Effect of in-situ moisture conservation structures for improving the yield of field crops in moisture stress areas at East Belessa district in North Gondar

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Abstract

There are different in-situ rainwater harvesting techniques that are used to support the production of field crops, trees and forages in moisture stress areas. Among these practices the efficiency and effectiveness of four in-situ rainwater harvesting techniques namely contour ridges, trapezoidal bunds, contour stone bunds, contour soil bunds and control (without in-situ water harvesting practice) were evaluated for growing chickpea and sorghum. Results showed that there were significant differences among the in-situ moisture conservation practices on the yield of chickpea in the first year (2005). Though there was no significant difference among the in-situ moisture conservation structures, trapezoidal bunds provided 82% yield advantage over the control in chickpea. In 2007, sorghum was planted on previously constructed structures at the beginning of July. In sorghum there was no yield advantage due to trapezoidal bunds. However, contour soil bunds gave the highest (69%) yield advantage over the control in sorghum . Based on soil moisture, grain yield, and cost-benefit analysis it can be concluded that compared to the other structures contour soil bund could conserve more water and provide highest yield. On the other hand, among others, contour ridges provided the highest internal rate of return. Farmers in Belessa area are therefore advised to construct either contour soil bunds, contour ridges or trapezoidal bunds alternatively on their farmlands.

Key words: Dryland, in-situ water harvesting, moisture stress, rainfed cropping.

Introduction

Rainfed agriculture has failed to provide the food requirements for the rapidly increasing population of the country. Failure in the rainfed production is a recurrent phenomenon particularly in the semi-arid areas of Ethiopia. In the semi-arid regions of Ethiopia, the amount of rainfall is usually inadequate and erratic in distribution and variable in nature. Consequently, moisture availability is the most limiting factor for rainfed crop production. In regions where crops are entirely rainfed, reduction of 50% in the seasonal rainfalls, for example, may result in total crop failure. If, however, the available rain can be concentrated on smaller area, reasonable yields will still be received (Critchley, 1991).

It is believed that substantial increase of crop yield can be achieved through the use of proper soil and water conservation and management practices. Efficient use of available water by plants has also an impact on crop management practices such as the use of fertilizer. In dry areas, the response of crops to fertilizer application is low compared to the areas with optimum soil moisture conditions. Although the reasons are complex, the primary constraint in the semi-arid area is lack of suitable soil moisture management practices used for crop production under relatively low and erratic rainfall conditions (Reddy and Kidane, 1993).

In North Gondar Administrative Zone, due to wide variation in topography and altitude (500-4620 m), there is wider coverage of different agro-ecological zones from k*ola* to *wurch* (BoFED, 1999). The majority of the areas have thus experienced shortage of rainfall during the crop growing season, which makes rainfed agriculture more difficult. However, there is now increasing interests in the application of in-situ water harvesting practices in drought prone areas. In the drought prone areas, rainwater harvesting is possible by the application of efficient and suitable in-situ water conservation structures. However, there is little information available about the efficiency and effectiveness of *in-situ* rain water harvesting techniques for field crop production in specific localities. Therefore, the objectives of this study were to evaluate the efficiency of different in-situ soil moisture conservation techniques and also to evaluate the effectiveness of the structures for improving yield of field crops.

Materials and methods

The study area

The study area is located in North Gonder at East Belesa district near Gohala. The experimental site is located at 12^0 25’ 28” N latitude and 38^0 05’ 36” E longitude with an elevation of 1890 m a.s.l. The area receives annual average rainfall of 630 to 950 mm.

Often the rainfall occurs from the fourth week of June to the end of August. The coincidence of late onset, early cessation and uneven distribution of rainfall has resulted in terminal dry spells, recurrent drought and consequently unreliable rainfed cropping in the area. The maximum and minimum reference evapotranspiration (ET_0) in the area is 5.86 mm per day in March and 2.78 mm per day in August, respectively. The mean daily temperature ranges from 19 ^OC to 24 ^OC. The maximum and minimum mean temperature is 29 ^OC and 14 ^OC, respectively. The slopes are gentle (below 5%), the topography is even and the soils are suitable for agriculture. Soils were well drained, light to dark brown in color, and with moderate depth. The major crops grown in the area are sorghum and teff.

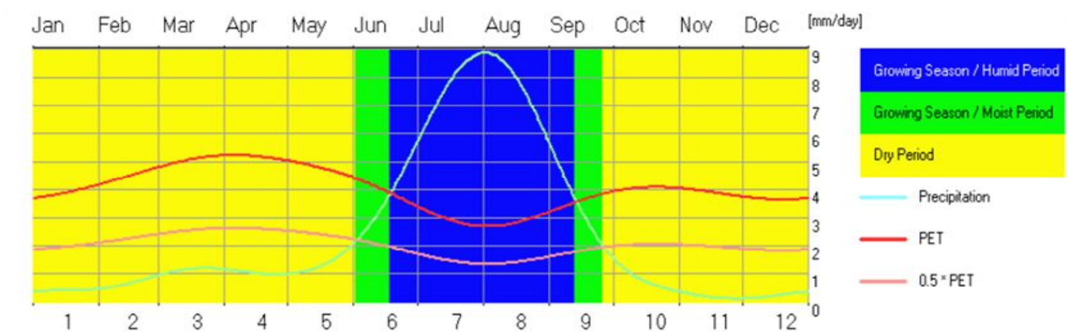

Figure 1. Length of growing season in East Belesa.

Experimental setup

The experiment was conducted from 2005 to 2007. The experimental design was RCB with three replications. Treatments were four in-situ rainwater harvesting techniques (trapezoidal bunds, contour stone bunds, contour soil bunds) and a control (without in-situ water harvesting). The construction and layout of the techniques described in Critchley (1991) was used with some modifications. The dimension of the experimental plot was 17 m x 7 m. Spacing between plots and blocks was 1 m and 1.5 m, respectively. Diversion ditch was constructed at the upper boundary of the plot to prevent the inflow of runoff from upslope area. The structural design of each experimental treatment is described and illustrated as follows.

Contour ridges (T1) are ridges that follow the contour at spacing of 2 meter. Runoff was collected from the uncultivated strip between ridges and stored in furrows just above the ridges. Crops were planted on both sides of the furrow. The system is so simple to construct by hand and can be even less labor intensive than the conventional tillage.

Design specification: Ridge height is 0.20 m, tie height is 0.15 m, spacing of ridges and ties is 2 m and 5 m, respectively, length of ties is 0.75 m.

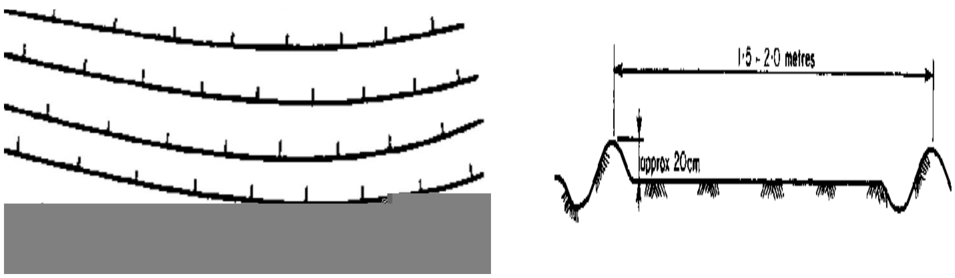

Figure 2. Field layout and cross-sectional view of contour ridges.

Trapezoidal bund (T2) is used to enclose larger areas (up to 1 ha) and to impound large quantities of runoff, which is harvested from an external or long slope catchments. Crops are planted with in the enclosed area.

Design specifications: Length of base bund is 3 m, angle between base and side bunds is 135^0, maximum bund height is 0.6 m, minimum bund height is 0.2 m, bund side slopes is 1:1, base width of bund is 1.8 m, top width of bund is 0.6 m.

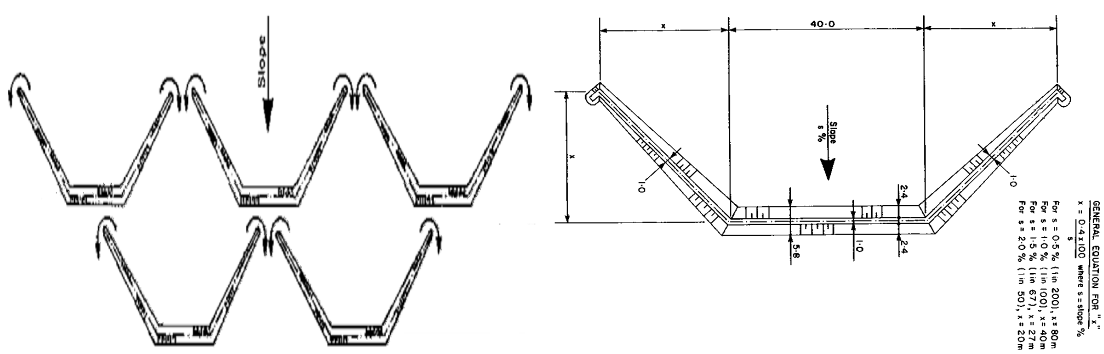

Figure 3. Field layout (top) and typical dimensions (bottom) of trapezoidal bunds.

Contour stone bunds (T3) are used to slow down and filter runoff, thereby increasing infiltration and capturing sediment. The water and sediment harvested lead directly to improve crop performance. This technique is well suited to small scale application on farmer's fields. When an adequate supply of stones is available it can be implemented quickly and cheaply.

Design specifications: Spacing of bunds is 7 m, bund height is 0.25 m, base width is 0.35-0.40 m, shallow trench for foundation is 0.10 m.

Contour soil bunds (T4) are used to hold overland flow of runoff, through the area in the surrounding space of two adjacent bunds.

Design specifications: Spacing of bunds is 7 m, bund height (minimum) is 0.35 m, base width is 0.75 m, spacing of ties is 5 m, length of ties is 2 m.

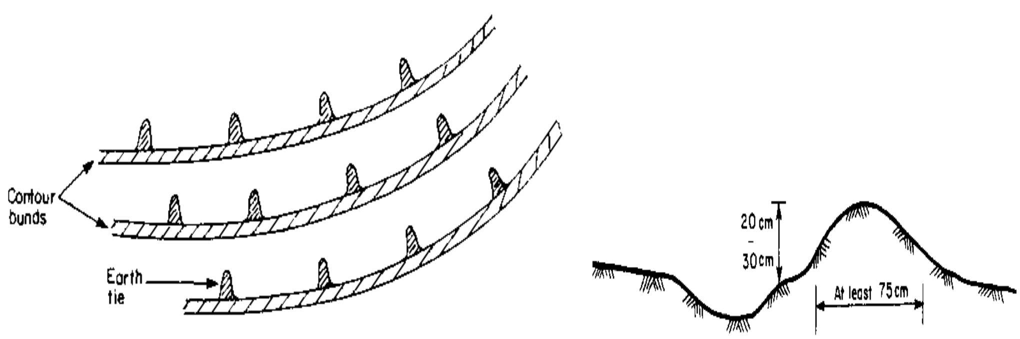

Figure 4: Field layout and cross-sectional view of soil bund.

Without water harvesting (T5) represents the local practice as a control. It is conventional ploughing of the land similar to the farmers' usual practice in the area.

The soil moisture conservation structures were constructed before the beginning of the rain, in May 2005. Once the conservation structures constructed, the field was ploughed and left without planting until the end of August. The test crop, chickpea, was planted at the end of

August using residual moisture conserved by the structures and later harvested in December. In 2007, sorghum was planted on previously constructed structures at the beginning of July and harvested at the beginning of January.

Local varieties of chickpea and sorghum were used as test crops. Fertilizers at the rate of 100 kg Urea and 50 kg DAP were applied equally for all plots for the sorghum crop. The data collected were grain yield of chickpea and sorghum, and moisture content of the soil for each experimental treatment using gravimetric method. Grain yield data was also used to calculate water use efficiency. The data were subjected to statistical analysis using SAS statistical package. Whenever the variance analysis revealed significant differences, means were separated using LSD at 5% probability level.

Composite soil samples were collected all over the experimental fields. Analysis was made following the standard laboratory procedures. Soil moisture characteristics of the site before the set up of the experiment were determined using a computer program developed by Saxton and Rawls (2006) using soil texture and organic matter as input data. Using the software program soil water parameters like field capacity, permanent wilting point, saturation percent, available water, hydraulic conductivity and bulk density were computed and estimated.

Results and discussion

Soil moisture characteristics

Some of the physicochemical properties of the experimental site are presented in Table 1. The soil texture was clay loam. Table 2 shows the estimated values of soil moisture characteristics before the start of the experiment. Rainfall usually ceases at the end of August when sorghum is at grain filling stage at which there is high demand of soil moisture.

Table 1. Soil Physicochemical properties of East Belessa experimental site.

Parameters (Method of analysis)		Unit	Value
Total nitrogen (Kjeldhal)		%	0.03
Organic matter (Walkley & Black)		%	1.32
Available P (Olsen)		ppm	4.84
CEC (Amm. Acet.)		$cmol^+/kg$	68.40
pH H_2O (1:2.5)		pH meter	8.60
Available K (Morgan solution)		ppm	84.00
Soil texture (Hydrometer method)	Sand	%	40
	Clay	%	38
	Silt	%	22

Table 2. Soil water characteristics of the site before the experiment.

Soil water characteristics	Unit	Value
Permanent wilting point	% weight	15.8
Field capacity	% weight	24.1
Saturation percent	% weight	30.3
Available water	mm/m	120
Saturated hydraulic conductivity	mm/hr	1.90
Matric bulk density	g/cm^3	1.47

Table 3 indicates the soil moisture content by weight measured nearly one month after the end of the rainfall period. The measurement of soil moisture content stored due to the construction of soil moisture conservation practices is used to evaluate the efficiency of the structures to store soil water. The soil moisture content at different soil depths showed that all of the in-situ moisture conservation structures stored soil moisture greater than the permanent wilting point of the soil. The soil moisture content generally increased as the soil depth increased.

There was statistically significant difference in soil moisture content by weight among the in-situ moisture conservation structures. The greater magnitude of soil moisture content was measured on plots treated with contour soil bund, contour ridges and trapezoidal bund in descending order. The plot managed by contour stone bunds and the plot without soil moisture conservation structures retained the lowest soil moisture. Hence, it can be said that construction of contour stone bunds on farmlands does not have a relative beneficial effect in soil moisture conservation. In general, the results indicated the relative efficiency or soil moisture retention capacity of the structures. Furthermore, this ensures the availability of soil water for subsequent growth and improved production of sorghum which otherwise exposed for terminal drought in the later growing season.

Table 3. Soil moisture content (% weight) 3 months before the harvest of sorghum under different soil moisture conservation techniques in East Belesa.

Structure	Soil moisture content (%) at 15 cm depth	Soil moisture content (%) at 30 cm depth	Soil moisture content (%) from 0-45 cm depth
Contour ridges	25.18^{ab*}	31.34^{ab}	28.26^{ab}
Trapezoidal bund	23.39^{ab}	32.00^{a}	27.36^{ab}
Contour stone bund	22.09^{b}	27.67^{b}	24.88^{b}
Contour soil bund	27.00^{a}	33.67^{a}	30.34^{a}
Without moisture conservation (Control)	20.83^{b}	27.66^{b}	24.25^{b}
CV (%)	11	8	16

**Means in a column followed by similar letters are not significantly different at P<0.05.*

Grain yield of field crops

The grain yield result (Table 4) showed that there was significant difference among the in-situ moisture conservation structures in the yield of chickpea planted at the end of August. According to the result, trapezoidal bunds provided better yield of chickpea than other in-situ moisture conservation structures. Though there was no significant yield difference among the other in-situ moisture conservation structures, the yield of chickpea planted on trapezoidal bund was significantly different from the control plot (500 kg ha^{-1} yield advantage).

In 2007, there was a positive response of sorghum yield planted at the end of June to the different in-situ moisture conservation structures. The grain yield of sorghum was 1514, 1256, 1089, 1083 and 897 kg ha^{-1} for plots treated with contour soil bund, contour ridges, trapizoidal bund, contour stone bund and control, respectively. Eventhough there was no significant yield difference among the structures, contour soil bund provided significant yield difference than the control plot by about 600 kg ha^{-1} yield advantage. There was symptoms of yellow leaf color and stunted growth of sorghum beneath the trapezoidal bund which is an indication of waterlogging. This most likely led to the relative reduction of sorghum yield planted on trapezoidal bunds.

Table 4. Effect of in-situ moisture conservation structures on yield of chickpea and sorghum.

In-situ moisture conservation structures	Chickpea (2005)		Sorghum (2007)	
	Grain yield (kg ha^{-1})	Yield advantage (%)	Grain yield (kg ha^{-1})	Yield advantage (%)
Contour Soil Bund	938[ab]*	47	1514[a]	69
Contour Ridges	992[ab]	55	1256[ab]	40
Trapezoidal Bund	1161[a]	82	1089[ab]	21
Contour Stone Bund	835[ab]	31	1083[ab]	21
Without moisture conservation (Control)	638[b]	-	897[b]	-
CV (%)	26		28	

**Means in a column followed by similar letters are not significantly different at P<0.05.*

Linear regression equation was fitted on sorghum yield and terminal soil moisture content taken at the beginning of October to see the relationship. The equation showed that there was strong relationship between terminal soil moisture content and yield of sorghum with high coefficient of determination, $R^2 = 0.8$ (Figure 5). The soil moisture content and yield relationship has proven that soil moisture availability during the late growing season is the most limiting factor explaining 80% of the yield variation for sorghum. The relationship has also indicated that through understanding the soil moisture retention and storage behaviour of conservation structures, one can reasonably forecast the yield of rainfed crops.

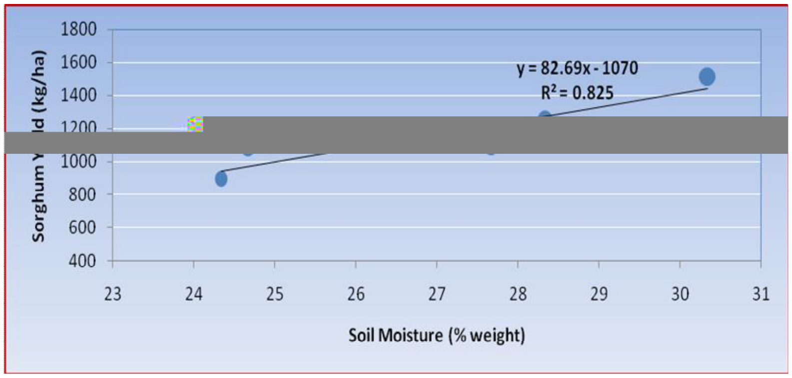

Figure 5. Relationship between sorghum yield and terminal soil moisture content in East Belessa.

Cost benefit analysis

The cost and benefit analysis was carried out for the in-situ moisture conservation structures taking into account the costs that vary which include both initial investment cost and maintenance cost every year. All other costs such as land and crop management costs are the same for all structures hence it was not considered in the analysis. The cost of labour was estimated based on labour cost during the construction period, ETB 8 per person per day. The cost of construction of contour ridges in the first year is estimated as ETB 500, including the price of animal drawn tie-ridger at ETB 250 and the remaining labour cost for construction. The prices of chickpea and sorghum were taken from the local market during the harvesting period and found as ETB 5 and ETB 4.50 kg^{-1}, respectively. The design period for trapezoidal bund, contour soil bund and contour stone bund were assumed as 10 years. The benefit terms were the yield of field crops harvested on the treated plots.

The partial cost and benefit analysis indicated that the benefit obtained from contour ridges was much better than all other structures because of low investment cost (Table 5). The net rate of return for contour ridge is 909%. Next to contour ridge application of contour soil bund gave 208% net rate of return. The least rate of return of 69% was obtained using the trapezoidal bund which is probably due to the high labour demand for construction of trapezoidal bund.

Table 5. Cost-benefit analysis of in-situ moisture conservation structures for 10 year design period

Parameters	Contour stone bund	Trapezoidal bund	Contour ridge	Contour soil bund
Design period cost	3556.8	8937.6	2750	3556.8
Annual Cost (Birr/ha)	355.68	893.76	275	355.68
Design period benefit	35127.4	35455.8	44408	45460.4
Annual benefit (Birr/ha)	3512.74	3545.58	4440.8	4546.04
Cost-Benefit ratio	9.88	3.97	16.15	12.78
Internal rate of return (IRR, %)	167%	69%	909%	208%

Conclusion and Recommendations

From the two year study it can be concluded that contour soil bund conserves more soil moisture alternately with trapezoidal bunds than other structures and gave the highest yield in rainfed cropping. On the other hand, since construction of tie-ridge using animal drawn ridger is simple and less costly, contour ridges gave the highest internal rate of return followed by contour soil bund. Relatively, contour stone bund constructions in moisture stress areas do not provide better benefit of soil moisture conservation and yield of field crops.

Though the construction of trapezoidal bund on cultivated areas have relatively low rate of return due to its high investment cost, this structure conserves better soil moisture which is beneficial for crops grown in residual moisture. It is also possible to redesign the trapezoidal bund to incorporate spillway so that the excess water can be drained off to avoid water logging. Sometimes when labor cost is cheap, interested farmers are encouraged to use trapezoidal bund for the production of field crops in dry land areas of East Belessa and similar moisture stress areas. Therefore farmers in Belessa areas are advised to construct contour soil bund, contour ridges and trapezoidal bund on their farm lands to improve yield of rainfed cropping.

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