Full Length Research Article

Evaluating the Effects of *In situ* Rainwater Harvesting Techniques on Maize Production in Moisture Stress Areas, Humbo *Woreda*, Wolaita Zone, Southern Ethiopia

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ABSTRACT

This study was conducted to investigate the effect of some In-situ water harvesting techniques on production of maize with respect to soil moisture content, yield and yield components. It also aimed to assess farmers' perception of water conservation techniques. To achieve these objectives of the study, data were collected through house hold survey and field experiment. The experiment was conducted in Wolaita Zone Humbo Woreda at Abela Sippa kebele, which has an irregular rain fall distribution and has a prolonged dry season which leads to low soil moisture during critical crop growth stages. The study was conducted over a period of one growing season (2017/18) using maize as indicator crop at the farmers training center of the Abela Sippa kebele. The experiment was made in a randomized complete block design, with three replications and four treatments. The four treatments used in the study were; Control, Targa, Tie-ridge and Zai pits . Findings from this study revealed that maize grain yield and yield components, such as, grain yield, dry matter biomass, and cob length were significantly high ($p<0.05$) at Targa treatments, but plant height was not significantly different. Soil-moisture content over the crop growing season at dry spell periods was significantly higher at Targa and Tie ridges than the control. Targa treatments increased maize yield to (7.15 t/ha), Tie ridge also significantly increased maize production to (6.19t/ha). Similarly, Zai pits yielded (4.5t/ha) and Control treatment yielded (4.9 t/ha). Targa and Tie ridge treatments recorded higher net returns (29712, and 25164 ha-1) than the Control (20370ha-1) and Zai (14350 ha-1) treatments. The results revealed that the rainwater harvesting technology by the community members was a good initiative in improving agricultural practices in periods of water scarcity. However, the utilization of the technology is affected by various constraints. The major constraints include: labor cost, lack of knowledge and types of crops planted on bunds. The findings suggest that Targa structure improved water availability during the growing season, thereby protecting crops from dry periods and it needs minimum cost, less labor power, and easily constructed by local farmers (not require complicated knowledge).

Keywords: In-situ rain water harvesting, farmers' perception, soil moisture, Maize yield

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1. INTRODUCTION

The efficient use of water in agricultural systems is needed to improve crop production and resilience to environmental adversities that may be caused by climate change and extended droughts, especially in arid and semi-arid areas. Marginal and erratic rain-fall aggravated by the loss of water by runoff and evaporation are the main causes of low crop production in these areas (Yosef and Asmamaw, 2015). Ethiopia has been dependent on subsidence rain-fed agriculture for centuries, and crop production has thus been heavily reliant on the availability of rainwater (Araya and Stroosnijder, 2010; Yosef and Asmamaw, 2015).

Out of the 13.6 million ha of cultivated land in Ethiopia, close to 97% is rain fed implying that the nation's annual harvests depend heavily on the patterns of the seasonal rains (Awulachew *et al*., 2005; FAO, 2005). 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 phenomenon in the semi-arid areas. Studies in Ethiopia 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 (Asnake *et al*., 2020).

Farmers in the semi-arid zones have, therefore, developed strategies, including Rain Water Harvesting (RWH), to cope with this uncertain and erratic rainfall patterns. RWH practices refer to all practices whereby rainwater is collected artificially to make it available for cropping or domestic purposes (Ngigia, 2005). Water harvesting techniques (WHTs) have played a key role in improving the efficient use of rain water and have increased the sustainability and reliability of rain-fed agriculture (Biazin *et al*., 2012). Rain Water Harvesting (RWH) has been promoted as an approach to integrate land and water management, which could contribute to recovery of agriculture production in rain fed systems and the general water resources (Rockström *et al*., 2010). In-situ WHTs improve the availability of water in the soil profile to decrease the effects of dry periods caused by the seasonal variation of rainfall. Soils contemporarily hold water, so in-situ water harvesting prolongs the availability of water in the root zone by reducing runoff and evaporation losses (Vohland and Barry, 2009). Accordingly, in-situ RWH, using different soil and water conservation activities, has gained renewed interest; as part of the world-wide effort to combat climate change and currently the scheme is in progress at an even larger scale (Mintesinot and Mitiku, 2002). The study area under consideration, Humbo Woreda, is characterized by erratic occurrence of rainfall with spatial and temporal variability and uncertainty (Ahmed and Naggar, 2003). During the '*Belg*' season, the rains are very rare; Farmers usually delay planting until a substantial amount of rainfall has occurred, to avoid the risk of crop failure in early stages of crop growth. Such delay often results in inadequate moisture supplies during the flowering stage of the cereal crops and hence minimum grain yield (Abiye *et al*., 2002). Therefore, this research was required to evaluate the contribution of selected in-situ rain WHT for crop production under rain-fed farming in moisture stress areas of Humbo woreda, Wolaita zone.

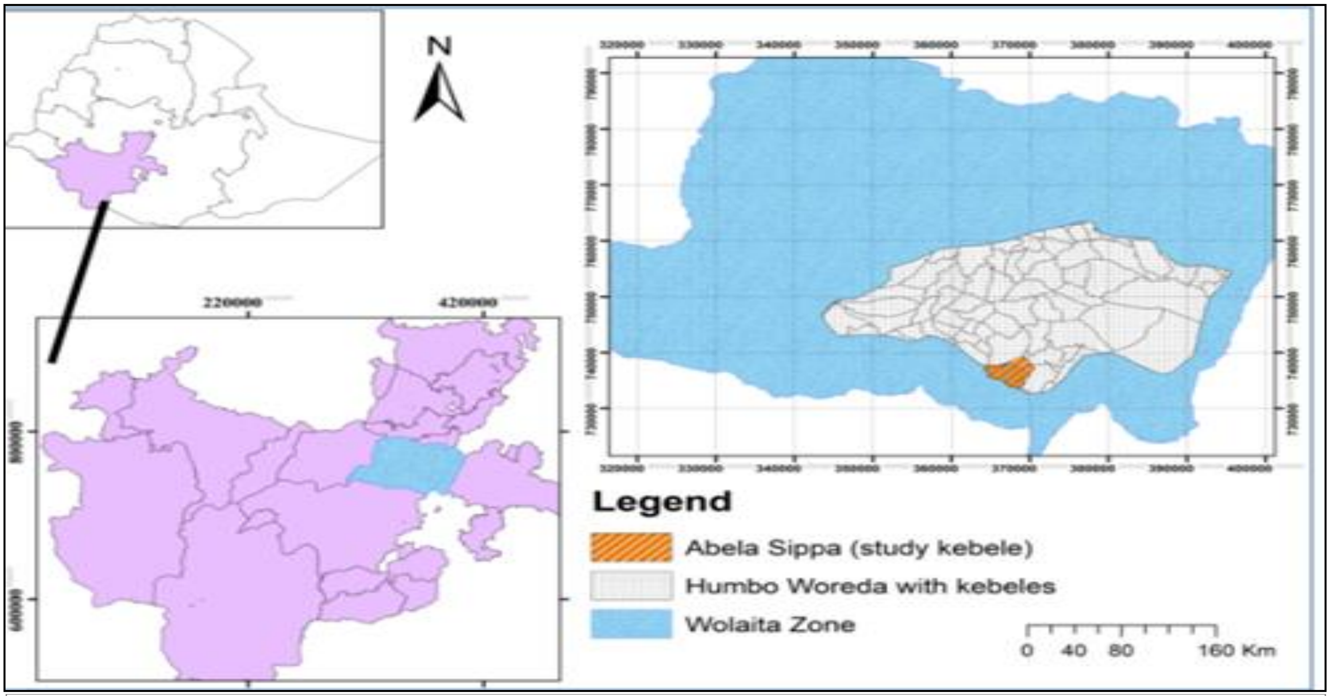
2. MATERIALS AND METHODS

2.1 Description of the Study Area

The field experiment was conducted at Humbo *Woreda* which is one of the 16 woredas of Wolaita Zone. Humbo is 380 kms away from Addis Ababa, the capital of Ethiopia and18 kms south of Soddo town on the main road to Arba Minch. The woreda is located 1420 meter above sea level, 6°43'44'N latitude and 37°45'51'’E longitude in Southern Nations Nationalities and Peoples Regional State (Humbo *Woreda* Office of Agriculture and Rural Development, 2011). The average daily temperature is 18.3^{o}C-21^{o}C, the annual rainfall varies between 710 mm and 1337 mm (CV = 16%) with a mean of 1148mm for the past 11years. The rainy season can further be divided into 2 periods: the ‘‘Belg’’ or small rains that take place from, February, March and April but high (peak) rain fall on May and low rain fall on June (flowering stage) these indicated that during the ‘Belg’ season, the rains are very rare and the ‘Kiremt’ or big rains that take place from July to September.

The erratic and unreliable nature of the rainfall in the woreda affects the rain fed crop production which is the main economic source for the dwellers of the area (Fitsum *et al*., 1999).

Figure 1: Map of the study location



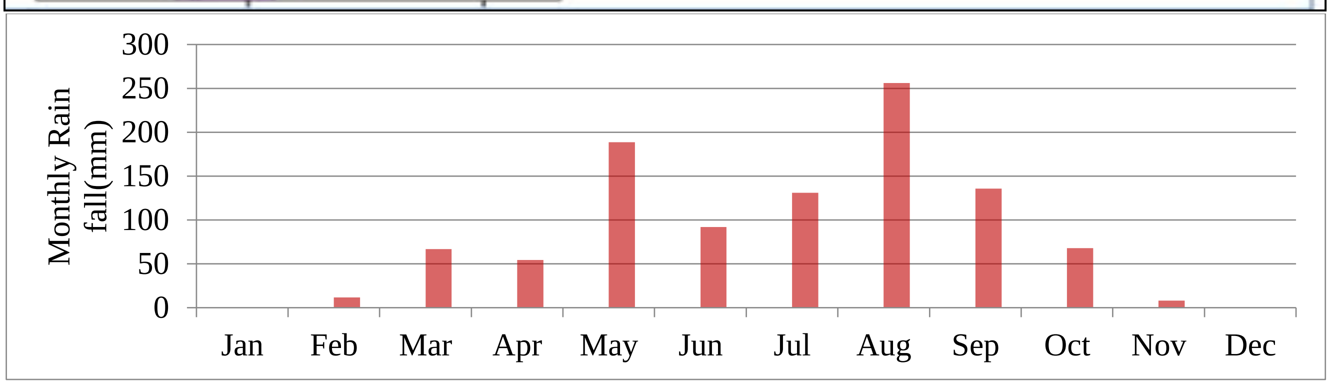


Figure 2: Average monthly rain falls of the study area

Soil physical characteristics such as bulk density (1.55g/cm$^{3)}$ and soil texture (clay 75%, sand 9%, silt 16%) as determined in a laboratory was sandy loam. Acording to Wolaita Zone Finance and Economic Development Main Department (WZFED). the Woreda is sub divided into 2 urban and 41 rural Kebeles, with total area of 86,646ha which is 70% lowland and 30% midland (WZFED, 2005). Mixed agriculture is the main economic activity, which accounts 92% of the total population in the study area. The major crops grown in the study area are cereals such as teff, maize, sorghum, cotton, cow pea and root crops like sweet potatoes, and fruits like mango, avocado and banana according to Humbo District Agricultural office.

2.2 Experimental Design

A field experiment was conducted on the effect of different in-situ soil moisture conservation structures for maize production under rain fed farming situations during cropping season of 2010 E.C at Abela Sippa *kebele*. The experiment consisted of four different in-situ soil moisture conservation techniques (Targa, Zai, Tie ridge and Control) with maize planting at spacing of 40cm by 75cm between plant and between rows. The experiment has used a completely randomized block design because there is fertility gradient on the experimental field.

A layout of completely randomized block design with four treatments and three replicates, for a total of 12 plots were applied. Each plot was 6m by 10m area with slope range of 3-5%. Plots were separated by 0.5m to facilitate crop management operations and 1m space between blocks.

Based on previous recommendations of fertilizer application on maize by Debelle and Friessen *et al*., (2001), 100 kg ha-^{1} Urea in two applications (50 kg ha-^{1} during sowing and another 50 kg ha^{1} was applied 40 days after sowing) and 100 kg ha-^{1} of DAP in one application (only during sowing) were applied on the plots. A local maize cultivar (Awassa BH540) was planted with density of 40,000 plants per hectare with spacing of 40cm and 75cm between plants and between rows, respectively.

Tied ridge: When the ridges or furrows are blocked with earth ties with intervals, they are known as ‘tied ridges’ or furrow disking. In Tied-ridges, the earth ties are spaced at fixed distances to form a series of micro-catchment basins in the field. Tie spacing for tied-ridge was 5m interval made manually with 75cm spacing between consecutive ridges constructed along contour line. One plot of tie-ridge was 6m by 10m.

Planting pit/*Zai*: Is pitting cultivation, which takes place in the form of Zai which is dug with distance between pit 40cm and between row 75 cm to a depth of 16 cm. Crop residue (4.5 Mg ha^{1})

was incorporated and decomposed in the soil before sowing on the Zai pits to keep the fertility level of the soil at optimum condition and 100kg ha^1 DAP and 100 kg ha^1 urea.

Targa: Is a rectangular basin built from soil or crop residue before the rainy season constructed along contour lines spaced 1.5 m apart, which are tied approximately at 1.43m interval by ridges made in horizontal 7 and vertical 4 number of Targa with a total 28 Targa constructed in each plot at staggered position across the contour. Within the Targa, two rows were prepared in 75cm spacing and with total of 8 rows and 24 planting pits in each row. The bund ridges of Targa rise about 0.2m above the ground and the embankment thickness 0.2m.

2.3 Methods of Data Collection

2.3.1 Determining soil moisture content

The state of water in the soil can be described in two ways: quantity present and energy status. The quantity present is expressed as gravimetric (mass) or volumetric. The gravimetric water content is the mass of water in a unit mass of dry soil (g of water/g of dry soil). The wet weight of soil sample is determined; the sample is dried at 105 °C to constant weight and reweighed (Gardner, 1986). The volumetric water content is expressed in terms of the volume of water per volume of soil (cm^3 of water/cm^3 of soil). Soil moisture measurements was conducted at three periods (initial, development and mid stage) to evaluate the amount of soil water during just after the rain fall and after 10 days of without rain fall during crop growing seasons.

An auger was used for soil sampling from the depth of 0-20cm and 20- 40 cm because70% of moisture extraction was taken from the rooting depth (0.4m). From each of the two depths collect sub samples of the auger sample and mix well in a plastic bucket. The weight of the wet soil samples was measured and put in an oven at 105°C for 24 hours and then the weight of dry samples was measured. The soil water stored (%) in each 0.4m incremental depth down was determined gravimetrically. It was then converted to water depth (mm) by multiplying by the specific bulk density values measured by the core sampler methods as described by Blake (1965).

Volumetric water content can be calculated from gravimetric water using the following equation:

$$SMC = \frac{Ww - Wd}{Wd} * 100$$

Where,

SMC = Soil moisture content dry base (%)

Ww = Weight of the wet soil (gm)

W_d = Weight of the dry soil (gm)

Volumetric soil water content (cm^3/cm^3) is determined as:

$$\theta = w * \rho d$$

Where:

w = gravimetric water content

ρd = bulk density (g/cm^3)

2.3.2 Agronomic data parameters

Agronomic parameters including grain yield, above ground biomass, plant height and cob length data were collected. To measure cob length and plant height six stands from each plot were randomly selected and measured. Above ground biomass was weighted from each plot at the end of the growing season; the plants were cut, tied in bundles and left to dry for 10 days in the sun. To get grain yield in each plot at the end of the growing season; the heads were cut and the grains were threshed and weighed and yield per plot was recorded.

2.4 Statistical Analysis of Data

All the agronomic data were recorded and being subjected to analysis. Analysis of variance was performed using the GLM procedure of SAS Statistical Software Version 9.1 (SAS, 2007). Effects were tested under P = 0.05. Means were separated using Fisher’s Least Significant Difference (LSD) test. Crop Watt 8.0 and survey data were analyzed and presented using different descriptive statistical methods in SPSS verion 20 that include mean,percentage and frequencies.

3. RESULTS AND DISCUSSIONS

3.1 Effect of Treatments on Volumetric Soil-moisture Content

The effects of the treatments on soil moisture content (SMC) just after one day of rain fall and after 10 days of rain fall at different growing seasons were shown in Table (1 and 2). The results obtained showed non-significant differences in SMC between all treatments ($P > 0.05$) at initial period just after one day of rain fall. There was significant difference between treatments Targa and Control ($P<0.05$) after 10 days of rain fall at initial period but no significant difference ($p>0.05$) between Tie ridge, Control and Zai shown in Table (1). The tested techniques at mid period during just after one day of rain fall on SMC can be put in a descending order as Targa > Tie ridge > Zai > Control although there was no significant difference among them. However, significant differences were observed between Targa and Control ($p<0.05$) during mid period after 10 days of rain fall and no significant difference ($P > 0.05$) between Tie ridge, Zai and Control as shown in Table 1.

Table 1: Treatments means for SMC (%) of the root zone during just after one day RF and after 10 days of rain fall.

Treatment	**Initial period SMC (%)**		**Development period SMC (%)**		**Mid period SMC (%)**	
	Just after one day of RF	After 10 days of rain fall	Just after one day of RF	After 10 days of rain fall	Just after one day of RF	After 10 days of rain fall
Targa	54.097^{a}	51.15^{a}	58.9^{a}	55.8^{a}	54^{a}	46.5^{a}
Tie ridge	45.5^{a}	43^{ab}	54.2^{a}	52^{a}	50^{a}	42.6^{ab}
Zai	42.32^{a}	35.6^{ab}	51.15^{a}	23.2^{b}	48^{a}	31.93^{ab}
Control	40.8^{a}	35.18^{b}	44^{a}	26.3^{b}	45^{a}	30.5b
CV (%)	16	16	19	16	19	18
LSD (0.05)	14	8	30	8	12	9

In Table 2, treatments Targa (82%), Tie ridge (72%), Zai (56%) and Control (55%) satisfy crop water requirement during dry spell periods (after 10days of rain rainfall). Similarly, there was no significant differences between treatments ($P > 0.05$) at development period just after one day of rain fall. In Table 2, the precents of crop water need satisfaction after 10days of rain fall was 100%, 93%, 42% and 47% for Targa, Tie ridge, Zai and Control, respectively. These results showed that the treatment Zai and Control were not satisfying crop water requirements during dry spell period more water lost from these structures. The result also showed the superiority of the tested techniques (Targa and Tie ridges) over the Control method by reducing run off and evaporation loss. This result was in agreement with McHugh *et al*. (2007).

Table 2: Comparing each structure for soil moisture content and maize water requirement in growth stages

Treatment	**After one day of RF**				**After 10 days of RF**				
Initial	Total SMC mm/m rz	Available SMC mm/m ,	Available SMC at **0.3m** rz	ETc/day	Total SMC mm/m rz	Available SMC mm/m	Available SMC at **0.3m** rz	ETc/dek	% of crop water need satisfaction at dry spell period
Targa	54.1	29.8	8.92	1.04	51.2	28.13	8.43	10.4	87
Tie-ridge	45.5	25	7.5	1.04	43	23.65	7	10.4	72
Zai	42.3	23.2	6.9	1.04	35.6	19.5	5.87	10.4	56
Control	40.8	22.4	6.7	1.04	35.2	19.3	5.8	10.4	55
Development			**0.86m**				**0.86m**		
Targa	58.9	32.3	27.7	2.63	55.8	30.7	26.3	26.3	100
Tie ridge	54.2	29.8	25.6	2.63	52	28.6	24.5	26.3	93
Zai	51.2	28.2	24.1	2.63	23.2	12.76	11	26.3	42
Control	44	24.2	20.8	2.63	26.3	14.46	12.4	26.3	47
Mid stage			1m				1m		
Targa	54.2	29.8	29.8	3.00	46.5	25.6	25.6	30	85
Tie ridge	50.15	27.58	27.58	3.00	42.6	23.4	23.4	30	78
Zai	48	26.4	26.4	3.00	31.9	17.5	17.5	30	58
Control	45	24.75	24.75	3.00	30.5	16.7	16.7	30	55

TAW (total available water), RAW (readily available water), SMC (soil moisture content), rz (root zone); RAW=TAW*P; Where, p is critical depletion (P = 0.5 for maize)

In Table 2 after 10 days of rain fall at mid period treatment, Targa, Tie ridge, Zai and Control satisfied 85%, 78%, 58% and 55% crop water requirement during dry spell periods, respectively. The results obtained showed that at all the growing season significant difference in SMC ($P<0.05$) between in-situ water harvesting structures and control on 10 days after rain fall (at dry season).

Next to Targa higher soil moisture content stored on Tie ridge structure. The present findings agreed with (Botha, 2006) who stated that RWH techniques reduced unproductive water losses, particularly evaporation (E) and run off (R) and optimized rain water productivity. The results indicated that the efficiency of Targa in retaining water was better because the ridges were made up of maize residue and soil are able to improve soil water content in the soil root zone during cropping period compared with control. According to studies from Northern Ethiopia on in-situ water harvesting systems, tied-ridging, open ridging and sub-soiling improved soil water content at the root zone during cropping period compared to the Traditional tillage by 24%, 15% and 3%, respectively (McHugh *et al*., 2007).

3.2 Effect of water conservation methods on growth of maize

As shown in Table 3 below, the grain yield of maize increased significantly (P < 0.05) in targa (7.15t/ha) followed by Tie ridge (6.19t/ha), and there was no significant difference (P > 0.05) between Zai (4.5t/ha) and Control (4.9t/ha) treatment. However, the treatment Targa (7.15t/ha) and Tie-ridge (6.19t/ha) has significant (P < 0.05) differences in grain yield than the Control (4.9t/ha). According to Agriculture and Natural Resource office of Humbo woreda (the study area), the average grain yield production of maize in the area with irrigation and without irrigation was reported to be 3.67t/ha and 2.25t/ha, respectively. Which indicates that, practicing of in-situ moisture conservation structures particularly Targa can produce more crop yield than Control.

Table 3: Mean growth parameters of maize under moisture conservation structures

Treatment	GY (t/ha)	DMB (t/ha)	pH (cm)	CL (cm)
Targa	7.15a	8.23a	208a	39.36a
Tie ridge	6.19a	7.8ab	202a	35.26b
Zai	4.5b	5.76c	201a	37.3ab
Control	4.9b	6.15bc	196a	35.5b
CV%	9.4	13	3.9	2.96
LSD (0.05)	1	1.9	15.8	2.18

GY, grain yield; DMB, dry matter biomass; pH, plant height; CL, cob length; treatments with the same letters have no significant difference

3.3 Plant Parameters

3.3.1 Grain yield

Control treatment in the present study showed the lower yield compared with Targa and Tie ridge. This may be attributed to the low ability to retain the soil moisture as Table (3 and 4) above has shown. This result is also in conformity with the findings of Solomon (2015) and Yoseph (2014) who reported that maize grain yield was significantly affected by moisture conservation practices. When available water content in the soil decreases, the number of grains per plant and yield per unit area declines (Mansouri and Saberali, 2010). Through RWH structures determining the production increases through the efficiency of the techniques in conserving rain water when compared with control. The current results agree with the findings of Botha, (2006) who reported that RWH was found to be the most appropriate measure of determining the efficiency of the techniques to improve dry land crop yields. Similarly, Barron and Okwach (2005) showed that RWH technique increased yield by about 70% in semi-arid Kenya.

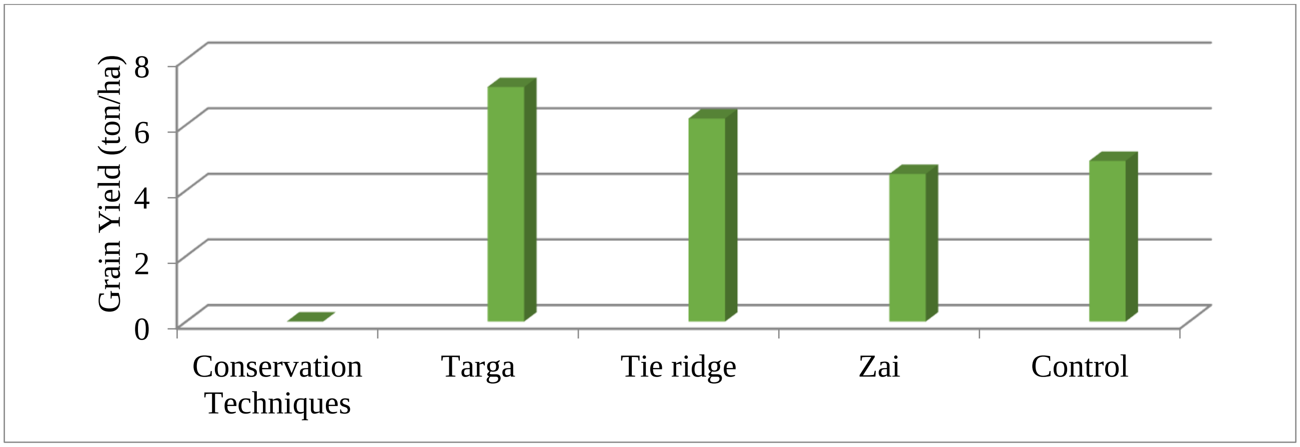


Figure 1: Effect of treatments on grain yield

3.3.2 Dry matter biomass

Biomass yields for different treatments were summarized in Table 3. There was significant difference (P < 0.05) between all treatments on the maize dry matter biomass. There was significant difference (P < 0.05) between Targa, Zai and Control, however, Targa does not differ significantly from Tie ridge and Tie ridge do not significantly differ (P > 0.05) from the control but there was significant difference (P < 0.05) between Zai and Tie ridge treatments. Values can be arranged in descending order as Targa, Tie-ridge, Control, and Zai. The treatments Targa and Tie ridge had the highest biomass production of 8.23t/ha and 7.8t/ha biomass yield for the maize growing seasons, respectively than the treatment Control (6.15 t/ha) and Zai (5.76t/ha). The lower biomass production was obtained under the treatment Zai and control due to in efficiency to conserve moisture during dry spell periods as shown in Table above.

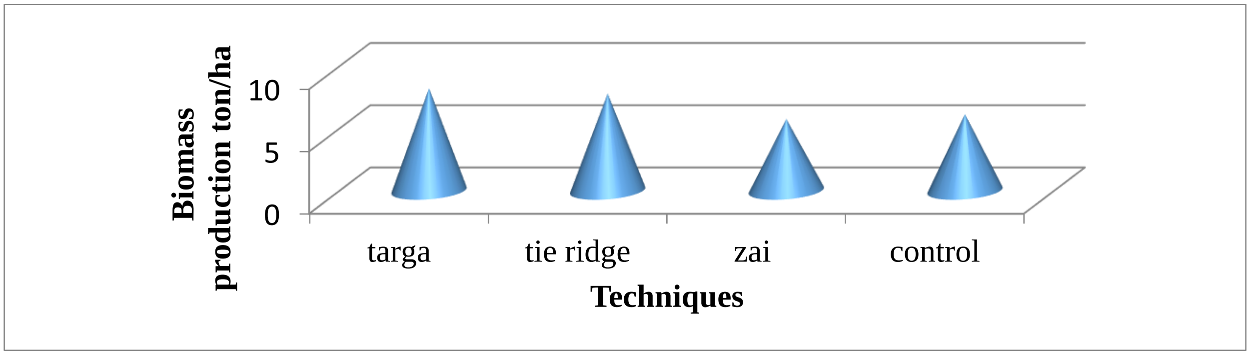


Figure 2: Effects of treatments on dry matter biomass production

3.3.3 Plant height

As can be seen from the Table 4 there was no significant (P>0.05) difference among all the treatments in plant height during the maize growing season. However, water harvesting technique was superior in plant height. The values of the tested techniques can be put in a descending order as Targa, Tie-ridge, Zai and Control in the maize growing season. The results showed that the water harvesting increased the plant height because it led to increase the rate of leakage of water into the soil and which led to increased soil moisture content as shown in Table (3).

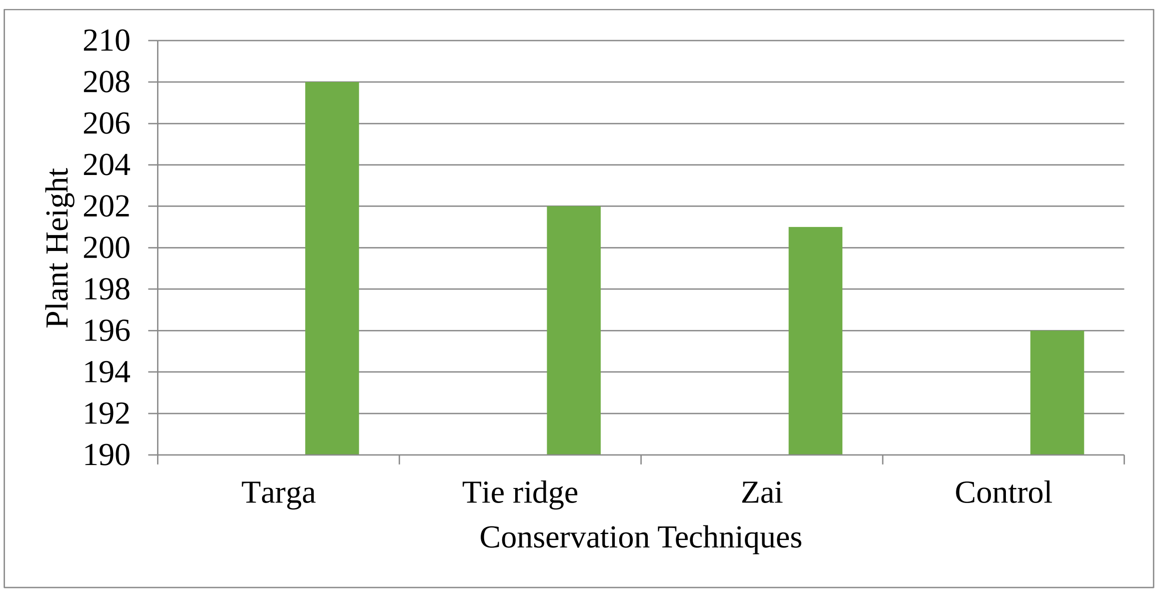


Figure 3: Effects of treatments on plant height

3.3.4 Cob length

As shown in the above Table (3) there was significant ($P < 0.05$) difference between treatments targa, zai, tie-ridge and control. There is no significant ($P > 0.05$) different between Tie ridge Zai and Control. The result showed that cob length of maize increased by Targa treatments compared to the Control. This was also in conformity with the findings of Solomon (2015) and Yoseph (2014) who reported that maize grain yield and yield components were affected significantly by moisture conservation practices.

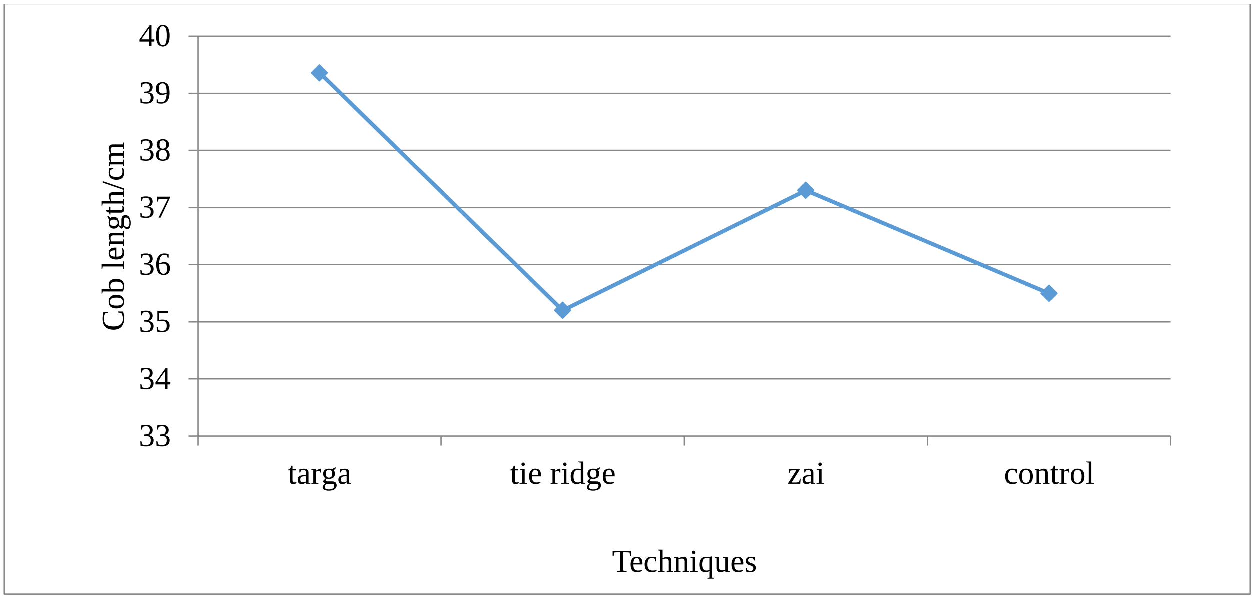


Figure 4: The effects of treatments on cob length

3.4 Economic costs and benefit analysis of treatments

Table 4: Estimated Economic costs per hectare of Treatments

Treatments	Average yield (t/ha)	Adjusted yield (t/ha)	Unit price /kg	Gross field benefit (ha)	Cost of labor	Cost of agro chemicals	Cost of maize seed	Cost of fertilizer	Total costs that vary(ha)	Net benefits/ha	Benefit cost ratio
Targa	7.15	6.435	7 ETB	45045	8833	1000	500	5000	15333	29712	1.93
Tie ridge	6.19	5.571	7 ETB	38997	7333	1000	500	5000	13833	25164	1.81
Zai	4.5	4.05	7 ETB	28350	7500	1000	500	5000	14000	14350	1.02
Control	4.9	4.41	7 ETB	30870	5500	1000	500	5000	12000	20370	1.69

ETB, Ethiopian Birr

3.4.1 Gross returns

Table (4) show the economic costs and benefit analysis among the different RWH techniques. Targa recorded the highest gross returns (45045 ETB ha-1) compared to the other conservation methods. The next was Tie ridge that showed higher gross returns (38997ETB ha-1) than the Control (30870 ETB ha^{-1}). Zai water conservation measures were the lowest gross return (28350 ETB ha^{-1}) compared to all other treatments.

3.4.2 Net returns

Table 4 shows the expenditure on materials and operations farmers incurred for production of maize. Net revenue computed as total revenue minus total variable costs was presented in Table 4. As in the Table, Targa and Tie ridge recorded higher net returns (29712 ETB/ha and 25164 ETB /ha) than Control (20370 ETB/ ha) and Zai (14350 ETB/ ha1). It means rainwater harvesting system with Targa and Tie ridge has direct effect on crop production and economic benefits over control due to better moisture holding capacity.

An average of 29712 ETB constituting 193% of the total revenue was earned as net revenue per hectare in the Targa technique. Similarly, the net revenue of the Tie ridge technique was an average of 25164 ETB constituting 181% of the total revenue while the average net revenue of the conventional was 20370 ETB constituting 169 % of the total revenue per hectare. These results indicated 24% and 12% net revenue increase per hectare for Targa and Tie ridge in-situ RWH techniques over the conventional, respectively. This is consistent with findings of Vohland and Barry (2009) that rainwater-harvesting systems and the adoption of the rainwater harvesting practices had positive effect on income, measured in return to labour. In the case of soil and water conservation measures (in-situ rainwater harvesting structures), it usually involves significant initial and on-going investment in both cash and labour with benefits being realized in the long term (Ellis-Jones and Tengberg, 2000).

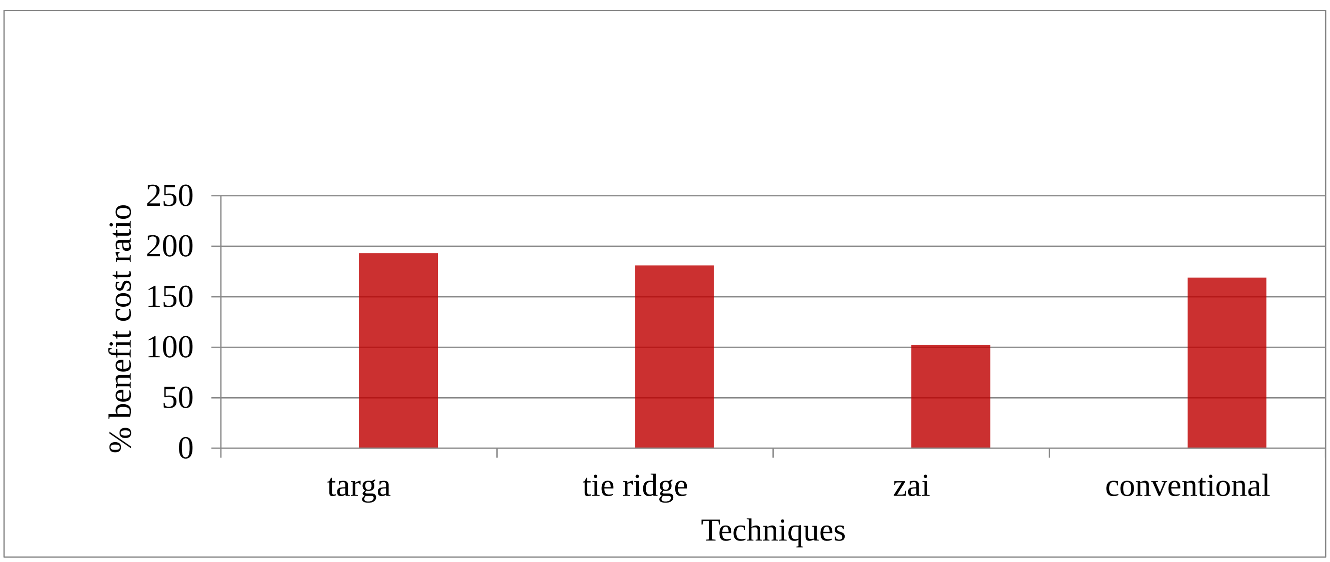


Figure 5: Percent of the treatments benefit cost ratio

4. CONCLUSIONS

Agriculture in Humbo woreda is predominantly rain-fed. This farming system resulted in fluctuating food crop productivity mainly due to moisture stress during mid and developmental season emanated from rainfall variability in the woreda. This study, therefore, was conducted to know the potential of in-situ WHT on maize yield, yield components and soil moisture. The comparative study between the Control and Zai, Targa and Tie-ridge showed that the soil moisture, grain yield and biomass for the Targa were consistently higher when compared to the control. Accordingly, out of RWH technologies, Targa was observed to be a climate smart technique which contributes to conservation of natural resources (conserve soil moisture and reduces surface runoff water) and increased yield at dryland condition. These water harvesting structures on farmers' fields had minimum cost, reduced labor, small space left and was simple to construct. This study clearly demonstrated that in-situ RWH techniques can play an important role in improving soil water storage, crop yields and extending the growing seasons in dry periods. The implementation and adoption of these techniques will however require careful planning, community participation and better understanding of the choices in making decision.

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