Evaluation of in-situ moisture conservation techniques on sorghum (*sorghum bicolor L.*) Production at dry low lands of Wag Himra, Ethiopia

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Abstract

The dry land areas of Ethiopia accounts for more than 66.6% of the total land mass. In this semi-arid region, the amount of rainfall is usually inadequate, erratic in distribution, short in duration and variable. Consequently, moisture availability is the most limiting factor for rain fed crop production. In response to solve moisture deficit problems for sorghum production, a field experiments was conducted to evaluate different in situ rain water harvesting techniques on growth and yields of sorghum at low lands of Wag-Himira. Tie ridge, contour soil bund, trapezoidal soil bund, zai-pit with manure evaluated against the conventional tillage were evaluated for two years. In situ rain water harvesting techniques have shown a significant ($p<0.05$) effect on both grain and biomass yields. Moreover, tie ridge provided the highest and significant($p<0.05$) grain and biomass yield advantage over other in situ rain water harvesting structures at Zequala in 2009 cropping season. However, in 2010, the in-situ moisture harvesting techniques did not show significant ($P<0.05$) yield advantage over the farmers conventional practice at Zequala due to occurrence of early rainfall, while significant ($p<0.05$) yield advantage over the conventional practices was obtained at Abergelle. The findings indicated that tie ridge and contour soil bund increased grain and biomass yields in dry lands areas of Wag Himra. Considering partial budget analysis tie ridge gave net benefits of about 10365 Birr/ha which is acceptable. Therefore, tie ridge is recommended as a best insitu moisture harvesting technique for Wag-Himra area and similar agro-ecologies.

Key words: Dry land areas, in situ rain water harvesting, moisture availability, sorghum

Introduction

The dry land areas of Ethiopia accounts for more than 66.6% of the total land mass ranging from arid with <45 days of LGP to sub moist zone with LGP of 60-120 days (Kidane *et al*., 2001). The semi-arid areas are characterized by low annual rainfall concentrated to one or two short rainy seasons. The average annual rainfall varies from 400 to 600 mm in the semi-arid zone, and ranges between 200 and 1000 mm from the dry semi-arid to the dry sub humid zone (Rockstrom, 2000). The length of the growing period ranges from 75 to 120 and 121–179 days in the semi-arid zone and dry sub-humid zone respectively. Potential evaporation levels are high, ranging from 5 to 8 mm/day (FAO, 1986) giving a cumulative evapo-transpiration of 600–900 mm over the growing period. The amount of rainfall is usually inadequate, erratic in distribution, short in duration and variable. Consequently, moisture availability is the most limiting factor for rain fed crop production in the dry lowland areas. Rain fed agriculture has failed to provide the food requirement for the rapidly increasing population of the country. Although the reason for this are complex, the primary constraint in the semi arid areas is lack of suitable technology for soil and water management and crop production under relatively low and erratic rain fall situation (Reddy and Kidane, 1993). In regions where crops production are entirely rain fed, reduction of 50% in the seasonal rain fall may result in total crop failure, however, the available rainfall can be concentrated on small area, and reasonable yield still will be received. (Critchley, 1991).

Dry land crop production is critically dependent on the amount of water availability during the crop-growing season. It is believed that substantial increase of crop yield can be achieved through proper water conservation and management practice. Efficient use of available water by plants has also an impact on other crop management practices such as the use of fertilizer application in dry areas which is low compared to the area with optimum soil moisture conditions.

As land pressure increase, more and more marginal areas are used for agriculture. Much of this land is located in the arid and semi arid belts where the rainfall is irregular and much of the rain is quickly lost as surface run off. Recent droughts have clearly indicate the risk to human beings and livestock, which caused mainly by the failure or shortage of rainfall.

Therefore, the objective of this study was to evaluate and select effective and feasible in situ soil moisture harvesting technologies for moisture stress areas of Wag Himra.

Materials and Methods

Description of the study area

The field experiments was conducted in semi-arid areas of Zequala and Abergelle Woredas in Wag Himra Administrative zone, located about 65 and 55 km away from the capital of the administrative zone, Sekota town, respectively. Figure 1 shows the location of the trail sites in reference to Amhara region and Wag Himra Administrative zone. The study sites were characterized with gentle slope, uniform or even topography, and the soils suitable for agriculture were selected; clay loam and silt loam soils for Zequala and Abergelle trial sites, respectively.

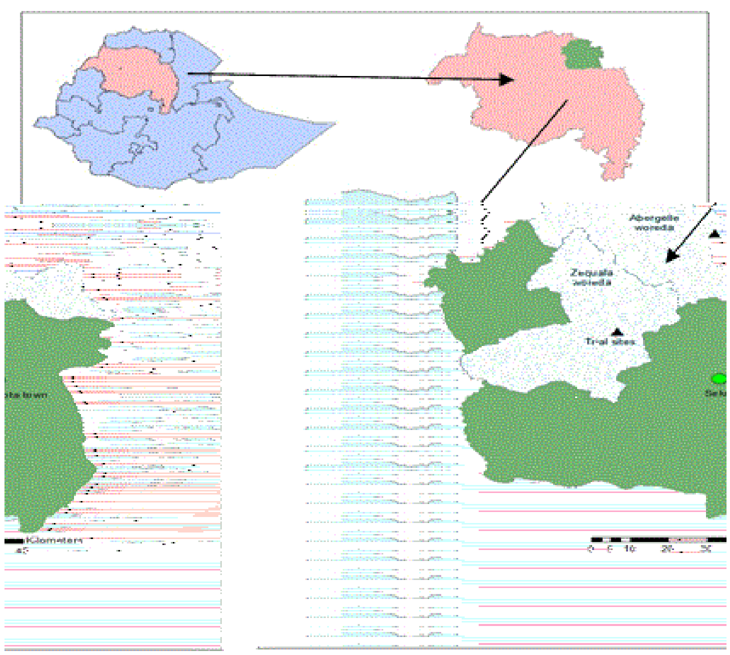

Figure 1. Location map of the trial sites

The rainfall distribution of the study areas is characterized by short, erratic and variable across different growing season. Based on the 10 years metrological data collected from the nearby metrological stations, the annual rainfall of Zequala ranges from 180 to 650 mm, with annual average rainfall of the area about 370 mm. Similarly, it ranged from 150 mm to 560 mm for

Abergelle with annual average rainfall of about 310 mm. Besides to this, the rainfall in these areas mostly starts lately around end of July and ceases then earlier around end of August. The rainfall usually stops during a critical (flowering) stage of major crops, and the availability of low moisture content in the soil during this stage is a limitation factor for crop production in the study areas.

The treatments were control (without any moisture harvesting techniques), contour soil bund, trapezoidal soil bund, zai pits with manure and tie ridges. The treatments were arranged in RCBD with three replications. The construction of the techniques described by Critchley (1991) was used for the study with some modification to fit the experimental sites. The dimension area for one treatment was 17 m*7 m and the distance between plots and blocks were 1 m and 1.5 m, respectively. Diversion ditch was constructed to divert inflow of runoff from the up slope.

Description and design specification in-situ moisture rainwater harvesting structures

1. **Contour soil bund**: is used to hold flowing surface run off, through the area in to surrounding space of two adjacent bunds. The bunds were constructed at a horizontal spacing of 3.5m with 35 cm minimum height of a bund. Moreover, the base width of the bund was fixed at 75 cm with a 6m distance between ties in the bund.

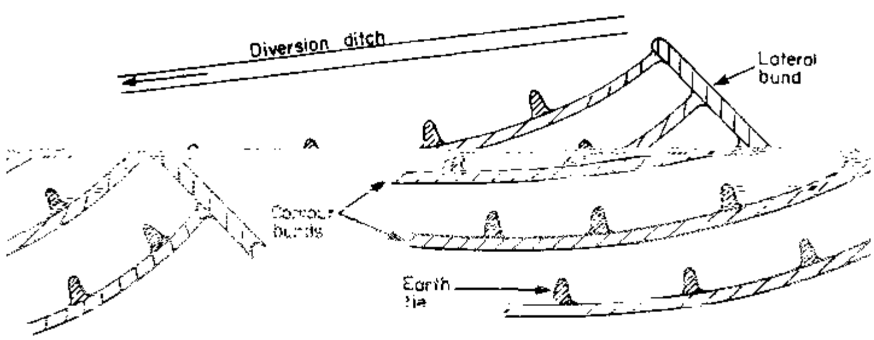

Figure 2. Field Layout and cross sectional view of contour soil bund

1. **Trapezoidal soil bund:** is used to enclose and to impound run off, which is harvested from rainfall in the area. Crops were planted with the enclosed area and external area to fill the plot size. The trapezoidal bund was constructed with a base length of 3m, angle between a base and side bund of 135^{o}, with a minimum and maximum bund height of 0.2

and 0.6 m, respectively. The bund had a 1:1 side slope with 1.8 m and 0.6 m top and base width, respectively.

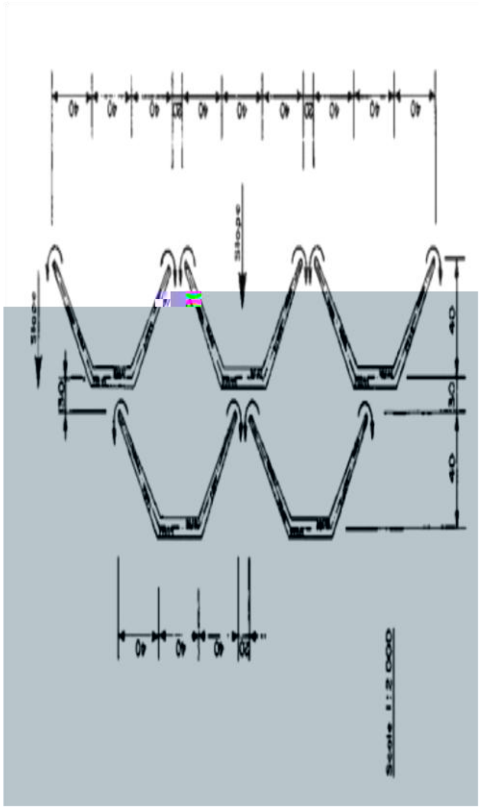

Figure 3. Field layout and typical dimensions of trapezoidal bund

2. **Zai- pit with manure**: the pits concentrate local run off coming from the nearby area. The pits had a dimension of 30 cm in diameter and constructed at a spacing of 1m and 50 cm between pit lines and between pits centre to centre distance, respectively.

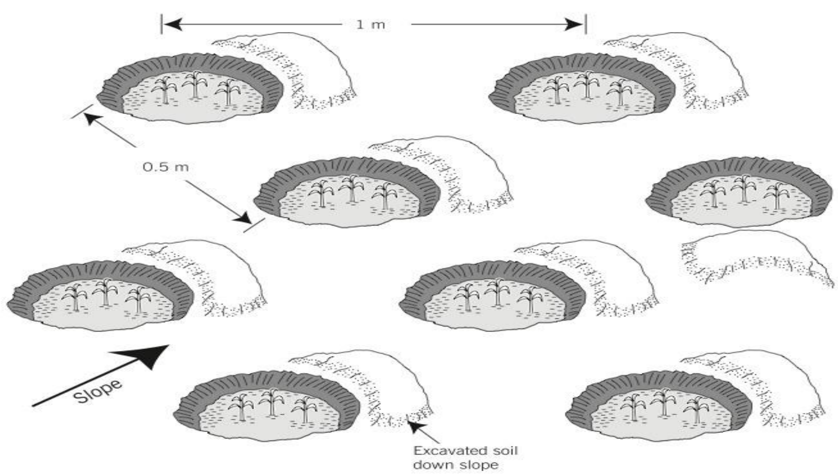

Figure 4. Field layout and cross sectional view of contour soil bund

3. **Tie-ridge:** ridges follow the contour at spacing 75 cm. Runoff was collected from the uncultivated strip between ridges or in the furrow tie at 2-3 m interval. The ridge was constructed with 30 cm height, and sorghum was planted on the ridges.

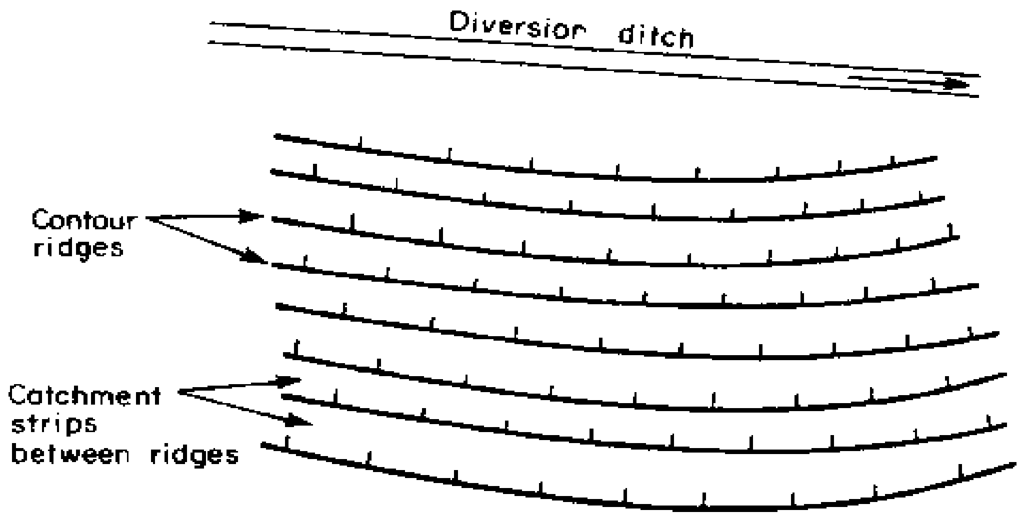

Figure 5. Field Layout and cross sectional view of contour soil bund

Agronomic Practices

Sorghum (*Sorghum bicolor*) was used as a test crop which is dominantly growing and staple food in the area. It has area coverage of around 15,200 ha in the zone, and took up 22.3 % of the grain production (CSA, 2009). Improved sorghum varieties Amsale and Abshir were used during the first and second year, respectively as an indicator crop to test the efficiency of the techniques. 100 DAP Kg and 50 Kg urea were used and applied to each treatment equally except zai pit which was applied with compost. All DAP was applied during planting and urea was applied in split half at planting and half after 35 days after planting. The fields were ploughed three times and sowing was done in the first week of July in both locations. Weeds were monitored and removed by hand three times.

Data collection and analysis

Data on grain yield and fresh stalk biomass were taken from all plants except two border rows in the plot. Plants height was measured by taking 10 randomly selected sorghum plants from each plot. Analysis of variance (ANOVA) was conducted in dependently for the two years and locations using SAS statistical software system for windows V8. For the purpose of cost benefit analysis, the grain and biomass yield of sorghum were adjusted down by 10% to minimize the plot management effect or to reflect actual farm level performance. We considered 5 Ethiopian Birr (ETB) as an average market price of one Kg of sorghum grain and 0.05 ETB for biomass at Sekota. Using the current prices in the season, the price of 100Kg UREA and DAP was taken 1165 and 875 ETB, respectively. The cost of labor was done by the standard work norm developed by World Food Program (WFP). Accordingly, 20 ETB was taken for one person per day.

Results and discussions

As presented in Appendix Table 1, in 2009, the analysis of variance showed that sorghum performance using in-situ moisture harvesting structures was significantly different ($p<0.05$) from framers' conventional practice. Tie ridge gave the highest and highly significant grain yield and biomass of 2301.81 and 7647 kg ha period. The advantages of moisture conservation practices on both grain and biomass yield on clay loam textured soil during a low rainfall season was therefore clearly seen in this experiment.

The result is in line with the findings of Kidane *et al.* (2001), who reported substantial yield increment ranging from 50% to 100% compared with the traditional practices for the crops (sorghum, maize, wheat and Mung been) grown using tie ridges and planted on flat seedbed at dry land areas. This finding is also in accordance with the results of Heluf (2003) and Mudalagiriyappa *et al*. (2012). Likewise, Tekle (2014), reported that grain yield of pearl millet was significantly influenced by moisture conservation practices. This might be due to the hypothesis that the conservation of moisture has been known to help in photosynthesis, fertilization of flowers, seed setting, protein synthesis and nitrogen metabolism thus improving the crop yields (Sakthivel *et al*., 2003).

In 2010, the response of the in-situ moisture harvesting structures in terms of sorghum grain yield and biomass at Zequala experimental site was different from the response obtained in 2009 (Appendix Table 2) due to the occurrence of high rainfall during the growing period, especially at germination period. Higher amount of rainfall was observed during this cropping season, amounting to 650 mm, which was the optimum and ideal water amount required for sorghum production. The farmers' conventional practice has therefore shown statistically significant grain and biomass yield difference with zai pits with manure and tie ridge. On the other hand, the grain and biomass yield response of contour soil bund and trapezoidal were not significantly different from farmers' conventional practices. Both contour and trapezoidal bunds have produced about 580 and 440 kg ha^{-1} more grain yield than zai pit, and 740 and 600 kg ha^{-1} than tie-ridges, respectively. The occurrence of high rainfall during germination resulted in yield response of treatments contrary to the response obtained in 2009. However, plant height did not show significant difference among the moisture harvesting structures which implies the influence of the early rainfall was not directly on plant height reduction rather on the stalk biomass per plant and grain weight per head.

During 2010, even though there was no significant difference among the structures, tie ridge provided relatively lower yield compared to the control. The crop under in-situ moisture harvesting structures showed deficiency symptoms to nitrogen i.e. yellowing of older leaves from the mid rib to the margin and stunned growth which in turn resulted in low grain and biomass yields. This might be attributed to the high rainfall during germination which in turn resulted in water logging which caused yield reduction. In addition, the soil of the study area had high clay content and low infiltration rate (5 - 6.35 mm/hr), and was vulnerable to water logging during this cropping season thus resulted in low yield. The result clearly showed that the tie ridge and zai pit were significantly affected by water logging problem.

Water logging is considered to be one of the major problems in crop production, affecting an estimated 12% of the global cultivated area (Li 1997). Previous studies had also reported negative effects of water- logging on crop yields. For example, increasing durations of water logging decreased maize yield (Yang and Chen 1998; Li *et al*. 2001). Similarly, Bhan (1977); Dickin and Wright (2008), observed in their studies that water- logging decreased crop yield. Water-logging significantly affects plant morphology, decreasing cell permeability (Patwardhan *et al*., 1988). The most unpleasant consequence of the water logging is hypoxia i.e. shortage of oxygen or anoxia i.e. total lack of oxygen in the soil medium which causes the reduced growth, inhibits the metabolic processes and finally reduces the yield of the wheat. The field experiment conducted at Zequala during the two cropping seasons revealed that in-situ moisture conservation structures have shown variable responses under low and high rainfall occurrence during the early stage of the growing season. This implies that the structures have different adaptation conditions.

Appendix Table 3 presents grain and biomass yield of sorghum in 2010 cropping season at Abergelle. The performance of sorghum was less by half than the performance obtained at Zequala due to location, soil type and difference in rain fall distribution of the area. Contour soil bund gave highly significant grain and biomass yields compared with other in-situ moisture harvesting structures. Tie- ridge, zai pits and trapezoidal bund have no significant difference to each other, but they have shown significant yield and biomass increment over the control. The amount of rainfall recorded during the 2010 cropping season at Abergelle was moderate, about 450 mm. However, as the experiment was conducted in silt loam soil which has a relatively high infiltration rate (10 - 12.7mm/hr), the grain and biomass yields of the crop were not affected by water logging.

Partial budget analysis is indicated in Appendix Table 5. At Zequala (2009) and Abergelle (2010) the partial budget analysis revealed that tie ridge gave the highest net benefit of 10364.71

ETB/ha and 1077.39 ETB/ha, respectively) with an acceptable marginal rate of return (MRR). The partial budget analysis for Zequala in 2010 showed that the net benefits of the new technologies were low, but the cost increase due to high rainfall during the early growing stage.

Conclusion and recommendation

The two years on farm evaluation experiment results indicated that among the evaluated in situ moisture harvesting structures tie ridge with spacing of 75 cm was effective and soil bund with 3.5 m horizontal spacing for gentle slopes were found to be suitable in the in the dry of Wag-Himra areas (study areas) and similar agro ecologies. The tie ridge also gave the highest net benefit in both locations with acceptable marginal rate of return (MRR). The results of the experiment also indicated that the efficiency of the moisture conservation practices varied based on the rainfall distribution and soil types. During a low rainfall season, the construction of in-situ moisture practices has paramount advantage with a significant yield increment especially in soils with high clay content. However, during a high rainfall season, there was a reverse response that there was a reduction of both grain and biomass yield of sorghum due to water logging.

To improve the efficiency of in-situ moisture harvesting structures, it needs on time sowing, safe disposal of excess water from the field whenever it occurs and maintenance of structures and altering the furrow and ridge based on the rain fall distribution. As a recommendation, further research need to be done regarding the tying time of the tie ridge and on safe disposal of excess water.

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References

Bhan, S. 1977**.** Effect of water logging on maize. Indian J. Agric. Res. 11: 147_150.

Critchely, W. and Siegert K. 1991**.** A manual for the design and construction of water harvesting schemes for plant production. Food and Agriculture Organization of the United Nations (FAO). Rome.

CSA (Central Statistical Authority). 2007**.** Agricultural sample survey 2009/2010 (2002 E.C), Volume 1, Report on area and production of crops, Addis Ababa, Statistical Bulletin 417.

Dickin, E. and Wright D. 2008. The effects of winter water logging and summer drought on the growth and yield of winter wheat (Triticum aestivum L.). Eur. J. Agron. 28: 234_244.

FAO (Food and Agricultural Organization of the United Nations). 1986. African Agriculture for the next 25 years. FAO, Rome, Italy

FAO (Food and Agricultural Organization of the United Nations). 1986. Irrigation Water Management: Irrigation Water Needs. FAO Training Manual 3, Rome, Italy, p. 38.

Heluf Gebrekidan. 2003. Grain Yield Response of Sorghum (*Sorghum bicolor*) to Tied Ridges and Planting methods on Entisols and Vertisols of alemaya Area, Eastern Ethiopia High Lands. *J. Agric. Dev. Trop. Sub-Trop.* 104(2): 113-128.

Kidane Georgis, Melese Temesgen and Shilima Goda. 2001**.** On farm evaluation of soil moisture conservation techniques using improved germplasm.

Li, J. C., Dong, Q. and Yu, S. W. 2001**.** Effect of waterlogging at different growth stages on photosynthesis and yield of different wheat cultivars. Acta Agron. Sin. 27: 434_442.

Li, J. C. 1997. Waterlogging physiology of wheat and its relation with wheat productivity. Plant Physiol Commun. 33: 304_312.

Mudalagiriyappa, B., Ramachandrappa, K. and Nanjappa H. V. 2012. Moisture conservation practices andnutrient management on growth and yield of rabi sorghum (*Sorghum bicolor*) in the vertisols of peninsular India. *Agric. Sci.*, 3(4): 588-593.

Patwardhan, A. S., Nieber, J. L. and Moore, I. D. 1988. Oxygen carbon dioxide and water transfer in soils: mechanisms and crop response. Trans. ASAE 31: 1383_1395.

Reddy, M.S. and Kidane Georgis. 1993. Dry land farming research in Ethiopia review of the past and thrust in nineties. LAR, Addiss Ababa.

Rockstrom, J. 2000. Water resources management in smallholder farms in eastern and southern Africa: an overview. Phys. Chem. Earth (B) 25 (3), 275–283.

Sakthivel, N., Balasubramanian, A., Radhamani, S. and Subbian P. 2003. Effect of *in situ* moisture conservation practices and intercropping system on yield of rain-fed maize in western zone of Tamil Nadu. *Madras Agriculture Journal* 90: 411-415.

Tekle, Y. 2014a. Performance Evaluation of Cowpea (*Vigna unguiculata* L.) Varieties under Moisture conservation practices for Yield and Yield Components at Alduba, Southern Ethiopia. *Int. J. Res. Agric. Sci.*1 (3): 2348 – 3997.

Tekle, Y. 2014b. Evaluation of Moisture Conservation Practices, Inter and Intra Row Spacing on Yield and Yield Components of Pearl Millet (*Pennisetum glaucum*) at Alduba, Southern Ethiopia. J. *Natl. Sci. Res*. 4(1): 9.

Yang, J. P. and Chen, J. 1998. The effects of waterlogging at different growth stages on the growth and development of spring corn. Acta Agric. Zhe jiangensis. 10: 188 - 193.

Appendices:

Appendix Table 1: Mean grain yield and biomass of sorghum in year2009 at Zequala

Treatment	Grain yield(kg/ha)	Biomass yield (kg/ha)
Control	0.00[d]	2400.5d
Contur soil bund	901.2c	4530.5bc
Trapizoidal soil bund	1102.5c	5045.0b
Zai pit with manure	1589.3b	3884.7c
Tie-ridge	2301.8a	7647.8a
Mean	1356.91	4701.7
CV(%)	15.22	11.43
LSD (0.05)	388.92	1011.5

Appendix Table2: Plant heights, grain and biomass of sorghum in year2010 at Zequala

Treatment	Plant height (meter)	Grain yield (kg/ha)	Biomass yield (kg/ha)
Control	1.43a	1749.1a	5414.6ab
Contur soil bund	1.31a	1599.9a	4761.3bc
Trapizoidal soil bund	1.46a	1462.0a	5991.3a
Zai pit with manure	1.36a	1019.2b	3699.2c
Tie-ridge	1.43a	860.3b	3968.5c
Mean	1.40	1338.2	4767.0
CV(%)	6.26	11.82	11.97
LSD (0.05)	0.16	297.87	1074

Appendix Table3: Plant heights, grain and biomass of sorghum in 2010 at Abergelle

Treatment	Plant height (meter)	Grain yield (kg/ha)	Biomass yield (kg/ha)
Control	1.20a	302.43c	1855.6c
Contour soil bund	1.36a	1082.85a	5218.5a
Trapizoidal soil bund	1.26a	454.06b	2818.2bc
Zai pit with manure	1.12a	537.00b	3609.2b
Tie-ridge	1.24a	567.23b	3511.2b
Mean	1.24	588.71	3402.6
CV (%)	6.64	11.27	15.31
LSD (0.05)	0.155	124.97	980.9

Appendix Table 4: Computation of costs

Cost that varies	**Treatment**	**Calculation**	**Total**
Labor cost for constructing structure	Control		-
	Contour soil bund	250Pd/ha*20birr/pd	5000
	Trapezoidal bund	300pd/ha*20birrr/Pd	6000
	Zai pit with compost	29629pit/50pit/PD*20 birr/PD	11851
	Tie ridge	20PD*20birr	400
Fertilizer cost(DAP and urea)	Control	1Dap*1165+ 0.5urea*875	1602.5
	Contour soil bund	1Dap*1165+ 0.5urea*875	1602.5
	Trapezoidal bund	1Dap*1165+ 0.5urea*875	1602.5
	Zai pit with compost	-	-
	Tie ridge	1Dap*1165+ 0.5urea*875	1602.5
Compost cost	Zai peat with manure	10PD preparation*20 birr + 10PD for transportation*20 birr	400
Labor cost for maintaining structure	Control	-	
	Contour soil bund	60PD/ha*20birr/day	1200
	Trapezoidal bund	75pd/ha*20birr/pd/day	1500
	Zai pit with compost	125pd/ha*20birr/pd/day	2500
	Tie ridge	20pd/ha*20birr/pd/day	400

Appendix Table 5: Partial budget analysis

	Treatments				
	Control	Contour soil bund	Trapezoidal bund	Zai pit with compost	Tie ridge
Average grain yield 2009 at Zequala(kg/ha)	-	901.20	1102.50	1589.30	2301.81
Average grain yield 2010 at Zequala (kg/ha)	1749.10	1599.90	1462.00	1019.20	860.30
Average grain yield 2010 at Abergelle (kg/ha)	302.43	1082.85	454.06	537.00	567.23
Adjusted grain yield 2009 at Zequala(kg/ha)	-	811.08	992.25	1430.37	2071.63
Adjusted grain yield 2010 at Zequala (kg/ha)	1574.19	1439.91	1315.8	917.28	774.27
Adjusted grain yield 2010 at Abergelle (kg/ha)	272.187	974.565	408.65	483.30	510.51
Average biomass yield 2009 at Zequala(kg/ha)	2400.50	4530.50	5045.00	3884.70	7647.80
Average biomass yield 2010 at Zequala (kg/ha)	3665.50	3161.4	4529.30	2680.00	3108.20
Average biomass yield 2010 at Abergelle (kg/ha)	1553.17	4135.65	2364.14	3072.20	2943.97
Adjusted biomass yield 2009 at Zequala(kg/ha)	2160.45	4077.45	4540.5	3496.23	6883.02
Adjusted biomass yield 2010 at Zequala (kg/ha)	3298.95	2845.26	4076.37	2412.00	2797.38
Adjusted biomass yield 2010 at Abergelle (kg/ha)	1397.85	3722.08	2127.73	2764.98	2649.57
Gross field benefit (ETB/ha)2009 at Zequala	756.16	5482.51	6550.43	8375.53	12767.21
Gross field benefit (ETB/ha)2010 at Zequala	9025.58	8195.39	8005.73	5430.60	4850.43
Gross field benefit (ETB /ha)2010 at Abergelle	1850.18	6175.55	2787.98	3384.24	3479.89
Labor cost(ETB/ha) for construction and maintenance 1st year		6200	7500	14351	800
Labor cost(ETB/ha) for construction and maintenance 2nd year		1200	1500	14351	800
Fertilizer cost 1st and 2nd year (ETB/ha)	1602.5	1602.5	1602.5	-	1602.5
Compost cost 1st and 2nd year (EB/ha)	-	-	-	400	-
Total Cost that varies 1st year at Zequala and Abergelle (ETB/ha)	1602.5	7802.5	9102.5	14751	2402.5
Total Cost that varies 2nd year (ETB/ha)	1602.5	2802.5	3102.5	14751	2402.5
Net benefit for 2009 at Zequala (ETB/ha)	-846.34	-2319.99	-2552.07	-6375.47	10364.71
Net benefit for 2010 at Zequala (ETB/ha)	7423.08	5392.89	4903.23	-9320.4	2447.93
Net benefit for 2010 at Abergelle (ETB/ha)	247.68	-1626.95	-6314.52	-11366.8	1077.39
MRR in Zequala 2009	-	D	D	D	14.01
MRR in Abergelle 2010	-	D	D	D	1.04