In-situ water harvesting technologies in semi-arid southern Zimbabwe: Part I. The role of biophysical factors on performance in Gwanda district

I. Nyagumbo[a*], M. Munamati[a] D., E. Chikwari[b], and Gumbo[c]

[a] *University of Zimbabwe, Department of Soil Science and Agricultural Engineering, email: inyagumbo@agric.uz.ac.zw; inyag@ecoweb.co.zw*
[b] *Department of Agricultural Research for Development, Chemistry and Soil Research Institute, Zimbabwe*
[c] *Practical Action, Zimbabwe*

Abstract

In-situ water harvesting technologies (WHTs) using structures such as dead level contours reinforced with infiltration pits, have featured prominently among others as a strategy for mitigating water shortages associated with droughts in rainfed cropping systems in the last two decades. Unfortunately little is known about the biophysical conditions necessary for these structures to effectively harvest water. This study explored the importance of biophysical factors on the performance of these structures. The methodology employed involved a two pronged approach, one using a questionnaire survey of 55 practising farmer respondents identified following community meetings and 14 key informant interviews. The other approach involved detailed pedological investigations of soils in fields of 14 randomly selected farmers who were a subset of the respondent farmers. Data analysis involved compilations of responses on roles of soil properties such as soil texture, depth and slope which were juxtaposed to corresponding pedological soil investigations data.

The results show that medium to heavy textured soils were considered more effective for water harvesting by farmers compared to the lighter textured soils. Gently sloping areas (slopes 2-3%) were also considered prime conditions for optimum performance. The majority of the farmers (83%) felt deep soils (>70 cm) were more effective and pedological investigations augmented much of the farmer perceptions. Deeper soils (>70cm) with a slightly indurated 'spongy' parent material overlying impermeable indurated bedrock were more conducive as this characteristic dominated sites of farmers who were classified as very successful with these water harvesting structures. Shallower soils (35-60 cm), with well indurated impermeable parent materials constituted soils of less successful farmers. Conclusions drawn suggest that maximum benefits from use of *in-situ* water harvesting technologies can be derived from conditions with gentle slopes, medium to heavy textured soils and the existence of an impermeable bed rock at soil depths greater than 70 cm. Farmers with fields characterized by such conditions in arid environments are thus recommended to invest in these water harvesting structures. Soils with impermeable materials at shallower depths expose the retained water to evaporative losses in such semi-arid environments and are therefore not ideal for efficient water harvesting.

Keywords: *parent material, pedological, in-situ Water harvesting, slope, soil texture*

Theme: Land and Water

Type of presentation: Oral

1. Introduction

Zimbabwe's semi arid regions suffer from periodic droughts and dry spells often causing complete crop failure, water scarcity, livestock deaths and leading to difficulties in sustaining livelihoods. The rainfall distribution is affected by altitude and is highly variable in space and time, with a country annual mean of 675 mm. Areas receiving the lowest rainfall also have the least reliable distribution ranging from 20 % variability in the north to 45 % variability in the south (Department of Meterological Services, 1981; Bratton, 1987). Analysis of long term rainfall data indicates that droughts are an inherent characteristic of the climate in Southern Africa (Unganai, 1993) and often occur at least once in every 4 years in the semi-arid areas. High intensity storms generally fall at the onset of the rainy season, often causing high levels of sheet erosion.

Analysis of maize crop yield patterns since the 1970s shows that crop yields are mainly dependent on season quality (rainfall quantity and distribution) thereby making rainfall the most important crop yield determinant (MLARR, 2001) Crop yield depression and crop failure due to moisture stress is thus a common phenomena in the semi-arid areas.

To mitigate the effects of these droughts there is therefore need for farmers to use water conserving technologies so as to increase the time period required for crop moisture stress to set in. Studies in the region have also shown that improved crop productivity can only be achieved in the region if policies and strategies are adopted by regional governments to improve agricultural water management (IMAWESA, 2007). Similar studies for Zimbabwe have also shown the need for implementation of policies for improved agricultural water management (AWM) that enhance 'green water' productivity particularly in rainfed systems (Nyagumbo and Rurinda, 2007). Such strategies include the use of improved water management technologies in both irrigated and dryland systems as summarized by IMAWESA in 2007 (Mati, 2007). Unfortunately for smallholder farmers most of the options for improved agricultural water management tend to require investments beyond the reach of smallholder farmers. Figure 1 shows a hypothetical hierarchy of options for improving agricultural water management and shows that the cheapest options for improved AWM start from using improved seed or germplasm, use of fertility ameliorants and then use of water harvesting (WHTs) and conservation technology options. Beyond these the scope for improved AWM is seriously constrained by costs associated with water delivery infrastructure. It follows therefore that the most immediate and rapid returns to investments can be derived from technologies that efficiently utilize natural rainfall.

In Zimbabwe, efforts to manage water in rainfed systems using water conservation technologies in the past 20 years have mainly focused on in-situ water harvesting techniques such as tied ridging, tied furrows and conservation tillage techniques (Nyamudeza and Jones, 1993; Nyagumbo, 1997, 1998). However despite their effectiveness such techniques have been poorly adopted by farmers. Instead farmers in semi-arid areas have tended to show more interest in large water harvesting mechanical structures that can work in place of the conventional standard contour ridge structures (Hagmann, 1994; Hagmann and Murwira, 1996a). By design standard contour ridges are pegged to dispose of excess run-off rather than retain it (Elwell, 1981). Contour ridges were introduced indiscriminately for use in smallholder farming areas in the 1930s without considering rainfall conditions to combat accelerated erosion that had become rampant after the introduction of the plough in the 1930s (Aylen, 1941b, a; Alvord, 1958) The use of mechanical contour ridges was thus resisted by farmers and was seen as a tool of oppression due to their enforcement, high labour demand, 15 % land taken out of production and irrelevance to drought prone regions where water is scarce.

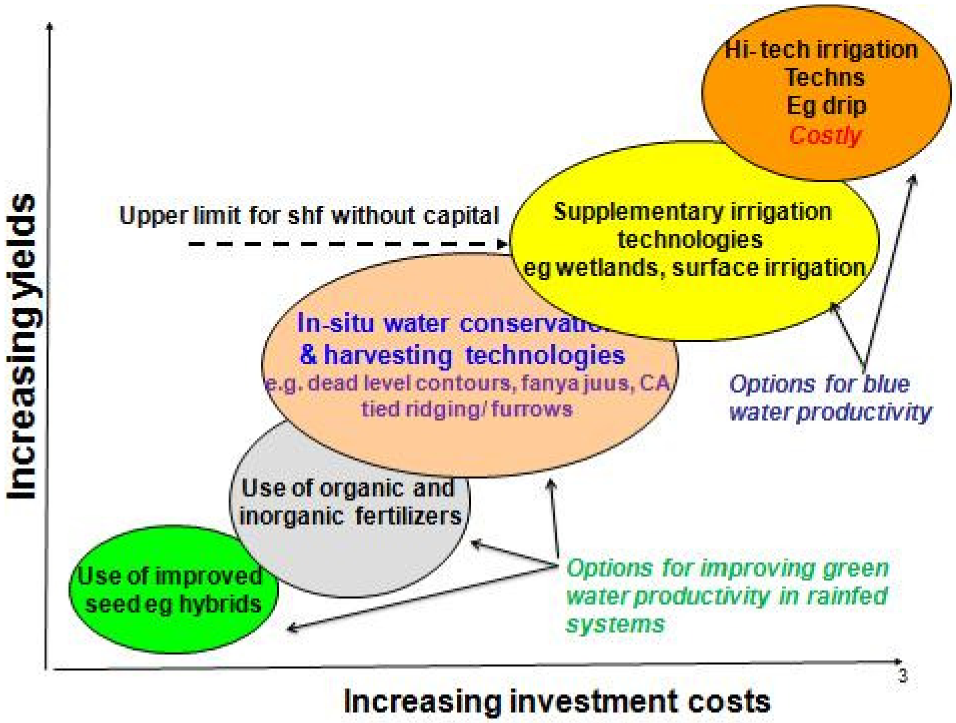

Figure 1. A hypothetical illustration of options for improving agricultural water management in cropping systems.

In recent years increased attention has been focused on introducing other options for water harvesting as alternatives to the standard contour ridges. These options include modifications of the standard contour ridges such as the use of infiltration pits (Maseko, 1995), cross tied graded contours, deepened contours and fanya juus (Hagmann, 1994). Contour ridges pegged at zero-grade or dead level contours reinforced with infiltration pits (rectangular trenches 1-2 m long, 1m wide and 0.5-0.7 m deep placed at intervals of 10 to 20 m along the contour channel) have received considerable attention from NGOs in semi arid areas of southern Zimbabwe in the last 15 to 20 years and have gained popularity in Gwanda, Zvishavane, Chivi and Buhera districts. Although considerable progress has been made with respect to their adoption by farmers (Hagmann and Murwira, 1996b; Gumbo, 2004), little is known about the technical merits of such techniques save for a few studies for example, (Mugabe, 2004). Parallel to the extension drive by NGOs promoting water harvesting techniques, research has not moved fast enough to scientifically justify the use of these techniques such that little is known about the conditions under which such techniques provide beneficial effects.

Discussions with farmers practicing these techniques suggest there are considerable benefits that can be derived by crops growing above and below these structures but unfortunately such information is only qualitative. There are no quantitative technical specifications of for example, what soil type, slopes and spacing, is optimum for best results. Consequently several research questions remain unanswered to this day:

For example do infiltration pits perform well on sandy or clay textured soils?
On what slopes do dead level contours with infiltration pits and fanya juus perform best and to what extent can crops below them benefit?
What is the optimum spacing for these water harvesting structures?
Does the existence of an impermeable bed rock enhance the performance of infiltration pits and fanya juus in comparison to standard contour ridges?

It is clear therefore that there is need for investigations to explore these issues so as to provide adequate technical support to farmers and to justify investing scarce labour resources in these water harvesting structures. Thus both extension staff and development agents are poorly informed to tackle the above questions when posed to them by farmers, a situation that often results in technically inappropriate recommendations being forwarded to farmers. At the same time farmers need to invest their scarce labour resources on technologies likely to benefit them in the long run.

This study sought to make a first step towards exploring these issues and explored the importance of biophysical factors on the performance of these dead level contours. The study therefore sought to explore biophysical conditions (soil type, depth, slope and topographic conditions) that characterize successful *in-situ* water harvesting using dead level contours based on the experiences of practicing farmers in Gwanda district.

2. Methodology

Study Area

The study was undertaken in wards 17 and 18 of Gwanda district, Matabeland South province, Zimbabwe between October 2008 and March 2009. The area is part of the Mzingwane Catchment forming part of the Limpopo river basin. The area falls under agro-ecological region V and receives annual rainfall of between 450-600 mm (Vincent and Thomas, 1960). Farming systems are characterized by livestock ranching and subsistence cropping. Livestock is the main source of income from agriculture while cropping is targeted mainly at ensuring household food security through small grains such as sorghum, pearl millet and rapoko. Although maize is not recommended for the area farmers often grow it due to its palatability. Due to the high frequency of droughts in the area, rainfed cropping is often risky as mid-season dry spells often lead to complete crop failure. As a result survival without food aid is not easily achievable and so a number of NGOs eg Practical Action, ORAP and World Vision, have been promoting in-situ water harvesting technologies (WHTs) as a means of reducing food insecurity.

Field Studies

The study deliberately targeted farmers who were already practicing in-situ water harvesting using dead level contours as these were perceived to have the most valuable experience that the study could learn from. Two types of questionnaires were developed prior to the field work i.e. one for the key informants and the other formal questionnaire for the main respondents. The key informant questionnaire addressed general constraints and factors of WHTs as well as information about the characteristics of farmers who use WHT technologies identified as respondents. The formal questionnaire captured detailed socio-economic information and details about the WHTs in use by the household.

In each of the two wards, a community meeting was held at the ward centre. Key informants were identified through these meetings by deliberately asking for the names of village heads, extension workers, traditional leadership and farmer leaders. With respect to water harvesting using dead level contours and through facilitated plenary discussions, farmers from each village were asked to identify and name their own peers who could be classified as

(i) *Very successful* (those achieving high crop yields through water harvesting)

(ii) *Medium performers* (those implementing water harvesting but not so successful)

(iii) *Poor performers* (those that have implemented but have failed to derive any benefits).

Each village was asked to identify 3 farmers in each category which resulted in a total of 55 respondents being interviewed in the two wards. A total 14 respondents also answered the key informant questionnaire in the two wards.

Physical factors governing performance of WHT

From each category of farmers in each village, the WHT fields of one farmer was selected for in-depth soil investigations so as to assess factors governing their performance. This was achieved by assessing the site and pedological soil characteristics in the field. Site characteristics that were assessed included landform type and shape; slope, size and aspect; vegetation and surface features such as stones, boulders and rock outcrops. Soil characteristics that were assessed included soil depth and nature of material limiting depth; texture; structure; colour; consistence; drainage, permeability and voids.

The soil depth limiting parent material was classified as well indurated, moderately indurated and slightly indurated. Well indurated parent materials were those with particles in the rock that are strongly bound together such that rock surface can only be broken with great difficulty using a standard rock hammer (< 1kg mass). Moderately indurated parent materials require multiple blows with standard rock hammer (< 1kg) to break rock while slightly indurated parent rock can be broken with single blow from standard rock hammer (< 1 kg mass). Due to resource and time limitations a total of only 14 farm sites were investigated

Data processing and analysis

Key informant data was compiled in an EXCEL spreadsheet with responses to each question put together in consecutive rows. Similar responses were then mathematically compiled through additions and summarized into tables or figures. Data from the main questionnaire, due to its extensive nature, was captured in an MS-ACCESS database. Farmers were grouped into three resource classes namely wealthy, medium rich and resource constrained based on resource ownership mainly livestock ownership as detailed in Part II of this paper. Summary outputs from the database were then fed into a statistical package Statistical Package for Social Scientists (SPSS) for statistical analysis. Categorical data were analyzed using non-parametric tests while quantitative data were analyzed using analysis of variance tools for comparisons between farmer resource and success classes.

3. Results

Water harvesting technologies in use

Of the water harvesting technologies being used in wards 17 and 18, key informants regarded that the dead level contours with infiltration pits were most effective (72%) as compared to standard contour ridges (14%) and other technologies such as conservation farming and ripping technologies (14%).

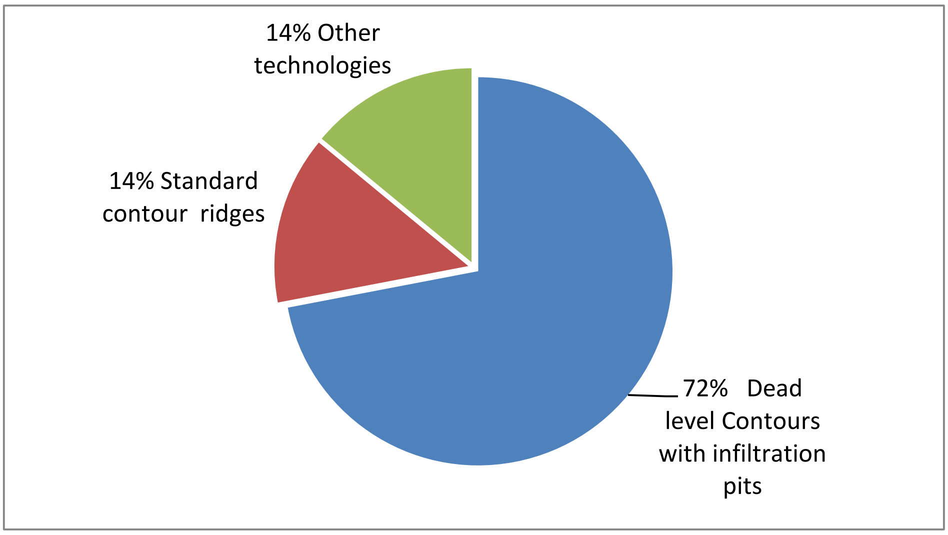

Figure 2. Key informant perceptions of effectiveness of various water harvesting technologies in wards 17 and 18 of Gwanda district, Zimbabwe in 2008. (N=14).

Field Location

Most of the water harvesting fields were found to be located in *out-* or far-fields compared to homesteads (Table 1). Only 4 fields were located on wetlands probably due to their scarcity in the area. However an insignificant Pearson's Chi-square correlation (p=0,221) between success and field location, was obtained suggesting that field location did not necessarily influence success with water harvesting technologies. Key informants generally felt that location of WHT fields was not an important factor for success (43%) while 36 % felt fields located near homesteads were more successful compared to 21 % who felt far-fields had more successful water harvesting. The statistical analysis thus supported the key informant perceptions that field location was not an important success factor. Some perceptions were however raised that because of their proximity, homestead fields were easier to manage than outfields. Nonetheless, field location was thus not considered an important attribute for success in water harvesting.

Table 1. Location of water harvesting fields in Wards 17 and 18 of Gwanda district by farmer performance category

Field type	**Farmer category**			**Total using field type**	**% using field type**
	Very successful	Average performer	Poor performer		
Homesteads	6	1	9	16	**29.1**
Far fields	12	4	19	35	**63.6**
Wetlands	1	2	1	4	**7.3**
Total	**19**	**7**	**29**	**55**	**100**
% in category	*34.6*	*12.7*	*52.7*		100

Note: Pearson Chi-square correlation test between success and field location insignificant p= 0.221, N=55

Slope

The area is generally gently sloping and almost flat with slopes generally in the range 2-5 %. No clear cut differentiation could be obtained among the various farmers' fields. It can be inferred that this general topography is supportive of water retention and minimal water loss through lateral flows. Fields with slope aspects 0-90 ºC and 270-360 ºC (slopes facing North-West and North-East) were considered to expose soils to sun's radiation, thereby increasing evaporative water losses and fast reducing amounts of harvested water. However 64 % of the key informants felt gentle to moderate slopes provided prime conditions for effectiveness. Statistical analysis on the small sample of physically measured slopes (N=14) suggested slope was insignificant. Focused group discussions with a group of men (>10) in ward 18 also suggested moderate slopes were prime to induce some lateral flow of water from the pits into the fields. Because of the limited range of slopes studied and prevalent in the area the effect of slope was not made apparent from the study.

Relationship between area under WHT and total arable area and farmer resource status

A significant linear relationship (r=0.84, *p* =0.000) was obtained between area under WHTs and total arable area (Figure 3). Farmers with large arable areas also tended to put bigger proportions of their land to water harvesting thereby suggesting that farmers were now considering this technology an important component of their farming system. One-way analysis of variance also showed a significant difference between resource status and area under water harvesting (p=0.001) with well resourced farmers also putting more land to water harvesting (Figure 4).

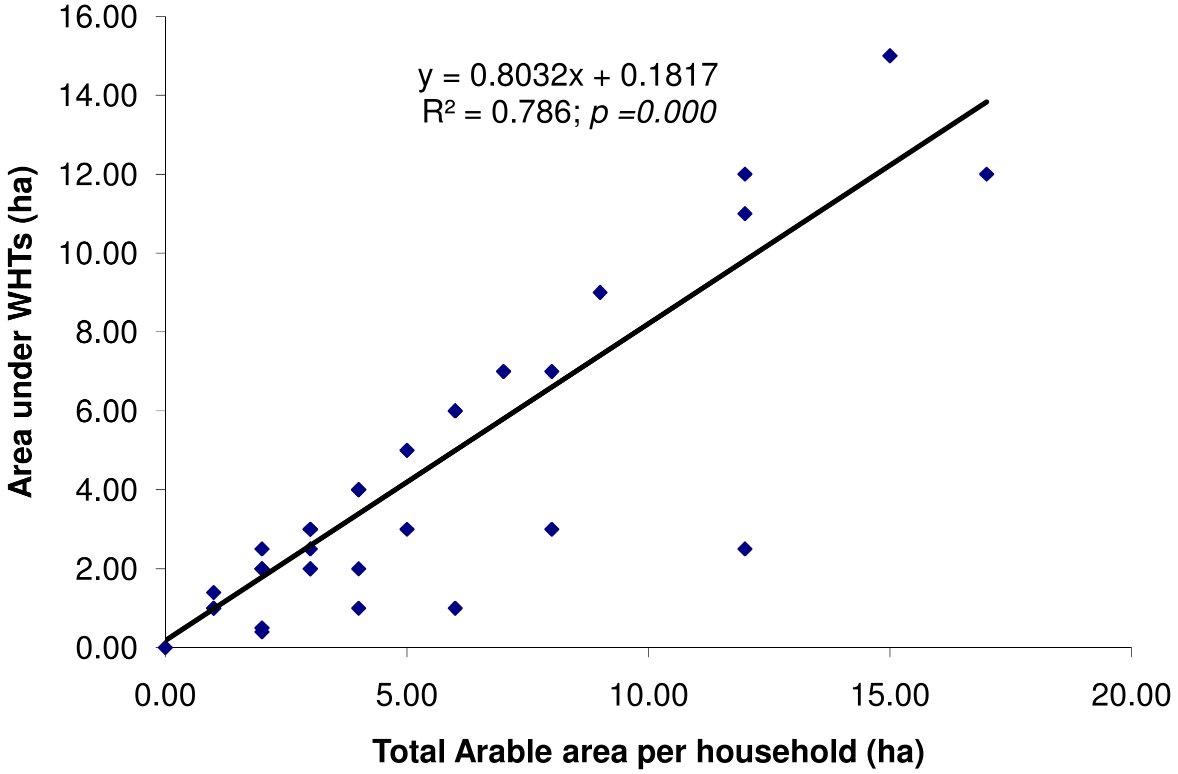

Figure 3. Relationship between area under water harvesting and total arable area per household (ha) in wards 17 and 18, Gwanda district Zimbabwe.

Soil texture , geology and depth

The most successful farmers with WHTs had fields with medium to heavier textured soils that included sandy loam to sandy clays (Table 2). Sixty percent of the sites analyzed in this category had heavy textured soils. Subsoils were generally heavier textured sandy clays. The soils on these sites of successful farmers were also generally characterized by mafic gneiss and dolerite parent materials. These soils hold about 12 to 14 % available water. Apart from their good water retention capacity, they have high nutrient retention which together with retained water synergistically supports better plant growth. Soil depths generally exceeded 70 cm in this category while the soil depth limiting parent material constituted slightly indurated and moderately indurated in some cases. This limiting material was obtained at depths greater than 70 cm with indurated and well indurated materials being obtained at greater depths underlying the permeable material. The slightly indurated material contributes to water holding capacity of the soils and capillarity. This provides a positive 'damming' effect and supports plants for their water needs. The water harvested is retained and is far from the evaporative effects but within reach of plant roots.

The average or medium farmers had predominantly sandy loam textures, although in some cases sandy clay loam soils were encountered. 100 % of the sites in this category qualified as being medium textured or better. The soils are derived from mafic and siliceous gneiss. Attributes for plant support by these soils are intermediate with water holding capacity of 10 to 12%. Soil depth in this class was generally shallower than 60 cm while the soil depth limiting parent materials constituted slightly to moderately well indurated parent materials at lower depths that contributed to a 'damming effect' at shallower depths than the successful class.

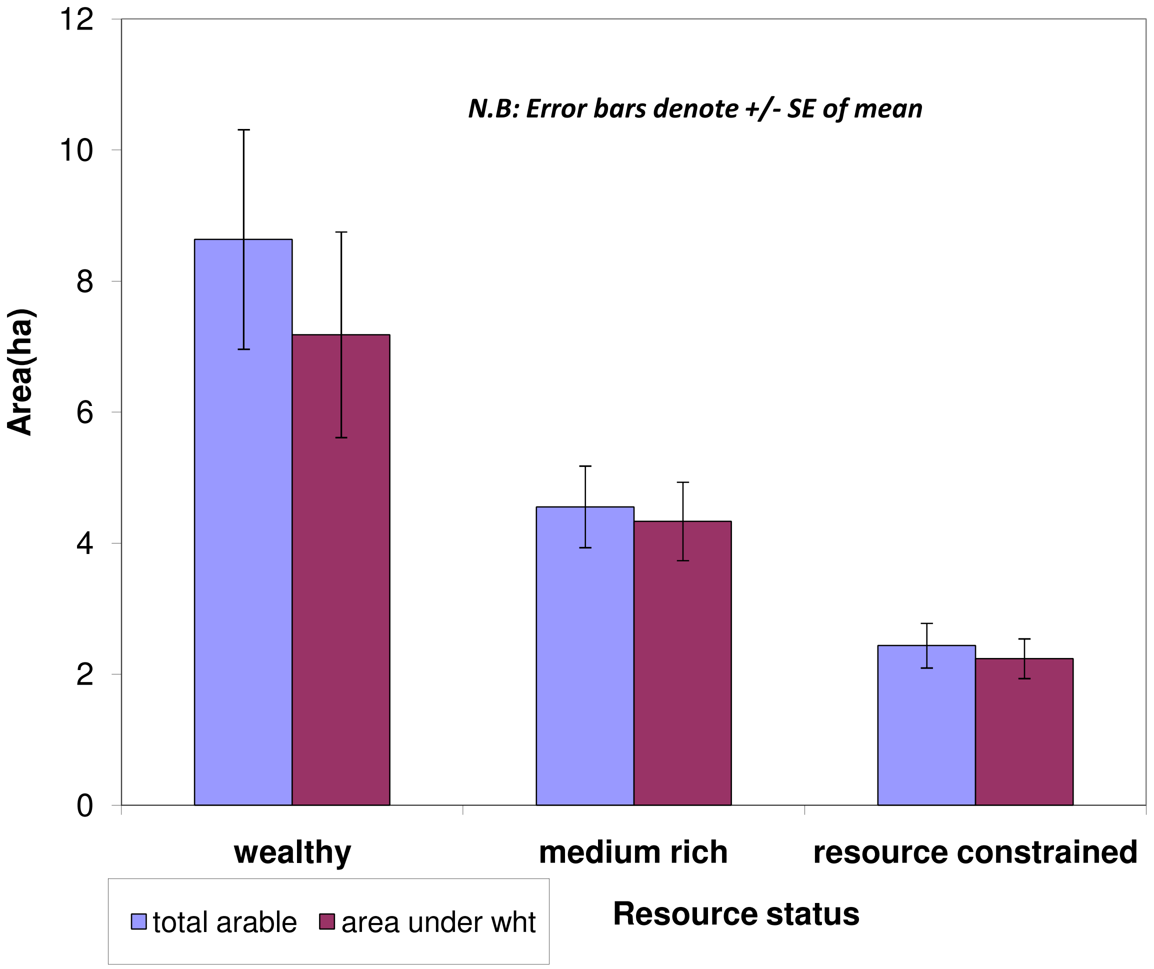

Figure 4: Effects of farmer resource status on area under water harvesting technologies in wards 17 and 18 of Gwanda district, Zimbabwe.

Note: Average area under water harvesting = 1.83 ha/hhd; Average total arable area= 4.49 ha per hhd. Resource status significantly influenced area put to water harvesting (p=0.001).

The poor performers class farmers' fields on the other hand were characterized by light textured loamy sand upper horizons with heavier textures on lower subsoils. Lighter textures hold less water with available water capacities as low as 7% and nutrient retention is very poor. Soil depths in this category were less than 60 cm on all sites investigated. The water impervious well indurated parent material was also obtained at shallower depths (<60 cm). Because the material is impervious, the water so captured is easily lost through evaporation under the prevailing arid environment. Because the soils are shallower and the well indurated material cannot aid water retention, less water is stored and plants are subject to water stress under these dry environments.

Table 2. Effects of soil geology, texture and depth on performance with water harvesting technologies in wards 17 and 18 , Gwanda district, Zimbabwe

Farmer class	**Geology**	**Soil texture**	**Slope %**	**Soil depth (cm)**	**Soil depth limiting material**	**Inference**
Highly successful (N=7)	Mafic gneiss and dolerite	Coarse Sandy Loam to Sandy Clay loam / Sandy Clay *(60 %)*	<3	>70 (71 %)	Slightly indurated (cemented) to moderately indurated in some cases (71%)	Deep soils hold more water . Limiting material causes bucket effect. Heavy texture enhancing water storage
Medium performers (N=3)	Mafic and siliceous gneiss	Predominantly Sandy Loam and some Sandy Clay loam (*100% medium texture)*	<2	<60	Moderately to slightly indurated	Medium texture close to surface. Shallow depth contributing to increased evaporation
Poor performers (N=4)	Mafic gneiss and granite	Loamy Sand to Sandy Loam on surfaces, Sandy Clay Loam in subsoils	<2	<60 (*100% shallow*)	Well to moderately indurated, some slightly indurated	Excessive water loss by evaporation due to shallowness. Light texture not holding much water

4. Discussion

The majority of the key informants generally perceived dead level contours with infiltration pits as being most effective of all the water harvesting technologies being tested. Although the communities mentioned the use of other techniques such as conservation farming basins and ripping technologies these were perceived to be playing a less significant role compared to dead level contours. Although the widespread use of the dead level contours can be attributed to mobilization by NGOs such as Practical

Action, their activities in the area were terminated in 2004 yet farmers were still practicing this water harvesting technology 4 years later. Moving around the two wards provided evidence of freshly prepared dead level contours thereby suggesting that farmers were seeing value in their use. Dead level contours have also been used extensively in other parts of the country such as Chivi, Zvishavane and Buhera (Hagmann and Murwira, 1996b). Unfortunately the study could not quantify the percentage of farmers using this technology in the area.

The lack of significant correlation between success and location of WHT fields suggested that this was not an important factor although 63 % of the farmers had installed the WHTs in their outfields. Studies in other parts of the country have suggested that in most cases homstead fields are generally better managed and in a better fertility status than out fields (Mutambanengwe, 2006). In Shurugwi similar studies on water harvesting technologies by the authors showed that water harvesting techniques were allocated more to outfields while fertility resources such as manure were more concentrated in homestead fields thereby resulting in lack of synergy between water harvesting and fertility amelioration. The same problem could also be in existence here although the study did not corroborate this. Thus while this could be an important issue it did not emerge here as a key factor for success.

The lack of significant slope effects was attributed to the narrow range of slopes in the area studied which ranged between 2 and 5%. In theory one would expect that steeper slopes would help to enhance lateral flow thereby feeding the crop on the downslope side with water, a point also raised by some farmers during discussions. Therefore there is need for further work to explore the importance of this factor.

The importance of this WHT to farmers is also evidenced by the fact that farmers with larger arable areas were also putting bigger proportions of their areas to water harvesting although other constraining factors prevented them from fully installing these on all their arable lands. If farmers were installing these structures just to please NGOs then this relationship between arable area and area under WHT would not have been significant. Access to resources however emerged as a significant factor promoting the farmers capacity to implement these WHTs, a fact also established in other studies elsewhere (Mutambanengwe, 2006). Labour issues explored in part II of this paper could be important factors contributing to the size of land under WHTs. The majority of the key informants (93 %) generally perceived labour resources as a key factor for success. Although part II of this paper did not confirm any relationship between success and labour resources, studies in many communal areas of Zimbabwe show labour as an important factor in farmers capacity to adopt technologies (Hagmann, 1999)

The fact that the most successful farmers had deeper soils of a heavier texture and semi-pervious parent materials with impervious materials at greater depths, makes an important finding for this study. While it is generally known that fine textured soils hold more water, the mechanism through which the dead level contours function to be so convincing to farmers remains poorly understood by science. For any dry soil water flow would naturally be driven by gravity and soil suction which points to a predominantly downward flow. Lateral flow through which water harvested in the contour channels could benefit crops can only take place theoretically in the presence of a flow impeding layer at depth. The well indurated or cemented material at depths greater than 70 cm in in successful farmer categories could be providing this function which could be described as the ‘bucket effect’. This means water harvested in the channels feeds the soil until it reaches the impervious layer and starts flowing laterally or rising, thereby providing a reservoir of water to the crop at depth which on clays or heavy textured soils, rises by capillarity during dry spells and ensure the crop benefits. On the contrary the shallow light textured soils with the cemented material occurring at shallow depths on poor performing farmers, tend to cause waterlogging of the crop in wet spells and at the same time lose the harvested water through soil evaporation during periods of prolonged dry-spells, hence leading to reduced benefits from water harvesting investments. This explains why studies on a few locations in the same area found no significant moisture and crop yield benefits from the use of dead level contours (Mupangwa, 2008), thereby placing more emphasis on the need to fine tune recommendations for such investments by farmers. As a result of some of these limitations, farmers were found to make various modifications to reduce evaporation such as covering the pits and altering the depth of the pits to shallow ones with the hope of enhancing lateral flow.

Lack of reliable data on crop yields which relied on farmers memory, unfortunately resulted in failure to show the differences in yields between the three different farmer success categories. Nevertheless, this study suggests that it is worthwhile investing in dead level contours for water harvesting purposes if there is an underlying bed rock at depths greater than 70 cm or at about 1m depth and that such benefits may be enhanced on heavy textured soils. On the other hand farmers should give lowest priority to dead level contour investments on shallow and light textured soils as returns to investments are generally poor.

5. Conclusions

The performance of the dead level contour water harvesting technology was found to be dependent on soil and site characteristics. The best performance resulting in highest yield returns to investments, were obtainable from deep (>70cm) and heavy textured soils with semi-permeable underlying bedrock parent material that helped to retain water in the rooting zone. Benefits to dead level contours tended to diminish as textures became lighter and soils became shallower.

Slopes studied in the area ranging between 2 and 5 %, had no apparent effects on performance of the WHT technology and this could be because of the limited nature of slope ranges studied. The study therefore failed to effectively establish the importance of the slope factor.

Although most (63%) of water harvesting fields were on outfields the study did not establish a significant link between success and location of fields where water harvesting is practiced. This suggested that other factors besides field location were more important in determining farmers capacity to succeed with the technology.

The study also established that the proportion of land under water harvesting increased with land ownership and that well resourced farmers had significantly more land under water harvesting, compared to the more constrained counterparts suggesting that resource ownership was a key factor in adoption of the technology.

6. Recommendations

Based on the findings of this study farmers in semi-arid areas should prioritize heavy textured and deep soils with an underlying impermeable bed-rock at depths exceeding 1m for investments in rain water harvesting using dead level contours with infiltration pits. Shallow and light textured soils should be given lower priority as the efficiency of water harvesting under such conditions is diminished may not give quick returns to their labour investments. Quick investigations using auger borings across proposed sites could help to establish conditions on each farm with the support of local extension where farmers are in doubt as to whether or not to install these structures.

The study failed to establish the contribution of slope to effectiveness of dead level contours due to the limited slope ranges in the area. It is recommended areas with steeper slopes and more variable soils be included in any further such studies so as to fully assess the contribution of slopes. In addition because of the limited nature of the sample of farmers whose soils were investigated, there is need for further work on more sites to increase confidence in the above findings on soil characteristics.

Lack of reliable crop yield data which limited comparisons between the farmer categories could be enhanced by use of remote sensing techniques which could help to provide indicators of crop condition on water harvesting sites during specific times of the year in the last 3 to 4 years since making physical assessments of yield on each site may be practically impossible in a resource constrained environment.

7. Acknowledgments

The authors of this paper would like to acknowledge the contribution of Waternet Project PN 17 to this study and Practical Action and Hlekweni for their facilitation of the farmer meetings.

Literature cited

Alvord, E. D. (1958). "*Development of Native Agriculture and Land Tenure in Southern Rhodesia*,", Waddilove, pp.

Aylen, D. (1941a). Hand Made Contourm Ridges and Piece Work. *The Rhodesia Agricultural Journal* **36**, 452-484.

Aylen, D. (1941b). Who built the first Contour Ridges. *The Rhodesia Agricultural Journal* **36**, 452-484.

Bratton, M. (1987). Drought, food and the social organisation of small farmers in Zimbabwe. **In** "*Drought and hunger in Africa denying famine a future*" (M. Glantz, ed.). pp. 31-35. Cambridge University Press, New York.

Department of Meterological Services (1981). "*Climate Handbook of Zimbabwe*,". Department of Meterological Services, Harare, Zimbabwe., pp.

Elwell, H. A. (1981). "*Contour layout Design*,", 1981. Conex publication, Government Printers, Harare, 61 pp.

Gumbo, D. (2004). "*Strategies and technologies for improved soil and water management*,", October 2004. ITDG- Southern Africa, 8 pp.

Hagmann, J. (1994). "*The Fanya juu system: An option for soil & water conservation in semi-arid Zimbabwe. A discussion paper.*,", March 1994. Agritex/ GTZ Conservation Tillage project, Institute of Agricultural Engineering, Harare, pp.

Hagmann, J. (1999). "*Learning together for change: Facilitating Innovation in Natural Resource Management Through Learning Process Approaches in Rural Livelihoods in Zimbabwe*," Margraf Verlag 1999, 320 pp.

Hagmann, J., and Murwira, K. (1996a). Improving the output of Agricultural Extension and Research through participatory innnovation Development & Extension: Experiences from Zimbabwe. *European Journal of Agricultural Education and Extension* **2**, 4, 15-24.

Hagmann, J., and Murwira, K. (1996b). Indigenous Soil and Water Conservation in Southern Zimbabwe: A study of techniques, historical changes and recent developments under participatory research and extension (part1). **In** "*Sustaining* *the Soil: Indigenous Soil and Water Conservation in Africa*" (C. Reij, I. Scoones and C. Toulmin, eds.). pp. 97-106. Earthscan, London.

IMAWESA (2007). "*Agricultural Water Management, a critical factor in the reduction of poverty and hunger: Principles and Recommendations for Action to Guide Policy in Eastern and Southern Africa*,", June 2007. The IMAWESA, Improving Management of Agricultural Water in Eastern and Southern Africa project, Nairobi, Kenya.www.asareca.org/swmnet, 30 pp.

Maseko, P. (1995). Soil & Water conservation for small-holder farmers in semi-arid Zimbabwe. **In** "*Proceedings of a technical workshop, Soil & Water conservation for smallholder farmers in semi-arid Zimbabwe-transfers between research and extension.*" (S. J. Twomlow, J. Ellis-Jones, J. Hagmann and H. Loos, eds.). 3-7 April 1995, Belmont Press, Masvingo, Zimbabwe.

Mati, B. (2007). "*100 Ways to Manage Water for Smallholder Agriculture in Eastern and Southern Africa: A compendium of Technologies and Practices*," Rep. No. SWMnet working paper 13, March 2007. Improved Management of Agricultural Water in Eastern and Southern Africa (IMAWESA), Nairobi, Kenya.www.asareca.org/swmnet, 51 pp.

MLARR (2001). "*The Agricultural Sector of Zimbabwe: Statistical Bulletin-2001*,". Ministry of Lands Agriculture and Rural Resettlement, Harare, 60 pp.

Mugabe, F. T. (2004). Evaluation of the benefits of infiltration pits on soil moisture in semi-arid Zimbabwe. 3(3): 188-190. *Journal of Agronomy* **3**, 3, 188-190.

Mupangwa, W. T. (2008). Water and Nitrogen Management for risk Mitigation in Semi-arid Cropping systems. Dphil Thesis, Faculty of Natural and Agricultural Sciences, Department of Soil, Crop and Climate Sciences, University of the Free State November 2008, Bloemfontein, South Africa. 350 pp.

Mutambanengwe, F. (2006). Soil Organic Matter Dynamics and Crop Productivity as Affected by Organic Resource Quality and Management Practices on Smallholder Farms. DPhil Thesis, Department of Soil Science and Agricultural Engineering, University of Zimbabwe, Harare. 245 pp.

Nyagumbo, I. (1997). Socio-cultural constraints to small-holder farming development projects in Zimbabwe: A review of experiences from farmer participatory research in conservation tillage. *The Zimbabwe Science News* **31**, 2, 42-48. April/June 1997.

Nyagumbo, I. (1998). Experiences with conservation tillage practices in southern and eastern Africa: A regional perspective. **In** "*Conservation Tillage For Sustainable Agriculture: International Workshop*" (J. Benites, E. Chuma, R. Fowler, J. Kienzle, K. Molapong, J. Manu, I. Nyagumbo, K. Steiner and R. van Veenhuizen, eds.), pp. 73-86. 22-27 June 1998, GTZ, Eschborn, Harare, Zimbabwe.

Nyagumbo, I., and Rurinda, J. (2007). "*Rapid Appraisal of Policies and Institutional Frameworks for Agricultural Water Management: Zimbabwe Country Report*,", November 2007. Improved Management of Agricultural Water in Eastern and Southern Africa (IMAWESA), Nairobi, Kenya.www.asareca.org/swmnet/imawesa, 70 pp.

Nyamudeza, P., and Jones, E. (1993). The effects of growing sorghum (sorghum bicolor) in furrows and on the flat at three populations and three row widths in semi-arid region of Zimbabwe 2: Soil water regime throughout the season. *Zimbabwe Journal of Agricultural Research* **31**, 11-21.

Unganai, L. S. (1993). Chronology of droughts in Southern Africa: The impacts and future management options. **In** " *Proceedings of the third Annual Scientific Conference*" (M. Kronen, ed.), pp. 10-19. October 5-7 1993, SADC Land and Water Management Research Programme, SACCAR, Windhoek, Namibia.

Vincent, V., and Thomas, R. G. (1960). "*An Agricultural Survey of Southern Rhodesia: Part I: The Agro-ecological Survey*,". Government Printer, Salisbury, pp.