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Evaluating different soil tillage surface conditions on their rainwater harvesting potential in Botswana

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ABSTRACT

Rain water harvesting (RWH) is described as concentration, collection, storage and use of rain fall via runoff for various purposes such as domestic, livestock and agricultural use. RWH systems can be classified as macro, mini, micro and in-situ. A study was carried out during the 2013/14 cropping season to (1) characterize the soil tillage surface conditions on their runoff generation potential using micro-catchment RWH systems and (2) appraise the micro-catchment RWH systems resulting from different tillage systems on crop performance. For the first objective, a Completely Randomized Block Design comprising of three blocks of runoff/catchment plots measuring 25 m^2, 50 m^2 and 100 m^2 were laid out. Within the same plots/ rainfall catchment, the following four soil surface conditions were imposed: Ploughed with mouldboard surface (PS), Ploughed with mouldboard and un-weeded surface (UP), Ploughed with mouldboard and subsequently harrowed surface (HS) and naturally vegetated surface (NV). At the bottom of the catchment area, a runoff collection system was laid and runoff was measured after every storm event. The second experiment was also a Completely Randomized Block Design with two factors i.e. catchment size (*in-situ*, 25 m^2, 50 m^2, and 100 m^2) and the four soil tillage surface conditions were repeated but this time a maize crop was planted at the bottom of the slope, such that runoff was collected at the cropped area. Plant performance (growth rate) was assessed fortnightly, by measuring 10 plants' height of the mid-leaf or growing point, from each plot. The results showed that a 5 x 5 m mouldboard ploughed and un-weeded surface yielded significantly more runoff than other catchment areas and surface condition combinations. With respect to crop performance, a 5 x 5 m catchment whose runoff was directed to a mouldboard ploughed cropped area had a significantly higher growth rate of maize than run-off from other catchment areas and surface condition combinations.

Key words: Catchment size, growth rate, micro-catchment rainwater harvesting, runoff, soil surface condition, tillage systems

RÉSUMÉ

La collecte d'eau de pluie (RWH) est décrite comme la concentration, la collecte, le stockage et l'utilisation des eaux ruisselantes de pluies à des fins diverses telles que : domestique, utilisations pour l'élevage et l'agriculture. Les systèmes de collecte d'eaux peuvent être groupés en macro, moyen, micro et in situ. Une étude a été conduite au cours de la saison agricole 2013-2014 pour (1) caractériser les conditions de systèmes de labours du sol sur leur capacités de collecte d'eaux de ruissellement en utilisant des systèmes de micro-bassins versants (RWH) et (2) évaluer les systèmes de micro-bassin versant (RWH) résultant de différent systèmes de labours sur le rendement des cultures. Pour le premier objectif, un bloc complètement aléatoire comprenant trois blocs de parcelles de ruissellement / bassins de 25 m^2, 50 m^2 et 100 m^2 ont été aménagés. Dans un bassin versant de mêmes parcelles, les quatre conditions de surface du sol suivantes ont été imposées: labouré avec surface de versoir (PS), labouré avec versoirs plus surface non désherbé (UP), labouré avec versoirs suivies d'hersage (HS) et surface à végétation naturelle (NV). Au fond de la zone de captage, un système de collecte d'eaux de ruissellement a été posé et le ruissellement a été mesuré après chaque orage. La deuxième expérience a également été un bloc complètement aléatoire avec deux facteurs à savoir la taille du bassin versant (in-situ, 25 m^2, 50 m^2 et 100 m^2) et les quatre conditions de labours de surface du sol ont été répétées, mais cette fois ci, une culture de maïs a été installée en bas de pente de manière à ce que l'eau de ruissellement soit recueillie au niveau de la superficie cultivée. La performance des plantes (taux de croissance) a été évaluée tous les quinze jours, en mesurant la hauteur à mi- feuille ou point de croissance de 10 plants sur chaque parcelle. Les résultats ont montré que le versoir de 5 mx5m labouré et de surface non désherbé a donné beaucoup plus d'eaux de ruissellements que les autres bassins versants et les combinaisons de conditions de surface. En ce qui concerne le rendement des cultures, le bassin versant de 5mx 5 m dont les eaux de ruissellement ont été dirigées vers un versoir de superficie cultivée a donné un taux de croissance beaucoup plus élevé de maïs que le ruissellement provenant d'autres bassins versants et combinaisons de conditions de surface du sol.

Mots clés: Taille du bassin, taux de croissance, micro-bassin versant de collecte d'eaux de pluie, ruissellement, conditions de surface du sol, systèmes de labour du sol

INTRODUCTION

The ever increasing world population is putting pressure on available agricultural land. In order to produce more food, new methods should be found to increase land productivity or to bring into production land which is marginal. There are almost 600 million hectares of potentially suitable arable land in semi-arid environments, where dry-land farming is still practiced. Arable farming in these areas is hampered by low and erratic rainfall, endemic droughts and uneven distribution of land and water resources (FAO, 1991). Botswana has a land area of 582,000km^2, but of this, 80% is covered by the Kalahari sands in the west and central regions. It is reported that only 5% of total land area is suitable for arable agriculture and of this area, less than 6,000 km^2 is under cultivation (African Development Bank, 2008). Botswana's climate is characterized as semi-arid in the northeast with mean annual rainfall of 650 mm; and arid in the southwest with less than 250 mm mean annual rainfall.

All the same, agriculture in Botswana plays a very important role in the economy as more than 80% of the population is involved in agriculture. The government considers arable and livestock farming as key areas for employment creation and income generation for the majority of rural families (Botswana Government, 2000). Climate is a key factor in determining the level to which both crop production and livestock rearing succeed in any particular year. Rainfall and temperatures are the main elements which influence whether a season is good or dry leading to drought. Rainfall is seasonal, unreliable and varies from year to year (Botswana Government, 2000). It is therefore very crucial that every effort is made to conserve and efficiently utilize the scarce rain water (Moroke *et al.*, 2009). For arable crop production, this requires improved soil management techniques that maximize the holding of rain-water into the soil, coupled with cultural and agronomic practices which ensure the most optimum use of the available soil-water by plants. An optimization of the rainfall management can contribute to improving the small scale farmers' livelihoods by increasing arable cereal yields by 17% (Kayombo *et al.*, 2004; Ibraimo and Munguambe, 2007).

Rain Water Harvesting (RWH) is defined as a process of collecting, concentrating and storing various forms of runoff for various purposes (Myers, 1975). The collected runoff can be used for several purposes such as to improve soil-moisture for plants, to supply water for livestock and domestic needs and to recharge the groundwater (Frasier, 1994).

Agriculture in semiarid areas depends on the vagaries of weather, especially of the rain. Without doubt, the greatest climatic risk to sustained agricultural production in these areas is rainfall variability, which unfortunately is usually greater in zones of lower mean annual rainfall. The annual rainfall may be sufficient to support continuous and economic cropping systems during the rainy season without irrigation. This zone is dominated by rain-fed farming. Rainfall is marginal in relation to water requirement, but its distribution is poor and water stress often occurs during one or more stages of crop growth, lowering the yield. Thus, the productivity of rainfall is low, even though much of it may be utilized by crops. Variations in rainfall from one year to the next create instability in production.

Depending on the storage capacity available in the root zone, the management of rainwater for plant growth can be carried out in three successive steps:

(1) Capture of rainwater to enhance its infiltration into the soil profile;
(2) Prevention or reduction of water losses from the root zone; and
(3) Implementation of cultural practices to ensure that the crop makes the most effective use of the scarce water.

The techniques for achieving these have been developed and promoted extensively under the subject of Soil and Water Conservation (Tiffen *et al.*, 1994; Tulu, 2002; Hellin, 2006).

In order to improve the productivity of rainwater in semi-arid areas, it is often necessary to concentrate it into a small area of use through some form of tillage. The broad aim of this research was to investigate to what extent common tillage systems and the resulting soil surface conditions practiced in Botswana can harvest rain water and also if those quantities harvested can support a maize crop. Common tillage systems and soil surface conditions prevalent in Botswana include:

a) Mould board ploughed, row planted and weeded soil surface
b) Mouldboard ploughed, disc harrowed, row planted and weeded soil surface
c) Mouldboard ploughed and un-weeded soil surface

The above soil surfaces, together with an un-ploughed soil surface with vegetation (control) were used as treatments in the study.

Objectives

The main objective of the study was to evaluate micro-catchment RWH using catchment size and soil surface tillage condition as variables for improved crop production. The specific objectives of the study were:

1. To determine the relationship between catchment size and runoff generation potential on differently tilled soil surface conditions;
2. To appraise the resultant micro-catchment RWH systems from common tillage systems on crop performance.

MATERIALS AND METHODS

A field study was conducted during the 2013/14 cropping season at the Botswana University of Agriculture and Natural Resources Farm (24^0 33’ S; 25^0 54’ E; 994 m above mean sea level), about 15 km North-East of Gaborone. The climate is semi-arid with an average annual rainfall of 538 mm. Most rainfall occurs in summer, which generally starts in late October and continues through March/April. Prolonged dry spells during the rainy season are common and rainfall tends to be localized. The soils are shallow, ferruginous tropical soils, mainly consisting of medium to coarse grain sands and loams with a low water holding capacity and subject to crusting after heavy rains. The soils in the area are classified as heplic lixisols, according to the FAO Soils Classification system (FAO, 1993). Mean maximum and minimum temperatures of the area vary between 33.1 - 34.7^{0}C and 19.2 - 19.5^{0}C, respectively (Ramolemana, 1999). The fertility status is medium and the farm was initially used for vegetable production. The study consisted of two experiments addressing each of the two specific objectives. For both experiments, a Completely Randomized Block Design comprising of three blocks was set up and blocking was against variability of soil and slope distance. Three runoff/catchment plots measuring 5 x 5 m, 5 x 10 m and 5 x 20 m were laid out, within the same plots/ catchment area, the following soil surface conditions were imposed: Ploughed with mouldboard surface (PS), Ploughed with mouldboard and un-weeded surface (UP), Ploughed with mouldboard and subsequently harrowed surface (HS) and naturally undisturbed vegetated surface (NV). To obtain different soil surface conditions as outlined previously, the mouldboard plough surface was effected first and thereafter a disc harrow was either used or not depending on the treatment. For the Un-weeded soil surface, mouldboard ploughing was followed by disc harrowing where-after the plot was not weeded for the entire period of experimentation, in order to distinguish this treatment from the Natural Vegetated soil surface. Ridges were then made with spades and rakes to ensure that the rainwater would be directed into the cultivated basins downslope. As part of characterization of the different soil surface conditions, soil parameters i.e. soil bulk density, field hydraulic conductivity, infiltration rate and soil moisture content were measured, whilst soil porosity was calculated. The soil cores for bulk density determination were collected prior to experiment commencement and during the rainy season, down to 10cm depth, for all treatments. The soil cores were placed in an oven at 105^{0}C and dried until a constant weight was achieved according to Blake and Hartge (1986). As for total porosity (i.e., the volume of voids in a core sample expressed as percentage), was calculated from the relationship between bulk density and particle density (i.e. the density of the solid material viz. 2.65 g cm^{-3} for most mineral soils), according to Danielson and Southerland (1986) and calculated as shown in equation 1 below:

$$f = 1 - \frac{\rho d}{\rho p} \times 100 \qquad \text{.................................. (1)}$$

Where:

f = total porosity
ρd = dry bulk density
ρp = particle density

Soil moisture measurements for all treatments were measured before experiment commencement, during the rainy season and after the rainy season by the gravimetric soil water measurement method according to Gardner (1986). Samples were obtained randomly for all treatments. The rate of water infiltration was measured before experimental commencement by the double ring infiltrometer with an inner ring diameter of 25.5 cm and the saturated hydraulic conductivity of the soil was determined also before experimental commencement by the variable head permeameter according to Klute (1986) by sampling to the depth of 30cm. In order to obtain the actual ratio of the overflow that drained into the collector drum a calibration of the runoff collection system was done and a depth to volume calibration curve (Figure 1) was produced for all the drums. Subsequently, the same ratio was used to calculate the total runoff from the catchment area in question.

A conventional method of measuring runoff from the various sized plots involved employing a number of collecting tanks (drums) with a divisor between any two of them (FAO, 1993). This consisted of the divider drum with 15 outlet pipes of diameter 2 cm. The central pipe was connected to the collector drum by a hose pipe. The overflow pipes of the divider drum were adjusted such that the overflow volume draining into the collector drum was 1/15 of the total overflow. The runoff collection system is shown in Plate 1.

After each rainfall event the depth of runoff collected into the 210 litre drums (of the runoff collection system)

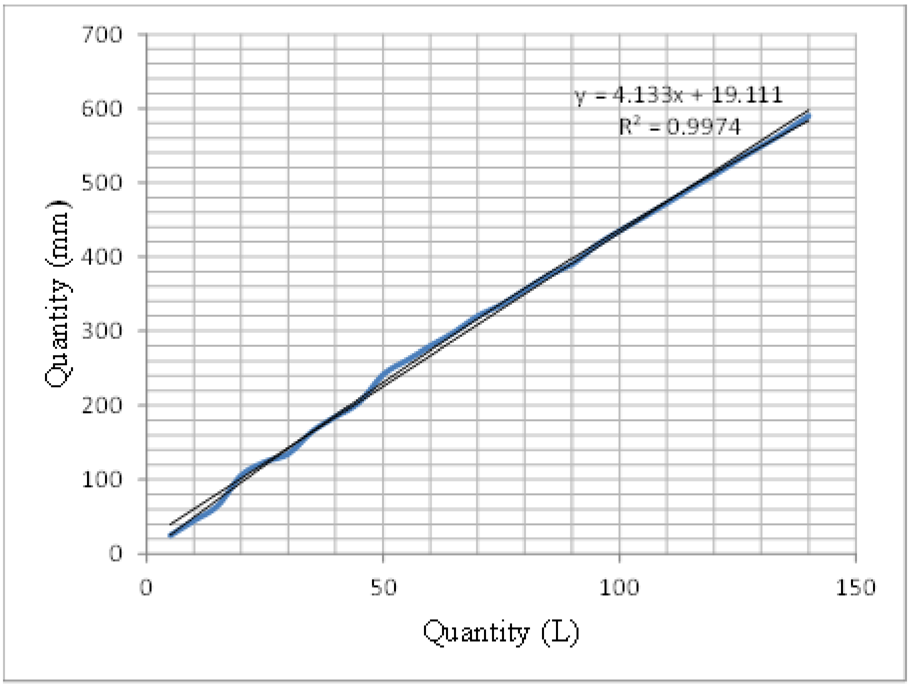

Figure 1: Calibration Curve for 210 liter runoff collection drums

Plate 1: Runoff collection system

was measured by a meter rule (mm). Then the conversions, from millimeter (mm) to litres (L), were obtained from the calibration curve.

An analysis of variance (ANOVA) was then conducted using Statistical Software (SAS Inst., 2008). Mean separations were achieved by using Duncan's Least Significant Difference (LSD). A probability level of less than 0.05 was designated as significant.

For specific objective two which was to appraise the micro-catchment RWH system on crop performance, a Completely Randomized Block Design, with two factors, i.e. soil surface condition and catchment area was laid out. Blocking was against varying slope length and soil type so that the variation did not cause any bias on the results. Just as it was done for the first experiment, the field experiment consisted of two factors, soil surface condition and catchment size. The same soil surface conditions and Catchment sizes imposed for the first objective were repeated. Maize (*Zea mays*) was used as a test crop and planted to 0.9 m inter-row spacing and 0.6 m intra row spacing using hands. Due to wildlife damage, only growth rate was used as a performance indicator. The plant height was measured fortnightly from ten random plants and the reading was taken from growth point of each plant measured and the data was analyzed as for the first objective experiment.

RESULTS AND DISCUSSION

Characterization of soil surface Conditions

Physical characteristics for the experimental field for objective 1 were almost similar, with range of infiltration varying from 12 mm h^{-1} to 14 mm h^{-1}, while hydraulic conductivity varied from 1.28×10^{-1} cm sec^{-1} to 1.33×10^{-1} cm sec^{-1} amongst the soil surface conditions. These results are shown in Table 1.

Soil surface conditions

When making a comparison between soil surface conditions, it was found that runoff collected from Un-Weeded Plot (UP), over the season, was significantly higher (Table 2) than runoff from Harrowed surface (HS), Natural vegetation (NV) and Ploughed with mouldboard (PS) surface by 59%, 45% and 34%, respectively. More runoff collected in Un-Weeded plot corresponds with soil physical properties (bulk density, porosity and infiltration rate) in the sense that soil bulk density of Un-Weeded plot was significantly higher (1.69 g cm^{-3}) than in Harrowed (1.54 g cm^{-3}), Ploughed with mouldboard surface (1.48 g cm^{-3}) and Natural vegetation (1.41 g cm^{-3}) surface. This explains why Un-Weeded plot recorded highest runoff over the season. An increase in soil bulk density (low porosity and slow water permeability) significantly increases runoff. This view is supported by El Atta and Aref (2010), who reported that as soil bulk density increased, soil porosity decreased which limited depth of water flowing through the soil thereby increasing the depth of water flowing on the surface as runoff.

Total runoff recorded on Un-Weeded Plot also correlated with porosity and infiltration rate (Table 1), as more runoff, less infiltration rate were recorded as compared to other soil surface. The results are similar to El Atta and Aref (2010)'s reports, the latter noted that the more the infiltration rate, the less the runoff and vice vesa.

Catchment area

A comparison between the catchment sizes (Table 3) revealed that a 5 m x 5 m catchment was significantly different from 10 m x 5 m and 20 m x 5 m catchments, at $P<0.05$. A 5 m x 5 m catchment recorded 67% more runoff than a 10 m x 5 m and 20 m x 5 m. From these results, it is possible to generate significant runoff from a small piece of land (vis. 25 m^2) for crop growth if soil properties are similar.

Table 2: Effects of soil surface condition on runoff

Soil surface	Runoff (*l*)	Percentage difference (%)
Un-weeded plot	26.7a	
Natural vegetation	17.75b	34
Ploughed with mouldboard	14.72b	45
Harrowed	10.94b	59

Means with same letters are not significantly different at $P<0.05$, using Duncan Least Square test

Table 1: Summary of the physical characteristics of the experimental field for objective 1

Soil surface	Bulk density (gcm^{-3})	Porosity	Infiltration rate (mmh^{-1})	Hydraulic conductivity ($cmsec^{-1}$)
HS	1.53b	0.41	12.5	1.31×10^{-1}
NV	1.41b	0.46	12	1.30×10^{-1}
UP	1.67a	0.37	12	1.28×10^{-1}
PS	1.48b	0.44	13	1.33×10^{-1}

Characterization of soil surface conditions

The physical characteristics of the experimental field are shown in Table 1. Moisture measured at the end of the season varied from the moisture measured at the beginning of the experiment. The results revealed that the soil surface ploughed with mouldboard was able to retain moisture than other soil surface conditions (Table 4).

Effect of soil surface condition on growth rate

There was significant difference of growth rate between Ploughed with mouldboard surface (PS), Harrowed surface (HS) and Un-Weeded plot (UP). Ploughed with mouldboard surface had an increase of 22% and 28% in growth rate over Harrowed (HS) and Un-Weeded plot (UP), respectively (Table 5). Growth rate was correlated to amount of moisture measured from the said soil surface conditions and catchment sizes. Soil moisture in Ploughed with mouldboard soil surface (1.95% w/w) was significantly higher than in Un-Weeded plot (0.53% w/w). This accounts for difference in growth rate between the Ploughed with mouldboard (PS) surface and Un-Weeded plot.

Table 3: Effects of catchment size on runoff means

Catchment size	Mean runoff (*l*)
5m x 5m	100.6a
10m x 5m	33.5b
20m x 5m	32.7b

Means with same letters are not significantly different at P<0.05, using Duncan Least Square test

Effect of catchment area on growth rate

Runoff collected from a 5m x 5 m catchment had 43% increase in growth rate over a control (where there was no runoff directed to cropped area) while a 10m x 5 m had an increase in growth rate of 34% (Table 6). These results agree with those of Kayombo *et al.* (2004) who reported that an increase of Catchment to Basin Area Ratio (CBAR) resulted in higher yields in a semiarid area of Tanzania. Similarly, moisture in a 5 m x 5 m was significantly higher (1.51% w/w) than in a control plot (0.96% w/w), which accounted for 43% of growth rate of maize in a 5m x 5m catchment (Table 6).

Practical implications of the findings

The generation of significant runoff from a 5 m x 5 m catchment area that led to higher maize growth rate has important implications to arable farming in semiarid areas such as in Botswana. Farmers are always in possession of some fallowed land inside the potentially cultivable land. The runoff from the catchment area can be directed to an adjacent cropped basin. The short transfer distance ensures that the system offers

Table 4: Amount of moisture recorded at the beginning and end of the experiment

Soil surface	Moisture (%)	
	Before	End
Ploughed with mouldboard	1.3a	1.95a
Harrowed	0.9a	1.13b
Un-weeded plot	1.2	0.53c

Means with same letters are not significantly different at P<0.05, using Duncan Least Square Means

Table 5: Effect of soil surface condition on growth rate

Soil surface	Growth rate (cm/week)	% difference
Ploughed with mouldboard	7.9a	
Harrowed	6.2b	22
Un-weeded plot	5.7b	28

Means with same letter are not significantly different at P<0.05 using Duncan Least Square Means

Table 6: Effects of catchment size on growth rate

Catchment size (m)	Growth rate (cm/week)	% increase due to RWH	Moisture %
5m x 5m	9a		1.51a
Control (no runoff)	5.1c	43	0.96b
5m x 10m	5.9b	34	1.07b
5m x 20m	5c	44	1.2b

Means with same letter are not significantly different at P<0.05 using Duncan Least Square Means relatively high runoff efficiency, possibly yielding as much as 50% of precipitation compared with as little as 5% contribution to stream flow in a natural catchment (Gowing *et al*., 1999). The small catchment size ensures that the flow volume and speed are limited and soil erosion is therefore relatively easy to control. This is one type of rainfall multiplier, using part of the land surface as a catchment to provide additional runoff onto cultivated basin on which crops are grown. The sheer small size of catchment makes it practical for the majority of farmers to take on RWH.

CONCLUSIONS

1. A 5 x 5 m un-weeded surface yielded significantly more runoff than other catchment area – surface condition combinations.

2. A 5 x 5 m catchment whose runoff was directed to a mouldboard ploughed cropped area had a significantly higher growth rate of maize than other catchment area – surface condition combinations.

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STATEMENT OF NO CONFLICT OF INTEREST

We the authors of this paper hereby declare that there are no competing interests in this publication.

REFERENCES

African Development Bank. 2008. Botswana Pandamatenga Agricultural Infrastructure Development Project Appraisal Report, OSAN.1, June 2008.

Blake, G.R. and Hartge, K.H. 1986. Bulk density. In: Methods of Soil Analysis, Part 1. pp. 363-375. Klute, A. (Ed.), American Society of Agronomy and Soil Science Society of America, Madson, Wisconsin, USA.

Botswana Government. 2000. Botswana National Atlas. Botswana Government, Gabonone.

Danielson, R.E. and Sutherland, P.L. 1986. Porosity. In: Methods of Soil Analysis, Part 1. pp. 443-460. Klute, A. (Ed.), American Society of Agronomy and Soil Science Society of America, Madson, Wisconsin, USA.

El Atta, H.A. and Aaref, I. 2010. Effects of terracing on rainwater harvesting and growth of *Juniperus procera* Hochst. ex Exndlicher. *International Journal of Environment Science and Technology* 7(1):59-66.

Food and Agriculture Organisation (FAO). 1991. Water harvesting: The significance of soil porosity. A Manual for the Design and Construction of Water Harvesting sechmes for plant production. Rome, Italy.

Food and Agriculture Organisation (FAO). 1993. Field measurement of soil erosion and runoff. FAO Soils bulletin 68. Rome, Italy.

Food and Agriculture Organisation (FAO). 2013. Irrigation Water Management: Irrigation water needs. Rome, Italy.

Frasier, G.W. 1994. Water harvesting/runoff-farming systems for agricultural production. In: *Water harvesting for improved agricultural production*. Proceedings of the FAO Expert Consultation, Cairo, Egypt, November 1993, FAO, Rome, Italy. pp. 57-71.

Gardner, H.W. 1986. Soil moisture. In: Methods of Soil Analysis, Part 1. pp. 493-541. Klute, A. (Ed.), American Society of Agronomy and Soil Science Society of America, Madson, Wisconsin, USA.

Gowing, J.W., Mahoo, H.F., Mzirai, O.B. and Hatibu, N. 1999. Review of rainwater harvesting techniques and evidence of their use in semiarid Tanzania. *Tanzania Journal of Agricultural Sciences* 2(2):171-180.

Hellin, J. 2006. Better Land Husbandry. Science Publishers, Enfield, New Hampshire.

Ibraimo, N. and Munguambe, P. 2007. Rainwater Harvesting Technologies for small Scale Agriculture in Arid and Semi-Arid Areas, Integrated Water Resources Management for Improved Rural Livehoods. Water net.

Kayombo, B., Hatibu, N. and Mahoo, H.F. 2004. Effect of micro-catchment rainwater harvesting on yield of maize in a semi-arid area. 13th International Soil Conservation Organisation Conference. Brisbane.

Klute, A. 1986. Methods of Soil Analysis, Part 1. American Society of Agronomy and Soil Science Society of America, Madson, Wisconsin,USA.

Moroke, T.S., Dikinya, O. and Patrick, C. 2009. Comparative assessment of water infiltration of soils under different tillage systems in eastern Botswana. *Physics and Chemistry of the Earth* 34: 316-323.

Myers, L.E. 1975. Water harvesting, 2000 B.C to 1974 A.D In: Fraiser, G.W. (Ed.). Proceedings of Water Harvesting Symposium, Phoenix, Arizona, March 1974. pp. 1-7.

Ramolemana, G.M. 1999. The phosphorus and nitrogen of Bambara groundnut (*Vigna subterrana* (L.) verdc.) in Botswana soils: An exploratory study. ISBN 90-5808-020X.

SAS, 2008. SAS release 9.2. SAS Institute Inc. Cary, North Carolina, USA

Tiffen, M., Mortimore, M. and Gichuki, F., 1994. More People Less Erosion. John Wiley & Sons, West Sussex.

Tulu, T. 2002. Soil and Water Conservation for Sustainable Agriculture. Mega Publishing Enterprise, Addis Ababa, Ethiopia.