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Evaluation of Trees and Shrubs for Degraded Land Restoration in the Central Rift Valley, Southern Ethiopia

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ABSTRACT

In Ethiopia, population increase and the demand for more agricultural land and forest products have resulted in the destruction of natural vegetation and land degradation. Planting multipurpose trees and shrubs for the rehabilitation of severely degraded land has been suggested as a management option. A field experiment was conducted in Choroqo, one degraded land vegetation restoration site of Halaba zone in the Central Rift Valley, Ethiopia, to determine the suitability of 12 multipurpose trees and shrubs. The experiment was set in a randomized complete block design (RCBD), and data on plant survival and growth parameters were collected every 6-month interval for 3 years. One-way ANOVA and Tukey's HSD test ($p < 0.05$) were computed to determine the effect of species on the measured variable. SAS software was used for statistical analyses. The highest mean survival was recorded by *Grevillea robusta* R.Br (99.542 ± 1.05), followed by *Senegalia polyacantha* Willd (88.88 ± 1.05) and *Eucalyptus camaldulensis* Dehnh. (83.33 ± 1.05). The largest (20.67%) overall plant death was recorded within the first six months of field plantation. *Acacia saligna* (Labill.) Wendl (4.48 m ± 0.81), *Eucalyptus camaldulensis* (4.38 m ± 0.99), and *Casuarina equisetifolia L.* (3.14 m ± 0.49) exhibited better growth in height at the end of the experiment. Moreover, early management was found to be very important in reducing the mortality rate of planted species for rehabilitation programs. The higher use value was calculated for *Eucalyptus camaldulensis*, followed by *Dodonaea angustifolia L.f.* and *Grevillea robusta.* Therefore, *Grevillea robusta, Eucalyptus camaldulensis*, *Dodonaea angustifolia*, and *Senegalia polyacantha* are found to be ecologically suitable and socially acceptable species for the rehabilitation of degraded lands of Halaba and the Central Rift Valley. Further research is needed to know the impact of these species on the physicochemical properties of the soil and the undergrowth flora.

1 | Introduction

Rapidly increasing population and unsustainable resource exploitation are causing multiple environmental impacts, including land degradation and climate change [1]. Land degradation is a man-made process of progressive deterioration of biological (flora and fauna) and physical (soil, water, microclimate, etc.) resources of the land, leading to declining productivity and unsustainable yields [2, 3]. Globally, it is estimated that more than 24% of land is affected by serious degradation, which affects 3.2 billion people who are poor and marginalized, mainly in rural landscapes, with minimal adaptation options [4]. Approximately 60% of the evaluated ecosystem services have been degraded or lost [5]. Tropical deforestation and land degradation are important causes of greenhouse gas emissions, responsible for about 25% of the total anthropogenic emissions worldwide [6]. The transfer of carbon to the atmosphere in the form of CO_2, thereby reducing ecosystem carbon pools, is also one of the major

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consequences of land degradation. It also reduces crop water productivity at field and landscape scales and affects water availability, quality, and storage [7]. Currently, degradation remains an important global priority issue requiring renewed attention by individuals, communities, and governments because of its adverse impact on agricultural productivity and the environment and its effect on food security and quality of life [8, 9].

Ethiopia is one of the countries in sub-Saharan Africa most seriously affected by land degradation [10]. The land is a key factor of production, and problems associated with land adversely affect the livelihoods and food security of the rural population in particular and the country's population in general [11]. The expansion of agriculture to marginal areas has resulted in land degradation. Trees have been cleared for thousands of years and still are cleared for agriculture and fuel wood [12–14]. In addition, Ethiopia also ranks first in Africa with a livestock population that exerts heavy grazing pressure and degradation of the natural vegetation. The removal of vegetation through grazing pressure reduces the protection of soil cover, minimizes the regrowth capacity of vegetation, and speeds up sheet and gully erosion [15]. Soil erosion is a very important and widely used indicator of land degradation by removing exchangeable cations adsorbed to clay particles [16]. The Central Rift Valley falls in two regional states: Oromia and the former Southern Nations, Nationalities, and Peoples' Region (SNNPR). Those two regions accommodate a large proportion of the natural forest in the country. The natural environment in the Ethiopian Rift Valley is gifted with a chain of several lakes between the Ethiopian plateau to the north and the Somali plateau to the south, with a wonderful landscape known for its unique ecology and natural resources endowment, and accommodates several National Parks with very important biological resources. Despite these realities, land degradation, deforestation, overgrazing, soil erosion, flooding, prevalence of invasive species, waste disposal, and sediment loads are the main features of the environment in the Central Rift Valley [17]. In addition, the natural vegetation has still served as a major source of fuelwood and charcoal supply for populations of metropolitan centers, including Addis Ababa [18].

Ethiopia has developed a new climate-resilient green economy strategy targeted to rehabilitate one million hectares of degraded lands [19]. Significant efforts have been made by the Government of Ethiopia to achieve the target and reverse the impacts of degradation through the planting of tree species [20, 21]. Many tree species have been planted by farmers and local governments for degraded land rehabilitation in the Central Rift Valley and in different corners of the country, but a low survival rate was reported [22–25]. These failures are partly explained by the use of seedlings without testing them to see whether they are genetically appropriate for the project's site conditions. Since most tree species used in reforestation are found over broad geographic ranges, different races within the same species have adapted to different environments [26]. The most reliable information is based on trial planting in the proposed restoration area. The first trial should be a species screening trial that will test the survival and early growth performance of the species for one to 3 years [27]. In addition, acceptance and success of tree planting and land rehabilitation activities depend upon the amount of attention given to local environmental and social conditions, cultural values, and people's needs and knowledge [28–30]. Ethnobotanical knowledge helps to understand species of special importance to local people [31]. Such information may help policymakers or planners to set priority species in rural forestry programs. The ecological performances of species in connection with ethnobotanical knowledge help to improve ecosystem services of the restoration site. Therefore, this research was carried out to investigate which species would show the best survival and growth under poor ecological conditions of degraded land, and which trees or shrubs have more use value to the local community? Therefore, the ultimate aim of this study was to evaluate early survival capacity, growth performance, and farmers' preference for multipurpose tree species for the rehabilitation of the degraded land of the Halaba Zone of the Central Rift Valley, Ethiopia.

2 | Materials and Methods

2.1 | The Study Area

The experiment was conducted at Choroqo—one degraded land vegetation restoration site, Halaba Zone in the Central Rift Valley, Southern Ethiopia (Figure 1). The experimental site is located at 7 °02′–7 ° 69′N and 37°.96′–38°.46′E and at an altitude 1825 m.a.s.l. The site has been protected since 2009 from human and livestock interference for natural regeneration, mainly through social fencing against any form of cultivation, cutting trees and shrubs, and grazing by livestock. This is meant to allow regeneration and foster natural ecological succession for the rehabilitation of deforested areas. A group discussion and field observation were conducted with district agricultural experts, development agents, and farmers to select a representative experimental site.

2.1.1 | Vegetation and Land Use

The natural vegetation of the Halaba Zone is categorized under *Acacia-Commiphora* woodland and bushland (ACB) vegetation [18]. This vegetation type is currently under strong environmental stress [15]. The extraction of fuel wood and charcoal for major towns in the country has increased the rate of deforestation and natural resource depletion. The study area is highly degraded [32]. *Acacia seyal* Delile, *Eucalyptus camaldulensis*, *Balanites aegyptiaca* (L.) Del., *Cordia africana* Lam., *Olea europaea* L. subsp. *cuspidata* (Wall. Ex G.Don) Cif., *Dodonaea angustifolia*, and *Croton macrostachyus* Del. were some of the woody species found in the study area. Homegarden agroforestry system is one of the land use systems that the local community practices. *Ensete ventricosum* (Welw.), *Musa acuminata* Colla *L.*, *Zea mays* L., *Catha edulis* (Vahl) Forssk. ex Endl, *Coffea arabica* L., *Saccharum officinarum* L., *Eragrostis tef* L., *Brassica carinata* A.Br., *Phaseolus vulgaris* L., *Sorghum bicolor* L., and *Capsicum* spp. are some cultivated food plant species in the traditional homegarden agroforestry system.

2.1.2 | Climate

The current study area is found in hot to warm subhumid lakes and the rift valley [33]. The meteorological data collected by the

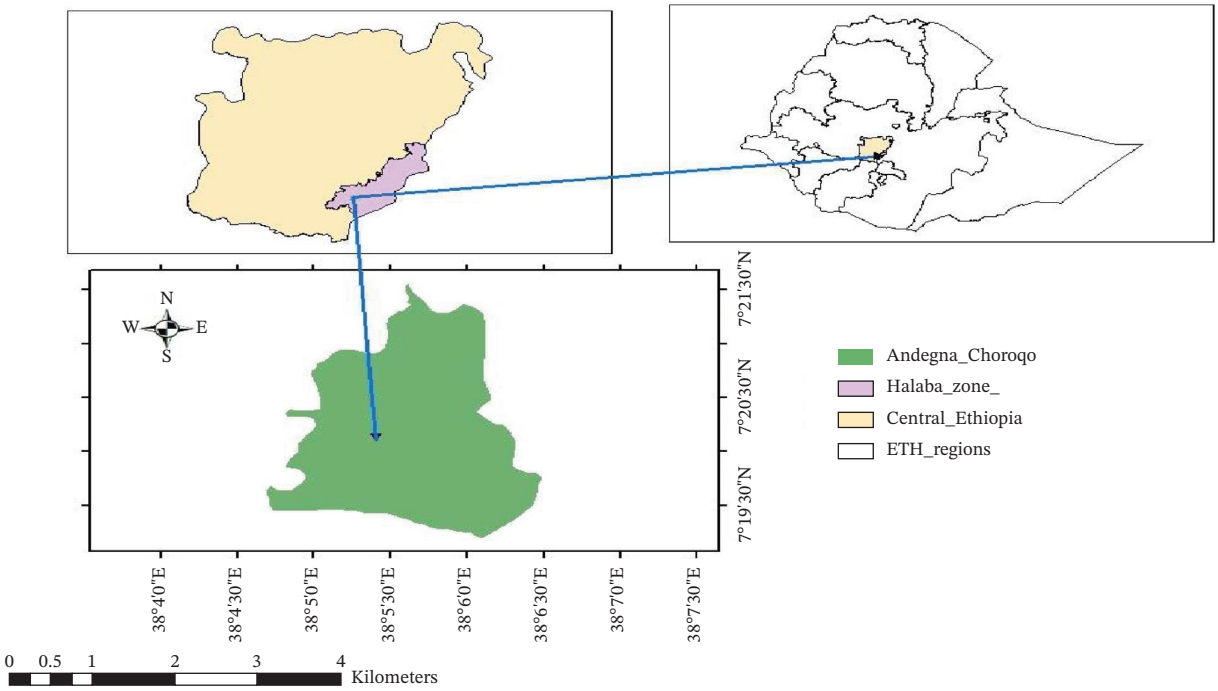


FIGURE 1 | Location of the study site.

Ethiopian National Meteorological Service Agency, Hawassa Branch, indicate that the mean monthly maximum rainfall is 130.8 mm in April, while the mean monthly minimum rainfall of 24.4 mm is recorded in December. Mean annual minimum temperature of the area is 12.1°C in November, while the mean annual maximum temperature recorded is 31.2°C in February (Figure 2). The mean annual rainfall ranges from 700 to 1100 mm, and the mean annual temperature is about 27.5°C. The mean annual potential evapotranspiration is 1400–1600 mm [33], which is greater than the mean annual precipitation of the study area.

2.1.3 | Treatments and Experimental Design

Species selection is part of an initial stage in the evaluation of multipurpose trees and shrubs. For this experiment, 12 (6 exotic and 6 native) species within 8 families and 9 genera were selected for evaluation. These species are extensively considered for the degraded land rehabilitation program in the district (Table 1). Seeds were collected from different locations, and seedlings were raised in plastic bags at the nearest Halaba forestry nursery site. Seedlings attaining a height of 20–40 cm were planted at a spacing of 2 × 2 m (2500 seedlings ha^{-1}) during the main rainy season (July 2010). Unestablished or wilted seedlings were replanted after 15 days of the first planting. Initial measurements of total height (from the soil surfaces to the highest living apical bud) were taken during field planting and were averaged (Table 1).

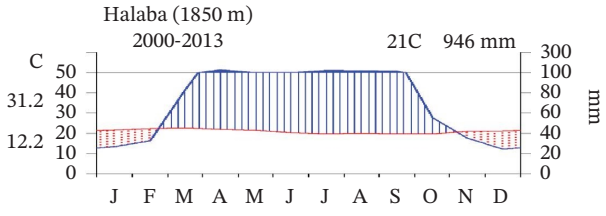


FIGURE 2 | Climate diagram of the study area.

2.1.4 | Experimental Design

Randomized complete block design (RCBD) with three replications and 12 treatments for each block was applied (Figure 3). The space between blocks and plots was 4 and 3 m, respectively. The blocks were constructed from east to west along the contour and divided into 12 plots. Location of the plot for each species within the array was determined randomly for every block, and then, the seedlings were planted. Each species was represented by one plot per block and 12 species per plot per block for a total of 36 seedlings per species. In aggregate, 432 seedlings were planted from 12 tree and shrub species. The term "shrub" in this paper is used to describe woody perennial plants that remain low and produce multiple shoots from the base, while "trees" refers to woody perennial plants that produce one main trunk or bole and a more or less distinct and elevated crown [34]. Rectangular shape 1 × 1 m direct rainwater harvesting structures were constructed to harvest direct rainwater to the rooting zone of seedlings.

2.2 | Methods of Data Collection and Analysis

Plant survival and height were recorded every six months over 3 years from August 2010 to August 2013. Survival percentage was computed as the percentage of the living seedlings from the total planted by subtracting the number of wilted or dead trees or shrubs. Seedling height was measured from the base to the highest point of the planted seedlings using a meter tape. Root collar diameter was recorded at the end of the experiment above 10 cm from the ground using a Vernier caliper (accuracy 0.02 mm), and the mean diameter for each tree/shrub species was computed. Diameter at breast height (DBH) was measured at a height of 1.3 m at the end of the experiments (after 36 months)

TABLE 1 | List of species tested, growth habit provenances, and mean seedling height during field planting.

Species	Families	Origin	Form	Sources	Mean initial height (cm)
Acacia decurrens Willd.	Fabaceae	Exotic	Tree	Holeta	26
Acacia saligna (Labill.) Wendl.	Fabaceae	Exotic	Tree	Halaba	37
Senegalia polyacantha Willd	Fabaceae	Native	Tree	Wolyita	32
Albizia gummifera (J. F. Gmel.) C. A. Sm.	Fabaceae	Native	Tree	Y/alem	19
Casuarina equisetifolia L.	Casuarinaceae	Exotic	Tree	Halaba	33
Cordia africana Lam.	Boraginaceae	Native	Tree	Halaba	24
Dodonaea angustifolia L.f.	Sapindaceae	Native	Shrub	Halaba	28
Eucalyptus camaldulensis Dehnh.	Myrtaceae	Exotic	Tree	Arsi	22
Faidherbia albida (Del.) A. Chev.	Fabaceae	Native	Tree	Wolyita	20
Grevillea robusta R. Br.	Proteaceae	Exotic	Tree	Hawassa	28
Olea europaea L. subsp. *cuspidata* (Wall. Ex G.Don) Cif.	Oleaceae	Native	Tree	Halaba	20
Terminalia brownii L	Combretaceae	Native	Tree	Halaba	16

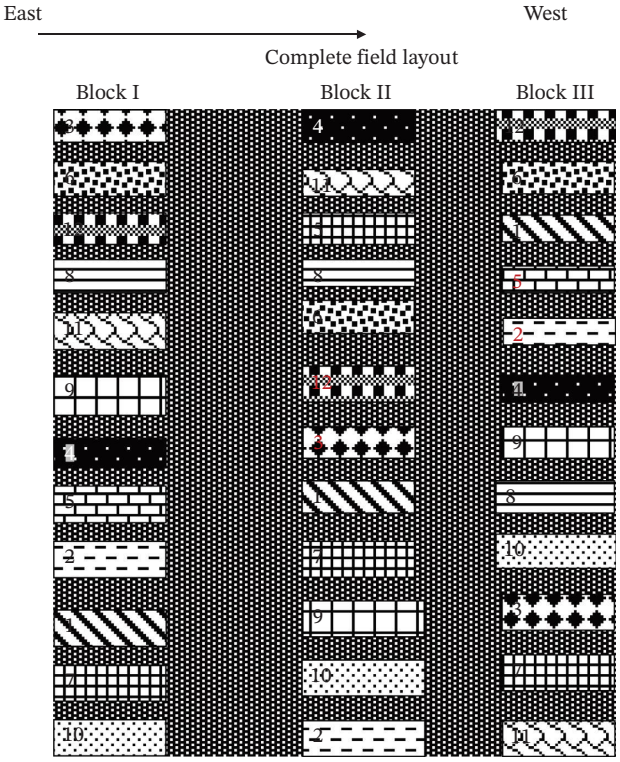


FIGURE 3 | Treatments and random numbers 1. *A. gummifera*, *2. O. europaea* subsp. *cuspidata*, *3. A. decurrens, 4. A. saligna, 5. F. albida, 6. T. brownii,* 7. *C. africana*, *8. C. equisetifolia*, 9. *G. robusta*, 10. *E. camaldulensis*, *11. D. angustifolia*, *12. S. polyacantha*.

[35]. In cases where a tree or shrub bole branched at breast height or below, the diameters were measured separately for the branches and each diameter was squared and put under the square root, the square root of the sum of all squared stems was averaged as one DBH [36, 37].

$$\mathrm{DBH} = \left((b_1)^2 + (b_2)^2 + (b_3)^2 + (b_4)^2\right)^{1/2} = \mathrm{DBH}, \quad (1)$$

where b_1 is the branch one and b_2 is the branch two; a maximum of four branches were measured. Finally, 10 knowledgeable local farmers were selected purposively to determine the relative importance of these evaluated tree species for the local community, applying use values.

2.3 | Data Analysis

2.3.1 | An Analysis of Variance (ANOVA) Among Species

The survival data showed more than 20% variation among treatments. Therefore, an angular (arcsine) data transformation method was employed to meet the normality assumption of the ANOVA [38]. Furthermore, Tukey's HSD test is applied for multiple comparisons in the survival of species. The least significant difference (LSD) test was used to compare mean values of growth in terms of height, root collar diameter, and DBH in each treatment at 5% level of significance using SAS software [39].

2.3.2 | Relative Growth Rate (RGR) per Year

Data collected on height were also used to examine the RGR of species. The relative growth rate for height (RGRH) was calculated using the following formula [40, 41]:

$$\mathrm{RGRH} = \frac{\mathrm{InST2} - \mathrm{InST1}}{t_2 - t_1} \times 100, \quad (2)$$

where ln—natural logarithm: TSL_2—total shoot length at final measurement, TSL_1—total shoot length at initial measurement, and $t_2 - t_1$—the number of months between consecutive measurement periods. Annual increment (I) in height (m/yr) was calculated per species using the following formula [41]:

$$I = \frac{h_1 - h2}{t}, \quad (3)$$

where h is the height measured at times 1 and 2, and t is time in years.

2.3.3 | Bole Volume of Young Trees and Shrubs

The bole volume of the species was calculated at the end of the experiment from the equation of Owino et al. [42], where volume is represented as follows:

TABLE 2 | Comparison of the mean survival rate (%) of species across growth periods.

Months	Mean	6	12	18	24	30
6	79.393					
12	77.834	1.559				
18	66.447	12.947*	11.388*			
24	65.058	14.336*	12.777*	1.389		
30	59.820	19.573*	18.014*	6.627	5.238	
36	59.599	19.794*	18.235*	6.847	5.458	0.221

Note: LSD all-pairwise comparisons test of survival rate for growth periods (months) at $p < 0.05$.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

$$\text{Bole volume of the species}\left(\text{m}^3\right) = \frac{\pi(\text{dbh})^2}{4} * h * f, \quad (4)$$

where dbh = bole diameter at breast height (1.3 m), h = tree height, and $\pi = 3.14$. The average form factor for multipurpose tree species is 0.5. However, dbh is usually in cm and basal area is usually expressed in square meters, that is, 10,000 cm per square meter. The volume calculated from this computation was multiplied by the number of trees per hectare (in this case, 2500 plants per hectare).

2.3.4 | Use Value

Recently, ethnobotanists have often used versatility (the number of uses) for species as a criterion for estimating the importance of tree species to support a recommendation for priority use in scale-up in a wider area for various objectives including degraded land restoration [43]. Use value was calculated for promising species in terms of survival and growth to give a quantitative measure of their relative importance to the local community [44, 45]. In this experiment, we used a targeted method for the selection of key informants with the help of the district offices of agriculture, development agents, and community members. The specific criteria used for selecting key informants included involvement in beekeeping, livestock production, medical practitioner, local craft work, and women's participation to get special knowledge on fuelwood use and the guarding of vegetation restoration sites. The values given by 10 local knowledgeable farmers were summed up as the average, and a rank was given. The tool we used for collecting their opinion on species use value was based on the personal interview:

$$\text{UV}_s = \frac{\sum_i^n U_{is}}{n_s}, \quad (5)$$

where UV_s: use value for species s, n_s: total number of informants interviewed about species s in case (10 key informants); and U_{is}: number of uses of species s according to informant i and value given 0 to 6 (0 means no use and 6 is assigned for 6 used by the informants).

3 | Results and Discussion

3.1 | Species Performance

In this experiment, under poor ecological conditions of degraded land, the highest mean survival percentage was recorded for *Grevillea robusta* (99.542 ± 1.05) for the last 36 months (Table 2). A similar study on the poor soil at an elevation of 2600 m and a mean annual rainfall of 1100 mm in the central highlands of Ethiopia shows a 100% survival rate of *Grevillea robusta* at the age of 48 months [46]. Likewise, other survival results from a semi-arid area of southern Ethiopia (Ziway) at an elevation of 1650 m and a mean annual rainfall of 690 mm on fluvial soil show 51% survival at an age of 5 years [12]. This shows a wider ecological adaptation of the species and survival differences among sites. The results also indicated that there were no significant differences among *Senegalia polyacantha*, *Eucalyptus camaldulensis*, and *Acacia saligna* in terms of survival ($p > 0.05$). They maintained their numbers above 80% of their original population at the end of the experiments (Supporting file 1). This shows their adaptability to the prevailing climatic and edaphic conditions of the site. MacLachian [47] reported similar observations for *Senegalia polyacantha* and *Eucalyptus camaldulensis*. Bekele [48] noted *Senegalia polyacantha* can also grow on the stony soil, and *Eucalyptus camaldulensis* is the most successful plantation species due to a wider range of ecological adaptation and is one of the most tolerant species under poor soil conditions. *Acacia saligna* is also among the introduced species and widely used for rehabilitation programs in the district and in many parts of the country. The wider acceptance of the species may be attributed to its nitrogen-fixing ability. In arid or semiarid regions, the major limiting plant nutrient is likely to be nitrogen. Hence, the use of nitrogen-fixing trees can be extremely valuable, as noted by FAO [49]. *Albizia gummifera*, *Casuarina equisetifolia*, *Terminalia brownii*, and *Faidherbia albida* maintain more than 70% of their population. It is considered an acceptable rate of survival of multipurpose tree species on degraded land (Table 3).

Low overall survival was recorded for *Acacia decurrens* (44.443 ± 31.56), *Olea europaea* L. subsp. *cuspidata* (35.183 ± 30.60), and *Cordia africana* (30.555 ± 38.18) at $p < 0.05$ (Table 3). Low performance was associated with poor soil fertility conditions at the experimental site. A*cacia decurrens* tolerates acidity and grows best in light, deep, and drained fertile soils [47]. The low survival rate in the current experimental site is partly explained by the poor soil fertility status of the experimental site. The area is the naturally growing ecological zone for *Cordia africana*, but the low survival records in this study may be attributed to the edaphic factors of the site. Similarly, the low survival rate of *Cordia africana* (4.00 ± 1.91%) planted for the rehabilitation of degraded arid lands in southeast Ethiopia was reported [50]. The reforestation trials have demonstrated that edaphic conditions may have a strong effect on species growth and survival [51]. *Cordia africana* is successful in forest soil and is the best tree for homesteads and cropland [52]. *Olea europaea* L. subsp. *cuspidata* is an indigenous tree species that does best in good forest soil [48, 53]. The low survival in this experiment may be due to poor soil fertility status of degraded land and the species being one of the forest-dependent species. The species needs stable environmental conditions, and successful regeneration of this species relies on shade from other plants and protection from grazing, at least during the seedling stage [53]. The low survival in the current study area may be attributed to a lack of shade tree species, so the species is more suitable for enrichment planting of degraded forest land because the forest environment is completely different from open land in terms of light intensity and related microclimate, water, and nutrient availability [54].

TABLE 3 | Mean survival of 36-month-old multipurpose trees and shrubs on degraded land.

Treatments	Mean ± SD
Grevillea robusta R. Br.	$99.542^{a} \pm 1.05$
Senegalia polyacantha Willd.	$88.880^{ab} \pm 4.20$
Eucalyptus camaldulensis Dehnh.	$83.367^{ab} \pm 6.11$
Acacia saligna (Labill.) Wendl.	$83.330^{ab} \pm 7.43$
Albizia gummifera (J.F.Gmel.)C.A.Sm.	$77.563^{abc} \pm 8.85$
Casuarina equisetifolia L.	$76.847^{abc} \pm 10.81$
Terminalia brownii L.	$73.605^{abc} \pm 12.79$
Faidherbia albida (Del.) A. Chev.	$70.257^{bcd} \pm 16.81$
Dodonaea angustifolia L. f.	$52.730^{cde} \pm 18.55$
Acacia decurrens Willd.	$44.443^{de} \pm 31.55$
Olea europaea L. subsp. *cuspidata* (Wall. Ex G.Don) Cif.	$35.183^{e} \pm 30.60$
Cordia africana Lam.	$30.555^{e} \pm 38.18$

Note: Means in columns with similar letters are not significantly different at $p < 0.05$, Std. dev. = standard deviation.

3.2 | Survival Rate of Species Across the Growth Periods

In general, the mean survival rate of species decreased within the growth periods (Figure 4, Table 4). Similarly, decreasing survival rate with increasing growing months was reported by the experiment conducted for the rehabilitation of degraded lands in Ethiopia by Tadele et al. [55], Cheneke et al. [56], and Kasaye et al. [57]. In the present study, the largest (20.67%) overall plant death was recorded within the first six months of field planting (Table 2). The largest plant death at the initial stage may be associated with the low root growth rate. The amount of water and mineral nutrients essential for the survival of species available to plants depends on the volume of soil occupied by their root. The results help to suggest that early management (weeding, watering, and fertilizer or farm yard manure application) for the first 6 months after field planting may be very important to reduce the mortality rate of planted tree species for rehabilitation programs. In the next growth (6–12 months of field planting), 1.56% nonsignificant loss was observed out of the population they had in the first 6 months (Supporting file 1). This may be partly associated with the rainfall pattern of the area. No significant losses of species were recorded after 18 months of field planting (Table 4 and Figure 4). This may be interpreted as root extension into previously unoccupied soil is important to increase the survival of the species because it makes additional water and minerals available to the planted trees and shrubs.

In terms of individual species, the mortality rate varies across the growth periods and replications. *Grevillea robusta* maintains its original population almost for the whole study period across all plots (Figure 5(a)), which indicates species performances to tolerate variation of soil fertility status across replication, as well as climatic variability mainly rainfall across the growth periods. For some species, survival ranges from 0% to 100% across replication; for example, *Terminalia brownii* and *Casuarina equisetifolia* had shown 0% survival in one replication. The results were in line with the report of Breugel et al. [54]; among the species with survival of over 80%, some suffered very high mortality in one or more plots as well. *Senegalia polyacantha* and *Eucalyptus camaldulensis* exhibit similar survival patterns (Figure 5(b)). They maintain their original population after 6 months of field planting. Therefore, early management is very important to reduce the seedling death rate for these species under poor field conditions of degraded land. The mortality rate of *Acacia decurrens* increased from 27.78% to 72.22% in 15 months of field planting. The drastic death of *Acacia decurrens* (Figure 5(c)) is associated with the sallow root growth pattern of the species as noted by the ICRAF multipurpose tree species database [52]. The physical property of the soil affects root growth directly by restricting root penetration and indirectly by effects on aeration and water contents [58, 59]. Digging into the root zones of the dead, tree species of *Acacia decurrens* indicated that the roots distributed laterally above the naturally occurring hard pan of the soil. Preparing deeper planting pits, commonly 40 by 40 cm, may improve the survival rate of Acacia decurrens in such soils. Figure 5(d) also shows that the two species, *Albizia gummifera* and *Terminalia brownii*, exhibited similar survival patterns. It is also found that *Acacia saligna* and *Casuarina equisetifolia* exhibit similar survival patterns (Figure 5(e)). Both species maintain 75% of their original population at the end of the experiment.

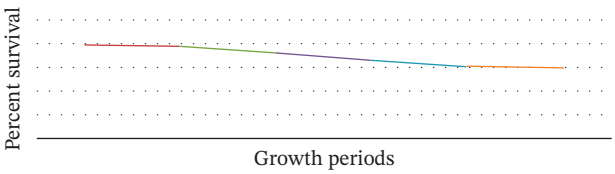


FIGURE 4 | Survival percent of seedlings across growth periods. Growth period 1—first 6-month period, 2—12-month period, 3—18-month period, 4—24-month period, 5—30-month period, 6—36 months of field planting.

3.3 | Vertical and Horizontal Growth Performances of Species

Generally, forest plantations, particularly even-aged and single-species plantations, are less favorable as the habitat for a wide range of taxa in different regions of the world [60, 61]. In the first 12 months, a significant difference was recorded between *Acacia saligna* (2.25 ± 0.43) and *Eucalyptus camaldulensis* (2.01 ± 0.48)

TABLE 4 | Mean growth height (m) of species across growth periods.

Treatments	12 months Mean ± SD	24 months Mean ± SD	36 months Mean ± SD
Grevillea robusta R. Br.	$1.08^{c} \pm 0.25$	$1.32^{e} \pm 0.07$	$2.68^{de} \pm 0.48$
Senegalia polyacantha Willd.	$1.00^{c} \pm 0.26$	$2.11^{c} \pm 0.15$	$3.07^{bc} \pm 0.59$
Eucalyptus camaldulensis Dehnh.	$2.01^{a} \pm 0.48$	$2.58^{b} \pm 0.30$	$4.38^{ab} \pm 0.99$
Acacia saligna (Labill.) Wendl.	$2.25^{a} \pm 0.43$	$3.79^{a} \pm 0.36$	$4.48^{a} \pm 0.81$
Albizia gummifera (J.F.Gmel.) C.A.Sm.	$0.28^{d} \pm 0.06$	$0.33^{g} \pm 03.0$	$0.45^{e} \pm 0.14$
Casuarina equisetifolia L.	$1.25^{bc} \pm 0.47$	$2.25^{c} \pm 0.33$	$3.14^{abc} \pm 0.49$
Terminalia brownii L.	$0.45^{d} \pm 0.05$	$0.55^{fg} \pm 0.10$	$1.6^{de} \pm 0.37$
Faidherbia albida (Del.) A. Chev.	$0.29^{d} \pm 0.04$	$0.36^{g} \pm 0.07$	$0.53^{e} \pm 0.12$
Dodonaea angustifolia L. f.	$0.46^{d} \pm 0.14$	$1.69^{d} \pm 0.40$	$0.65^{e} \pm 0.37$
Acacia decurrens Willd.	$1.56^{b} \pm 0.40$	$2.65^{b} \pm 0.39$	$2.95^{cd} \pm 0.60$
Olea europaea L. subsp. *cuspidata* (Wall. Ex G.Don) Cif.	$0.30^{d} \pm 0.02$	$0.40^{g} \pm 0.10$	$0.65^{e} \pm 0.14$
Cordia africana Lam.	$0.49^{d} \pm 0.10$	$0.75^{f} \pm 0.09$	$0.98^{e} \pm 0.25$

Note: Means in columns with similar letters are not significantly different at $p < 0.05$, SD, standard deviation of mean.

at $p < 0.05$. No significant difference was found between *Grevillea robusta* and *Senegalia polyacantha* (Table 4). A study conducted on Acacia saligna by the Tigray Agricultural Research Institute, Ethiopia, at three sites—Kite-Awlaelo, Atsbe-Wenbera, and Saesie-Saedaenba—reported mean heights of 3.28 m ± 1.24, 2.16 m ± 0.16, and 3.48 m ± 0.92, respectively, at 3 years of age [62]. A similar growth rate was reported for 5-year-old *Eucalyptus camaldulensis* (7.62 m ± 1.63) from the semiarid area of southern Ethiopia (Alagie) [12]. These species are found to be fast-growing species over other examined species. The least growth was recorded in *Faidherbia albida* in the first 12 months; this may be due to the low soil moisture content of the area, because this species is one of the characteristic species of the river-side vegetation [63]. According to Wood [64] and Fredrick et al. [65], *Faidherbia albida* is reported to be among the fastest growing species. Watering the seedlings until they grow deep roots could be advisable [64]. The species is known to be a drought avoider with deep roots able to access the groundwater. Therefore, these low growth performances may be due to low soil moisture content or due to wrong provenance selection. Berry and Chairman [21] noted that species' suitability to a particular site can vary depending on the race used. In the second period at 24 months, statistically significant differences were recorded between treatments at $p < 0.05$, and the best growth was recorded for *Acacia saligna* (3.79 ± 0.36) followed by *Acacia decurrens* (2.65 ± 0.39) and *Eucalyptus camaldulensis* (2.58 ± 0.36). At the end of this experiment, the best growth in terms of height was recorded for *Acacia saligna* (4.48 ± 0.81) followed by *Eucalyptus camaldulensis* (4.38 ± 0.99) and *Casuarina equisetifolia* (3.14 ± 0.49) (Table 4). *Acacia saligna*, *Senegalia polyacantha*, *Eucalyptus camaldulensis*, and *Casuarina equisetifolia* showed similar growth patterns (Figures 6(a), 6(b)). Exotic species, for example, *Acacia decurrens* and *Grevillea robusta*, revealed better growth than indigenous tree species *Terminalia brownii* and *Dodonaea angustifolia* (Figures 6(c), 6(d)). In general, Evans [40] reported that exotic tree species fulfilled the requirements of fast early growth better than indigenous species, which has been noted generally in tropical forest plantations. Furthermore, the result revealed that there were no significant differences at $p < 0.05$ in growth height among *Dodonaea angustifolia, Albizia gummifera, Olea europaea* L. subsp. *cuspidata*, and *Cordia africana* (Table 4 and Figures 6(e), 6(f)).

A large difference (20–40 cm) between seedlings in terms of height was observed at the initial stage of field planting. This observed difference between seedlings is due to variation in time taken by the seed to germinate and the nursery environment, particularly light, which plays an important role in the growth difference among species. Some species had shown best growth under high-light environment, while others had shown best growth under medium-light environment, as reported in most tropical tree species.

3.4 | RGRH (cm) Per Month

The RGR is an ecologically important parameter because it is one of the primary variables that determine the outcome of competitive interaction between plants growing under natural conditions. The RGRs of species from initial field planting to the end of the experiment were investigated following Evans [40]. The results indicated that the highest value of RGR was recorded by *Acacia saligna* (0.150 cm per month) followed by *Acacia decurrens* (0.147 cm per month) and *Casuarina equisetifolia* (0.111 cm per month) (Table 5). These differences in RGR may be due to either morphological or physiological differences between species. The highest height increment, 138.3 cm per year, was recorded for *Eucalyptus camaldulensis*, followed by *Acacia saligna* (137.7 cm) per year. In the case of younger plantations, a height increment of 60 cm per annum is considered necessary for fast-growing species. In this experiment, *Acacia decurrens, Acacia saligna*, *Casuarina equisetifolia*, *Dodonaea angustifolia, Senegalia polyacantha*, and *Grevillea robusta* score height increment above 60 cm per year. This concept of fast growth in forestry is relative, and it depends upon several factors like locality, age, and management. In general, in the present experiment, the majority of species exhibit the best growth value per month during the initial growth period in the first 1 year of field planting. Therefore, growth variation may result from differences in soil conditions; as the root growth increases, the soil becomes

less conducive to seedling root penetration, thereby hindering the growth rate of the seedling in the second year. In general, young seedlings are photosynthetically more active than old trees as reported by Gorte [66].

3.5 | DBH and Mean Root Collar Diameter

Horizontal growth in terms of DBH and root collar diameter was investigated at the end of the experiment. Statistically, there were no significant differences between *Eucalyptus camaldulensis* (5.41 ± 2.49), *Senegalia polyacantha* (5.14 ± 2.22), and *Acacia saligna* (4.67 ± 1.45) in terms of DBH at $p < 0.05$ (Table 6). These species were found to have relatively better field performances in terms of survival, and growth height had higher DBH. *Dodonaea angustifolia* scores a low DBH due to the shrubby nature of the species. It produces large leaf litter (personal observation), which may be important to improve the soil fertility status of degraded land. This is in line with the report of Bekele et al. [48] who noted that *Dodonaea angustifolia* is a useful indigenous species to reclaim poor land from marshes to sand dunes.

3.6 | Mean Root Collar Diameter

The root collar diameter of the tree is a good indicator of the planted species field performance in terms of survival and growth. Performances of the mean root collar diameter of promising multipurpose trees and shrubs were calculated at the end of the experiment, and results indicated positive relationships between root collar diameter growth and increasing growing months. A positive correlation between tree height and tree root collar diameter rather than tree bole diameter was reported [12]. In the present experiment, the

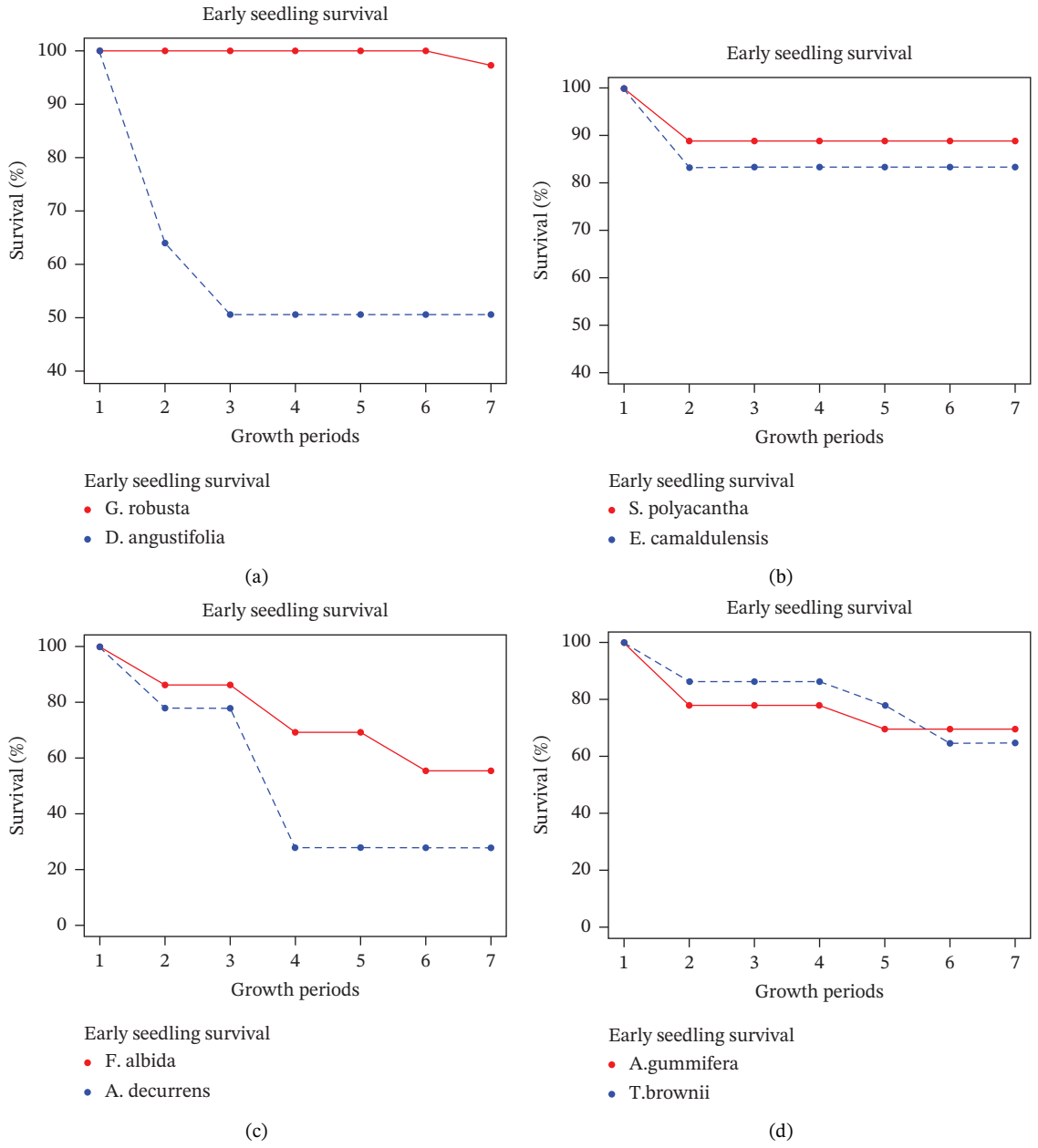


FIGURE 5 | (Continued)

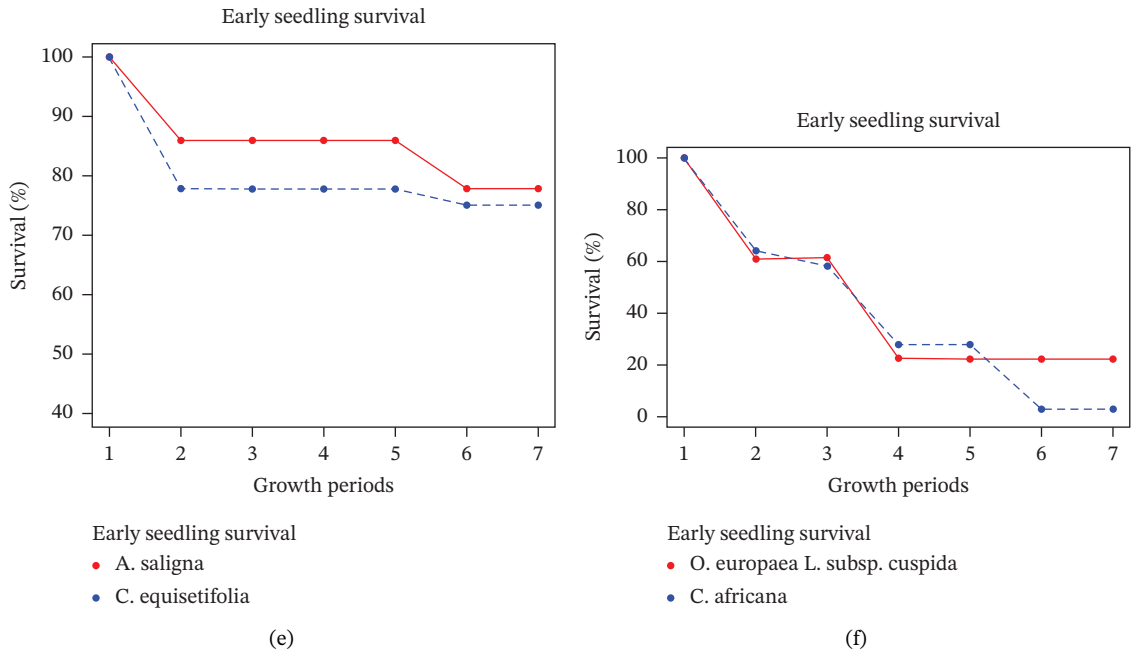


FIGURE 5 | (a, b, c, d, e, f). Survival curve of seedlings across growth periods. Growth period 1—initial planting time, 2—first 6 months, 3—12 months, 4—18 months, 5—24 months, 6—30 months, 7—36 months of field planting.

highest root collar diameter was recorded by *Acacia saligna* (11.69 ± 2.44 cm) followed by *Eucalyptus camaldulensis* (7.51 ± 1.27). Similar results were reported from the Wag-Lasta area, northeastern Ethiopia [57]. The higher value of root collar diameter for *Acacia saligna* was reported in the central highlands of Ethiopia [65]. Statistically, no significant differences were found between C*asuarina equisetifolia* and *Dodonaea angustifolia* (Table 6) (Figure 5). These species that exhibited relatively better field performances also had better root collar diameters.

3.7 | Preliminary Approximation of Bole Volume Promising Multipurpose Trees and Shrubs

The relative importance of tree species in a forest can better be depicted from the measurements of basal area than from the stem counts [67]. The calculated mean bole volume of 3-year-old planted species from height and DBH data indicated that *Eucalyptus camaldulensis* shows better bole volume (12.59 m^3 per hectare) followed by *Acacia saligna* (9.59 m^3) per hectare and *Senegalia polyacantha* (7.95 m^3) per hectare compared to other

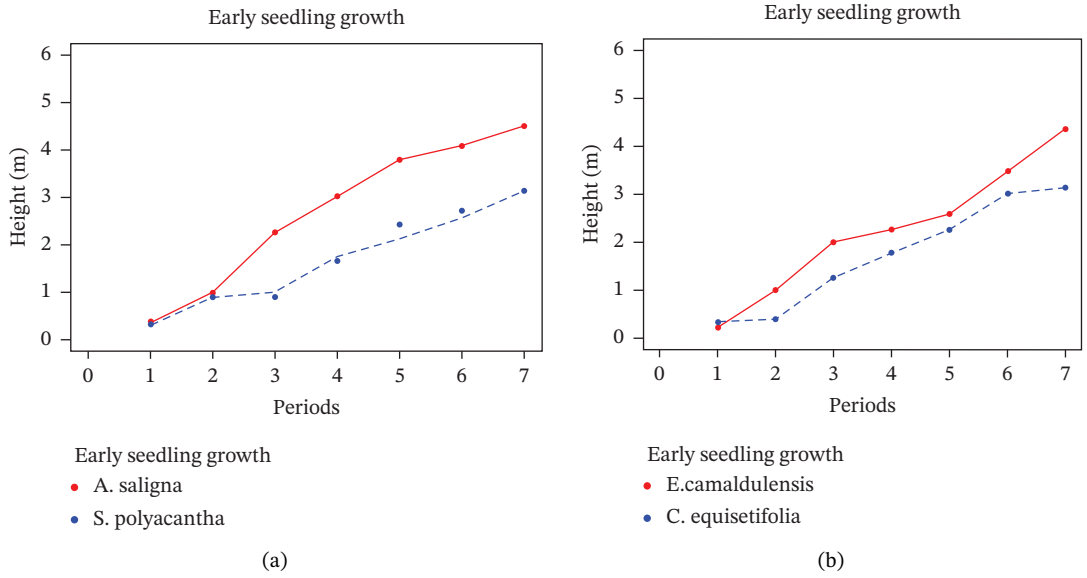


FIGURE 6 | (Continued)

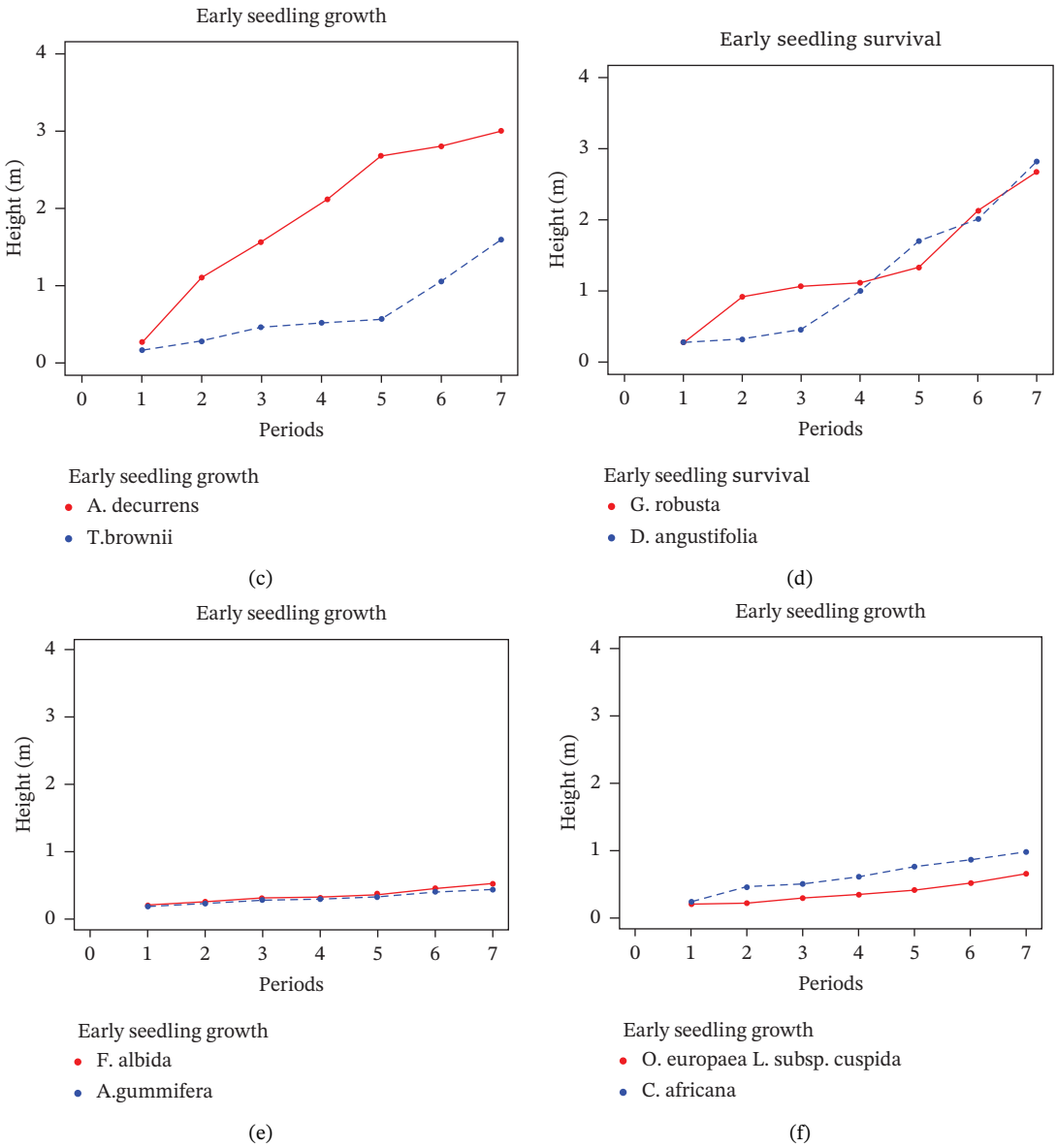


FIGURE 6 | (a, b, c, d, e, f). Growth curve of species per growth periods (Period 1—first 6-month period, 2—12-month period, 3—18-month period, 4—24-month period, 5—30-month period, 6—36 months of field planting).

species. In the current study, the contribution of tree DBH was found to be higher than tree height for volume. The results also indicated that *Terminalia brownii*, *Dodonaea angustifolia*, *Grevillea robusta*, and *Casuarina equisetifolia* attained 0.42, 0.23, 0.45, and 1.82 m^3 per hectare per year, respectively. According to Rendig and Taylor [68], fast growing species yield a minimum of 10 cubic meters of wood per hectare per annum. Those fast-growing species are best for the rehabilitation of degraded land within a short period of time, as indicated in Figures 7(a) and 7(b).

3.8 | Relative Importance of Species to Local Community Based on Use Value

Conservationists also widely recognized that success in biodiversity conservation cannot be fully achieved unless the needs and priorities of local communities, as well as traditional and indigenous resource use practices, are understood and taken into account [69]. The use value technique is widely acknowledged as an objective and reliable tool to quantify the relative importance of a plant species to a community, as it is simultaneously based on the number of uses linked to the plant and the number of informants that mention it [70]. In the present study, use values were calculated for 8 promising (in terms of growth and survival results) multipurpose trees and shrubs planted for the rehabilitation of degraded land. *Albizia gummifera*, *Olea europaea* L. subsp. *cuspidata*, *Acacia decurrens*, and *Cordia africana* were omitted from the calculation of use value because of their inferior performance compared to other species under evaluation. For this study, the plants were grouped into six main use categories, namely, construction, timber, fuelwood, medicine, fodder, and bee forage. The results showed that the highest average use value was recorded for *Eucalyptus camaldulensis* (1.65) followed by *Dodonaea angustifolia* (1.59) and *Grevillea robusta* (1.38) (Table 7). These are multipurpose species used for more than four use categories. The use of quantitative ethnobotanical parameters (use value) in connection with the ecological performance of

TABLE 5 | Relative growth rate (RGR) in height (cm) per month across years (1–3) and height increment (cm) per year.

Species	Year 1	Year 2	Year 3	Height increment (cm)
Grevillea robusta R. Br.	0.096	0.018	0.075	79.7
Senegalia polyacantha Willd.	0.096	0.063	0.030	91.7
Eucalyptus camaldulensis Dehnh.	0.084	0.021	0.0144	138.3
Acacia saligna (Labill.) Wendl.	0.150	0.045	0.012	137.7
Albizia gummifera (J.F.Gmel.) C.A.Sm.	0.033	0.012	0.024	8.3
Casuarina equisetifolia L.	0.111	0.048	0.051	93.7
Terminalia brownii L.	0.087	0.015	0.087	48.0
Faidherbia albida (Del.) A. Chev.	0.030	0.015	0.030	10.6
Dodonaea angustifolia L. f.	0.042	0.108	0.042	84.7
Acacia decurrens Willd.	0.147	0.045	0.003	91.3
Olea europaea L. subsp. *cuspidata* (Wall. Ex G.Don) Cif.	0.093	0.024	0.039	15.0
Cordia africana Lam.	0.0252	0.036	0.018	47.0

TABLE 6 | Growth of diameter at breast height (DBH) and root collar diameter (RCD) in cm.

Treatments	Mean ± SD (DBH)	Mean ± SD (RCD)
Grevillea robusta R. Br.	$1.32^{bc} \pm 0.62$	$3.87^{e} \pm 1.93$
Senegalia polyacantha Willd.	$5.14^{a} \pm 2.22$	$6.82^{bc} \pm 1.93$
Eucalyptus camaldulensis Dehnh.	$5.41^{a} \pm 2.49$	$7.51^{b} \pm 1.27$
Acacia saligna (Labill.) Wendl.	$4.67^{a} \pm 1.45$	$11.69^{a} \pm 2.44$
Casuarina equisetifolia L.	$2.43^{b} \pm 1.38$	$4.70^{de} \pm 0.37$
Terminalia brownii L.	$1.64^{bc} \pm 0.58$	$4.40^{de} \pm 0.54$
Faidherbia albida (Del.) A. Chev.	$0.17^{c} \pm 0.41$	$2.22^{f} \pm 0.54$
Dodonaea angustifolia L. f.	$1.84^{b} \pm 1.84$	$5.83^{cd} \pm 1.43$

Note: Mean ± SD (mean and standard deviation). Different letter within each column indicate significant differences at ($p < 0.05$).



(a) (b)

FIGURE 7 | (a) Initial site and (b) 18 months of field planting.

TABLE 7 | General use values of trees and shrubs under evaluation.

Species	Med	Tim	Con	Fod	Fw	BF	Tuv	Auv	Rank
Grevillea robusta R. Br	0.0	3.1	2.5	2.0	4.8	1.4	13.8	1.38	3
Senegalia polyacantha Willd	0.0	1.2	1.6	2.8	3.2	3.6	12.4	1.24	5
Eucalyptus camaldulensis Dehnh	0.9	1.5	5.8	1.0	6.00	1.3	16.5	1.65	1
Casuarina equisetifolia L.	0.0	3.4	2.4	2.00	5.2	0.0	13.0	1.30	4
Terminalia brownii L	0.0	0.0	1.0	6.00	2.5	1.00	10.5	1.05	7
Faidherbia albida (Del.) A. Chev	0.0	1.0	1.9	4.0	2.7	1.1	10.7	1.07	6
Dodonaea angustifolia L. f.	4.8	0.0	3.2	2.5	2.4	3.0	15.9	1.59	2
Acacia saligna (Labill.)Wendl	0.0	0.06	1.6	1.3	3.1	1.2	7.3	0.73	8

Note: Use values range 0 to 6: 6, Excellent; 0, no use key; UVs = use values; MD = medicinal; Tim = timber; Con = construction or furniture, FD = fodder.
Abbreviations: Auv, average use value; BF, bee forage; FW, fuel wood; Tuv, total use value.

species in terms of growth and survival improves the quality of vegetation restoration sites at each ecological successional stage because most restoration sites lack economically important tree species in early successional stages. In addition, *Eucalyptus camaldulensis* has a high-income generation capacity for the local community, and the coppicing ability of the species makes it preferable to the community. On the other hand, the local government has banned *Eucalyptus camaldulensis* seedling production at the nursery level on unjustifiable ecological reasons (consumes a large volume of water, negative impact on undergrowth flora due to the allopathic effect without research findings). *Dodonaea angustifolia* provides five uses to the community; its leaf and bark are used for medicine, its leaf for fodder, flowers for bee forage or sources of nectar, its stem for local house construction, and the preparation of farm implements. The lowest use value was calculated for *Senegalia polyacantha, Terminalia brownii*, and *Acacia saligna* (Table 7). According to Edwards and Hedberg [71], *Senegalia polyacantha* has several uses. Its gum is used in confectionery and adhesives, the wood ash is used as a substitute for salt in southwestern Ethiopia, and the wood is hard, durable, and termite-resistant, making it preferable for construction. Therefore, the uses of plant species are determined by cultural groups.

4 | Conclusion

Species screening trials are an essential initial step in selecting ecologically viable and socially acceptable tree species for reforestation and restoration of degraded land among hundreds of tree species that are potentially available. In the present experiment, early performances of 12 multipurpose trees and shrubs were evaluated with the goal of selecting ecologically suitable and socially acceptable species for the rehabilitation of degraded lands in the Central Rift Valley, Ethiopia. The results of the experiment revealed that there is variation among species in terms of survival, growth height, DBH, and root collar diameter. More than 80% of G*revillea robusta, Senegalia polyacantha*, and *Eucalyptus camaldulensis* seedlings survived after 36 months of field planting, which indicates their adaptability to the stressful conditions of a degraded land. Moreover, 20.67% of overall seedling mortality was recorded in the first 6 months of field planting, indicating that early management was very important to reduce the mortality rate for seedlings planted for rehabilitation programs. Furthermore, ethnobotanical indices indicated that *Eucalyptus camaldulensis*, *Grevillea robusta*, *Dodonaea angustifolia,* and *Senegalia polyacantha* scored the highest use values, and the local community used those species for various purposes. The use of quantitative ethnobotanical parameters in connection with the ecological performance of species was important to improve the quality of the vegetation restoration site at each ecological successional stage. Therefore, to help the ongoing local land restoration and support the livelihoods of the local community, these four species were found ecologically suitable and socially acceptable for the rehabilitation of the degraded land of the Halaba zone. It would be important to conduct a preliminary study before planting these species in other similar agroecological zones, for the restoration program. Furthermore, sometimes survival and growth performances might not be the only criteria to select tree species for a restoration program. Therefore, it is vital to consider the indigenous knowledge of the local community to select economically and socially acceptable tree species for restoration programs. Thus, more research is needed to see the influences of these species on the undergrowth flora and physicochemical properties of the soil.

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Ethics Statement

This study was approved by the former Southern Agricultural Research Institute.

Consent

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data used to support the findings of this study are available from the Supporting File 1, "Survival per growth periods."

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. *(Supporting Information)*

Supporting File 1. The survival records of species per 6-month growth intervals in the degraded land of Halaba district.