Effect of Different Moisture Harvesting Techniques on Seedling Survivals and Growth of Trees in degraded lands of southern Tigray

Abstract

Tree planting on degraded lands play a key role in forest rehabilitation processes through afforestation and/or reforestation. Moisture harvesting structures (MHSs) has significant impact on seedling survivals at degraded lands. The objectives of this study were to investigate the impact of water harvesting techniques on seedling survival and growth performance of trees. Field experiments were conducted for two rainy seasons in southern Tigray, Atsela watershed. The experimental design followed was the split plot design. The MHSs as main plot used were eye-brow basin (EBs), micro trench (MTs), improved pit (IPs) and as control normal pit (NPs). The tree species grown as subplots were *Eucalyptus camaldulensis*, *Grevillea robusta*, *Olea europaea* and *Cupressus lusitanica*. The four tree species were planted by using seedlings. The tree survival rate, height, crown width (CW) and root collar diameter (RCD) of the four tree species were measured every six months after transplanting. The result shows that MHSs were significant in tree seedling height, CW and RCD but not in tree survival rate. Tree seedling height and CW grown in EBs were significantly higher than grown in MTs, IPs and NP ($P \leq 0.05$). RCD of tree seedling was higher grown in EBs than NP (control) ($P \leq 0.05$). The interaction of tree species seedlings and MHSs shows that those seedlings grown on MHSs were significantly thicker, taller and more survived than those grown on the NPs (control) ($P \leq 0.05$). So based on the experiments, it is concluded that MHSs particularly the eyebrow basin was considered as the most appropriate planting pit. Therefore, further demonstration of eyebrow basin tree planting should be carried out.

Key words: Northern Ethiopia, Plantation, Reforestation, Rehabilitation, Tree species

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Introduction

More than 60 % of Tigray region has a mountainous topography and it aggravates the land degradation [1]. The severity of soil erosion in the region is the result of the mountainous and hilly topography, erratic rainfall, and low degree of vegetation cover [2]. In many parts of Tigrai, soil erosion has made cultivation of old farmland impossible. Farmers have been forced to constantly cultivate new and more marginal areas.

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Deforestation in the highlands of Ethiopia started already 2000 years ago [3]. Forest plantation on degraded lands can play a key role in harmonizing long-term forest ecosystem rehabilitation process (4]. Forest resources in Ethiopia in general, particularly in Tigray have experienced so much pressure due to increasing need for wood products and conversion to agriculture [5]. The trend in the region today is to protect the remaining natural forests for their various social, economic and environmental values. To strike the balance between the two interests, afforestation/ reforestation is very important. According to different scholars, "afforestation", "reforestation" is used to distinguish new planted forests. The term "afforestation" is used in describing forests established artificially on land that previously did not carry forest for at least 50 years whereas, reforestation is activity of planting on forest exists area to replace or enrich the previous one [6]. The purpose can be wood production or protection under the ownerships of the private sector, individual farmers, the community, or the state.

Afforestation/reforestation is the common approach of rehabilitation on degraded lands [2,7–10]. Hence, millions of tree seedlings have been planted by different afforestation/reforestation programs in order to provide a basis for environmental improvement and increase the forest cover of the degraded lands. As cited by [11] the national average for tree seedling survival is less than 20%.

In most cases, the afforestation/reforestation are suffering from multiple environmental factors like limited water availability, free grazing, lack of proper management, premature cutting by peasants and inadequate care [9,10,12–14]. Limited water availability is the primary factor controlling plant establishment and growth in the degraded lands [7–10,12,15–17]. Therefore, to insure success of establishment of tree species MHSs can be used to collect rain water in areas close to the trees. Among the widely used micro catchment MHSs are eye-brow basin (EBs), micro trench (MTs), improved pit (IPs) and as control normal pit (NPs [10,18).

So, the hypotheses of the research were;

1) Hypothesis about the WH techniques

HO: The growth performance and survival of tree is the same under the four types of WH techniques

HA: The growth performance and survival of tree is different under the four types of WH techniques

2) Hypothesis about the tree species

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HO: The growth performance and survival of the four tree species is the same.

HA: The growth performance and survival of the four tree species is different

3) Hypothesis about the interaction effect

HO: The difference in growth performance and survival among the four tree species does not depend on types of WH techniques

HA: The difference in growth performance and survival among the four tree species depend on types of WH techniques

Thus, the main aim of the study was to investigate the possible contribution of MHSs in improving survival rate of tree seedlings and to estimate their effects on the performance of the seedling.

The specific objectives of this study were; 1). To evaluate the effect of different MHSs on growth performance and survival rates of tree species seedlings 2). To determine the interaction effect of MHSs and tree species seedlings 3). To evaluate the four tree species seedling performance in the in degraded lands/ moisture stressed areas of Southern Tigray, Atsela watershed, Northern Ethiopia.

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Materials and methods

Description of the study area

The study was conducted in Southern Tigray, Atsela watershed, Northern Ethiopia

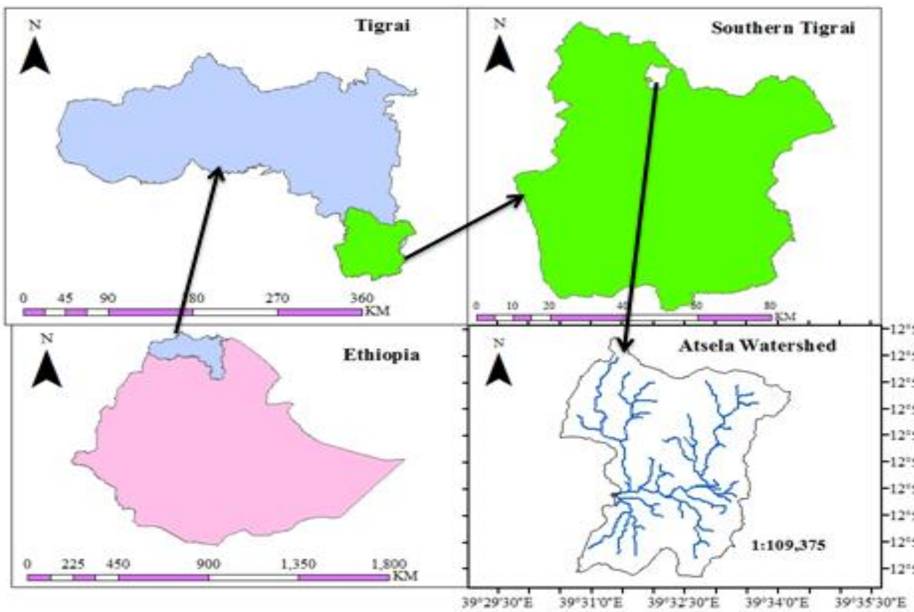

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Figure 1). It is located 702 km north of Addis Ababa and about 90 km south of the Tigray Regional capital state Mekelle. The agro ecology of the experimental site is classified as high land with an average temperature and annual rain fall of 15.8 degree centigrade and 570.2 mm respectively. The altitude of the district ranges from 2,907-2,938m.a.s.l.The occurrence of rain is highly variable in the study area, and rain is not evenly distributed throughout the months when it rains. The annual mean precipitation ranges from 238-939 mm.

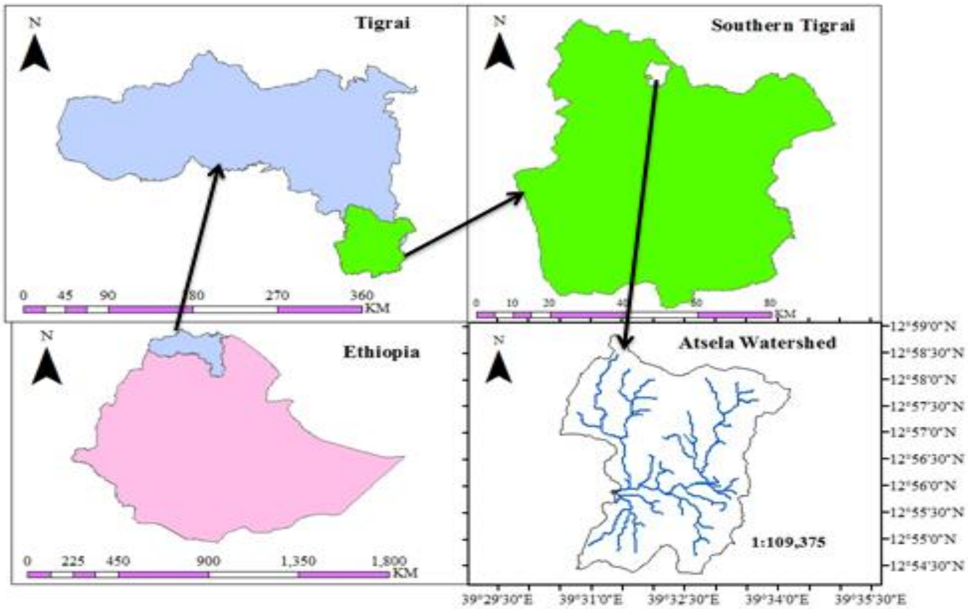

Figure 1: Study area

Species selection

Four woody species were carefully selected for experimentation based on the preference of the community's multi-criteria decision approach taking into account indicators of ecological suitability, socio-economical functions, protection functions and root characteristics. The selected species have the following characteristics based on [19–21]:

I. *Eucalyptus camaldulensis* Labill.

Eucalyptus camaldulensis is from the Myrtaceae family. It has been planted in Africa since around 1900, it does well in semi-arid regions and tolerates a long dry season as well as some salinity. It does well in deep silt or clay soil in Dry and Moist Kolla agroclimatic zones in Tigray, 200–2,800 m. *E. camaldulensis* is very suitable for fuel, construction and soil conservation. In local medicine, the steam from boiled leaves is inhaled to relieve the common cold and other bronchial problems. Steam from eucalyptus is believed to kill disease causing bacteria and microbes in sick rooms. It is used as a steam inhalant for chest congestion. Eucalyptus is rarely used internally.

***Grevillea robusta* R. Br.**

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Grevillea robusta is from Proteaceae family with medium-sized to tall tree up to 30 m high, usually less than 10 m in Ethiopia. It is very successful Australian tree planted and widely used in dry, moist and wet Weyna Dega and Dega agroclimatic zones, 0–3,000 m. It is used as firewood, charcoal, timber (furniture), poles, fodder (leaves), bee forage, shade, ornamental, soil conservation and windbreak.

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***Olea europaea* L. subsp. cuspidata**

It is from Oleaceae family with a height of 10-15 m. It is widely distributed in dry forest in east Africa and Ethiopia. It reaches southern Africa, it is best in good forest soil, but hardy and drought resistant once established, even in poor soils. The species found in moist and Wet Weyna Dega and lower Dega agroclimatic zones in all regions, 1,400-3,100 m. In Ethiopia, the leaves, twigs and wood of the African olive are used to fumigate pots for milk and for the local beverages, Tella and Tej. Twigs are used as toothbrushes (tooth sticks) and hard wood for carving. In addition, it used for firewood, charcoal, timber (furniture, floors, panelling, walking sticks), poles, posts, medicine (stem, bark, leaves) and bee forage.

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***Juniperus procera* Hochst. ex Endl.**

Juniperus procera (Cupressaceae) an erect evergreen tree grows up to 40 m tall, trunk in old trees up to 1 m in diameter. It is valuable timber tree indigenous to Ethiopia and eastern Africa highland forests. Juniperus is very common plant generally in the northern and northern central parts of Ethiopia and particularly in Tigray about 1100 to 3500 m altitudes. It is widely used for firewood, timber, poles, posts, medicine (bark, leaves, twigs, buds), shade, ornamental and windbreak.

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Moisture harvesting structures (MHSs)

The effective MHSs which are familiar in the watersheds of Tigray region for rehabilitation of degraded land were adopted for the experiment from Ministry of Agriculture and Rural Development. According to [18] the specification and design of the structures we used were as follows.

EYEBROW BASINS (EBs): are larger circular and stone faced structures for tree and other species planting. They are effective in low rainfall areas to grow trees and harvest moisture. The technical standards constructed were;

Size: 2.5 m diameter;

- Stone riser with 0.25 m depth of the foundation;

- Height 0.5 m;
- Stone riser sealed with soil excavated from water collection area;
- Water collection area: dug behind the plantation pit: 1 m width x 1 m length x 25 cm depth (lower side);
- Three plantation pits of 40cm depth x 40cm diameter dug between riser and water collection area as in the left figures [2,3 and 4) shown.

MICROTRENCHES (MTRs): are rectangular and deep pits constructed along the contours. The technical standards constructed and design we follow was;

- Size of the trench: 1.5 length x 0.4 m width x 0.5 m depth (downside);
- Trenches were provided with a small and low tie in the middle to regulate water flow (15 cm width);
- Trees were not planted in the middle of the trench but in front of it;
- Plantation pit 40cm depth x 40 cm width.

IMPROVED PITS (IPs): Was square shaped water collection pits constructed along the contours with a plantation pit in front of the main water storage pit.

- Dimension: 0.60m length x 0.60 width x 0,5 m depth
- Planting pit 40cm depth x 40 cm width, were prepared in front of the square shaped water collection pit

NORMAL PIT (NPs): are circular and deep pits constructed along the contour.

- Size: 40cm depth x 40 cm width

Experimental design and method of implementation

Experimental design

Four tree species were established in four MHSs in a split-plot design. There were 16 treatments combination of two factors (Four MHSs * Four Tree species = 16 treatments) (Table 1). Each treatment combination was tried on 3 replications and thus a total of 48 plots (Four MHSs * Four Tree species* Three replication= 48 plots). MHSs were the main plot factor in this experimental design, and tree species were randomly assigned to one of four MHSs. The tree species were planted by using seedlings.

Table 1.The treatments of the experiment

No.	Type of pit	Tree species	Treatments (Code)

1	EYEBROW BASINS (EBs)	*Eucalyptus camaldulensis* (E)	EBsE
		Grevillea robusta (G)	EBsG
		Olea europaea (O)	EBsO
		Cupressus lusitanica (C)	EBsC
2	MICROTRENCHES (MTRs)	*Eucalyptus camaldulensis* (E)	MTRsE
		Grevillea robusta (G)	MTRsG
		Olea europaea (O)	MTRsO
		Cupressus lusitanica (C)	MTRsC
3	IMPROVED PITS (IPs)	*Eucalyptus camaldulensis* (E)	IPsE
		Grevillea robusta (G)	IPsG
		Olea europaea (O)	IPsO
		Cupressus lusitanica (C)	IPsC
4	NORMAL PIT (NPs)	*Eucalyptus camaldulensis* (E)	NPE
		Grevillea robusta (G)	NPG
		Olea europaea (O)	NPO
		Cupressus lusitanica (C)	NPC

Data collection

The data collected were growth variables of tree species like 1st tree survival rate (December, 2016) in %; 2nd survival rate (May, 2016) in %; 3rd survival rate (December, 2017) in %; Tree height (H) in cm; Root collar diameter (RCD @$_{10cm\ stamp\ height}$) in cm and Crown width (CW) in cm.

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Statistical analysis

Results were analyzed using R software. Analysis of variance (ANOVA) was made to determine the significance of variation between the tree species and MHSs. Tukey Multiple Range Test was used to compare mean values of various growth variables in each treatment.

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Results and discussions

Response of tree growth to different MHSs

The result of this study showed that 1st survival, 2nd survival and 3rd survival rates of tree seedlings grown in different MHSs were not varied significantly ($P \geq 0.05$). However, it was significantly different ($P \leq 0.05$) for the growth variables tree seedling height, root collar diameter (RCD) and crown width (CW) (Table 2). Tree height and CW was significantly higher in EBs than MTs, IPs and NP. In addition, RCD was higher in EBs than NP (control) and not varied significantly with MTs and IPs. No differences were shown in tree height grown in MTs, IPs and NP.

Even though the MHSs doesn't affect the survival of tree seedling, those structures that can conserve water and soil like EBs has a positive and significant effect on growth variables. This finding confirms, these structures could solve the moisture stress that commonly limits growth, survival and distribution of tree seedlings [22]. The results of this study clearly indicated that the rehabilitation of degraded land and ensuring the survival of tree seedling is possible using MHSs. However, the implementation of various MHSs depends on local rainfall characteristics, construction materials and site conditions. MHSs have proved to be a valuable tool, especially in degraded lands to establish trees and to allow reforestation.

Similar results were shown in different studies of MHSs. According to [23] the impact of MHSs is high and showed an 8 times increase in total biomass compared with the normal pit and also proved that there was an increase in tree height by 20%. Similarly other study showed that *Ziziphus mauritiana* growth rates in the Jodhpur province of India were from 25-33% higher in shallow one meter[24]. The results from the semiarid loess region of China [25] also showed that water harvesting treatments had a prominent effect on the growth characteristics of *Tamarix ramosissima*.

Table 2: The effect of different MHSs on growth variables of tree species

Growth variables	Moisture harvesting structures (MHSs) (Mean ± SE)				*P*-Value
	EBs	MTs	IPs	NP (control)	
1st survival (%)	91.67 ± 5.98	97.22 ± 2.78	88.89 ± 6.27	91.67 ± 5.98	NS
2nd survival (%)	63.89 ± 13.27	63.92 ± 11.19	55.56 ± 9.48	41.67 ± 10.95	NS
3rd survival (%)	63.89 ± 13.27	63.89 ± 11.21	55.56 ± 9.48	33.33 ± 10.05	NS
Height (cm)	75.50 ± 17.73^{a}	34.83 ± 8.16^{b}	42.08 ± 8.19^{b}	27.33 ± 8.1^{b}	0.002
RCD (cm)	1.36 ± 0.27^{a}	0.95 ± 0.14^{ab}	1.01 ± 0.14^{ab}	0.63 ± 0.16b	0.023
CW (cm)	70.54 ± 13.88^{a}	43.17 ± 8.58^{b}	38.50 ± 8.72^{bc}	18.58 ± 5.89^{c}	0.001

Note: EBs (eyebrow basin), (MTs) micro trench, (IPs) improved pit and (NPs) normal pit as control. Similar letter in the row shows not significant difference and different letters indicate significance differences, NS: not significant difference between moisture harvesting structures (MHSs) at $P \leq 0.05$

The interaction effect of tree species and MHSs

The interaction effect in (Table 3) shows that those seedlings grown on MHSs were significantly thicker, taller and more survived than those grown on the NPs (control). The 2nd survival, 3rd survival and height of *Grevillea robusta* seedlings planted in EBs MHSs were significantly higher than the same species planted in MTs, IPs and NPs ($P \leq 0.05$). In addition, RCD and CW were higher in EBs MHSs as compared to the control (NPs).

The survival rate of *Eucalyptus globulus* was not varied with the different MHSs. It could be the ability of the species to survive to the different MHSs. However, height was significantly higher in MHSs of EBs and MTs than IPs and NPs ($P \leq 0.05$). Furthermore, RCD and CW growth variables were significantly higher in *Eucalyptus globulus* seedlings grown in EBs MHSs than seedlings planted in MTs, IPs and NPs ($P \leq 0.05$). These results agreed with the results of [10] who showed EBs showed a significantly higher survival rate, RCD and DBH in growing trees seedlings.

Whereas, the two indigenous tree species i.e. *Olea europaea* and *Juniperus procera* were not varied significantly with the different MHSs. It could be the late response of the tree seedlings to the growth variables.

Table 3 The interaction effect of different *MHSs* on seedling survival and growth performance of tree species

		Moisture harvesting structures (MHSs) (Mean ± SE)				
Tree species	Growth Variables	EBs	MTs	IPs	NPs	*P*-value
Grevillea robusta	1st survival (%)	100	100	88.89 ± 11.11	100	NS
	2nd survival (%)	100^{a}	55.56 ±11.11^{b}	44.44 ± 11.11^{b}	55.55 ± 11.11^{b}	0.015
	3rd survival (%)	100^{a}	55.56 ± 11.11^{b}	44.44 ± 11.11^{b}	55.56 ± 11.11^{b}	0.015
	Height (cm)	70 ±9.6^{a}	24 ± 6^{b}	37.67 ± 5.24^{b}	35.33 ± 7.06^{b}	0.01
	RCD (cm)	1.7 ± 0.2^{a}	1.17 ± 0.17^{ab}	1.13 ± 0.07^{ab}	1.07 ± 0.07^{b}	0.041
	CW (cm)	91.33 ± 9.49^{a}	57 ± 16.29^{a}	28 ± 9.5^{b}	21.67 ± 6.11^{b}	0.006
Eucalyptus globulus	1st survival (%)	100	100	77.78 ± 22.22	100	NS
	2nd survival (%)	100	66.67 ± 33.33	44.45 ± 22.22	44.44 ± 29.4	NS
	3rd survival (%)	100	66.67 ± 33.33	44.45 ± 22.22	11.11 ± 11.11	NS
	Height (cm)	155 ± 17.35^{a}	56 ± 28.48^{ab}	51.33 ± 25.69^{b}	24.33 ± 24.33^{b}	0.023
	RCD (cm)	2.27 ± 0.18^{a}	0.8 ± 0.42^{b}	0.83 ± 0.42^{b}	0.33 ± 0.33^{c}	0.022
	CW (cm)	113.33 ± 12.39^{a}	48 ± 25.15^{b}	47.67 ± 28.32^{b}	13.33 ± 13.09^{c}	0.05
Olea europaea	1st survival (%)	77.78 ± 22.22	88.89 ± 11.11	88.89 ± 11.11	77.78 ± 22.22	NS
	2nd survival (%)	11.11 ± 11.11	33.44 ± 19.15	55.56 ± 50.92	11.11 ± 19.24	NS
	3rd survival (%)	11.11 ± 19.24	33.33 ± 33.33	55.56 ± 29.4	11.11 ± 11.11	NS
	Height (cm)	12.33 ± 12.33	15.67 ± 7.88	17.33 ± 8.69	8.67 ± 8.67	NS
	RCD (cm)	0.43 ± 0.43	0.67 ± 0.33	0.67 ± 0.33	0.33 ± 0.33	NS
	CW (cm)	14.33 ± 14.33	13 ± 7	16 ± 8.72	5 ± 5	NS
Juniperus procera	1st survival (%)	88.89 ± 11.11	100	100	88.89 ± 11.11	NS
	2nd survival (%)	44.43 ± 29.4	100	77.77 ± 11.11	55.55 ± 29.4	NS

Tree species	Growth Variables	Moisture harvesting structures (MHSs) (Mean ± SE)				*P*-value
		EBs	MTs	IPs	NPs	
	3rd survival (%)	44.44 ± 29.4	100	77.78 ± 11.11	55.56 ± 29.4	NS
	Height (cm)	64.67 ± 33.79	43.67 ± 7.12	62 ± 12.49	41 ± 20.52	NS
	RCD (cm)	1.03 ± 0.58	1.17 ± 0.09	1.4 ± 0.1	0.77 ± 0.39	NS
	CW (cm)	63.17 ± 32.37	54.67 ± 6.77	62.33 ± 8.45	34.33 ± 17.7	NS

Note: EBs (eyebrow basin), (MTs) micro trench, (IPs) improved pit and (NPs) normal pit as control. Similar letter in the row shows not significant difference and different letters indicate significance differences, NS: not significant difference between moisture harvesting structures (MHSs) at $P \leq 0.05$**.**

Response of tree species under different MHT in the site

Species differed significantly in all growth variables, except the 1st survival % in the study site (Table 4). *Olea europaea* had significantly lower survival in the watershed when statistically compared to *Juniperus procera and Grevillea robusta* in the 3rd survival rate. Similarly, height and CW of *Olea europaea* were significantly lower from *Eucalyptus globulus, Grevillea robusta* and *Juniperus procera* tree seedlings. This could be the morphological characteristics of the species.

Table 4 Response of tree species in different MHSs for the different growth Variables

Growth Variables	Tree seedling species				*P*-Value
	Eucalyptus globulus	*Juniperus procera*	*Olea europaea*	*Grevillea robusta*	
1st survival (%)	94.44 ± 5.56	94.44 ± 3.75	83.33 ± 7.68	97.22 ± 2.78	NS
2nd survival (%)	63.89 ± 12.62^{ab}	69.44 ± 11.21^{a}	27.81 ± (9.90)^{b}	63.89 ± 7.63^{ab}	0.019
3rd survival (%)	55.56 ± 13.19^{ab}	69.44 ± 11.21^{a}	27.78 ± 9.91^{b}	63.89 ± 7.63^{a}	0.015
Height (cm)	71.66 ± 18.2^{a}	52.83 ± 9.52^{a}	13.50 ± 4.19^{b}	41.75 ± 6^{ab}	<0.001
RCD (cm)	1.06 ± 0.26^{ab}	1.09 ± 0.17^{ab}	0.53 ± 0.16^{b}	1.27 ± 0.1^{a}	0.014
CW (cm)	55.58 ± 14.11^{a}	53.63 ± 8.91^{a}	12.08 ± 4.22^{b}	49.50 ± 9.49^{a}	0.001

Note: EBs (eyebrow basin), (MTs) micro trench, (IPs) improved pit and (NPs) normal pit as control. Similar letter in the row shows not significant difference and different letters indicate significance differences, NS: not significant difference between moisture harvesting structures (MHSs) at $P \leq 0.05$. Values are means ± (SE).

Conclusions and recommendations

The study results revealed that moisture harvesting structures (MHSs) are verified as effective structures in producing well survived and grown trees species. The growth variables of the tree species planted in the eyebrow basins (EBs) is better than micro trenches (MTs), improved pits (IPs) and normal pits (NPs). Tree species planted in micro trenches (MTs) and improved pits (IPs) were also the most appropriate planting pit than normal pit (NP). The moisture harvesting structures (MHSs) shows great potential in increasing tree survival and growth performance due

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So, expanding moisture harvesting structures (MHSs) is the most appropriate afforestation method particularly for degraded area. More elaborative studies are required with more representative locations and in different soil and agro ecology.

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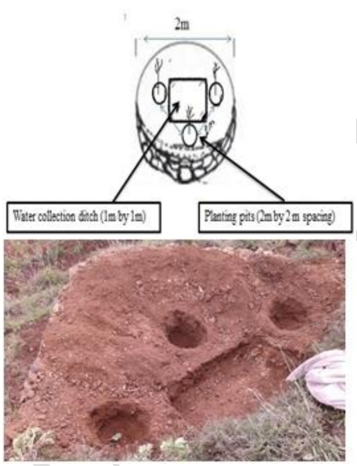

Fig. 2. Figure showing water collection ditch and planting pits

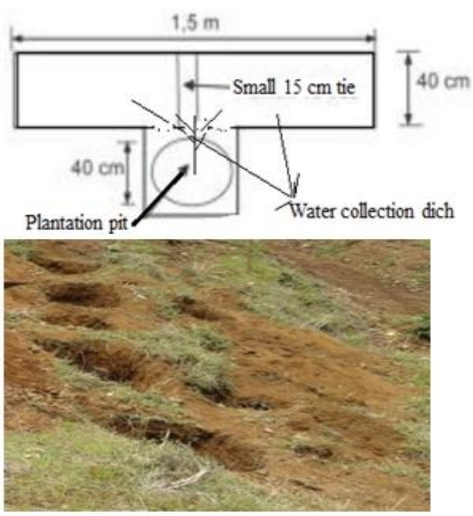

Fig. 3. Plantation pits of 40cm depth x 40cm diameter dug between riser and water collection Area

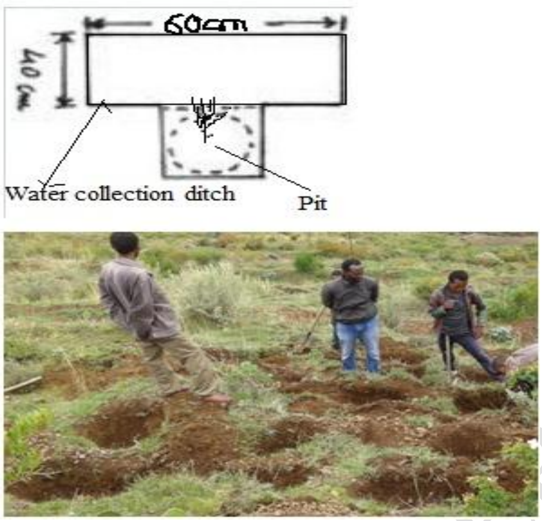

Fig. 4. Preparation of planting pit (40cm depth x 40 cm width) in front of the square shaped water collection pit