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Investigation of Moisture Collection Structures and Introduction of Resistant Tree Species in the Semi-Arid Slopes of Tigray, Ethiopia

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Vegetation cover degradation is a serious problem in low-rainfall areas of Ethiopia. A field experiment was carried out for three years on two degraded hillsides in Kilte Awlaelo district, Tigray, Ethiopia. The objective was to evaluate the effect of moisture harvesting structures on the survival and growth of tree seedlings. The treatments were micro basin, micro trench, eyebrow basin, and conventional pit as moisture harvesting structures combined with three multi-purpose tree seedlings, namely, *Schinus molle, Grevillea robusta*, and *Olea europaea*. The set-up was a split-plot design with three replications. Seedling survival, plant height, and collar diameter data were collected. The collected data were analyzed using GenStat 16 edition software by general liner model. Statistically significant differences between and among treatment means were

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assessed using the least significant difference (LSD) at the 5% level of significance. The results in the main effect showed eyebrow basin > micro basin > micro trench > conventional pit in the upper site, and micro basin > eyebrow basin > micro trench > conventional pit in the lower site in their order of level of significance in enhancing the seedlings survival and growth performance. The interaction effects also showed *Schinus molle* backed with an eyebrow and micro-basin in the above structure pit position had the highest survival rate and growth performance. Hence, the eyebrow basin and micro basin as moisture harvesting structures planted with *Schinus molle* tree species at the above pit position should be demonstrated and scaled up in moisture-stressed areas of Kilte Awlaelo district.

Keywords: Moisture harvesting structure; tree species; seedling survival; growth performance.

1. INTRODUCTION

Arid environment constitutes a large part of the globe and suffers from various degrees of land degradation with dry hydro-climate; where water is a limiting factor for biomass production, combined together with fragile and inherently less fertile soils [1,2]. The main source of livelihood in arid environments, is generally linked to poor management of water resources and exploitation of vegetation cover which is one of the major constraints of eastern and central African [3]. In the Sahelian zone, more than 90% of the population depends on land resources for their livelihood [4]. The combined effects of physical, chemical, and biological processes and human activities result in land degradation [5]. According to Yirdaw et al. [6] land degradation is a serious problem affecting 1.5 billion people globally.

Ethiopia as part of the globe, land degradation has been widespread and affecting people’s livelihoods through limiting agricultural production, wood biomass and various ecosystem goods and services [7-8]. The major ecological problems in Ethiopia are forest degradation and soil erosion [9-11]. To alleviate forest degradation and deforestation, seedling plantation-based landscape restoration were practiced using appropriate tree and shrub species, as an important solution in the tropical ecosystem rehabilitation options [12,13]. In-situ rainwater harvesting supported seedling plantation is recommended to enhance water infiltration and reduce runoff so as to increase seedling survival and growth performances [14,15]. Vegetation establishment on degraded lands are constrained by insufficient moisture availability as the main constraint [16-18]; as a result, survival and growth of seedlings are influenced by season [19] since the principal limiting factor controlling the growth and survival of tree seedlings is moisture.

To redress the low survival and growth performances of planted seedlings, integration of moisture harvesting structures have been practiced in dryland areas [20,21]. Physical soil and water conservation structures such as micro basin, eyebrow basin, micro trench, herring bones etc. are classified as conservation structures for collecting, storing and spreading various forms of runoff from different sources used to enhance agro-forestry, forage development and forestry [22]. The function of physical soil and water conservation is to protect erosion and to harvest moisture [23]. Moisture harvesting soil and water conservation structures help to reduce velocity of runoff and collect water behind the structures and the stored water facilitates plant growth and improves vegetation cover in dryland areas [24,25]. However, the choice of moisture harvesting structures for best seedling survival and growth performances has not been identified through research and remain a key challenge in implementing suitable moisture harvesting structures in degraded land rehabilitation efforts [26]. Evaluating different moisture harvesting structures to enhance planted tree seedlings survival and growth performances are crucial in degraded hillsides. Therefore, an experiment was conducted aimed at evaluating different moisture harvesting structures and their pit positions on survival and growth of different multi-purpose tree seedlings in Kilte Awlaelo district of Tigray region Ethiopia.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study area Kilte Awlaelo is found in Tigray, Ethiopia (Fig. 1). Kilte Awlaelo is geographically located at about 45 km north of Mekelle the capital of the Tigray region at a distance of 898 km from Addis Ababa to the northern Ethiopia and found in 13° 30' to 13° 59' N latitude and 39°

20’ to 39º 40’ E longitude. The experimental site is found at an elevation of 2081 ma.s.l in the Upper slope and 2021 ma.s.l in the lower slope.

The Agro-climate classifications of Kilte Awlaelo district is characterized as highland with an average annual temperature of 20 °C and the annual rain fall ranges from 350-400 mm (Fig. 2). The rain fall pattern of the study area is characterized as mono-modal and start rainfall on the middle of June and lasts at early September [27]. Concerning the hydrological aspects there are many seasonal rivers in the district, which flow to Tekeze River basin and Afar basin and have moderately hot temperature from the end of February to the end of May [28].

2.2 Experimental Design

The experiment was conducted for three years from 2017 to 2019, in a split plot design with three replications moisture harvesting soil and water conservation structures was assigned as main plot and tree seedlings as subplots. Four plots of each 13 × 14 m (182 m^2 area) was laid in two sites as upper site and lower site at 17% slope gradient. Three moisture harvesting structures and one conventional plantation pit as control and three tree seedlings in each site were included. The seedling plantation pit positions in case of micro basin and eyebrow basin are above the structure and below the moisture harvesting structure; whereas the pits positions in the micro trench are inside the moisture harvesting structure, below the moisture harvesting structure and between the two moisture harvesting structures. The control pit is the conventional pit with no moisture harvesting structures around. The soil type of the study area is classified as Leptosols [29].

2.3 Treatment Description

The treatments and treatment set up are presented in Table 1. Micro basins, micro trenches, eyebrow basins and conventional pit were used as moisture harvesting structures. The tree seedlings were *S. molle*, *Grevillea robusta* (*G. robusta*) and *Olea europaea* (*O. europaea*) planted in each plot at the starting of the rainy season in June 2017. Seedlings of 45 cm average height and 0.40 cm mean collar diameter was used. Spacing between seedlings and was dependent on the type of structure and tree seedlings.

2.4 Moisture Harvesting Structures

Three moisture harvesting structures were carefully selected based on the community based participatory watershed development guideline ministry of agriculture of Ethiopia [22]. The specification and design of the structures used for evaluation in the study area are described below:

Micro basins: Are small circular and stone-faced structures for tree seedling planting. Its dimension was 2.50 m diameter, 40 cm height, 20 cm depth at the base of the structure with 40 cm diameter and 50 cm depth of plantation pit. This is suitable for medium and slightly low rain fall areas, stony areas and shallow soils. Also applicable in steep and degraded hillsides.

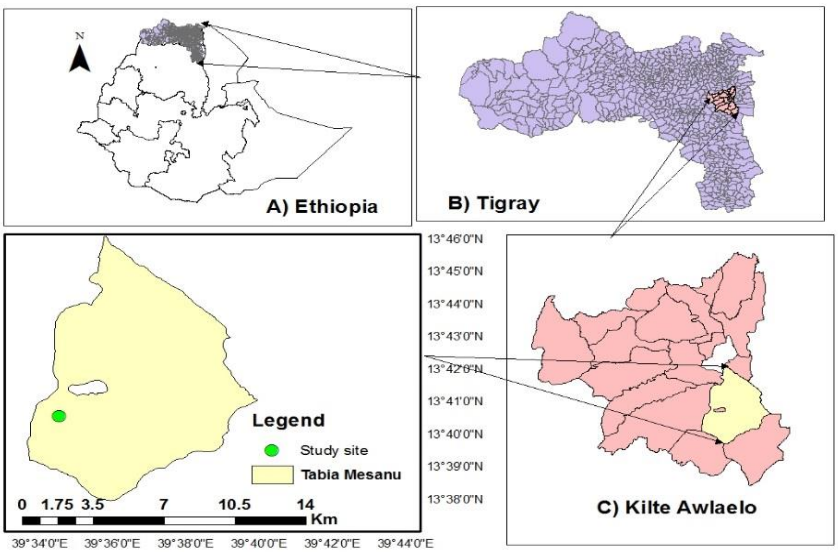

Fig. 1. Study area

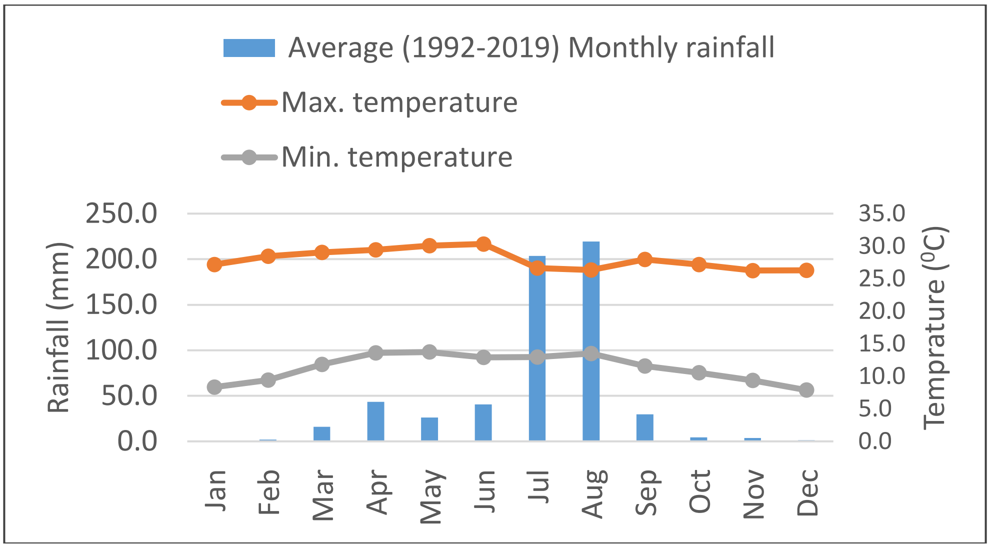

Fig. 2. Monthly average rainfall (mm) and temperature (°C) of 27 years

Table 1. Description of the treatments

Moisture harvesting SWC structures	Pit position	Tree species	Treatments
Micro basin (Mb)	Above structure (As)	*G. robusta* (Gr)	MbAsGr
		S. molle (Sm)	MbAsSm
		O. europaea (Oe)	MbAsOe
	Below Structure (Bs)	*G. robusta*	MbBsGr
		S. molle	MbBsSm
		O. europaea	MbBsOe
Micro trench (Mt)	Inside structure (Is)	*G. robusta*	MtIsGr
		S. molle	MtIsSm
		O. europaea	MtIsOe
	Between structure (Bts)	*G. robusta*	MtBtsGr
		S. molle	MtBtsSm
		O. europaea	MtBtsOe
	Below structure (Bs)	*G. robusta*	MtBsGr
		S. molle	MtBsSm
		O. europaea	MtBsOe
Eyebrow basin (Eb)	Above structure (As)	*G. robusta*	EbAsGr
		S. molle	EbAsSm
		O. europaea	EbAsOe
	Below structure (Bs)	*G. robusta*	EbBsGr
		S. molle	EbBsSm
		O. europaea	EbBsOe
Conventional pit (Cp)	Inside the pit (Ip)	*G. robusta*	CpIpGr
		S. molle	CpIpSm
		O. europaea	CpIpOe

Micro trenches: These were rectangular structures with 40 cm depth, 300 cm length, 40 cm width constructed along the contours. The length of the tie within the structures was 50 cm with 40 cm diameter and 50 cm depth plantation pit. This can support the growth of tree seedlings and applicable in a broad range of soils and slopes.

Eyebrow basins: Eyebrow basins are recommended on hillsides where stone is available. The height of the structure was 40 cm, diameter 250 cm and the depth or base of the structure was 30 cm with water collection area of 100 cm length x 100 cm width x 25 cm depth. The plantation pit was 40 cm diameter and 50 cm depth (Fig. 3).

Conventional Pit: Following the contour line the normal plantation pits was constructed with a dimension of 40 cm diameter and 50 cm deep. The pits were spaced at 300 cm between plants and lateral differences.

2.5 Tree Seedling Selection

Three tree seedling types were selected based on the local community preference and considering the indicators of ecological suitability, protection functions and socio-economic functions of the species. Based on Orwa et al., [30] the selected species have the following characteristics:

Grevillea robusta:

G. robusta R. Br. is a Proteaceae family which reaches up to 30 m tall. It is a very successful Australian tree planted and widely used in dry, moist and wet mid highland and highland agro climatic zones.

Olea europaea:

O. europaea is from Oleaceae family with 10-15 m height. It is widely distributed in dry forest in east Africa and Ethiopia. It is best in good forest soil, but hardy and drought resistant once established, even in poor soils. The species is found in moist and wet mid highland and highland agro climatic zones in all regions 1, 400-3,100 ma.s.l.

Schinus mole:

According to Orwa et al. [30] *S. molle* is an evergreen tree with 3-15 m height and tolerates high temperatures and once established is extremely drought resistant. It is shallow rooted and can be brittle and broken by strong wind. It grows in altitude zero to 2400 ma.s.l with mean annual temperature 15-20 ^{0}C., mean annual rainfall 300-600 mm and it prefers well-drained sandy soils.

2.6 Data Collection

Data on planted seedling survival, plant height and collar diameter were collected at the end of the rainy season for three consecutive years. However, only the third year data are used for this article.

2.7 Statistical Analysis

The collected data were analyzed using GenStat16 edition [31] software by general linear model multiple comparison with Fisher's protected least significant difference (LSD). Statistically significant difference between and among treatment means were assessed using at LSD 5% level of significance [32].

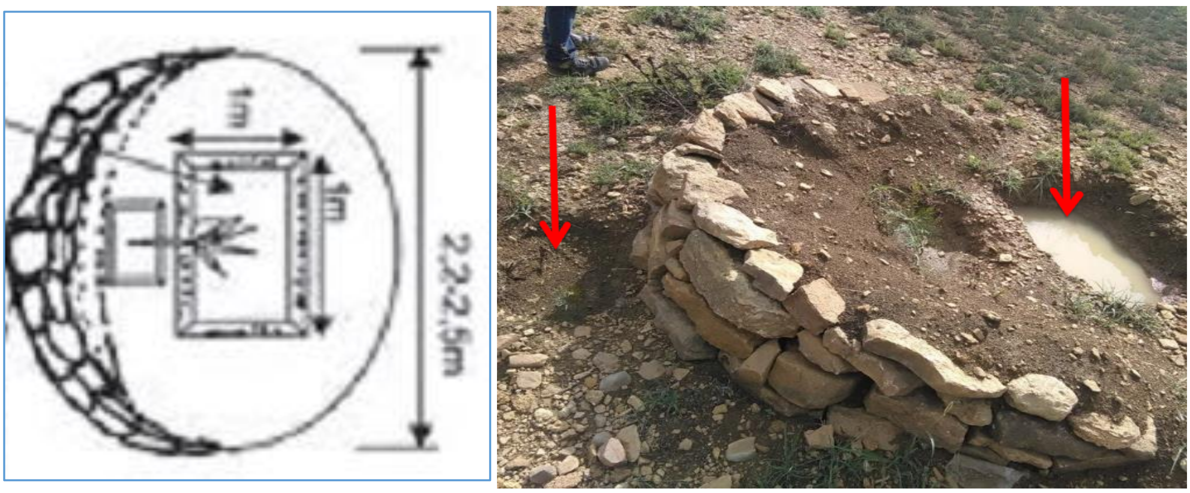

Fig. 3. Design and constructed eyebrow basin structure

3. RESULTS AND DISCUSSION

3.1 Contribution of Moisture Harvesting Structures on Seedling Survival

The planted seedling survival rate in percent due to the moisture harvesting structures both in the upper and lower sites are presented in Fig. 4. The lower site performed higher seedling survival rate as compared to the upper site. The result showed that all moisture harvesting structures at the lower site have higher seedling survival than the upper site, but in the upper site there was even a complete loss of the seedling at the conventional pit (control). This result supports to the findings of Daws et al. [33] who reported that bottom site area showed better seedling survival on similar moisture harvesting structures of plantation than upper site. The reason they forwarded was that nutrient and moisture could be translocated to the bottom site, so that water and nutrient was very important for tree seedling survival. As discussed by Yu et al. [34] seedling survival was significantly increased from upper to lower along slopes. Therefore, the collected water helped the seedlings to get more moisture compared to the upper site.

Generally, the moisture harvesting structures showed highest seedling survival than the conventional pit in both the upper and lower sites. This result was in line with the findings of Eyasu et al. [21] who found seedlings planted in moisture harvesting structures survived better compared to the conventional pit. Other authors also reported almost all moisture harvesting structures play a crucial role in conserving and storing moisture [35] and have a significant impact on seedling survival [36] on degraded lands.

3.2 Tree Survival (%) in the Area

Fig. 5 shows the survival of tree seedlings both in the upper and lower sites. The ANOVA results of the seedling survival showed significant ($p < 0.05$) difference in both the upper and the lower sites. *S. molle* showed the highest survival rate both in the upper and the lower sites. The lower site performed higher seedling survival rate as compared to the upper site. Therefore, the best tree survived for the area was *S. molle* compared to *G. robusta* and *O. europaea*. According to the authors like Orwa et al. [30] *S. molle* survived better than *G. robusta and O. europaea* in moisture stressed areas.

3.3 Interaction Effect of Moisture Harvesting Structures and Tree Species on Seedling Survival

Table 2 shows the survival rate of different tree species in percent due to the moisture harvesting structures both in the upper and lower sites.

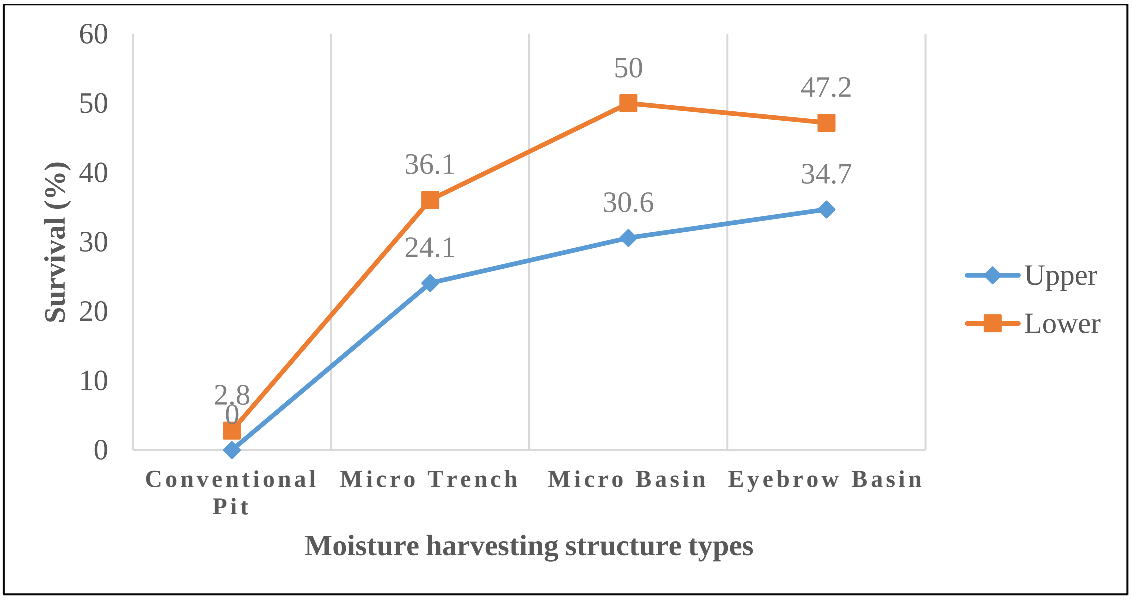

Fig. 4. Average seedling survival (%) comparison in moisture harvesting structures

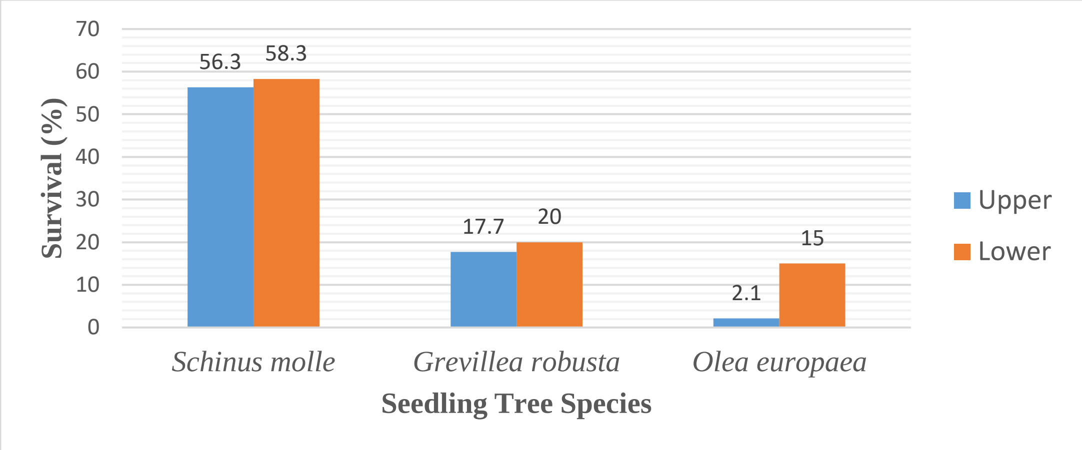

Fig. 5. Average seedling survival (%) comparison of tree species

The tree seedling survival was highly significantly ($p < 0.01$) affected by the main effect moisture harvesting structures and tree species both in the lower and the upper sites. Survival rate was also significantly ($p < 0.05$) affected by the treatments as a result of the interaction effects of small moisture harvesting structures and tree species. The interaction effect between moisture harvesting structures and tree species was highly significant ($p < 0.01$) in the lower site, while in the upper site, it reached significance at ($p < 0.05$). Even though, moisture harvesting structures generally helpful for seedling survival and enhance tree growth [37]; there was a specific structure for a specific tree species. The highest survival rate was recorded in *S. molle* tree species at eyebrow basin and micro basin moisture harvesting structures. This result strengthens to the findings of Derib et al. [26] who found eyebrow basin and micro basin moisture harvesting structures the best solution for dry spell mitigation and enhance the overall seedling performance. Singh, [38] also proved efficiency of moisture harvesting structures varied for the survival, growth, and productivity of seedlings.

O. europaea was totally dried in the upper site in the moisture harvesting structures and the control except in the micro trench. The reason why *O. europaea* survived in micro trench was due the volume of water harvested in the micro trench (0.48 m^3) which was wider than the other structures. However, this trench has also a side effect for seedling survival due to water logging effect for seedlings such as *S. molle* and *G. robusta.* This shows *O. europaea* was less tolerant to moisture stress but tolerant for water logging (personal observation) compared with *S. molle* and *G. robusta* with no moisture harvesting structures. Unfortunately, all three types of seedlings planted in the conventional pit completely dried out in the upper site. This result strengthens to the findings by Siraj et al. [39] who found planted seedlings in moisture harvesting structures survived well; whereas seedlings planted in a conventional pit dried out after four years. Similarly, *G. robusta* and *O. europaea* dried out totally but *S. molle* survived only 8.3% in the lower site. As Abdella and Cheneke, [40] proved *G. robusta* showed the least survival rate and performance as compared to *Moringa oliefera,* and *Susbania sesban* after three years of establishment in Ethiopia.

3.4 Effect of Pit Position of Moisture Harvesting Structures on Seedling Survival (%)

The results of the survival of different tree species due to the pit position on the moisture harvesting structures both in the upper and lower sites are presented in Table 3. The interaction effect of tree species and pit position was highly significantly ($p < 0.01$) affected in seedling survival among the tree species in the different moisture harvesting structures' pit position both in the lower and the upper sites except the eyebrow basin in the lower site. Both in the micro basin and eyebrow basin moisture harvesting structures the above structure pit position of the upper site significantly ($p < 0.05$) affected in *S. molle*. Hence, *S. molle* survived better in the above and below micro basin and eyebrow basin structure's pit position. The lowest seedling survival was recorded in the convectional pit and micro trench. From this result it can be concluded that *S. molle* seedling has either the ability to absorb by its roots the moisture harvested all around the moisture harvesting structures stored by micro trench, eyebrow and micro basin structures without preferring the pit position, or it was moisture stress tolerant tree. However, in case of *G. robusta* tree seedlings, it is better to plant on the pit above the eyebrow and micro basin moisture harvesting structures both in the upper and lower sites. Tadele et al. [35] reported that a weak and short rooting system is unable to absorb conserved moisture from a distance far from seedling roots. They consequently recommended planting seedlings with longer roots to effectively absorb the stored water.

3.5 Contribution of Moisture harvesting Structures on Seedling Growth

The growth of tree seedling due to the moisture harvesting structures both in the upper and lower sites of the third year are presented in Table 4. The height and diameter increment of the seedlings in different moisture harvesting structures in the third year were highly significantly affected in the upper site at ($p < 0.01$). Similarly, height showed significant ($p < 0.05$) difference in the lower site. However, there was no significant ($p > 0.05$) difference in diameter in the lower site. The significant differences were observed mainly between the moisture harvesting structures and the conventional pit, but there were no as such significant difference among the moisture harvesting structures in seedlings growth.

The better growth performance on the moisture harvesting structures was due to the moisture advantage collected by the water collection ditch of the moisture harvesting structure (see section 2.3). Therefore, the water collection ditch helped the seedlings to get more moisture advantage to grow better. So many authors [21,36,41] proved the advantage of moisture harvesting structures on tree seedling growth. Generally, the lower site showed better height and diameter increment of seedlings compared to the upper site. It was expected that if there was no moisture stress in the area, there could have not been significant difference on the tree seedling growth. That is why the no significance difference in the lower site in case of diameter due to the presence of better moisture compared to the upper site, because of the wider catchment area to harvest the overtopped runoff from the upper site's structure.

3.6 Interaction Effect of Moisture harvesting Structures and Tree Species on Seedling Growth

Table 5 shows interaction effect of the different moisture harvesting structures and tree species on height and diameter of the different seedlings both in the upper and lower sites. The plant growth parameters such as plant height and plant diameter were significantly ($p < 0.05$) affected by the treatments as a result of the interaction effects of moisture harvesting structures and tree species (MHS × Tree sps) in the upper site. However, the interaction effect in the lower site was highly significantly ($p < 0.01$) affected by the treatments as a result of the interaction (MHS X Tree sps) effects of moisture harvesting structures and tree species.

Table 2. Moisture harvesting Structures with tree species on seedling survival (%)

MH Structures	Tree species	Treatment	Upper	Lower
Micro basin	*G. robusta*	MbGr	25.00^{c}	37.5^{c}
	S. molle	MbSm	66.67^{ab}	91.7^{a}
	O. europaea	MbOe	0.00^{d}	20.8^{de}
Micro trench	*G. robusta*	MtGr	13.89^{cd}	16.7^{de}
	S. molle	MtSm	52.78^{b}	69.4^{b}
	O. europaea	MtOe	5.56^{d}	22.2^{d}
Eyebrow basin	*G. robusta*	EbGr	25.00^{c}	37.5^{c}
	S. molle	EbSm	79.17^{a}	83.3^{ab}
	O. europaea	EbOe	0.00^{d}	20.8^{de}
Conventional pit	*G. robusta*	CpGr	0.00^{d}	0.0^{f}
	S. molle	CpSm	0.00^{d}	8.3^{ef}
	O. europaea	CpOe	0.00^{d}	0.0^{f}
Significance (p=0.05)	MH structure (MHS)		**	**
	Tree species (Tree sps)		**	**
	MHS X Tree sps		*	**

*Note: Means with the same letter across column of the treatments are not significantly different at p < 0.05, * = significant (p < 0.05), ** = highly significant (p < 0.01), MH= Moisture Harvesting*

Table 3. Average seedling survival (%) on moisture harvesting structure's pit position

Tree species	Pit position	Micro basin		Eyebrow basin	
		Upper	Lower	Upper	Lower
G. robusta	Above	33.3^{b}	50.0^{b}	41.7^{c}	50.0^{bc}
	Below	16.7^{c}	25.0^{c}	8.3^{d}	25.0^{cde}
	Control	0.0^{d}	0.0^{e}	0.0^{d}	0.0^{e}
S. molle	Above	91.7^{a}	91.7^{a}	91.7^{a}	91.7^{a}
	Below	41.7^{b}	91.7^{a}	66.7^{b}	75.0^{ab}
	Control	0.0^{d}	8.3^{de}	0.0^{d}	8.3d^{e}
O. europaea	Above	0.0^{d}	25.0^{c}	0.0^{d}	33.3^{cd}
	Below	0.0^{d}	16.7^{cd}	0.0^{d}	8.3^{de}
	Control	0.0^{d}	0.0^{e}	0.0^{d}	0.0^{e}
Significance (p=0.05)	Pit position (Pit p)	**	**	**	**
	Tree species (T sps)	**	**	**	**
	Pit p X T sps	**	**	**	*

Tree species	Pit position	Micro Trench	
		Upper	Lower
G. robusta	Inside	25.0^{c}	25.0^{cd}
	Between	0.0^{e}	8.3^{de}
	Below	13.3^{de}	16.7^{cde}
	Control	0.0^{e}	0.0^{e}
S. molle	Inside	66.7^{a}	83.3^{a}
	Between	50.0^{ab}	50.0^{a}
	Below	41.7^{bc}	75.0^{a}
	control	0.0^{e}	8.3^{de}
O. europaea	Inside	0.0^{e}	25.0^{cd}
	Between	8.3^{de}	33.3^{bc}
	Below	8.3^{de}	8.3^{de}
	Control	0.0^{e}	0.0^{e}
Significance (p=0.05)	Pit position	**	**
	Tree sps	**	**
	Pit p X T sps	**	**

Table 4. Height and collar diameter of seedlings on moisture harvesting structures third year

Moisture harvesting structures	Upper		Lower	
	Height (cm)	Diameter (mm)	Height (cm)	Diameter (mm)
Micro Trench	28.2^{ab}	4.7^{a}	41.3^{a}	8.6
Eyebrow Basin	38.5^{a}	6.3^{a}	44.2^{a}	8.3
Micro Basin	23.0^{b}	3.9^{a}	35.2^{ab}	7.6
Conventional Pit	0.0^{c}	0.0^{b}	18.9^{b}	3.3
P_value (0.05)	**	**	*	ns
CV (%)	14.5	13.1	8.9	7.1

Table 5. Interaction effect of moisture harvesting structures and tree species on plant height and diameter

WH structures X Tree species		Upper		Lower	
		Height (cm)	Diameter (mm)	Height (cm)	Diameter (mm)
Eyebrow basin	*G. robusta*	31.2^{bcd}	4.8^{bd}	27.2^{cd}	4.5^{fg}
	S. molle	65.3^{a}	11.7^{a}	66.8^{a}	11.1^{b}
	O. europaea	19.0^{def}	2.5^{de}	38.5^{bc}	9.5^{bcd}
Micro basin	*G. robusta*	26.2^{cde}	3.3^{de}	25.3^{cd}	4.2^{fg}
	S. molle	35.3^{be}	7.7^{b}	47.0^{b}	9.7^{bcd}
	O. europaea	7.5^{fg}	0.7^{e}	33.2^{bcd}	9.2^{bcde}
Micro Trench	*G. robusta*	27.7^{cd}	4.1^{d}	38.2^{bc}	5.9^{cef}
	S. molle	41.7^{b}	7.7^{bc}	64.7^{a}	15.3^{a}
	O. europaea	15.1^{efg}	2.3^{de}	20.9^{def}	4.8^{f}
Conventional pit	*G. robusta*	0.0^{g}	0.0^{e}	34.0^{bcd}	0.0^{g}
	S. molle	0.0^{g}	0.0^{e}	22.7^{cde}	10.0^{bc}
	O. europaea	0.0^{g}	0.0^{e}	0.0^{e}	0.0^{g}
Significance (p=0.05)	WH structure	**	**	**	**
	Tree species	**	**	**	**
	WHS X Tree sps	*	*	**	**

In the upper site highest plant height and diameter was recorded in *S. molle* tree species at eyebrow basin moisture harvesting structure. Similarly, in the lower site *S. molle* has the highest plant height on eyebrow basin and micro trench but the highest diameter was recorded on the micro trench by *S. molle*. This is in line with the findings of Cheneke et al. [36] diameter of seedlings at breast height grown in micro trenches were significantly higher than those grown in moisture conservation structures conventional pit. Poor growth performance was observed in the conventional pit for all types of the species. The interaction of tree seedling species and moisture harvesting structures showed that those seedlings grown on moisture harvesting structures were significantly thicker and taller than those grown on the conventional pit.; especially *O.europaea* was totally dried in the upper site in the moisture harvesting structures and the conventional pit but *O. europaea* existed in the micro trench in the lower site. Alem et al. [42] found significant increment on diameter and height of *A. saligna* and *C. equisetifolia* on trench supported plantations.

4. CONCLUSIONS

The study revealed that the potential advantages of selected moisture harvesting (micro basin, eyebrow basin and micro trench) types of soil and water conservation structures for the survival and growth of different tree species (*S. molle, G. robusta and O. europaea*) in the Leptosols soil type of degraded hillslopes in Kilte Awlaelo district in eastern Tigray hills. Based on the results of this study the following conclusions can be forwarded. The first part provided the effect of the moisture harvesting structures on the survival rate and growth of tree seedlings. The second part focused on the identification of the best tree species that survived in the area without supporting any moisture-harvesting structures. The third point also identified the best moisture harvesting structure that fits with which tree species for survival and growth rate. The final result discussed is the identification of the effective pit position from the water collection ditch by the structure so that the moisture will be easily accessed by the root hairs of the planted seedlings.

Accordingly, almost all the three moisture harvesting structures have a significant positive effect on survival and growth of tree seedlings compared to the conventional pit but with some efficiency differences among the structures. The results in the upper site showed eyebrow basin > micro basin > micro trench > conventional pit; but micro basin > eyebrow basin > micro trench > conventional pit in the lower site in their order of level of efficiency in enhancing the seedlings survival and growth performance. In some cases, construction materials for moisture harvesting structures and supporting seedlings with moisture may be difficult; therefore, in this case the best tree species survived for degraded areas like Kilte Awlaelo is *S. molle*. The results of the combined effect of moisture harvesting structures and tree seedlings showed eyebrow basin and micro basin moisture harvesting structure gave best performance on survival and growth of *S. molle* in this study. On the other hand, *O. europaea* survived best in micro trench, so that it can be used as an alternative moisture harvesting structure in areas with no stones for construction of micro basin and eyebrow basin moisture harvesting structures with enough soil depth. The effective pit passion for *G. robusta* on eyebrow and micro basin was above the moisture harvesting structure. Whereas, species like *S. molle* were selective no pit position.

Therefore, in moisture-stressed plantation areas like Kilte Awlaelo, it is better to plant *S. molle*, supported by either eyebrow or micro basin structures. Further research related to root length and root biomass, especially during the seedling stage of *G. robusta, S. molle,* and *O. europaea*, should be conducted to enhance understanding of these tree seedlings.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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