Infiltration and runoff losses under fallowing and conservation agriculture practices on contrasting soils, Zimbabwe

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Abstract

Fallowing and conservation agriculture are sustainable farming practices that can be used for soil and water conservation. The objectives of the study were to evaluate the effects of different conservation agriculture practices on rainfall infiltration and soil and water losses across 4 sites, using simulated rainfall. The study was carried out at Domboshawa and the Institute of Agricultural Engineering and Chikwaka smallholder farming areas, 4 sites with different soil types. Conservation agriculture practices evaluated were mulch reaping (MR) and clean reaping (CR) at Domboshawa with 5% clay and the Institute of Agricultural Engineering (IAE) with 50% clay. The study also evaluated runoff losses from fallow plots subjected to no tillage (NT) and conventional tillage (CT) at ICRAF Domboshawa site (20% clay) and fallows subjected to CT in Chikwaka smallholder farming areas (4% clay). Infiltration rates were greater under conservation agriculture practices (>35 mm·h^{-1}) when compared to CT (<27-29 mm·h^{-1}). On fallows infiltration rates ranged from 24-35 mm·h^{-1} when compared to <15 mm·h^{-1} in maize under CT. Runoff losses were highest under CT at both Domboshawa and IAE sites, and were 21.5 and 15% respectively, while there was no runoff under MR and CR. At the ICRAF Domboshawa site, runoff ranged between 0-31% in fallows and was 57% in maize under CT. At Chikwaka runoff in CT maize was 58%, while in fallow plots runoff ranged 37-44%. Soil losses ranged from 0.2-0.3 t·ha^{-1} per rainfall event in maize, while in fallows, soil loss ranged from 0-0.1 t·ha^{-1}. The results showed that CT resulted in reduced infiltration rates, increased soil and water loss when compared to fallowing and conservation agriculture across different range of soils. Conservation agriculture practices and fallowing are potential sustainable cropping practices that reduce soil and water loss and increase water use efficiency.

Keywords: Conservation agriculture, fallowing, tillage, rainfall simulations

Introduction

Soil and water loss is a major challenge in the smallholder farming sector all over the world. In semi-arid Africa, losses of up to 50% of received rainfall have been reported (Stroosnijder, 2003). In Ethiopia, runoff losses of 39% (under no till (NT)) to 46% (under conventional till (CT)) were reported by Welderufael et al. (2008). In South Africa, Hensley et al. (2000) reported runoff losses of between 3.6% and 29.2% for conventional-tilled and left bare and no-till, bare flat crusted surface, respectively. In a separate study, Zere et al. (2005) also reported runoff losses of 7 and 29% for maize under CT and NT bare surface, respectively. High soil losses have been blamed for declining yields and increasing food insecurity among smallholder farmers in most of Sub-Saharan Africa including Zimbabwe (Hernanz, 2002).

In Zimbabwe, several researchers, among them Elwell (1987), Vogel (1992), Moyo (1987) and Munyati (1997), have reported soil losses ranging from 10 to 50 t·ha^{-1}·y^{-1}, in both low and high rainfall zones. Many researchers studying soil erosion are in agreement that parts of Zimbabwe's smallholder areas face serious erosion problems (e.g. Elwell, 1983; Elwell and Stocking, 1988; Whitlow, 1988). A study by Whitlow and Campbell (1989) reported that over 25% of the smallholder areas are severely eroded and this has been cited as the major cause of poor yields (Hernanz, 2002). The same sentiments were also expressed by Elwell (1983), who stated that if soil erosion was not checked immediately by a dynamic policy based on reliable technical information, then we will witness mass starvation within our lifetime.

High levels of runoff losses in smallholder farming areas not only limit water availability, but are also an erosion hazard (Rao et al., 1998) and cause nutrient losses. Elwell and Stocking (1988) reported losses of up to 50% of applied fertilisers in Zimbabwe. High levels of soil and water loss have been attributed to inappropriate tillage practices which have resulted in reduction of soil organic carbon and destruction of soil structure (Mrabet, 2002; Nyamadzawo et al., 2008b; Thierfelder and Wall, 2009).

Most smallholder areas in Zimbabwe are located in low rainfall areas, where the amount of rainfall in recent years has been up to 100 mm lower than the average rainfall (Zimbabwe, Department of Meteorological Service, 2002). Climate change has become a major threat to the African continent with many local communities already affected and struggling to adapt or cope with its impacts (Scholes et al., 2008). Climate change models have predicted more moderate drying (5 to 15% per century) over large parts of Botswana and Zimbabwe and the former Transvaal Province of South Africa (Hulme et al., 2001). There is now general scientific agreement that the mean annual temperature over Southern Africa will rise by 2 to 5°C by 2050 (IPCC, 2001; 2007). Increasing temperatures will directly affect water availability, through increased evaporation. Thus, there is a need for farmers use land management

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Received 16 February 2011; accepted in revised form 2 April 2012.

http://dx.doi.org/10.4314/wsa.v38i2.8
Available on website http://www.wrc.org.za
ISSN 0378-4738 (Print) = Water SA Vol. 38 No. 2 April 2012
ISSN 1816-7950 (On-line) = Water SA Vol. 38 No. 2 April 2012

practices that increase water use efficiency by increasing infiltration rates and reducing evaporation (Marongwe et al., 2011)

Conservation agriculture (CA) practices that minimise soil disturbance and which involve the spreading of crop residues on the soil surface are viable options for increasing water use efficiency because they reduce erosion (Giller et al., 2011) and increase water infiltration and storage in soil (Nyagumbo, 2002; Mzezewa and Van Rensburg, 2011). Some of the benefits of CA are immediate, e.g., improved infiltration rates and reduced soil loss (Thierfelder and Wall, 2009). Conservation agriculture also maintains soil aggregation and higher soil organic carbon (SOC) levels when compared with conventional tillage (CT) (Zotarelli et al., 2005; Chivenge et al., 2007; Thierfelder and Wall, 2009; Marongwe et al., 2011).

Improved fallowing is another option which can be used in the smallholder sector of Zimbabwe. In improved fallows, legumes are planted on fallow land for 1 to 2 years to improve soil fertility. The other advantage of fallowing is that it also improves soil physical properties, such as infiltration rates, hydraulic conductivity, and soil porosity (Nyamadzawo et al., 2008a), besides reducing soil and nutrient losses through runoff (Nyamadzawo et al., 2003).

The integration of improved fallowing and conservation tillage can further improve the soil hydraulic properties (Alegre and Rao, 1996; Norwood, 1994), soil water-holding capacity (Nyamadzawo et al., 2008a) and improve organic carbon stocks in soils (Nyamadzawo et al., 2008b). Improved fallows can play an important role in mitigating climate change through carbon sequestration. This study reports results from soil and water conservation research carried out from 2000 to 2004 at different sites across Zimbabwe. The objectives of the study were to evaluate the effects of different conservation agriculture and fallowing practices on infiltration rates and soil and water losses across 4 sites in Zimbabwe with contrasting soils, using simulated rainfall at an intensity of 35 mm·h^{-1}.

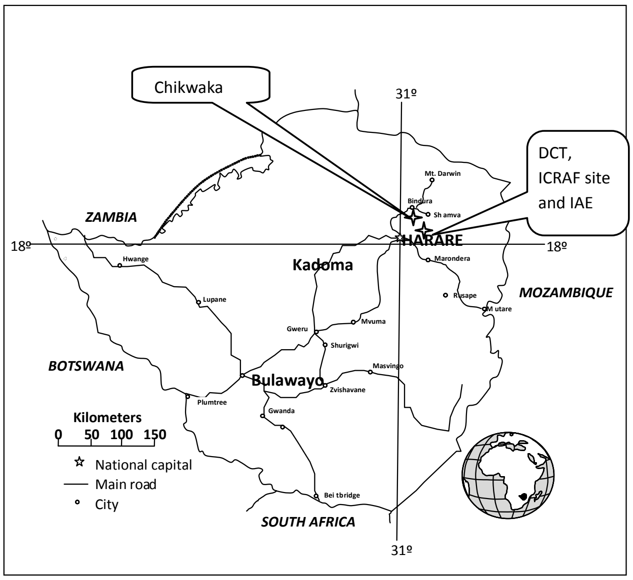

Figure 1
Map of Zimbabwe showing the location of the 4 study sites: Chikwaka, Institute of Agricultural Engineering (IAE), Domboshawa ICRAF site and Domboshawa Conservation Tillage (DCT) sites.

Materials and methods

Study sites

Zimbabwe can be divided into 5 main natural regions based on rainfall regime, soil quality and vegetation, among other factors (Vincent and Thomas, 1960). Annual rainfall is highest in Natural Region (NR) I (>1 000 mm·yr^{-1}), which covers approximately 2% of the land area, and is lowest in NR V. Crop production progressively deteriorates from NR I through to NR V (Moyo, 2000; Vincent and Thomas, 1960), mainly as a result of erratic rainfall.

The study was carried at 4 sites: the Institute of Agricultural Engineering (IAE) is in Natural Region IIa and receives an average annual rainfall of 850 mm; Domboshawa ICRAF site, Domboshawa Conservation Tillage (DCT) site and Chikwaka site are in Natural Region (NR) IIb (Fig. 1), and receive an average of 750 mm of rainfall annually from November to April. Natural Region II comprises 15% of the country's land area, and is suitable for intensive farming based on crops or livestock production. It accounts for 75-80% of the area planted to crops in Zimbabwe and is where most of the staple maize crop is grown (FAO, 2006).

Generally, soils in Zimbabwe that are derived from granite are infertile and deficient in nitrogen (N), phosphorus (P) and sulphur (S). About 70% of Zimbabwe is covered with sandy soils, mostly derived from coarse granite (Thompson and Purves, 1978). Zimbabwe's sandy soils are low in N, P, and S and in cation exchange capacity (CEC), owing to low clay and organic matter contents (Nyamapfene, 1981). As these soils are inherently of low fertility and subject to rapid depletion in fertility, regular applications of organic and inorganic fertilisers are necessary in order to obtain reasonable and sustainable yields. In addition, the sandy soils are generally acidic and require liming.

Domboshawa ICRAF site

Domboshawa ICRAF site is located at approximately 19° 35' S, 31° 14'E, at an altitude of 1 474 m. The soils are classified as Lixisols (FAO, 1998). Annual rainfall received during the study period was 750 mm. Figure 1 shows the locations of the study sites and Table 1 summarises soil properties at the study sites. The treatments studied were fallows of *Acacia anguistissima (A. anguistissima)* and *Sesbania sesban (S. sesban)*; natural fallow (NF) and maize (*Zea mays*) were the controls.

The experimental layout was a randomised block design and was replicated 3 times. The experiment was initiated in the 1991-92 season, to compare planted fallows of different duration. The different duration fallows were established in a phased manner on 12 x 9 m plots, separated from each other by a distance of 2 m. Fallows were established from seedlings. Three-year fallows were first established in 1991-92, two-year fallows in 1992-93, and one-year fallows in 1993-94. The fallow phase was followed by a cropping phase during which all plots were cultivated by ox-drawn plough and planted to maize. After the end of 4 years of cropping, a second 2-year fallow phase was reinstated in the original plots in November 1998 (Table 2). At the end of the fallow period, in October 2000 when the plots were cropped again, the plots were divided into conventional tillage (CT) and no tillage (NT).

Plots were weeded using hoes twice during the growing season and this disturbed the top 0-5 cm of soil. Fertiliser was applied at the following rates; nitrogen (N) = 60 kg·ha^{-1}, phosphorus (P) = 15 kg·ha^{-1} and potassium (K) = 10 kg·ha^{-1}. These

http://dx.doi.org/10.4314/wsa.v38i2.8
Available on website http://www.wrc.org.za
ISSN 0378-4738 (Print) = Water SA Vol. 38 No. 2 April 2012
ISSN 1816-7950 (On-line) = Water SA Vol. 38 No. 2 April 2012

Table 1 Physical and chemical properties of soils sampled from 0-20 cm depth at Domboshawa ICRAF experimental site, Chikwaka experimental site, Domboshawa conservation tillage (DCT) site and the Institute of Agricultural Engineering (IAE) site										
	Clay %	Silt %	Sand %	pH ($CaCl_2$)	Organic C (%)	Total N (%)	Resin P ($mg \cdot kg^{-1}$)	K ($cmol_c \cdot kg^{-1}$)	Ca ($mg \cdot kg^{-1}$)	Mg ($mg \cdot kg^{-1}$)
Domboshawa (ICRAF) site	22	7	71	4.8	0.6	0.04	3.8			
Chikwaka	4	4	92	4.8	0.35	0.03	5	0.09	0.83	0.37
DCT	4				0.5	0.02	2	0.03	1.2	1.2
IAE	59	20	21		1.1					

Table 2 A timeline showing the management systems that were applied from initial fallow establishment (1992) to October 2001 at Domboshawa ICRAF experimental site											
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1st fallow Phase	x	x	x								
Cropping phase				x	X	x	x				
2nd fallow phase								x	x		
2nd cropping phase										x	x
Rainfall simulations											x

were half the generally recommended fertiliser application rates, in order to evaluate if farmers could save on fertiliser costs by using residual fertility from fallows. Compound D fertilizer (N=8, P=6 and K=6) was used as a basal application and this was followed by ammonium nitrate (33.5% N), which was applied as split application at knee level and tussling. The maize variety planted was hybrid Seed Company (SC) 513.

Chikwaka smallholder farming area

The second fallow site was an experimental site that was established on a smallholder farm in Chikwaka (17° 38' S, 31° 29'E) in December 2000. The site was established in the 2000/2001 season and was a fallow field prior to trial establishment. Soil was sampled from the 0-20 cm layer, air-dried and chemical compositon analysed (Table 1). The soil was highly leached, coarse-grained sand derived from granite, classified as Arenosols (FAO, 1998) with very low soil organic carbon (SOC) and nitrogen. During the 2000/2001 season, 1 100 mm of rainfall was received, against an annual average of 750 mm.

The experiment was set up to evaluate the potential of improved fallows for improving soil physical properties in comparison to maize under CT. Fallow land was ploughed and subdivided into 10 m by 12 m plots. Improved-fallow legumes, *Acacia anguistissima, S. sesban,* velvet beans *(Mucuna pruriens),* soyabean and *Tephrosia vogeli,* were planted in the plots in December 2000. As controls, natural fallow and maize under CT were also included. A complete randomised block design was used and the treatments and controls were replicated 3 times. After a 1-year fallow period, rainfall simulations were carried out in the different plots, in November 2001. Rainfall simulation results for maize, soya bean and *Mucuna* only are reported in this paper. During the fallowing period soya bean received basal application of 18 $kg \cdot ha^{-1}$ P and 12 $kg \cdot ha^{-1}$ N, in the form of ammonium nitrate, and the seed was inoculated with *Rhizobium*. After harvesting soya bean seed, the stover and leaf litter were incorporated back into the plots. *Mucuna* biomass was determined at flowering stage, and sown under in April 2001; no crop was grown in the plots until after the November 2001 rainfall simulations.

Domboshawa Conservation Tillage site

Domboshawa Conservation Tillage (DCT) site is located at 19°35' S, 31°14'E, 30 km north of Harare; soils are classified as Arenosols (FAO, 1998). The experiment at Domboshawa was established in the 1988/89 season. The shallow granite-derived sands have a clay content lower than 5%; bulk density was 1.6 $Mg \cdot m^{-3}$ while SOC levels were low (Vogel, 1992; Nyagumbo, 1999), and the land had an average slope of 4.5%. Pedologically, granite-derived sandy soils are typical of many of the communal areas of Zimbabwe (Vogel, 1992). At DCT site the 3 tillage systems, conventional tillage (CT), clean reaping (CR) and mulch reaping (MR), were established in a randomised block design experiment that was replicated 3 times. Each tillage system was based on animal-drawn implements which disturbed the top 15-20 cm. Conventional tillage was carried out by an ox-drawn mouldboard plough in plots where all residues had been removed; under CR all the residues were removed from the plots before reaping, while under MR plots had residues that provided at least 30% soil cover. Maize was planted continuously as the test crop. Basal fertiliser was applied at a rate of 24 $kg \cdot ha^{-1}$ N, 18.5 $kg \cdot ha^{-1}$ P, 17.5 $kg \cdot ha^{-1}$ K. A split top dressing of ammonium nitrate, providing 138 $kg \cdot ha^{-1}$ N, was applied at 5 and 10 weeks after planting (Vogel, 1993), from the 1990/91 season onward.

Institute of Agricultural Engineering (IAE)

The Institute of Agricultural Engineering (IAE) site (17°43'S; 31°06'E; 1 500 m a.m.s.l.) has deep, well-drained, red clay soil (clay = 59%; silt = 20%; sand = 21%) derived from gabbro parent material, classified as Chromic Luvisol (FAO, 1998). The soil had 1.1% SOC (IAE, 1989) and the average slope was 3%. Experimental design, treatments and test crop at IAE were similar to those at DCT; the main difference between the two sites was soil texture and slope. All treatments received annual fertiliser additions of 114 $kg \cdot ha^{-1}$ N, 22 $kg \cdot ha^{-1}$ P and 25 $kg \cdot ha^{-1}$ K. Rainfall simulations at DCT and IAE were carried out from August to September, when it was hot and dry, before the start of the rainy season.

Rainfall simulations

Rainfall simulations at all 4 sites were conducted at a rainfall intensity of 35 mm·h^{-1} on 1 m^2 plots which were surrounded by a 50 cm buffer zone. A portable rainfall simulator based on a single full cone nozzle principle, calibrated after Panini et al. (1993), was used. The plots were demarcated and hydrologically confined using aluminium metal sheets installed on all sides leaving approx. 7 cm of the sheet above the ground. A metal flume was anchored at the outlet, leading into a small trench to collect runoff. During the simulation events, the soil within the rainfall simulation plots was not disturbed. Rainfall simulations were carried out once in each plot during the dry season (September-October) at all 4 sites. All rainfall simulations involved a dry and wet run, dry runs were conducted on dry soil (5-6% soil moisture) and wet runs were carried out the following day at the same spot that was used for dry runs.

A container was anchored at the base of the outlet to collect all of the runoff and sediment. Some runoff samples were periodically grabbed to estimate the change in rate of runoff. Runoff was then estimated by summing the runoff collected from the container and that collected during periodic sampling. The sediment collected in the container was weighed before being mixed with the solids separated from runoff collected during the simulations. Solids were separated from water through centrifugation, dried at 60°C for 12 h and weighed. At DCT and IAE soil loss data was not compiled.

However, for DCT and IAE the CR (dry runs) and MR (dry and wet runs) did not produce runoff, thus no steady-state conditions were reached. The same applied to the *A. angustissima* and natural fallow treatments which did not produce runoff after 30 min of rainfall simulation. The simulations were limited to 30 min because this is the normal duration of natural rainfall storms of this intensity. The same rainfall intensity was maintained across sites to enable comparisons of sites.

Data analyses

For the estimation of infiltration rate, the empirical approach first introduced by Horton (1940) was used. The balance of rain minus runoff estimated infiltration ($I= P–Q$), where I is the infiltration rate, P is the precipitation and Q is the runoff. The infiltration data obtained were fitted to a modified version of the Horton-type equation proposed by Morin and Benjamin (1977), given in Eq. (1).

$$i = i_f + (i_o - i_f)\, e^{-R/K} \qquad (1)$$

where:
i = estimated instantaneous infiltration rate (mm·h^{-1});
i_f = final infiltration rate (mm·h^{-1});
i_o = initial infiltration rate (mm·h^{-1});
R = cumulative rainfall (mm; intensity x time);
K = infiltration rate decay coefficient which determines the infiltration dynamics or changes in infiltration as affected by soil properties like aggregation, porosity (mm).

Data on time to runoff, amount of runoff and quantity of soil loss were subjected to analysis of variance (ANOVA) using Genstat Statistical package (GENSTAT, 2003).

Results

Domboshawa ICRAF site

At Domboshawa ICRAF site the time to runoff was significantly different among treatments ($p < 0.05$). Runoff time was 15-17 min for maize, 21-24 min for *S. sesban* and there was no runoff from *A. angustissima* plots and NF fallow plots as all the rainfall infiltrated. Tillage had no significant effect on time to runoff in all treatments. Runoff losses were significantly higher in maize plots (57%) when compared to the fallows treatment (Table 3). Maize also had a correspondingly low total rainfall that infiltrated (Fig. 2). Runoff losses in *S. sesban* averaged 30% and the final infiltration rates (steady state) were ~24 mm·h^{-1} (Fig. 2), which translated to 12 mm of water infiltrating in 30 min (Table 3). The total amount of water that infiltrated for *S. sesban* was 60% greater than for maize under CT.

Chikwaka site

Time to runoff was comparable for maize and soya bean during dry runs. However, during wet runs, time to runoff for maize was 2 min, when compared to > 4 min for *Mucuna* and soya

Table 3
Runoff and soil losses from plots under planted fallows, natural fallow and continuous maize cultivation during 30 min of simulated rainfall at Domboshawa, Zimbabwe, October 2001

Treatments	Time to runoff (min)	Runoff losses (%) October 2001**	Rainfall that infiltrated (mm)*	Soil loss (t·ha^{-1}) October 2001**
Maize CT	15	57^a	7.5^c	0.2^a
Maize NT	17	57^a	7.5^c	0.2^a
Acacia angustissima CT	>30	0^c	17.5^a	0^c
Acacia angustissima NT	>30	0^c	17.5$_a$	0^c
Sesbania sesban CT	21	31^b	12.1$_b$	0.1^b
Sesbania sesban NT	24	29^b	12.0^b	0.1^b
Natural fallow CT	>30	0$_c$	17.5^a	0^c
Natural fallow NT	>30	0^c	17.5^a	0^c

CT = conventional tillage, NT = no tillage, tonnes per hectare (t·ha^{-1})
**infiltration (mm) in 30 min, derived from infiltration rate (mm·h^{-1} x time (0.5 h)*
***Adopted from Nyamadzawo et al. (2003). Initial soil moisture content was 5%.*
The same symbols (a, b and c) in the same column show no significant differences, while different symbols show significant differences.

http://dx.doi.org/10.4314/wsa.v38i2.8
Available on website http://www.wrc.org.za
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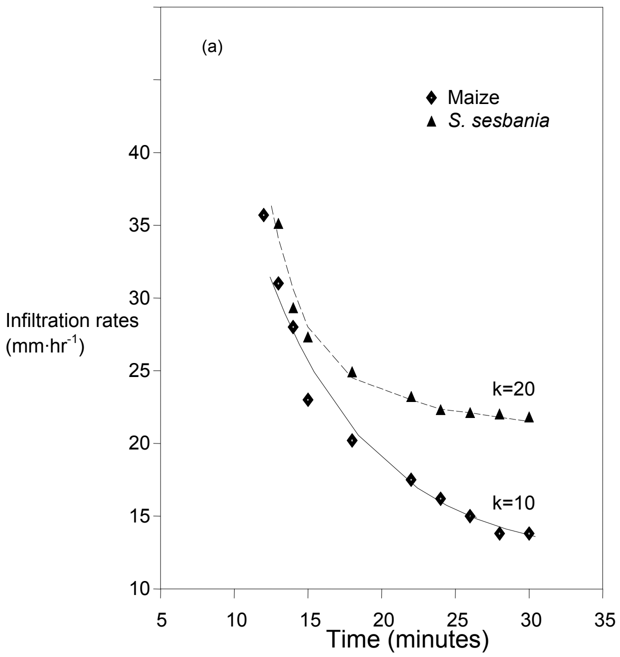

Figure 2
Infiltration rates for Sesbania sesban *and continuous maize cultivation plots at Domboshawa ICRAF site in October 2001. Symbols show plotted data and lines show fitted curve using the Morin and Benjamin Model. K = infiltration decay coefficient.*

bean. Runoff losses during dry runs were significantly higher (p<0.05) for maize (58%), when compared to nil and 15% for *Mucuna* and soya bean, respectively. Even during wet runs, maize still had significantly higher runoff losses (64%) compared to *Mucuna* (10%) and soya bean (33%). The amount of rainfall that infiltrated was significantly higher in plots with legumes (12-15.6 mm) when compared to maize under CT (6-7.4 mm) (Table 4). The amount of rainfall that infiltrated for soya bean was 100% greater when compared to CT maize during dry runs, while for wet runs the rainfall that infiltrated was 100 and 148% greater for soya bean and *Mucuna*, respectively, when compared to CT maize. During dry runs soil losses were not significantly different between soya bean and maize under CT. However, during wet runs soil loss was significantly higher under maize when compared to *Mucuna* and soya bean. Soil losses were 2.27 t·ha^{-1} for maize under CT, compared to 1.1 and 1.8 t·ha^{-1} for *Mucuna* and soya bean, respectively (Table 4).

Domboshawa Conservation Tillage site

At DCT, runoff was only obtained from CT plots after 18 min during dry runs and there was no runoff for CR and MR treatment plots. However, during wet runs, the CR treatment produced runoff after 11 min, while for CT runoff was obtained after only 7.5 min. Conventional tillage had significantly higher (p < 0.05) per cent runoff losses (21%) for dry runs, compared to no runoff losses under CR and MR. Runoff losses during wet runs were significantly higher (p < 0.05) under CT (65%), when compared to 23% under CR and nil under MR (Table 5). Infiltrations were significantly lower under CT, when compared to CR and MR plots (Table 5) for both dry and wet runs. During dry runs 13.8 mm of the applied rainfall infiltrated under CT compared to 17.5 mm under CR and MR. However, during wet runs 6.1 mm of the applied rainfall infiltrated under CT compared to 15.2 mm under CR and 17.5 mm under MR. The total rainfall that infiltrated was 150% greater under CR than CT plots during wet runs.

IAE Conservation Tillage site

At the IAE, time to runoff and per cent runoff losses showed the same trend as for DCT. There was no runoff on MR plots for both dry and wet runs. On CR plots, runoff was only obtained during wet runs and on CT plots there was runoff during both dry and wet runs. Runoff losses were significantly higher (p < 0.05) under CT when compared to CR and MR.

Table 4
Runoff and steady-state infiltration under rainfall simulations at Chikwaka in October 2001

Treatment	Time to runoff (min)		Runoff losses (%)		Rainfall that infiltrated (mm)*		Soil loss (t·ha^{-1})	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
cT. maize	4.5	2.0	57.7^a	64%^{a}	7.35^c	6.3^c	0.31^b	2.27^a
Mucuna	>35	4.41	0^c	10.3^c	17.5^a	15.6^b	0^c	1.05^c
Soya bean	5	4.05	14.9 ^{b}	31.1 ^{b}	14.9 ^{b}	12.1^a	**0.41**^{a}	1.78 ^{b}

C. maize: continuous maize, nd: not determined
** Infiltration (mm) in 30 min, derived from infiltration rate (mm·h^{-1} x time (0.5 h).*
Soil moisture contents were 4% for dry runs and 11% for wet runs.
The same symbols in the same column indicated no significant differences, while different symbols indicate significant differences.

Table 5
Time to runoff and runoff loses under rainfall simulations at DCT and October 2002

Treatment	Time to runoff (min)		Runoff losses (%)		Rainfall that infiltrated (mm)*		Soil loss (t·ha^{-1})	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
MR	>30.0	>30	0^b	0^c	17.5^a	17.5^a	0	0
CR	>30.0	11	0^b	23^b	17.5^a	15.2^b	0	-
CT	18	7.5	21^a	65^a	13.8^b	6.1^c	-	-

CT = conventional tillage, CR = clean reaping and MR = mulch reaping.
Initial moisture content was 6% for dry runs and 12% for wet runs
**Infiltration (mm) in 30 min, derived from infiltration rate (mm·h^{-1} x time (0.5 h)*
The same symbols in the same column indicate no significant differences, while different symbols indicate significant differences.

http://dx.doi.org/10.4314/wsa.v38i2.8
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Table 6
Time to runoff and runoff loses under rainfall simulations at IAE and October 2002

Treatment	Time to runoff (min)		Runoff losses (%)		Water that Infiltrated (mm)*		Soil loss (t·ha^{-1})	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
MR	>30.0	>30	0^{b}	0^{b}	17.5^{a}	17.5^{a}	0	0
CR	>30	14	0^{b}	20^{b}	17.5^{a}	14.0^{b}	0	-
CT	23	15	15^{a}	43^{a}	14.9^{b}	10.0^{c}	-	-

CT = conventional tillage, CR = clean reaping and MR = mulch reaping. Initial soil moisture content was 6% for dry runs and 14% for wet runs.
** Infiltration (mm) in 30 min, derived from infiltration rate (mm·h^{-1} x time (0.5 h).*
The same symbols in the same column indicate no significant differences, while different symbols indicate significant differences.

Per cent runoff losses were 15% for CT plots (dry run), 43% for CT plots (wet run) and 20% for CR plots (wet run). In MR and CR dry-run infiltration rates were equal or greater than the rate of water supply and therefore there was no runoff on these plots. Infiltration rates were significantly higher ($p < 0.05$) under CR and MR when compared to CT. In CT plots, 14.9 and 10 mm of the applied rainfall infiltrated when compared to >35 and 14 mm under CR, for dry and wet runs, respectively (Table 6). During wet runs, the rainfall that infiltrated under CR was 40% greater when compared to CT.

Discussion

The results across the different fallow systems and tillage systems showed that conventional tillage (CT) resulted in reduced infiltration rates, thus causing greater runoff losses, which supports the findings of earlier research by Elwell and Stocking (1988) and Vogel (1992). In fallow systems, maize had runoff losses of 57% at Domboshawa ICRAF site and Chikwaka site. There were no significant differences in per cent runoff between NT and CT at the Domboshawa ICRAF site. *Sesbania sesban* was the only fallow treatment which had runoff at Domboshawa. The total rainfall that infiltrated after 30 min under fallow systems at Domboshawa ICRAF sites was 60% greater than for CT maize, while at Chikwaka fallows had 100-148% greater infiltration rates when compared to CT maize after only 1 season of fallowing, showing that CA practices can have immediate benefits of increasing infiltration rates (Thierfelder and Wall, 2009).

At DCT and IAE, runoff losses were highest under CT, and were 21 and 15%, respectively. The total amount of rainfall that infiltrated under CT was 13.8 and 14.9 mm for DCT and IAE, respectively. The conservation agriculture practice of CR resulted in 40 and 150% greater infiltration rates when compared to CT. These results showed that CT resulted in greater runoff losses, which also cause low infiltration rates. Thierfelder and Wall (2009) reported results of similar magnitude; in their study 50% of the rainfall was lost as runoff under CT compared to 30% under MR plus legume bean, infiltration rates were 66% higher and soil moisture was 18% higher under CA practices than under CT at some sites. With between 15 and 64% of rainfall received being lost as runoff at the 4 study sites, crops may be affected by moisture stress, as models are predicting a 2 to 5°C increase in temperature by 2050 in southern Africa (IPCC, 2007); this will result in reduced plant water availability, and reduced crop yields.

High rates of soil loss have been attributed to CT using an ox-drawn plough, which destroys soil structure (Thierfelder and Wall, 2009). Conventional tillage weakens soil aggregation because it exposes SOC, which binds soil particles together, to microbial oxidation (Grandy and Robertson, 2006; Thierfelder and Wall, 2009). Traffic during CT pulverises the soil and breaks down soil structure, which can result in clogging of soil pores, surface sealing, reduced infiltration rates and increased runoff and soil erosion (Sumner, 1992). The increase in runoff losses 1 year after fallow termination in fallow treatments at Domboshawa ICRAF site and Chikwaka sites could be attributed to introduction of tillage. The leaf and grass litter that protected the soil surface during fallowing had disappeared through soil incorporation as a result of tillage.

Soil losses were not quantified at all sites; the only available data on soil loss were from sites that were under fallows. At Domboshawa ICRAF site, soil losses were 0.1 t·ha^{-1} per rainfall event for S. *sesban*, and 0.2 t·ha^{-1} for maize. At Chikwaka soil loss was even higher; 0.3 and 0.4 t·ha^{-1} for maize and soya bean, respectively, per rainfall event during dry runs. However, because of high initial moisture, soil losses were higher during wet runs at Chikwaka site. Although estimates of runoff losses made from small plots such as these cannot readily be extrapolated to the field or landscape scale (Stomph et al., 2002; Van de Giesen et al., 2000), they are indicative of the differences between treatments and management. Elwell and Stocking (1988) reported soil loses of up to 1 t·ha^{-1} per rainfall event under CT using runoff plots in red clay soils, but this varied depending on rainfall intensities, while Vogel (1992) reported seasonal soil losses of between 10 and 50 t·ha^{-1} under CT. An 8-year study by Munyati (1998) found mean annual soil losses of 5.1 t·ha^{-1}, compared to 1 t·ha^{-1} under MR. These levels of soil losses are very high and unsustainable and can cause reduction of crop yields. Results from both micro-plots and runoff plots indicate that CT causes high soil losses; thus there is need for a shift from the traditional CT to more sustainable cropping practices that reduce soil and water loss and increase water use efficiency (Marongwe et al., 2011).

Conservation agriculture (CA) offers potential benefits to smallholder farmers in Africa. Among the benefits are: avoiding the need for tillage meaning that planting can take place with the first rains; savings on labour and fuel (Smith, 1988) and reduction of soil erosion (Nyagumbo, 2002). Conservation agriculture has the benefit of improving SOC, resulting in less disturbance of the soil and covering the soil surface with plant and leaf residues, all of which conserve the soil (Giller et al., 2011; Vogel, 1992). Benneh et al. (1996) estimated SOC loses of up to 1.1 t ha^{-1}·yr^{-1} from improved fallows under conservation agriculture systems such as no-tillage (NT), and losses of up to 5.6 t ha^{-1}·yr^{-1} under conventional (CT) systems. However,

http://dx.doi.org/10.4314/wsa.v38i2.8
Available on website http://www.wrc.org.za
ISSN 0378-4738 (Print) = Water SA Vol. 38 No. 2 April 2012
ISSN 1816-7950 (On-line) = Water SA Vol. 38 No. 2 April 2012

factors such as soil type, rainfall intensity and amount, and slope, among others, can affect SOC losses. Franzluebbers (2002) reported that greater stratification of SOC under NT than under CT also reduced soil bulk density by 10% and improved water infiltration nearly threefold.

The challenges hindering uptake of fallows as a management practice include lack of appropriate knowledge, lack of seedlings, and difficulties in establishing fallows in smallholder farming areas where there is free ranging during the dry season, among other challenges. The challenges to the uptake of conservation agriculture in Zimbabwe include problems of weed control (Anderson and Giller, 2012) and failure by farmers to meet the requirements for use of the technology, such as poor residue retention, lack of labour, lack of knowledge and the inflexible mindset of the farmer. Thus, research and development of CA will need to address these challenges to ensure widespread adaptation (Marongwe et al., 2011) for the benefit of farmers, particularly in marginal areas with low rainfall.

Conclusions

This study provided an opportunity for a comparison of different management and soil types, given the same rainfall intensity and same duration of rainfall. Comparisons involving the same rainfall intensity are very difficult to achieve with natural rainfall, as intensity varies from place to place. Data from measurements carried out across a range of soils, conservation agriculture practices and fallowing systems at the same rainfall intensity showed that CT reduced runoff losses and infiltration rates, while conservation agriculture and fallowing reduced soil runoff losses and increased infiltration rates. These findings support those of earlier long-term research. Lower soil losses were also measured for fallows compared to CT. Conservation-agriculture practices such as CR, MR, NT and fallowing are possible options for achieving soil and water conservation. Adoption of these technologies in the smallholder farming sector can assist in reducing the loss of rainfall as runoff.

Acknowledgements

We thank ICRAF, Domboshawa Training Centre and The Institute of Agricultural Engineering for allowing us to use their sites. We are grateful to the European Union for funding the work through the Improved Fallows for Africa (IMPALA) Project No. ICA4-CT 2000- 30011.

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Available on website http://www.wrc.org.za
ISSN 0378-4738 (Print) = Water SA Vol. 38 No. 2 April 2012
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