Water Harvesting: Improving Tree Seedling survival & Biomass production at *Kalu Woreda*, South *Wolo*, Ethiopia

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Abstract

An experiment was conducted to compare and evaluate three different micro-basin structures (eyebrow, half-moon and trench) and the normal seedling plantation practice by farmers (normal pit). Trench and eyebrow structures showed better performance in improving tree growth parameters as compared to the normal pit: a 65%, 90% and 50% increase in root collar diameter (RCD), diameter at breast height (DBH) and height of the tree seedling was recorded respectively. The trench technique increased grass production in the plantation area by 41 %. Eyebrow is recommended on hillsides where stone is available and trench can be used where stone is scarce.

The results indicate that micro-basin structures can mitigate both flood and dry spell shocks with low investment and skilled manpower costs. It increases livestock water productivity as more feed can be produced with the existing variable rainfall.

Key words: In situ water harvesting, micro-basins, water productivity, hillsides.

Introduction

Although Ethiopia is known as the "Water Tower of East Africa" with 12 major river and lake basins and high rainfall amounts, recurrent drought, erosion, flooding and drying of streams, springs and lakes hit the country several times. The country's annual rainfall is estimated at about 1090 mm, while the total annual runoff is estimated at 110 Billion cubic meters or 98 mm. Only 5% of this runoff is used in the country and the rest is lost (Getachew, **A.,** 1999. Rainwater Harvesting in Ethiopia: An Overview, pp.387-390. In: 25th WEDC Conference on Integrated Development for Water Supply and Sanitation, Addis Ababa, Ethiopia. (Retrieved February 16, 2005, from http://www.lboro.ac.uk/wedc/papers/25/387.pdfPoverty, undulating and steep topography, and mismanagement of water and land resources together result in the low productivity of this runoff. Climatic change and mismanagement of water and land cause erosion, low production, and famine and food insecurity.

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The dry land areas of North-Eastern *Amhara* around the eastern escarpment are characterized by undulating topography in which hillslopes alternate with bottom farmlands. The high population growth has forced people to clear off trees from the hills and plow very steep slopes and marginal lands. This disturbs the natural hydrological cycle by reducing the water holding capacity of the soil and infiltration and percolation to the ground water table. It is familiar to observe formation and expansion of gullies on productive grazing and farmlands that are caused by seasonal runoff. Although annual cumulative rainfall is relatively high, it´s distribution is erratic with many dry weeks even within the main rainy season from July to September. Occasionally, high-intensity rain produces high runoff with low soil water storage.

In order to increase the forest coverage and biomass production and to improve the environmental conditions of the area, millions of tree seedlings were repeatedly planted by different afforestation programs, but almost none survived. In addition to browsing and loose follow-up, water stress is the major limiting factor, which reduces the survival rate and productivity of tree seedlings in the semi-arid areas in the region.

One of the recent approaches to overcome such problems of low water availability in semi-arid areas is the use of different in situ water harvesting structures that fits with the existing social, technical and economical conditions of the society. Water can be harvested above the ground as above ground tankers, on the ground as large dams and small micro-basins and with in the soil profile as a soil moisture conservation. Different kinds of structures and techniques exist, differing from each other with respect to catchment area and storage type, like roof top, runoff, flood, above-ground tank, excavated cisterns, small dams and soil moisture (or in situ) water harvesting (Mitiku, H., Sorsa, N. 2001). The experience of water harvesting in the drylands of Ethiopia. Workshop proceeding. Deutschen Cichliden Gusdiffering from8 huge dams from siltation. The research results in other areas show that v-shape structures are effective in Kenya (Mugwe J., Mick O., Samual G., Jonathan M., Jack M., 2001. Participatory Evaluation of Water Harvesting Techniques for Establishing Improved Mango Varieties in Smallholder Farms of Mbeere District, Kenya. Pages 1152-1157. In: D.E. Stott, R.H. Mohtar and G.C. Steinhartt (Eds.). Sustaining the Global Farm, 10th International Soil conservation Organization Meeting, Perdu, May 24-29, 1999. Perdu University, USA.Experimental results on in situ water harvesting in eastern Ethiopia show that micro-catchments of 100m^2 result in a 7.8% seedling survival increment for Acacia *saligna* compared to 50m^2 area at Dire Dawa (Abdelkdair A., Richard, C.S., 2005. Water harvesting in a 'runoff–catchment' agroforestry system in the dry lands of Ethiopia. *Agroforestry Forum.* 63: 291–298

Awareness campaigns were held and huge investments were made to promote harvesting and use of the runoff water at household level using concrete structures. Approximately, 70,000 ponds and tanks were constructed during 2002 (UN OCHA, 2003). However, the structures need more skilled manpower, follow-up and investment than the households are capable of. According to the assessment report of UN OCHA (2003), cracking and leakage problems of constructed tankers, safety and mosquito hazards, siltation, and irrigation technology needs were the challenges faced when implementing rainwater harvesting technology.

The general aim of the study was to contribute to alleviating water stress and improve biomass productivity in water stressed areas of north eastern Amhara region in Ethiopia. The specific objectives of this study were:

- To evaluate the effect of different micro-basin water harvesting techniques (eyebrow, half moon and trench) on survival rates and growth of trees and grasses in moisture stressed areas of north eastern *Amhara*, Ethiopia.
- To formulate recommendations towards development planners and experts, farmers and catchment treatment programmers on the use of micro-basin water harvesting structures.

Materials and methods

Description of the study site

The field experiment was conducted at *Kalu* district about 350km north of the capital city of Ethiopia, Addis Ababa, at a geographical location of 10°56'25"N and 39°46'57"E on the way to Desie. The area has more than 1000mm average annual rainfall with the average monthly distribution shown in *Figure 1:* Average monthly rainfall, mean daily temperature and number of years that had less than 14.7mm monthly rainfall out of 16 years of data from *Combolcha* meteorological station *(*1985-2000). From near by meteorological station, Combolcha. About half of the year is dry with 50% probability to get a monthly rainfall of less than 14.7 mm, which is the threshold rainfall to fill interception losses before deep infiltration and runoff. On the other hand, the main rainy season goes to a climax abruptly in July, when surface vegetation cover is low due to the dry spell in June. This is an indication of severe erodibility unless mitigated by appropriate soil surface management. November, December and January are the driest months of the year that need moisture management to increase seedlings survival rates and to increase the water productivity of rain events in August and September.

Area closure is advised and it is practicing in the area to rehabilitate hillsides and protect hill bottom farmlands from gully erosion. Farmers are using cut and carry system to feed their livestock from the closed area. The regional government is trying to distribute and certify hillsides for individual farmers.

Table 1 Base line information on soil, and slope of the experimental plots.

Plot No. (*)	P^H	N (%)	P (ppm)	OC (%)	Texture			Texture class	Slope (%)	Soil depth (cm)
					Clay (%)	Silt (%)	Sand (%)			
R_1T_1	6.2	0.186	16.8	1.998	32.25	30.0	37.75	Clay Loam	17.4	60
R_1T_2	6.4	0.189	16.4	2.014	49.75	27.5	22.75	Clay	18.8	70
R_1T_3	6.5	0.203	5.6	1.497	42.25	30.0	27.75	Clay	13.9	60
R_1T_4	6.6	0.169	7.2	2.016	37.25	30.0	32.75	Clay Loam	18.2	70
R_2T_1	6.4	0.214	15.2	2.590	54.75	27.5	17.75	Clay	20.7	40
R_2T_2	7.0	0.253	8.4	2.253	49.75	35.0	15.25	Clay	43.3	70
R_2T_3	6.5	0.234	12.8	2.687	47.25	35.0	17.75	Clay	28.8	90
R_2T_4	6.7	0.211	8.4	2.464	54.75	30.0	15.25	Clay	36.6	80
R_3T_1	7.0	0.245	10.8	1.713	22.25	32.5	45.25	Loam	26.0	60
R_3T_2	6.9	0.291	6.4	2.853	42.25	37.5	20.25	Clay	81.5	35
R_3T_3	6.7	0.221	16.0	1.702	37.25	37.5	25.25	Clay Loam	61.1	45
R_3T_4	7.0	0.151	12.0	1.626	34.75	30.0	35.25	Clay Loam	41.4	55

(*) KEY: R=Replication T_1=Half-moon T_2=Eyebrow T_3=Trench T_4=Normal pit

Experimental set up

The experiment was designed as randomized complete block with four water harvesting structures and three replications established in a 50m by 25m treatment plot area with 2m spacing between the treatments. Base line data was collected at the beginning of the experiment from each experimental plot (*Table 4* Base line information on soil, and slope of the experimental plots).

The structures were half-moon, eyebrow basin, water collection trench, and normal pit as control. Normal pit is a small cylindrical hole normally dug by farmers. The construction techniques described in (Carucci, V., 2000. Guidelines on water harvesting and soil conservations for moisture deficit areas in Ethiopia: The productive use of water and soil. Manual for trainers. World Food Programme, Addis Ababa**, Ethiopia.** were employed for the study, taking into account to have an equal number of seedlings in each experimental plot.

The dimension of the normal pit was 30cm diameter and 50cm depth. Acacia *saligna*, an adaptable and multi-purpose tree species for the area, was selected as a test plant. Experimental data was collected every three months for 2 years starting from plantation. These data include survival rate, root collar diameter (RCD, i.e. diameter of the seedling at the ground surface), diameter at breast height (DBH, i.e. at 1.3m above the ground surface), height of the tree and annual grass biomass production. RCD, DBH and height were taken from all the seedlings surviving, except from the borderlines of the plots. Survival rate was calculated as the percentage of seedling surviving at data collection time to the total number planted in the treatment. The diameters were taken using precise caliper. Three 3m by 3m sample areas per treatment were harvested to determine sun dried grass biomass.

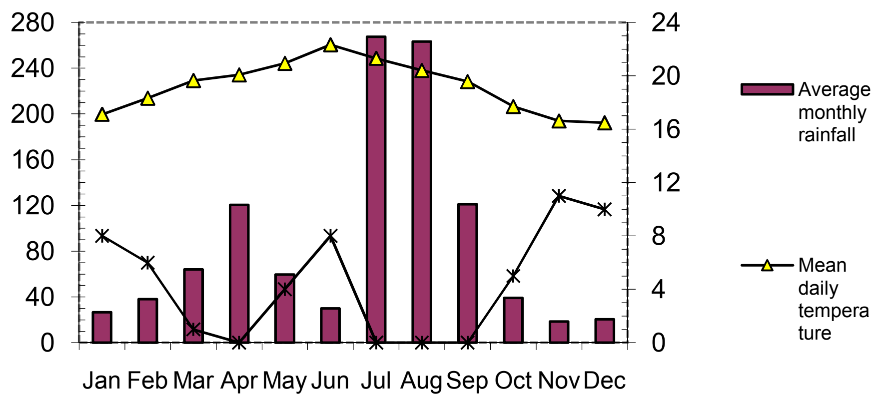

Figure 1: Average monthly rainfall, mean daily temperature and number of years that had less than 14.7mm monthly rainfall out of 16 years of data from *Combolcha* meteorological station *(*1985-2000).

Statistical analysis

Analysis of variance was used to identify significant differences among treatment means of the variables considered in the experiment. When analysis of variance showed significant differences at α=0.1, α = 0.05 and α =0.01, further mean separations were made using Fisher's LSD mean separation test. Time series graphs were drawn for growth variables to indicate treatment effect and seedling response along the age of the seedling.

Results and discussion

The time series graphs (see Figure 2) of growth variables show that, after high moisture stress during the winter dry spells (at 6th and 18th months age) and the autumn dry spells (at 12th and 24th months age), increment rates are minimal. During the first 15 months, seedlings need careful management for survival and fast growth. Trench and eyebrow show efficiency to promote seedling survival and growth. The dimension and shape of eyebrow and half-moon are similar, but they differ with respect to growth and seedling survival efficiency. The reason might be the location of the water collection pit. It is located above the plantation pit for the eyebrow structure and around the plantation pit for the half-moon structure. In the latter case, there is a chance to lose some water as subsurface flow away from the root zone due to the hydrostatic (gravitational) head of the harvested water. For the eyebrow on the other hand, the water flow is towards the root zone since the water collection pit is located upstream from the plantation pit. This assumption can be verified by determining the moisture profile over time of each structure around the water collection pit.

All three micro-basins have better results for all measured variables as compared to the normal pit (Table 2. Mean values of root collar diameter-RCD (cm), diameter at breast height-DBH (cm), height (cm), survival rate (%) and grass biomass (kg/ha) of each treatment at the 15th month.. At the age of 15 months (i.e. when corresponding grass biomass data are available), treatments are highly significantly different at $\alpha = 0.01$ for survival rate. For RCD and grass biomass differences are significant at $\alpha = 0.05$ and for DBH & height at $\alpha = 0.1$. Therefore, 32.2-45% for survival rate, 54.8-70.4% for RCD, -5.5-41.1% for grass biomass, 69.5-97.8% for DBH and 35.5-52.6% for height increments are shown as compared to the normal pit by eye-brow, trench and half-moon, respectively (see *Table* 3 **Increments/decrements as compared to the normal pit.** The disturbance of the surface area due to the construction of the structures influences grass production. The effect of the treatments on grass biomass production may therefore be seen clearly only in the next years.

Table 2. Mean values of root collar diameter-RCD (cm), diameter at breast height-DBH (cm), height (cm), survival rate (%) and grass biomass (kg/ha) of each treatment at the 15th month.

Half-moon	2.26A	0.78AB	173.19AB	50.55A	6656.4A
Eye-brow	2.49A	0.91A	195.13A	63.65A	4808.0B
Trench	2.40A	0.88A	193.25A	61.95A	7181.0A
Normal pit	1.46B	0.46B	127.85B	18.33B	5087.4B
	**	*	*	***	**
CV	13.46	26.13	16.56	15.77	12.74
LSD	0.539	0.355	51.31	13.77	1359.0

Note:* significant at 10% ** Significant at 5% *** Significant at 1%

NB: Numbers indicated with the same alphabets are not statistically significant at a given significant level.

Table 3 Increments/decrements as compared to the normal pit.

Half-moon	54.8	1.08	69.5	0.32	35.5	45.3	32.2	30.8
Eye-brow	70.4	1.03	97.8	0.45	52.6	67.3	45.3	-5.5
Trench	64.9	0.94	91.3	0.42	51.1	65.4	43.6	41.1

Figure 2: Time series of growth variables: (a) Root collar diameter (RCD), (b) diameter at breast height (DBH) in cm, (c) seedling height in cm and (d) survival rate in %.

Table 4 shows the overall combined time series statistical analysis of the eight observations which were conducted with 3 months time interval. All three structures show statistically significant differences from the normal pit in all variables and especially with respect to the survival rate of tree seedlings. There is an almost insignificant difference between trench and eyebrow, except for height and survival rate. Eyebrow shows a significantly higher survival rate at $\alpha=0.1$ in the second year.

Conclusion and recommendations

Generally, it can be concluded from the data of this study that the three micro-basins improve the biomass production and land cover as compared to the normal practice with in the existing erratic rainfall. It is possible to interpret the additional biomass production to livestock water productivity for the area. For example, using 12kg/day dry forage biomass need for one animal unit-AU (equivalent to 454kg heavy cow), 1569.0 – 2093.6 kg/ha additional grass biomass produced by the micro-basins can feed for 131-175 days for one AU. Safe and sustainable production at down stream farmlands, additional biomass production during small rainy season and biomass from survived seedlings increases the productivity of rainwater. Small harvesting capacity to water for long dry spell season and frequent maintenance were observed as short comings of the micro-basins. The following points are derived from the data listed and the observation during experimentation period as recommendations.

1. Trenches are a very important water harvesting technique for hillsides with relatively gentle slope, less stony and deep soils and for areas where the availability of stones is insufficient to construct eyebrows. Eyebrows are effective on steep slopes with shallow soils and on stone available areas for construction.
2. The water productivity of the afforested hillslopes could be increased more if high value multi-purpose fruit trees, forages and grasses would be used. This would not only increase rainwater productivity but also minimize hillside plowing for short-term benefits and create ownership feeling. This will fill the gaps of the existing hillside land distribution policy of the region.
3. The studied in situ structures have few complications for the farmers. Risk of malaria, sedimentation, cost recovery and the need for additional technology to use the stored water for irrigation is almost none.
4. Some rain events at the beginning of the main rainy season are beyond the capacity of the in situ water harvesting structures. The excess water needs to be removed safely through cut-off drains and waterways to the main drainage system. Big reservoirs are important at the downstream side to store this excess runoff after treating the hillsides with in situ water harvesting structures.

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Appendices

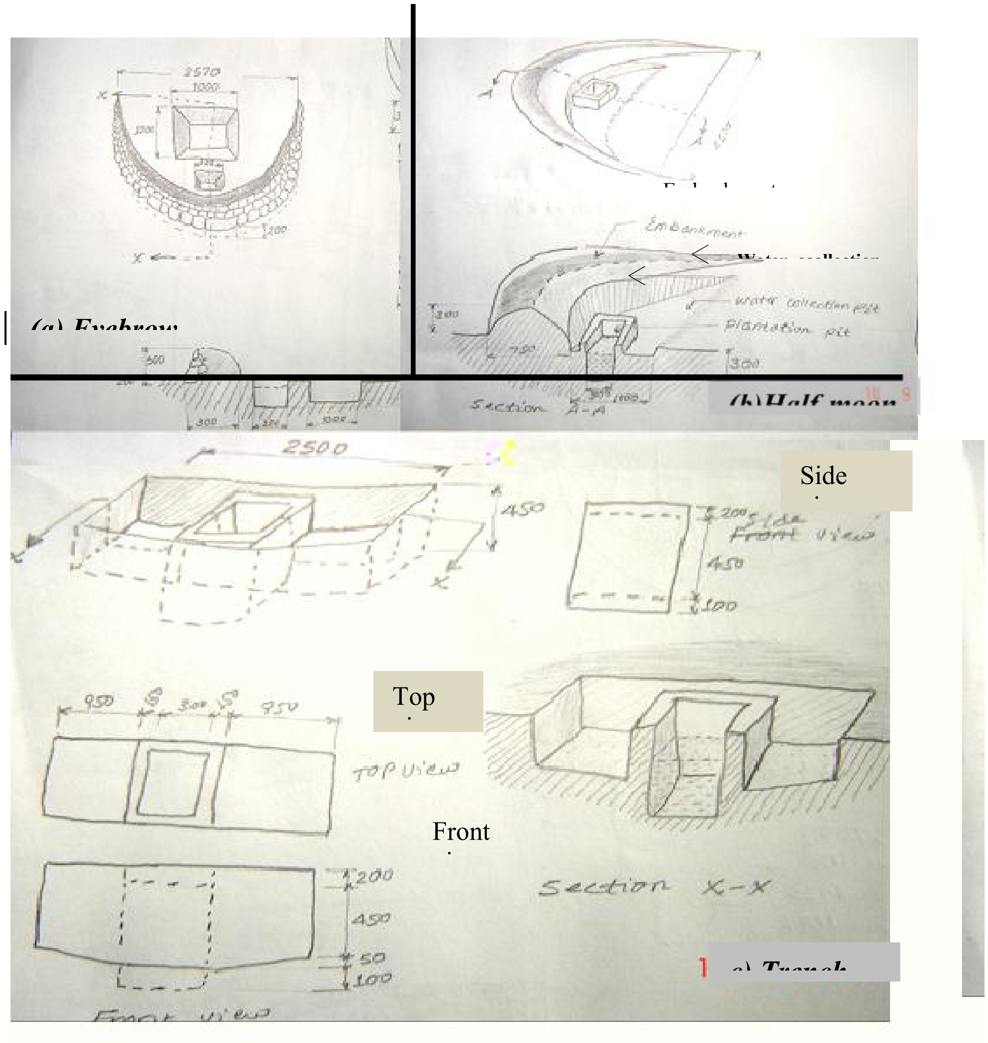

Figure 3 Dimensions of the water harvesting strictures (All numbers are in mm): (a) Eyebrow, (b) Half-moon and (c) Trench.

Table 4: Average growth variables (Combined analysis of root collar diameter (RCD), diameter at breast height (DBH), height) and survival rate for different treatments and seedling age

Age (months)	Treatment	RCD (cm)	DBH (cm)	Height (cm)	Survival rate (%)
3	Normal pit	0.52C	0	29.02B	36.67B
	Half-moon	0.60BC	0	38.31B	71.77A
	Eye brow	0.79A	0	65.37A	72.06A
	Trench	0.69AB	0	55.23AB	74.60A
	CV	**15.67**	**-**	**21.83**	**16.38**
6	Normal pit	0.63A	0	42.61C	29.67B
	Half-moon	0.83A	0.08AB	54.75BC	68.92A
	Eye brow	0.97A	0.19A	83.08A	70.76A
	Trench	1.00A	0.22A	73.17AB	70.13A
	CV	**30.37**	**89.11**	**25.91**	**16.58**
9	Normal pit	0.74B	0	52.00C	21.83B
	Half-moon	1.21A	0.46A	88.81B	63.30A
	Eye brow	1.52A	0.50A	130.21A	68.25A
	Trench	1.49A	0.54A	117.88AB	67.78A
	CV	**20.11**	**48.3**	**23.21**	**14.23**
12	Normal pit	1.04B	0.18B	77.71C	20.17B
	Half-moon	1.50A	0.45A	102.8BC	54.88A
	Eye brow	1.78A	0.64A	145.70A	65.75A
	Trench	1.78A	0.64A	130.57AB	63.85A
	CV	**16.03**	**31.07**	**16.05**	**18.11**
15	Normal pit	1.45B	0.46B	127.85B	18.33C
	Half-moon	2.26A	0.78A	173.19A	50.55B
	Eye brow	2.48A	0.91A	195.13A	63.65A
	Trench	2.40A	0.88A	193.25A	61.95AB
	CV	**13.46**	**26.13**	**16.56**	**15.77**
18	Normal pit	1.67B	0.55B	130.82B	18.33C
	Half-moon	2.65A	0.90AB	175.79AB	50.55B
	Eye brow	2.82A	1.04A	205.27A	63.65A
	Trench	2.79A	1.03A	204.60A	61.95AB
	CV	**18.91**	**25.39**	**16.2**	**15.77**
21	Normal pit	2.11B	0.92B	176.94C	18.33C
	Half-moon	3.15A	1.20AB	214.98B	50.55B
	Eye brow	3.38A	1.43A	251.08AB	63.65A
	Trench	3.55A	1.53A	261.63A	61.95AB
	CV	**19.06**	**22.28**	**10.37**	**15.77**
24	Normal pit	2.34B	1.04B	190.26B	18.33C
	Half-moon	3.44A	1.43AB	233.99AB	50.55B
	Eye brow	3.61A	1.59A	261.00A	63.65A
	Trench	3.87A	1.74A	267.66A	61.95AB
	CV	**18.63**	**20.22**	**12.43**	**15.77**

A, at α=0.05 and AB at α=0.1, CV is coefficient of variation.