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Soil–water conservation and rainwater harvesting strategies in the semi-arid Mzingwane Catchment, Limpopo Basin, Zimbabwe

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Abstract

Various soil water management practices have been developed and promoted for the semi arid areas of Zimbabwe. These include a variety of infield crop management practices that range from primary and seconday tillage approaches for crop establishment and weed management through to land forming practices such as tied ridges and land fallowing. Tillage methods evaluated in this study include deep winter ploughing, no till tied ridges, modified tied ridges, clean and mulch ripping, and planting basins. Data collected from the various trials since the 1990s show that mulch ripping and other minimum tillage practices consistently increased soil water content and crop yields compared to traditional spring ploughing. Trial results also showed higher soil loss from conventionally ploughed plots compared to plots under different minimum tillage practices.

Keywords: Dead level contours; Infiltration pits; Planting basins; Soil–water conservation

1. Introduction

Smallholder agriculture in the semi-arid areas of eastern and southern Africa is largely rainfed, and thus risky, due to high interannual variability and the occurrences of dry-spells during the rainy season (Twomlow et al., in press). Potential evapotranspiration exceeds rainfall for more than 6 months of the year. Rainfall is seasonal and highly variable both within space and time. Annual rainfall for a single site can vary by up to 1000 mm from year to year – although a drought year may easily record less than 250 mm, such as the 2004–2005 season in southern Zimbabwe and Mozambique (unpublished data, ICRISAT). By the end of the dry season, i.e. just before planting, the top 0.3 m of the soil horizon frequently holds negligible water content (Twomlow and Bruneau, 2000).

Research work in Southern Africa has concluded that the four most important constraints to rainfed crop production are timeliness of planting, soil hydrological properties, weed control and labour (Gollifer, 1993; Twomlow, 1994; Ellis-Jones and Mudhara, 1997). In order to improve the effectiveness of crop production in these marginal rainfall regions, cultural practices which conserve and extend the period of water availability to the crop are essential (Falkenmark and Rockström, 2003; Gollifer, 1993; Nyamudeza, 1999; Twomlow and Bruneau, 2000) if the full benefits of soil fertility amendments are to be realised (Mapfumo and Giller, 2001).

A typical semi-arid cropping enterprise is based on a farming family unit cultivating an average of 1–5 ha using family labour, often with draft animal inputs. The most important category in terms of production is the medium-scale farmer, cultivating 3–10 ha of land using animal power. The second most important type of farmer, and the focus of many of the relief projects in the region since the early 1990s, is the small-scale subsistence farmer, cultivating 1–3 ha with a hand hoe or cutlass (machete).

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In Zimbabwe water management under rainfed cropping systems has been the focus of many research studies, outside the Limpopo Basin, encompassing effects of weeding on soil water regimes (Twomlow and Bruneau, 2000), tillage effects on soil water dynamics and crop yields (Nyamudeza, 1993; Nyakatawa et al., 1996; Nyamudeza, 1998; Twomlow and Bruneau, 2000), tillage effects on weeds (Dhliwayo et al., 1995) and soil erosion control (Chuma, 1993; Chuma and Haggman, 1998; CONTILL, 1998). The Department of Agricultural Research and Extension Services (AREX) through the Lowveld Research Stations, Cotton Research Institute, Makoholi Experiment Station and Agronomy Institute conducted studies on *in situ* rainwater harvesting (soil and water conservation) systems from the early to mid-1980s (Twomlow and Hagmann, 1998). However, few such investigations have been carried out in the Mzingwane Catchment, which contains the driest areas of Zimbabwe. A major feature of the aridity of the catchment is that the mean annual potential evapotranspiration rates (1800 mm) are higher than the mean annual rainfall (465 mm) suggesting low runoff generation and aquifer recharge potential.

The purpose of this paper is to review soil water management techniques that have been developed for the semi-arid southern Zimbabwe. The review then identifies soil and water management technologies that have been taken up by the farming communities and those that have been recently introduced in the Mzingwane Catchment of the Limpopo Basin (Fig. 1). The study looks at both macro and microcatchment, and in-field strategies that have a potential to mitigate drought and mid-season dry spells for the farming community in the area.

2. Soil water management techniques developed for semi-arid areas of southern Africa

Good soil water management in rainfed agriculture can be achieved through various tillage, both conventional and reduced, and rainwater harvesting techniques/structures. Various researchers and development agencies have explored *in situ* rainwater harvesting. For upgrading rainfed agriculture in semi-arid tropics Rockström (2002) classified rainwater management methods into the following categories:

(i) Systems that prolong the duration of soil moisture availability in the soil for example mulching practices.
(ii) Systems that promote infiltration of rainwater into the soil. These techniques include pitting, ridging/furrowing and terracing.
(iii) Systems that store surface and sub-surface runoff water for later use, e.g. rainwater harvesting systems with storage for supplementary irrigation.

2.1. Tillage and other in situ soil water management strategies

Soil tillage, to be defined as 'The manipulation, generally mechanical, of soil properties to modify soil conditions for crop production' (SSSA, 1986) has, through the ages been applied in farming systems where natural vegetation is replaced by arable crops. The majority of the soils (sands, loamy sands and sandy loam) in the drier regions of southern Africa are poorly structured, self compacting and have a tendency to crust. The primary functions of tillage in these areas are to prepare a seed bed, control weeds, incorporate crop residues and manures, enable water infiltration into the soil and permit the growth of roots down the profile, where moisture may be stored. Studies in Zimbabwe working with maize on a sandy soil (Grant et al., 1979) and in Botswana working with sorghum on a sandy loam (DLFRS, 1985), have demonstrated the benefits of depth of ploughing (0.20–0.25 m compared to 0.10 m) in terms of grain yield increases of 25% to more than 100% depending on the season. The effect of deep

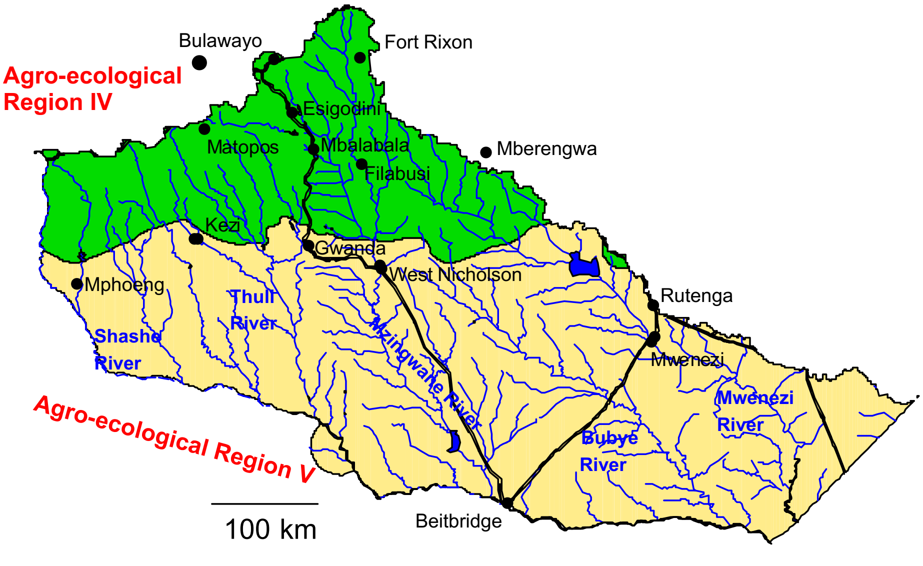

Fig. 1. Location of the study areas in southern Zimbabwe.

primary tillage was to permit earlier and more vigorous rooting into the undisturbed soil below the cultivated layer, a reduction in weed pressure and enabled a greater utilization of water stored at depth. The residual effects of the deep tillage (0.25 m) in terms of reduced bulk densities, and improved root development, crop performance and reduced weed pressures were still apparent in the second season. Similar responses have been observed for other soil types in Tanzania (Northwood and McCartney, 1971).

Throughout southern Africa the timing of primary tillage operations such that cultivation is done during the post-harvest autumn period has been advocated as a sound practice, as weeds are destroyed (Willat, 1967), draught animals are still in good condition at the end of the growing season, and the soil surface is in a state which permits infiltration of the early spring rains. However, few smallholder households manage to achieve this post harvest plowing, despite the obvious advantages on some soil types (Grant et al., 1979; DLFRS, 1985). The reasons for this are many and varied, and include the fact that the soils are too hard to plough at the end of the season when dry, traditional practices in many areas is to allow livestock to graze crop residues *in situ* over the winter period, other household activities such as marketing of produce take priority in allocation of labour. To overcome the inability to carry out an autumn ploughing, work in Botswana clearly demonstrated the advantages of a double spring ploughing, increasing yields by as much as 71% across a range of soil types (Table 1). Similar results have been observed in Zimbabwe for a range of soil types (Twomlow and Bruneau, 2000; Twomlow et al., in press).

From recent studies of smallholder farmers in southern Africa it is clear that they already employ tillage practices with the aim of accomplishing several short-term goals including seedbed preparation, weed control and rainwater retention (Waddington, 1991; Morse, 1996; Twomlow and Bruneau, 2000). In Zimbabwe, as in Tanzania, it has been reported that farmers recognise that timely inter-row cultivation is important for both weed control and for maintaining a rough soil surface which can retain subsequent rainfall.

Minimum tillage has been explored as a soil and water conservation strategy for the semi-arid areas of Zimbabwe. Studies have been conducted on no till tied-ridges in the semi-arid areas (Vogel, 1992; Nyagumbo, 1999). At Makoholi and Domboshawa, Vogel (1992) evaluated the effect of conventional ploughing, mulch ripping and no till tied-ridging on soil and water loss from fields. At Makoholi Research Station, tied ridging reduced soil and water loss from fields to greater extent than other technologies (Vogel, 1992). The effect of five tillage methods on soil loss was evaluated at Makoholi Research Station using plots that had been opened up from dense vegetation. The results showed that soil loss was highest from conventionally ploughed plots (Table 2).

Mulch ripping gave higher soil moisture in the topsoil especially at the beginning of the cropping season. Mulching protected the soil from erosion and promoted infiltration. Regrettably smallholder farmers have not taken up this technique. The technology was developed and tested in a non-participatory, top-down approach. The development of the technology did not address the competition for crop residue between crop and livestock enterprises common in the smallholder farming system (Twomlow et al., in press).

Twomlow and Dhliwayo (1999) conducted a study on the effect of conventional ploughing and improved tied ridges and weeding on hydrological and physical responses of three different soil types. Results from the study showed that the amount of water in the top 0.3 m at the end of dry season is negligible while there was a lot of variation in amount of water within the 0.9 m depth. Tied ridges created after crop emergence (often referred to as modified tied ridges) collected more water than the conventionally

Table 1
Effect of double spring plowing on sorghum grain yield for seven soil types in Botswana in 1988/89

Soil type	Adjusted grain yields kg ha^{-1} at 10% moisture content						
	Shallow ferric luvisol	Shallow ferrallic arenosol	Calci cambisol	Orthic luvisol	Deep ferric luvisol	Cambic arenosol	Luvic arenosol
Conventional plowing	790	1996	1255	1059	606	1351	1365
Double spring plowing	1020	2674	1369	1273	682	2812	1470

Table 2
Annual total soil losses for five tillage treatments at Makoholi Research Station (t ha^{-1}), after Vogel (1992)

Year/treatment	1988/89	1989/90	1990/91	1991/92	Cumulative total
Conventional plough	0.7	1.3	5.7	0.7	8.4
Clean ripping	0.5	1.3	2.1	0.4	4.3
Mulch ripping	0.5	1.3	2.1	0.4	4.3
Hand hoe	–	0.9	1.8	0.8	3.5
Tied ridging	0.0	0.1	0.1	0.1	0.3

Table 3
Maize grain yield (kg ha^{-1}), total crop water use (mm ha^{-1}) and water use efficiency (WUE, kg mm^{-1}) in response to conservation tillage practices and time of weeding at Makoholi Research Station, after Twomlow and Dhliwayo (1999)

Tillage	1994/95			1995/96			1996/97		
	Grain yield	Crop water use	WUE	Grain yield	Crop water use	WUE	Grain yield	Crop water use	WUE
OPFP	1282	294	4.4	707	331	2.1	2435	307	7.9
OPFP + MR	1471	297	5.0	1073	335	3.2	1981	290	6.8
Tied ridge	1280	290	4.4	495	332	1.5	3429	312	11.0
Tied furrow	1234	304	4.1	302	335	0.9	2577	300	8.6
S.E.D.	158.6	4.4*	0.947	82.9***	5.5	0.44***	259.7***	15.0	1.29*
Weeding regime (weeks)									
4	1165	299	3.9	466	328	1.4	2604	303	8.6
2 + 6	1468	293	5.0	823	338	2.4	2608	302	8.6
S.E.D.	112.1**	3.1	0.669	58.6***	3.92*	0.32***	183.6	10.6	0.91

Significant treatment effects.

OPFP – Open plough furrow planting; MR – post emergent mid season ridging (often referred to as modified tied ridging).

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

ploughed plots. Good weed management ensured maximum utilization of soil moisture for crop productivity. Weeds compete for the scarce water with crops especially at the beginning of the season. Timeliness of weeding also increase crop yield and water use efficiency (Table 3) irrespective of the tillage practice.

2.2. Inter field water management practices

Inter field-water harvesting techniques that are being promoted throughout southern Zimbabwe include dead level contours with or without infiltration pits, graded contour ridges (<5% slope) and *Fanya Juus*. A fanya juus is a ditch dug on the contour with soil thrown uphill to form a bank that is then seeded with grass (Twomlow et al., 1999). In a recent study carried out by Motsi et al. (2004) a participatory approach was used to introduce a range of rainwater harvesting/management techniques to farmers in Mudzi, Gutu and Chivi districts of Zimbabwe. The technologies tested were *in situ* (tied ridges and conventional ploughing) and between-field structures (fanya juus and infiltration pits). Results showed that tied ridges retained more soil moisture than all the other techniques. The average maize yield from tied ridges was 3.4 t ha^{-1} compared with 1.5 t ha^{-1} from conventional ploughing. However, the comparisons made could be misleading given the location of rainwater harvesting structures relative to the position of in field crop management practices. Crops growing in the field might not access water from the in-contour structures as easily as water from in-field structures because of water losses through deep drainage.

An alternative approach that has been explored as a soil moisture conservation strategy is land fallowing (Nyamudeza and Maringa, 1992). Land previously cropped was used as a control in a series of on-station trials run from 1988 to 1991 at Chiredzi Research Station. The trials aimed at comparing the effects of bare fallowing and previous crop on soil water carried over to the next season and crop yield. Maize and sorghum yields from previously fallowed land were significantly higher than from cropped land. Sorghum left less residual moisture than maize for the crop that was planted in the same plots a season after fallowing (Table 4). Sorghum was left to ratoon and utilized a significant proportion of moisture that had been left the previous season (Nyamudeza and Maringa, 1992). Even though the on-station results were positive, the availability of land the need for winter weed control on uncropped land might scare away potential adopters of the technology. For a farmer with limited land, the previously fallowed land should produce at twice as much grain to compensate for time when it has no crop.

Table 4
Total soil water (mm) to a depth of 0.9 m showing the effect of the previous crop after harvesting in 1989, 1990 and 1991, after Nyamudeza and Maringa (1992)

Previous crop	1988/89	1989/90	1990/91	Mean
Maize	133	109	121	121
Sorghum	117	103	116	112
Cotton	130	109	117	119
Bare fallow	154	125	157	145
S.E.	7.2	5.9	6.3	
Significance	*	NS	*	
CV	9.6	9.4	9.8	

Infiltration pits within contour ridges are still being used as a soil water management technique. Mugabe (2004) conducted trials aimed at quantifying soil moisture contributions of infiltration pits along contour ridges. Soil water storage was monitored above and below infiltration pits over one season. The study was conducted in Masvingo communal areas and results showed that infiltration pits could capture significant quantities of runoff water. Water captured by the pits replenished soil water on the up and down slopes of the pit. The depth of infiltration pits currently being promoted ranges from about 0.5 m to

2.0 m (Mwenge Kahinda, 2004). Although the study demonstrated the soil water benefits of infiltration pits, a significant proportion of water collected at 1 m depth by the pit could be lost through deep drainage. Crops with a rooting depth of less than a metre might benefit marginally. The infiltration pit depth of less than 1 m could benefit shallow rooted crops such as legumes while cereals might still extract water from more than a metre depth.

Few farmers who have been exposed to a number of soil water conservation technologies have continued to use them. There are a number of reasons that explain the lack of uptake of such technologies that have a potential to address challenges of the smallholder farming sector. Lack of appropriate and affordable equipment for some of the conservation techniques has hampered uptake of these techniques as viable options to conventional practices. Limited labour resources also handicaps the use of technologies developed for smallholder farming communities. The scarcity of necessary information and technical support from government and development agencies partly accounts for lack of uptake of technologies.

Soil water conservation studies that have been conducted so far have lacked a holistic approach to problems currently facing the smallholder farming community. Lack of response to soil water management is sometimes compounded by poor soil fertility. There is need to exploit synergies between water and soil fertility management under rainfed crop production. This would increase water and crop productivity in the semi-arid regions.

3. Soil and water management techniques in the Mzingwane Catchment

Current efforts in water management in the semi-arid areas of Zimbabwe involve several national and international organizations. The Department of Agricultural Research and Extension Services (AREX) and Mzingwane Catchment Council are participating in the on-going work in the Mzingwane river catchment.

3.1. In-field rainwater harvesting

Trials were conducted in Gwanda district to determine the effect of livestock manure or basal fertilizer and modified tied ridging on sunflower and sorghum yields (Rusike and Heinrich, 2002). The trials were conducted through the Farmer Field School approach with Agricultural Research and Extension (AREX) department facilitating the programme. Crop yield results showed that combining soil fertility amendments and tied ridges gives the highest yield benefits (Table 5).

Table 5
Effect of combining manure or compound D (8:14:7 – $N:P_2O_5:K_2O$) with modified tied ridges on crop yield, after Rusike and Heinrich (2002)

Treatment	Plot size (ha)	Yield (kg ha^{-1})
Sorghum + manure + ridges	0.1	400
Sorghum + 0 manure + 0 ridges	0.1	300
Sunflower + compound D + ridges	0.1	550
Sunflower + 0 compound D + 0 ridges	0.1	495
Groundnut + ridges	0.1	0
Groundnut + 0 ridges	0.1	0

Techniques being applied between fields also include dead level and ordinary contours, dead level contours with underground storage tanks and infiltration pits. *In situ* water management techniques include planting basins and deep winter ploughing. The microcatchment structures include dead level contours with or without infiltration pits (Fig. 2) and ordinary contour ridges (<5% slope) (Fig. 3). Within the field, the dead level contours harness water originating from the area upslope. The contour ridges vary in size, the minimum having a cross-sectional dimension of 1.5 m width and 0.5 m depth (Mwenge Kahinda, 2004). The length of each contour varies according to the length of the field. Currently there is no quantitative data on crop response to soil water contributed by dead level contours with or without infiltration pits. However, from focus group discussions that have been held by researchers from ICRISAT and farmers located within the Mzingwane river

Fig. 2. Dead level contours.

Fig. 3. Graded contours.

Fig. 4. Storage pits in a dead level contour.

catchment, crops grown on fields with dead level contours show less moisture during periods of dry spells.

The water harvesting techniques used are dead level contours with storage facilities (Fig. 4). The underground tanks are constructed by bricks and plastered. They have a capacity of 2 m × 1 m × 4 m and the water collected from the home yard (20 m × 10 m) is used by the household mainly for laundry or watering small gardens.

The basin tillage practice is part of the recently introduced Conservation Agriculture (CA) package which is targeted for vulnerable households. Planting basins are dug in September or October in the same positions annually. The recommended dimensions of each basin are 15 cm (length) × 15 cm (width) × 15 cm (depth) and the basins are spaced at 90 cm × 60 cm. Rain water is collected into the basins during the early season rainfall events (October and November) (Fig. 5). Planting follows in December after the basins have captured rainwater at least once. Smallholder farmers without draft power can plant at the right time in terms of days after an effective rainfall event. During the 2004/05 season World Vision established trials on planting basins in Gwanda and Beitbridge districts which lie within the Mzingwane catchment. However, these initial trials yielded nothing because of drought. Maize yield benefits derived from the use of planting basins were observed in other districts outside the Mzingwane catchment in southern Zimbabwe (Table 6).

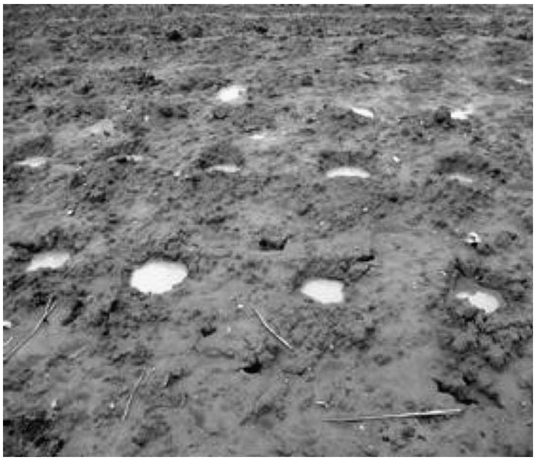

Fig. 5. Planting basins harvesting initial rainfalls.

Table 6
Rainfall patterns and maize grain yield (kg ha^{-1}) responses to farmer practice and planting basins for eight districts in southern Zimbabwe in 2004–2005, after Twomlow et al. (in press)

Province	District	n	Rainfall mm	Farmer practice kg ha^{-1}	Basins kg ha^{-1}
Matabeleland North	Hwange	22	350 to 600	781	1086
	Lupane	13	350-450	524	796
	Nkayi	4	530	702	1134
Midlands	Chirumhanzu	7	380-450	533	1017
	Zvishavane	8	380	531	336
Masvingo	Gutu	7	458	301	395
	Masvingo	37	260-410	603	1010
	Mwenezi	8	314	114	120

Deep winter ploughing is a technique which has been in practice for decades. It is now the standard recommendation by the government's agriculture research and extension department. The technique involves ploughing to a depth of 0.2 m soon after harvesting, and is favoured due to improvements in weed control. However, the majority of smallholder farmers plough to a depth of 0.1–0.12 m, resulting in the formation of a hardpan within the soil profile. The plough pan restricts root penetration and rainwater infiltration. Crops grown under shallow ploughing cannot withstand extended periods of soil moisture stress during mid-season dry spells. During focus group discussions facilitated by ICRISAT researchers, farmers acknowledged deep winter ploughing as a recommended soil water conservation practice for the region. However, deep winter ploughing is still not being practiced in the lower Mzingwane subcatchment.

3.2. Macrocatchment rainwater harvesting

Small-scale irrigation has become increasingly important in the semi-arid districts of Zimbabwe. In the Mzingwane catchment, dams have been constructed primarily for irrigated community projects. While serving the irrigation purpose, the dams are also watering points for livestock. Studies conducted by Mwenge Kahinda (2004) in the Mzingwane catchment showed that earth and sand dams, and rock outcrops are being used as rainwater harvesting techniques at a macrocatchment scale.

4. Discussion

Soil water conservation and rainwater harvesting strategies have developed for the different agroecological regions of Zimbabwe. For the semi arid districts of Zimbabwe these practices include mulching ripping, various tillage practices and weed management. Soil and water conservation research has shown the variable but positive impact of both macro and microcatchment rainwater harvesting on soil moisture regimes and crop yields. Most of the soil water conservation research has been concentrated in districts which receive more rainfall than the Mzingwane catchment. The flow of technologies developed in wetter parts of southern Zimbabwe into the districts of Mzingwane catchment area has been minimal or nil. This is evidenced by lack of any in-field soil water management practice on smallholder farms within the catchment despite years of research in other parts of southern Zimbabwe. More is still to be done in the Mzingwane catchment on the impact of *in situ* rainwater harvesting on crop and water productivity, as well as the economics and downstream impacts. Rainwater harvesting techniques need to be evaluated as part of the community and water resources systems, not as isolated farm units.

Most studies on *in situ* rainwater harvesting systems overlooked the problem of soil fertility, which can curtail the benefits associated with improved soil water status. Exceptions are studies by Nyakatawa et al. (1996) and Nyamudeza (1998), which investigated the interaction of tied ridge/furrow system and soil fertility. Further work is required to explore the impacts of combining soil fertility management, especially Nitrogen and Phosphorus with dead level contours, infiltration pits and basin tillage on water and soil productivity. This will generate a basket of options for the resource constrained smallholder farmers in semi-arid areas. The effective spacing and depth of infiltration pits within contours need to be determined for different soil textural classes.

Saunders (1997) suggested that socio-economic studies still need to be carried out to determine limitations to adoption of water conservation techniques on different soil types. Monitoring and evaluation of currently promoted rainwater harvesting techniques is critical in order to determine impact of technologies on the whole farm, and the community.

There is need to pursue an integrated approach to soil water and fertility management challenges facing farmers in the semi arid areas of southern Zimbabwe. Soil water and crop yield benefits derived from management practices such as planting basins, dead level contours and infiltration pits need to be quantified and documented. Intensification of technology transfer is also critical if the developed and developing soil water management technologies are to have a positive effect on national food security.

An opportunity now exists under the Water and Food Challenge program to systematically evaluate a range of practices being promoted by various organizations in the catchment and improve the process of technology transfer and have a positive impact on local food security.

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