

Full Length Research Paper

Impact evaluation on survival of tree seedling using selected *in situ* rainwater harvesting methods in Gerduba Watershed, Borana Zone, Ethiopia

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Establishing forest plantation on degraded rangelands play a key role in forest rehabilitation processes through afforestation or/and reforestation. *In-situ* rainwater harvesting has positive impact on seedling survivals at degraded rangelands. A quadrant of 10 m × 10 m of five times replication at three slope classes under area enclosure was used. Both survived seedlings and soil physical parameters were collected from three soil depth profiles (0-10, 10-20 and 20-30 cm) and then analyzed. Of the transplanted seedling to the area enclosure with pits (66.53, 46.13, and 25.66%), half-moon (66.53, 41.80, and 20.40%), and soil bund embankment (55.46, 42.60, and 28.80%) were survived at bottom, middle and upper slope classes respectively. The interaction of seedling survival in both planting methods were not significantly different at $P>0.05$, particularly, in half-moon and pits except soil bund embankment. Because, tree seedling rose at nursery site transplanted to the embankment of structures, that is, on the dig out soils. The conserved moisture is far from seedling roots as a result needs long roots to absorb but weak and short rooting system. Pits and half-moon showed good performance than soil embankments at bottom parts. This explains that almost all *in-situ* structures play a crucial role at flat land rather than middle and upper parts but highest bulk density achieved for the upper parts, which might be due to risks of soil erosion and only left with very compacted cobbles. Therefore, slope gradient have implication on *in-situ* rainwater harvesting devices efficiencies in conserving moisture for tree seedling survival so as to establish good forest stands.

Key words: Growth, *in-situ* rainwater harvesting, moisture stress, seedlings, survival.

INTRODUCTION

Forest plantation on degraded rangelands can play a key role in harmonizing long-term forest ecosystem rehabilitation process (Sharma and Sunderraj, 2005). The process of forest ecosystem rehabilitation can be accelerated through human intervention like afforestation

or/and reforestation with moisture stress tolerant tree seedling transplanting from nursery sites in dryland areas (Jha and Singh, 1992).

Afforestation is the common approach of restoration on degraded land and biodiversity conservation, and eco-

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environmental improvement (Cao, 2011). However, the vegetation establishment on degraded land is constrained by many factors in which the insufficient moisture availability listed as the top constraint (Li et al., 2008). The conserved and stored rainwater supports flourishing plant growth and tree seedling survivals in dry areas (Suleman et al., 1995). These could be possible through *in-situ* rainwater harvesting devices which have hydrological functions as it modifies water flows and facilitating plant growth (Gupta, 1995) and improve vegetation cover (Singh et al., 2010). This was enhanced by reducing velocity of runoff and the water is collected behind the structures. However, it only could be realized through well designed and improved soil and water conservation and harvesting devices (Gowing et al., 1999).

How the environment is much more degraded, tree seedling plantations, with appropriate and well designed *in-situ* rainwater storing structures can rehabilitate the denuded areas (Founoune et al., 2002). In such cases, transplanting of nursery-raised seedlings may accelerate regeneration and afforestation of the degraded lands (Yirdaw and Luukkanen, 2003). Because, tree seedling is the primary means by which they are recruited into the forest canopy after disturbance (Smith and Ashton, 1993).

Successful tree seedling survival and growth depends on the soil condition and stored soil moisture available to ensure tree seedling survival into the next growing season (Warren et al., 2005). It was enhanced at field level, conserving surface runoff water to productive purposes by storing water in the form of soil moisture (Rockström et al., 2002). According to Grubb (1977), geographic distributions also determine tree seedling establishment. Because, seedlings of some trees are sensitive to drought, and may be killed by even short dry spells (Engelbrecht et al., 2007).

In the degraded lands of Borana rangeland, particularly, Gerduba watershed, pastoralists have been planting many tree seedlings species year after year but the survival of those seedlings are poor and variable as the area is mainly affected by moisture stress and soil fertility problems. The impact of in-field rainwater harvesting technique (IRWH) practices on the number of planted seedling survival per unit area has so far scarcely been investigated. Again, the area has not been given much research attention and are still lacking regarding the title. Therefore, the general objective of this study was to evaluate the performance of selected IRWH structures in conserving moisture and tree seedling survival as well as physical soil quality under area enclosure of rangeland.

MATERIALS AND METHODS

Description of the study area

The study was carried out in Gerduba watershed which is found in

Yabello district of Borana zone in the southern part of Oromia National Regional State. Yabello is the capital town for the Borana zone and is situated south to Addis Ababa at a distance of 570 km. The Borana lowland is usually known as the southern rangelands. The Gerduba catchment is located in the southern parts of Ethiopian lowlands (Figure 1) and they cover a total land of 3220 ha (WLRC and CDE, 2013). It extends from 4 to 5° latitude and 38 to 40° longitude and the maximum and minimum altitudes of the watershed are 1970 and 1550 m above sea level, respectively. The annual average temperatures and rainfall is (19-24°C) and (300 - 1000 mm), respectively. The annual precipitation distribution is bimodal, with 60% falling from April to May and 30% from October to November.

The vegetation comprised in Borana is mainly a mixed savanna which is dominated by perennial grasses (*Cenchrus*, *Pennisetum*, and *Chrysopogon* species) and woody plants (Desta and Coppock, 2004).

In terms of age composition (Figure 2), most of the family members are youthful, in which the age groups under 15 years comprise 56.9%.

The Borana pastoralists traditionally depend mainly on cattle, but also on goat and sheep and nowadays though few on camel for household food security and a few donkeys and camels for transport.

Site selection and field layout

The different conservation practices with planted seedling in enclosure catchment area, at variable slope positions are sought for this study were: pits, level soil bund embankments and half-moon or semi-circular bunds. Area enclosure was selected due to the presence of the three types of *in-situ* rainwater harvesting structures with planted tree seedling to control the variations from human or livestock's on seedling survival as well as on structures or to accommodate the similar data of survived seedlings.

The reconnaissance survey and discussion was made with experts who have a deep knowledge of the site starting from its initial management practices to its present situation. In order to establish similar topographical position, the slope position was classified into three slope classes. The three catchment parts identified for this study were bottom part (0-5%), (6-10%), and (>10%). Because, soil moisture and nutrient availability mostly influenced by natural slope gradient. These classifications were done based on recommended *in-situ* rainwater harvesting suitability. The way of classification is similar with that of slope position classification adopted by Engda (2009) and Alem et al. (2016). Then, 10 × 10 m² size quadrants were used to sample the transplanted seedling for the survival counting. The area of interest was clearly identified in such a way that detail observation was made around the area to be sampled to assure that the sampled plots do not fall in the area of least dense seedling area.

Experimental sampling and study

The present study was carried out at three different topography positions classified into similar classes in the protected parts of the catchment. The study components were tree seedling survivals in different *in-situ* rainwater harvesting methods (infiltration pits which was prepared with depth of 0.5 m, width=0.5 m, space across the slope=0.5 m, along the slope in staggered manner=2 m apart, half-moon (semicircular micro basin) which was prepared with diameter of 1.5 m, space across the slope=0.5 m, ridge around periphery=0.3 m high and 0.6 m wide, down the slope in staggered manner=2 m apart and pits which was prepared with diameter=0.4 m, depth=0.4 m, and soil level bund embankments which was constructed with the of the depth=0.5 m, length=38 m and 1.1 m wide)

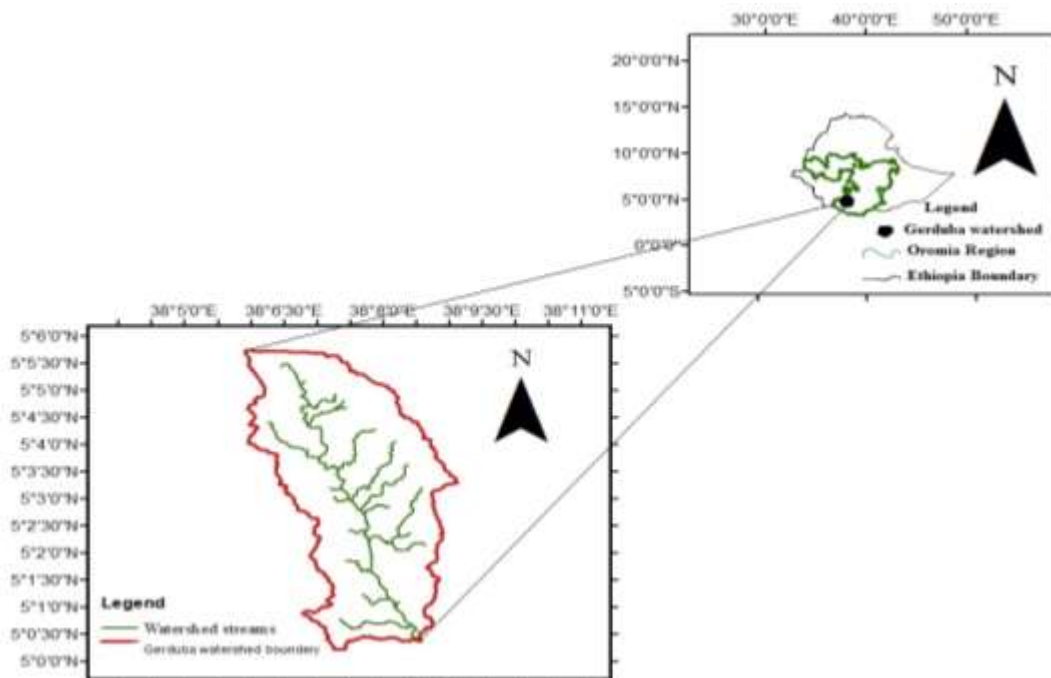


Figure 1. Map of the study area, showing the specific site in Yabello district.

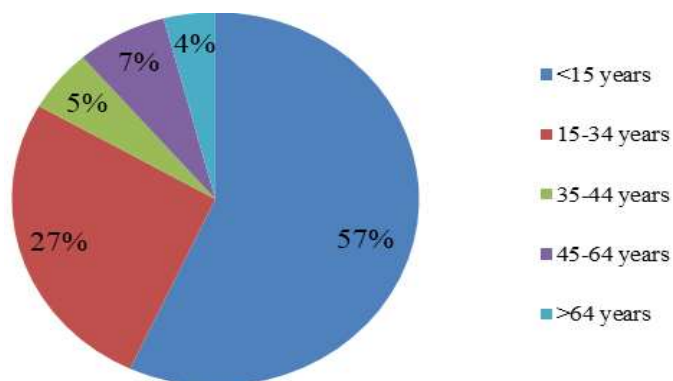


Figure 2. Age categories of Gerduba community (Source: WLRC and CDE, 2013).

and selected soil physical properties. The topographic position was classified into upper parts, middle parts and bottom area used in the whole studies. The details of the methodologies and field plot layout are here under (Figure 3).

Transplanted tree seedling sampling techniques

Stratified, random samplings of $10 \times 10 \text{ m}^2$ size quadrants from each slope classes were taken repeatedly after transect walk thoroughly the slope classes. A single quadrant cannot be expected as a representative sample of the whole seedling population adequately. So, once collected, the sampled data from all quadrants added together and considered to constitute an adequate sample of survived seedling at each slope classes in

conservation systems. At each quadrant, the total numbers of survived tree seedlings transplanted were thoroughly counted. Samplings less than 2 cm of diameter at breast height were excluded because most likely they would not survive. In each slope classes, a total of 45 quadrants of $10 \times 10 \text{ m}^2$ size were used to count seedling survival in the each conservation devices of area enclosure parts. Fifteen quadrant samples that were collected from each slope class (plots) were bulked together to represent a block. The numbers of quadrants were determined based on number of transplanted seedling survived.

Sampling of soil physical parameters

Soil texture was determined by using hydrometer method (Day,

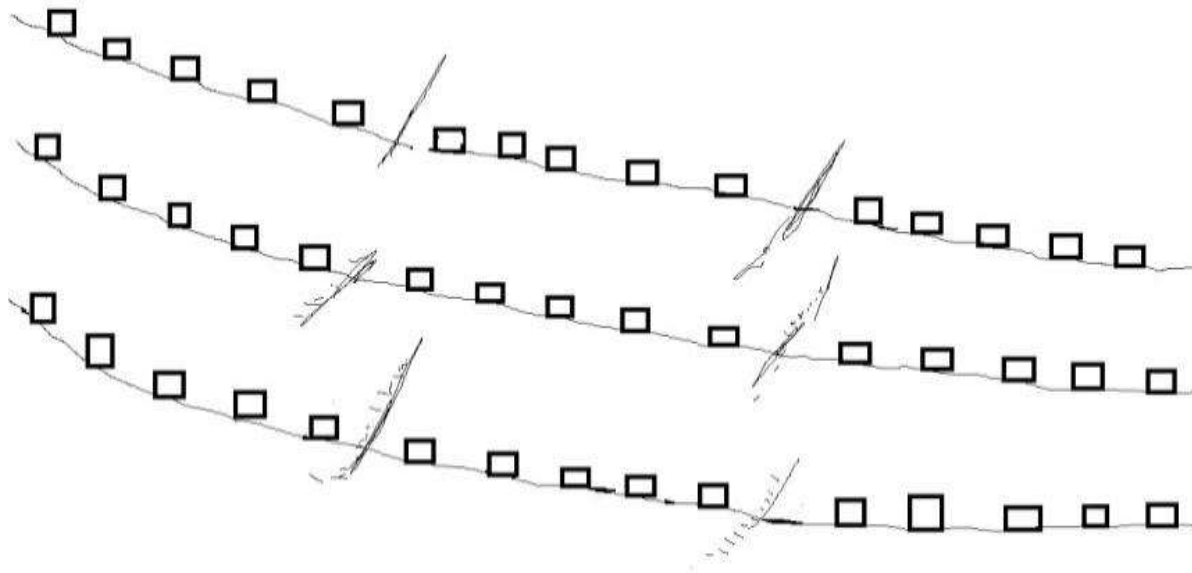


Figure 3. Field plot layout of the experimental site. Transects at 10x10 m were allotted for quadrant tree seedling sampling; quadrants were sampled at the three within each plot or slope classes with five respective replications. NB: Plots or slope classes orientation (the 30 m side of the plot always runs from South to North or vice versa and the 40 m side of the plot always runs from East to West or vice versa to make all plots arrangement uniform).

1965), while bulk density was determined by core method (Blake, 1965). A known volume of core sampler with a radius of 2.983 cm was used for determination of soil bulk density for the three depth levels, that is, 0-10, 11-20 and 21-30 cm. When the intended depths were attained, the soil core was pulled out of the soil with care and then struck by a rubber hammer that does not harm the coring ring to release the soil contained in the soil core into a bucket. Soil core sampling was done from five points per plot and then the soil samples from the five points were composited to represent a plot according to their respective depths. The composited soil samples by their depths were then oven dried at 105°C for 24 h. Bulk density was finally calculated as the ratio of the mass of oven dried soil sample to its core volume.

Methods of data analysis

The survived seedling was calculated as the proportion of surviving trees to total number of trees of the same species planted in the enclosure parts of different *in-situ* rainwater harvesting structures. Plot means for three variables were calculated. Treatment comparisons of means were made at 5% level of significances using Least Significant Difference test (Steel and Torrie, 1980), independently and dependently. Independent analyses were executed for tree survival in different *in-situ* rainwater harvesting and then combined analysis was done to observe if there is significant variation between slope classes in relation to planting techniques. The tree seedling survival and soil attributes data were analyzed using the statistical analysis system (SAS, 2002). The analysis of variance (ANOVA) was attributed to all data that were generated from tree seedling survival and Least Significant Difference (LSD) test with $p < 0.05$ employed for mean comparison. The data that was generated from soil attributes were analyzed as 3x3 factorial experiments with RCBD using SAS (SAS, 2002); the three *in-situ* rainwater harvesting method practices and three levels of slope classes were used as the two factors with both three levels, respectively. The model included the effect of *in-situ*

rainwater harvesting methods, slope classes and their interactions.

RESULTS AND DISCUSSION

The role of *in-situ* rainwater harvesting methods on tree seedling survivals

The impacts of selected conservation devices, namely, infiltration pits, semi-circular bunds and level soil bund embankments on moisture availability across the slope classes were evaluated indirectly using some indicators. Different grass regeneration and maintaining around structures, namely, infiltration pits and level of soil bund as well as transplanted tree seedlings alive are excellent indicators of moisture availability (Figure 4). This finding supports Abraham (2014) who reported that the effects of moisture stress account for more than 87.9% in the death of tree seedlings. In similar ways, the moisture stress commonly limits growth, survival and distribution of tree seedlings (Warren et al., 2005). These reduced soil moisture conditions may be viewed as a significant barrier to artificial reforestation (Padilla and Pugnaire, 2007).

The ANOVA revealed that the interaction of seedling survival with planting methods was found to be insignificant ($P > 0.05$), particularly, in half-moon and infiltration pits implemented in enclosure parts of the study area. The main effect of moisture conservation structures on conserving and storing moisture was not significant except level soil bund embankment (Table 1). Because, in embankment, tree seedling raised at nursery



Figure 4. Tree seedling survived in (a) pits and (b) level soil bund embankments.

Table 1. Mean survival (%) of the tree seedling in different planting methods at three slope classes at enclosure parts of Gerduba watershed.

Planting method	Mean survival (%) of tree seedlings at different slope classes		
	Slope class (0-5)	Slope class (6-10)	Slope class (>10)
Infiltration pits	66.53 ^a	46.13 ^a	28.80 ^a
Half-moon	66.53 ^a	42.60 ^{ab}	25.67 ^a
Level soil bund embankment	55.47 ^b	41.80 ^b	20.40 ^b
CV (%)	12.39	12.40	22.86
P- value	0.0003	0.0760	0.0009

Means in columns with the same letters are not significantly different.

site transplanted to the embankment of structures, that is, on the dig out soils. The finding confirmed the previous finding of Malik and Bhatt (2016) who concluded that the amount of moisture conserved in soil profile mostly influenced by type and design of *in-situ* rainwater harvesting devices. In order for the moisture to be conserved in the structure, which is not nearby to the transplanted seedling roots, as a result needs more energy to absorb weak and short rooting system. The finding is in line with the previously stated from some scholars which indicated that the major limitations of plantation survival are soil nutrients and moisture availability within the rooting zone and a planted seedling's ability to access it (Grossnickle, 2005). On the other hand, level of soil bund embankment covers a large open space exposed to sunlight for more evaporation than infiltration pits and half-moon conservation methods. Moreover, reduced precipitation combined with evaporation commonly decrease soil moisture in the upper soil profile to below the requirement for seedlings to easily access (Warren et al., 2005).

With respect to planting methods, species planted, that is, *Grevillea robusta* in pit and half-moon pits relatively highly survived when compared with soil bund, respectively (Figure 5). This is in line with the previous findings of Malik and Bhatt (2016) that as shape and design of conservation methods have contributed to the establishment of seedlings. In similar way, Boers and

Ben-Asher (1982) suggested that poor tree seedling establishments are related to an insufficiency of moisture available within rooting zone rather than to an insufficiency of rainfall.

Pits and half-moon showed good performance at bottom parts, while soil bund embankments are relatively least performed at bottom parts (Table 1). The finding strengthens the report that seedling survival and establishment is significantly decreased from lower slope gradient to upper (Yu et al., 2013). The previous study stated indicated that the efficiency of conservation method in conserving and storing rainwater for the dry season is determined by its depth, design and slope position (Hudson, 1987; Hatibu et al., 2001). Pits attain significantly higher performance at both 0 - 5 and >10% slope position where the soil is relatively better in moisture status and infiltration capacity as compared to half-moon and level soil bund embankments, respectively. Although the ANOVA reveals that there was no significant difference in survival (%) of seedlings with respect to planting methods during the assessment periods, the mean survival of seedlings planted in half-moon (41.80%), infiltration pit (46.13%) and level of soil bund embankment (42.60%) at 6-10% slope classes (Table 1). But there was significant difference in survival % of *Grevillea robusta* species at >10% slope classes for the mean survival of seedlings planted in half-moon (25.67%), infiltration pit (28.80%) and level soil bund

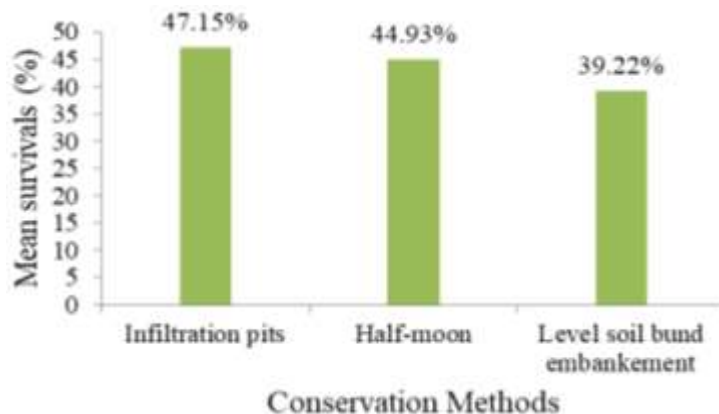


Figure 5. Total mean seedling survival (%) comparison between selected *in-situ* rainwater harvesting structures.

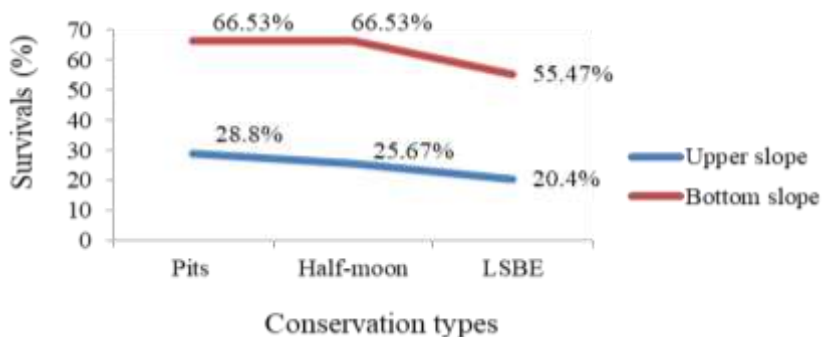


Figure 6. Mean seedling survival (%) comparison in *in-situ* structures at bottom and upper slope classes.

embankment (20.40%).

At bottom parts of the catchments, 66.53, 66.53 and 55.47% of tree seedlings survived in infiltration pits, half-moon and level soil bund embankments, respectively (Figure 6). In contrast, 28.80, 25.67, and 20.40% tree seedlings survived at upper parts in infiltration pits, half-moon and soil level bund embankments, respectively. This explains that almost all *in-situ* rainwater harvesting structures play a crucial role at bottom rather than middle and upper parts of the catchment. This finding was in congruent with previous results of Daws et al. (2002) that slope site with an upslope area is a niche that could contribute to the translocations of essential soil nutrient and moisture while plateau sites had no upslope area, so the water standing is very important for tree seedling survival.

During the assessment of quadrant, the mean tree seedling survival in infiltration pits increases from lower to upper, namely, in quadrants 8 and 15 within slope class III (Appendix Table 1). For reason that, there was stoniness in planting structures and additionally might be from inappropriate seedling plantation due to

carelessness during site selection and seedling roots pruning. This is in agreement with Wolancho (2015), who pointed out that under lack of appropriate structure site selection, design and spacing, appropriate tree species selection resulted in poor seedling survival rate (<5%) observed in micro-watersheds.

The mean seedling survival in level soil bund embankment showed highly significant difference at ($p < 0.01$) in the bottom part with that of upper part (Appendix Table 2). Even if the conserved and stored moisture and nutrients are far from transplanted seedling roots, it stay prolong for infiltration which might be easily accessible for seedling roots at bottom parts. Similarly, moisture and soil nutrients availabilities are the potential sources of spatial heterogeneity in micro-environment to maintain tree seedling survival (Denslow et al., 1990; Pacala et al., 1994). Tree seedlings survived in bottom parts where the soil is relatively better in moisture status and infiltration as compared to upper slope classes. This supports the previous results of Gebretsadik (2009) who reported that most tree species planted to rehabilitate degraded lands are restricted to gentler slopes, and

Table 2. Means of soil physical parameters across soil depths and slope class of area enclosure with selected (IRWH) practices.

Parameter	Soil depths			±SE	P-value
	0-10 cm	10-20 cm	20-30 cm		
Clay (%)	33.17 ^b	36.3 ^{ab}	40.33 ^a	1.56	0.048
Sand (%)	54.17 ^a	48.17 ^b	46.83 ^b	0.987	0.0042
Silt (%)	12.67 ^a	15.5 ^a	12.83 ^a	0.97	0.15
Bulk density (g/cm ³)	1.46 ^c	1.56 ^b	1.66 ^a	0.01	0.0001
Parameter	Slope classes			±SE	P-value
	Upper	Middle	Bottom		
Clay (%)	25.3 ^b	44.0 ^a	40.5 ^a	1.53	0.0003
Sand (%)	65.33 ^a	43.5 ^b	40.3 ^b	2.09	0.0003
Silt (%)	9.33 ^c	12.5 ^b	19.17 ^a	0.81	0.0004
Bulk density (g/cm ³)	1.64 ^a	1.54 ^{ab}	1.49 ^b	0.034	0.045

Means with the same letter superscripts across the rows of each respective factor that is soil depths and slope classes in area enclosure with selected *in-situ* rainwater harvesting practices are not significantly different at 0.05 and/or 0.01 level of significance. SD: Soil depth, ns: non-significant at 0.05 and/or 0.01 level of significance, SE: standard error of the mean.

survival increased in planting pits compared to a significant decline on steep slopes. Because, the infiltration pits conserve and store moisture at <10% slope efficiently due to the fact that there is no variation in moisture availability across the slope. However, half-moon is performs well in conserving moisture at bottom parts than middle and upper parts of the catchment, respectively (Appendix Table 2).

There is a significance difference in seedling survival in half-moon at $p < 0.05$ between bottom and upper parts and significant differences at $p < 0.05$ between middle and upper parts of the catchment (Appendix Table 2). This is because the direct rainwater harvested from the whole corners was collected at the center bottom embankment parts structures. Though, slope position suitability is the most determinant for efficiently conserving of moisture in half-moon. Due to slope gradient, the moisture gets very close to embankment as a result, high probability of absorption and lateral water movement of moisture to unusable by seedling. Similar evidence from Burkina Faso (Zougmore et al., 2003) suggested that the soil moisture and nutrients increases significantly below half-moon. Moreover, successful tree seedling establishment and growth mostly depends on the stored moisture in the structures to ensure survival of tree seedlings into the next growing session.

The important factors determine *in-situ* rainwater harvesting efficiency

Soil texture

Analyzed soil texture data across depths and slope

classes of area closure with selected conservation devices are shown in Table 2. Different plant seedlings have adaptations to and preferences for specific soil types and the distribution of tree seedling survival is often associated with soil properties or moisture with more seedlings survives on sites of the greater nutrient or water availability (Furley, 1992). For instance, this study indicated that the soil textural classes for bottom and middle parts in area enclosure were almost similar which is predominantly sandy with clay contents ranging mostly from 40.5 to 44% clay. However, the textural class for the upper of the area enclosure with some *in-situ* rainwater harvesting methods was classed under sandy-clay loam as depicted in Appendix Table 3. Hence, the textural classes of the study soil were influenced by the topographical position though the influence was not pronounced between bottom and middle parts of the enclosure (Table 2).

The variation in soil texture of the experimental sites indicates that soil texture can play a role in determining moisture availability which is very important for seedling survival in a certain region. This soil texture in turn could be influenced by *in-situ* rainwater harvesting devices and slope gradient. The finer textured soils are usually higher in bases and provide a favorable nutrient supply for vegetation. The sandier soils are usually deeper and provide a more favorable root zone for tree seedlings (Troeh and Thompson, 1993). The contents of silt, clay and sand contents of the different topographic positions indicate that the soil is derived from different parent materials which results in geological differences in the study area. So, water holding capacity also varies with different parent materials.

The topographic position through its effects of exposing

land to agents of erosion has an impact on variation in soil texture classes. Silt and clay size particles are more easily removed by agents of erosion than sand particles. High sand and low contents of clay and silt can therefore be expected in erosion susceptible parts of slope classes. As it was depicted in Table 2, there were increment in percentage of silt and clay from the upper parts through enclosure to bottom area enclosure with selected IRWH practices. The low percentage of silt and clay in the upper parts might be due to the processes of erosion as a result of natural slope gradient which in turn affects IRWH efficiencies in conserving and storing moisture.

Bulk density

Bulk density ranged from 1.64 g/cm³ in the upper part of the catchment to 1.49 g/cm³ in the bottom enclosure parts (Table 2). The three slope gradient classes were almost significantly influenced ($p < 0.05$) by soil bulky density. The highest bulk density achieved for the upper parts might be due to risks of soil erosion and only left with very firm or compacted cobbles.

The higher values of soil bulk densities for upper parts areas relative to those of middle and bottom might be due to the lowest incorporation of organic carbon as also reported by Pande and Yamamoto (2006). Loss of vegetative and litter cover coupled with rangeland degradation allows direct impact of rain drops on upper parts, resulting to enhanced splash impacts, crust formation, surface sealing, and may also produce hydrophobic substances that can reduce water infiltration into soil (Stavi et al., 2008). This finding is also in accord with the results of Assefa (2004), who concluded that lands with a higher bulk density more than 1.6 g/cm³ are not at acceptable level for plant root development.

Conclusion

It can be concluded from this study that conservation methods are the most important in conserving and storing soil moisture as well as soil nutrients. It acts as a supplemental moisture and soil nutrients for vegetation growth and survival. Thus, it has a potential to form a chief component in the rehabilitation of degraded land and forest establishment. Particularly, *in-situ* rainwater harvesting devices are an important way in facilitating favorable conditions for plant growth as well as tree seedling survival in moisture stress areas. The main effect of conservation structures on conserving and storing moisture was not significant except level soil bund embankment. Because the moisture conserved in level soil bund is far from seedling roots which is below the requirement for seedlings to easily access.

Tree seedlings survived in bottom parts where the soil is relatively better in moisture and soil nutrient status as compared to upper slope classes. Natural slope gradient

Determines soil physical properties which in turn determine the conservation structures efficiencies. Almost all *in-situ* rainwater harvesting methods play a crucial role in conserving and storing moisture and soil nutrient at the bottom part rather than middle and upper parts of the catchment. Based on the findings of the study, it is recommended that future research and development studies and activities need to focus on the following recommendations. For the best results of tree seedling survival, the moisture conservation suitability evaluation should be carried out for slope, type and runoff storage capacity before transplanting. Further investigation should be carried out on the factors contributing to low seedling survival and appropriate techniques tested in order to recommend appropriate management interventions for tree seedling survival in moisture-stressed areas.

CONFLICT OF INTERESTS

The author has not declared any conflict of interest.

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