270pp
- Whitlow, R., 1988. Potential versus actual erosion in Zimbabwe. *Applied Geography* 8 (2), 87-100

Table 1: Physical and chemical properties of soils at the experimental sites used in Gwanda and Insiza districts during 2006/07 farming season.

Farm	Depth (cm)	Bulk density (g/cm ³)	Soil texture (%)			Soil pH (1:1 water)	Soil O.C. (%)
			Clay	Silt	Sand		
Sibanda	0-15	1.51	4	6	90	4.8	0.48
	15-30	1.49	5	6	89	4.4	0.49
	30-45	1.46	5	8	87	4.4	0.44
	45-60	1.47	5	3	92	4.0	0.41
Mpofu	0-15	1.46	3	6	91	5.3	0.58
	15-30	1.45	4	5	91	5.4	0.41
	30-45	1.43	6	5	89	5.4	0.46
	45-60	1.46	7	4	89	5.5	0.42
Nyathi	0-15	1.50	6	13	81	6.3	0.71
	15-30	1.51	10	9	81	6.5	0.68
	30-45	1.48	16	8	76	6.7	0.66
	45-60	1.48	17	10	73	6.9	0.59
Ncube	0-15	1.50	10	4	86	5.2	0.26
	15-30	1.47	11	3	86	4.9	0.38
	30-45	1.49	16	6	78	5.3	0.37
	45-60	1.48	18	6	76	4.5	0.34

Table 2: Relationships between runoff and rainfall at the 2 experimental sites in Insiza district.

Farmer	Tillage	Regression equation	R ² value	Runoff: rainfall ratio
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Mpofu	CP	$R_{\text{off}} = 0.022\text{Rain} + 1.21$	0.24	0.071
	DP	$R_{\text{off}} = 0.025\text{Rain} + 1.09$	0.28	0.069
	Ripper	$R_{\text{off}} = 0.038\text{Rain} + 0.38$	0.35	0.054
	Basins	$R_{\text{off}} = 0.043\text{Rain} - 0.19$	0.48	0.036
Nyathi	CP	$R_{\text{off}} = 0.034\text{Rain} + 0.74$	0.37	0.063
	DP	$R_{\text{off}} = 0.035\text{Rain} + 0.65$	0.31	0.060
	Ripper	$R_{\text{off}} = 0.032\text{Rain} + 0.69$	0.24	0.059
	Basins	$R_{\text{off}} = 0.055\text{Rain} - 0.31$	0.53	0.040

* R_{off} = runoff

Figure 1: Location of study sites in the Mzingwane river catchment in southern Zimbabwe.

Figure 2: Cumulative rainfall recorded at Sibanda, Ncube, Mpofu and Nyathi farms in Insiza and Gwanda districts between 1 October 2006 and 30 April 2007.

Figure 3: Total seasonal runoff measured under each tillage treatment at Mpofu, Nyathi, Ncube and Sibanda farms in Insiza and Gwanda districts between 30 December 2006 and 30 April 2007.

Figure 4: Relationship between daily rainfall and runoff at Mpofu farm (Insiza) between 30 December 2006 and 30 April 2007.

Figure 5: Relationship between daily rainfall and runoff at Nyathi farm (Insiza) between 30 December 2006 and 30 April 2007.

Figure 6: Soil water variation in the 0 – 0.6 m soil layer under 4 tillage treatments at Mpofu farm (Insiza district) between 14 December 2006 and 30 April 2007. Bars indicate standard error.

Figure 7: Soil water variation in the 0 – 0.6 m soil layer under 4 tillage treatments at Nyathi farm (Insiza district) between 14 December 2006 and 30 April 2007. Bars indicate standard error.

Figure 8: Soil water variation in the 0 – 0.6 m soil layer under 4 tillage treatments at Sibanda farm (Gwanda district) between 14 December 2006 and 30 April 2007. Bars indicate standard error.

Figure 9: Soil water variation in the 0 – 0.6 m soil layer under 4 tillage treatments at Ncube farm (Gwanda district) between 14 December 2006 and 30 April 2007. Bars indicate standard error.