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Potential of eight exotic species for fast and high-volume timber production at moist Tepi in southwestern Ethiopia

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Report summary

Ethiopian smallholder farmers practice eucalypt (*E. globulus* and *E. camaldulensis*) short rotation forestry extensively, and the existing industrial plantations are also largely composed of the two species. The potential of eight selected exotic tree species for fast and high-volume timber production was evaluated aiming at diversification of plantations with productive timber species. Thus, this study aimed to evaluate the early growth performance of eight timber species at Tepi, South-western Ethiopia. The species were planted in RCBD with three replications and 25 seedlings per plot with a spacing of 2.5 m X 2.5 m. Statistical analyses were done using a univariate general linear model. The species were rated and grouped based on survival and growth data at the age of four. The mean survival rate, diameter at breast height and total height differed significantly between the species. Based on the combined rating of the species, *Eucalyptus grandis* and *Cordia alliodora* were the best performing species exhibiting high survival and high growth conditions. *Cupressus torulosa* and *Eucalyptus pilularis* performed poorly as compared to the rest. We conclude that six of the species can strategically be promoted for use in fast and high-volume timber production in short-rotation forestry as well as in long-term forest plantations in a moist southwestern region of Ethiopia. However, tree growers interested in *Cupressus torulosa* and *Eucalyptus pilularis* should be aware of their relatively low performances. More data should be generated on the long-term performance of the species.

1. Introduction

The Ethiopian natural forests are vanishing at an alarming rate, and a study suggested that the average deforestation rate of Ethiopia lies somewhere between 1-1.5% annually (Lemenih and Woldemariam, 2010). The unabated deforestation and their poor replacement on the one hand and the ever-increasing demand for wood products (Hunde et al., 2003; Sandewall et al., 2015) on the other can have economically unfavourable consequences. For instance, on the year 2015 alone, the country imported over 3 million m^3 Roundwood equivalent (RWE) of various industrial wood products that cost about 182.53 million USD while the import and export show a negative trend balance (MEFCC, 2018b).

Globally, planted forests are increasing and constitute 7% of the total forest cover, or 264 million ha, but are responsible for more than 50% of world's industrial round wood production (FAO, 2010). Similarly, the focus was given to establish forest plantations and improve the wood supply situation in Ethiopia, and exotic tree species such as eucalypt introduced a century ago. Especially, large-scale plantation programme was initiated in the early 1970s, with support from Sweden, aiming at improving timber and fueldwood production in the country (Bekele, 2011; EFAP, 1994). Recent estimates suggest that planted forests (industrial and smallholder plantations together) in Ethiopia amount to over 827 thousand ha (MEFCC, 2018a).

In addition to the development of plantation with exotic tree species, different efforts have been made to develop plantations with native trees. The native tree plantations are, however, hampered by many factors and most importantly by herbivory. Thus, the existing data show only that success stories in developing native tree plantations are very minimal, and instead suggest that the planted forests in Ethiopia are mainly composed of exotic tree species (Bekele, 2011; MEFCC, 2018a).

The selected study species (*Cupressus torulosa*, *Cordia alliodora*, *Eucalyptus deglupta, Eucalyptus grandis, Eucalyptus pilularis, Pinus patula, Tectona grandis and Terminalia ivorensis)* are among the introduced timber species, but most of them are limited only on the Forestry Research Center's experimental sites and to a few other plantation sites. Therefore, the objective of the study was to evaluate the survival rate and growth of eight timber species at Tepi for possible diversification of industrial and smallholder plantations with productive tree species in moist southwestern Ethiopia.

2. Materials and methods

2.1. Site description

The experiment was carried out at Tepi National Spice Research Center (TNSRC), Sheka Administrative Zone of the Southern Nations, Nationalities and Peoples National Regional State, Ethiopia (Figure1). Geographically, the area is located between 070 10' 54.5" and 070 11' 17.1" North and 350 25' 04.3" and 350 25' 28.2" East. The altitude ranges from 1182 to 1220 m a.s.l. The mean annual rainfall was 1678 mm and well distributed over eight months. The minimum and maximum mean annual temperature were 14.2 °C and 25.5 °C, respectively. The soil types in the study area are variable, but the dominant is Nitisols.

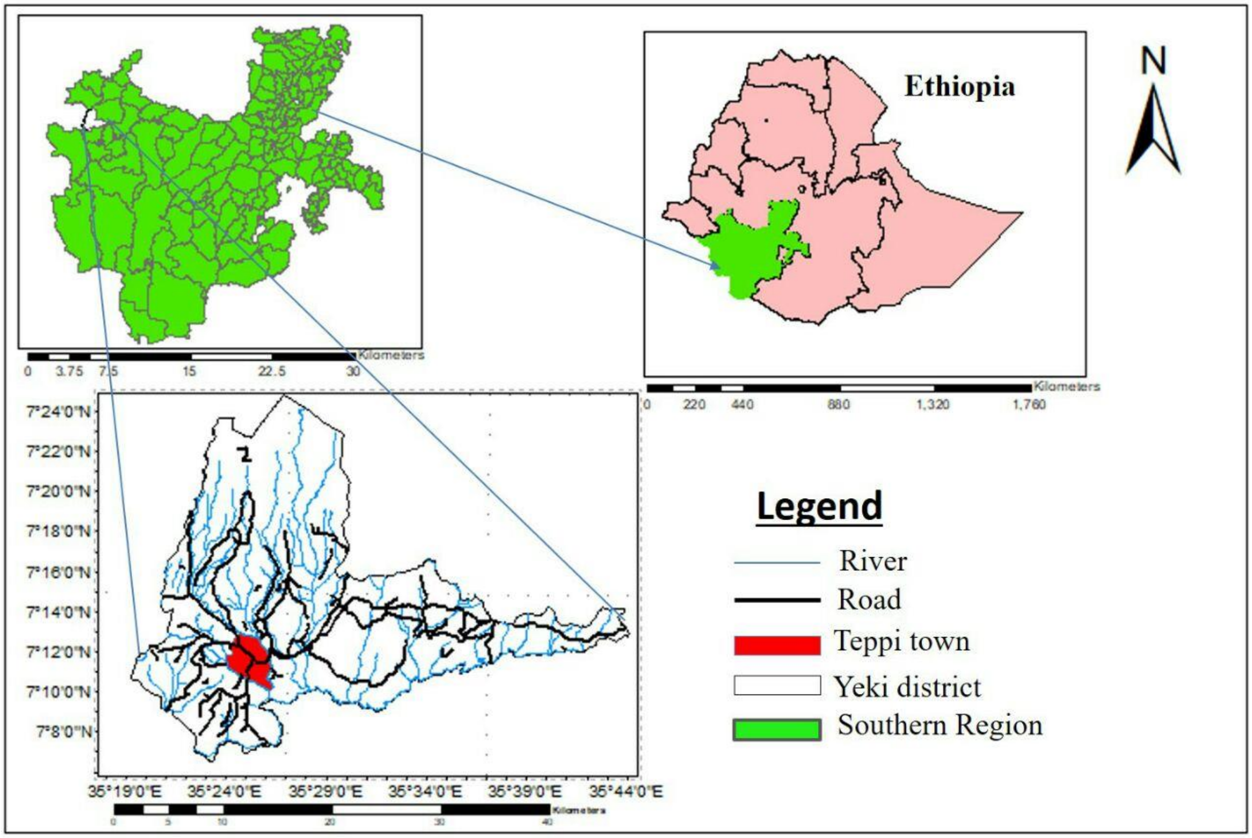

Figure 1: Map of the study site in Tepi, South-western Ethiopia

2.2. Species description

Table 1 presents brief descriptions and ecological ranges of the eight selected tree species.

2.3. Seed collection and raising seedlings

Seeds of selected timber species (*C. torulosa*, *C. alliodora*, *E. deglupta, E. grandis, E. pilularis, P. patula, T. grandis and T. ivorensis*) collected from stands of the Forestry Research Center located in southwest Ethiopia were used. Seed pretreatment was done only to *T. ivorensis* (removal of arils by hand) and *T. grandis* (overnight cold water soaking and then air drying). Seeds of the eight species were sown on the Tepi nursery site seed bed on 20 February 2012 and then transplanted to polyethylene bags. Seedlings were grown on pot sizes of 8 cm with a soil mix of 3:2:1 (local soil, forest soil and sand, respectively). They were provided with the necessary shade with wood support and grass top and watered and weeded until they attained planting height. Six of the species were grown for ten months while *P. patula* and *T. grandis* were grown for 16 months in the nursery.

2.4. Experimental establishment and data collection

The species were planted out in the field in a randomized complete block design (RCBD) with three replications laid along the contour. 25 seedlings per plot with spacing of 2.5 m X 2.5 m between trees, 3 m between plots and 4 m between blocks were used. The planting was carried out in two phases: while the six species were planted on October 2013, the two species (*P. patula* and *T. grandis*) were planted in

August 2014. The experimental site was given protection with fencing. Weeding was carried out continuously whenever needed, and mulch with coffee husk was also applied once after planting. Data were collected from the inner 9 trees in every plot and the rest were considered as border trees while the whole tree count was used for survival rate assessment.

Table 1. Tree characteristics, natural distribution and ecology of the eight exotic-species

Species name	Form and size	Distribution and Ecology
Cupressus torulosa *	A tree 15-25 (45) m tall and with dbh of 40-60 (90) cm, crown large oval to broadly conical.	It is a shade intolerant species, thriving in tropical and subtropical rainforests with altitude of 800-3000 m, mean annual temperature: 12-22 °C and mean annual rainfall of 650-1600 mm.
*Cordia alliodora**	Grows to over 30 m tall and 30-50 cm dbh, usually straight, cylindrical; often clear of branches for up to 50-60% of the total tree height.	It is a pioneer plant found in a wide range of habitats. it is common in drier areas with altitude of 0-2000 m, mean annual temperature: 24 °C, mean annual rainfall: 750-2000 mm.
*Eucalyptus deglupta**	It is a huge evergreen tree grown up to 60 (max. 75) m tall; bole generally of good form, 50-70% of the tree height, up to 240 cm in diameter.	It is generally adapted to lowland and lower montane rainforest habitats, with altitude: 0-1800 m, mean annual temperature of 23-31 °C and mean annual rainfall of 2500-5000 mm
Eucalyptus grandis *	It attains a height of 45-55 m, usually with an excellent trunk and with a dbh of 120-200 cm.	It grows in tall, open forest in sheltered valleys and on hill slopes, with altitude of 0-2700 m, mean annual temperature between -1 to 40, and mean annual rainfall of 100-1800 mm.
*Eucalyptus pilularis***	It is a tree to 70 m high; bark persistent on full trunk, grey-brown, shortly fibrous to stringy, smooth above, white to grey, shedding in long ribbons.	It is widespread and frequently dominant, in wet sclerophyll or grassy coastal forest on lighter soils of medium fertility, north from Eden district.
Pinus patula ***	A tree up to 40 m tall and 100 cm diameter, usually with a single, straight, slender trunk	It is generally restricted to humid, subtropical to warm-temperate sites, with annual precipitation 1000-2200 mm and at elevations from 1400 -3300 m. Cold hardiness limit between -12.1°C and -6.7°C)
*Tectona grandis**	It is a large, deciduous tree grown over 30 m in height and dbh up to 60 cm in favorable conditions, with open crown and many small branches	It grows in various types of tropical deciduous forests with altitudinal range between 0-1200 m, mean annual temperature of 14-36 ^{0}c and mean annual rainfall of 1200 - 2500(4 000) mm.
*Terminalia ivorensis**	It is a large deciduous forest tree height from 15 to 46 m, branchless for up to 30 m, dbh 2-4.75 m. Bole clean, very straight with small buttresses and sometimes fluted.	It is found in rainforest conditions but is predominantly a tree of seasonal forest zones with Altitude of 0-1200 m, mean annual temperature 20-33 ^{o}C and mean annual rainfall of 1250-3000 mm

Source: * Agroforestry Database 4.0 (Orwa et al.2009); ** http://plantnet.rbgsyd.nsw.gov.au on 30 September 2019;*** Adapted from the Gymnosperms database, www.conifers.org, on 31 May 2018

Survival count, and height measurement were done 12, 24, 36, 48 and 60 months after planting, while dbh were measured when all the species attained 1.5 m height at 24, 36, 45 and 60 months after planting.

2.5. Data analysis

Descriptive statistics (mean and standard deviations) were computed for survival, collar diameter, diameter and total height. Survival assessment of the timber species was based on the original number of trees planted. To test statistically the mean survival rate of timber species, data was arcsine square root transformed to meet normality assumptions. A univariate general linear model (GLM) ($\alpha = 0.05$) was employed to determine the existence of significant differences among the species for growth and survival. Species were considered as fixed effects, block as random effect and age (counted as of field planting to time of measurement) was considered a covariate. Multiple comparisons of means were conducted using LSD test were conducted in cases of statistically significant differences ($P \leq 0.05$) in the parameters analysed. SPSS 21 (IBM, Armonk, NY, USA) was used for the statistical analysis.

A combined trait (growth, survival) analysis was carried out to rate the different species based on the age 4 data by adapting the method used in Alexander and Edminster (1981). First the relative height, dbh and survival values of each species was computed as the ratio of the species values to plantation means and expressed in percentages. Then the ranges between the relative percentage values for each trait were subdivided in to six, and scores of 0 (lowest performance) to 5 (highest performance) were given for each species separately. After rating the height and dbh (0 to 5), the mean rate of the species for growth was computed. Total score for each species then was computed as the summation of mean scores for growth traits and survival, and values then ranged from 0 to 10. Afterwards, the species were categorized in to four groups as having relatively low or high survival and growth.

3. Results and discussion

3.1. Survival and growth performance

3.1.1. Species survival rate

The percentage survival differed significantly between the species ($p < 0.05$) (Table 2). This survival varied from 83% at age 1 to 73% at age 5. At the age of one, the highest survival rates were recorded for *P. patula* and *T. grandis* (96%) and the least was recorded by *E. deglupta* (55%). From age 2 to age 5, *C. alliodora and T*. *ivorensis* maintained their survival rate whereas *E. deglupta*, *E. pilularis* and *C. torulosa* species had higher mortality rate with advancement of their ages.

The variation in seedling sizes at the nursery could be due to variation in the time of emergence and/or due to growth rate differences among the species. The phenotypic variation of each species in the nursery site could also be due to variation in species response to environmental variables (Hirata et al., 2015; Westoby et al., 2002). The significant difference in seedling survival among the species might be due to differences in initial seedling vigour, susceptibility to pest and diseases, drought and extreme weathers, nutrient deficiency and herbivory (Moe et al., 2016; Shono et al., 2007; Villar-Salvador et al., 2012). Maintaining of the higher survival rate could also be associated with the initial higher quality of seedlings (Grossnickle and MacDonald, 2018; O'Reilly et al., 2002). In contrast, the highest mortality rate of *E. deglupta and E. pilularis* could be associated with physical factors like browsing damage by small antelopes, goats and rodents. The browsing (debarking of the tree bark) effect was highly observed on the

E. deglupta species. *E. deglupta* was also cited as extremely site-sensitive, and susceptible to different pests and diseases (Eldridge et al., 1994).

Table 2. Mean survival (%) of five years old timber species at Tepi, South-western Ethiopia

Species	Survival (% ± Sd)				
	Age 1	Age 2	Age 3	Age 4	Age 5
C. alliodora	91 (±8)	89 (±9)	89 (±9)	89 (±9)	89 (±9)
C. torulosa	73 (±12)	72 (±12)	72 (±12)	72 (±12)	67(±13)
E. deglupta	55 (±8)	55 (±8)	55 (±8)	53 (±9)	53(±9)
E. grandis	88 (±8)	88 (±8)	88 (±8)	80 (±10)	80(±10)
E. pilularis	68 (±18)	65 (±22)	63 (±14)	61 (±20)	53(±9)
P. patula	96 (±4)	95 (±5)	92 (±4)	92 (±4)	-
T. grandis	96 (±4)	96 (±4)	93(±8)	93(±8)	-
T. ivorensis	95 (±2)	95 (±2)	95 (±2)	95 (±2)	95(±2)
Mean total	83 (± 17)	82 (±18)	81(±17)	81(±17)	73(±19)
p-value	0.002	0.001	0.000	0.000	0.003

3.1.2 Species growth indices

The analysis of variance in the general linear model revealed significant differences among the timber species.

Table 3: Mean (± SD) DBH (cm) of the eight planted species at Tepi, South-western Ethiopia

Species	DBH (cm)			
	Age 2	Age 3	Age 4	Age 5
C. alliodora	7.66(±1.35) ^{d}	9.81(±1.74) ^{e}	10.85(±2.66) ^{f}	13.27(±3.19) ^{b}
C. torulosa	4.43(±1.63) ^{b}	7.18(±2.52) ^{bd}	9.11(±3.16) ^{cd}	12.29(±2.60) ^{b}
E. deglupta	7.10(±2.76) ^{d}	10.27(±3.21) ^{e}	12.25(±3.60) ^{f}	17.89(±3.7) ^{d}
E. grandis	7.21(±1.50) ^{d}	10.68(±1.49) ^{e}	12.53(±2.00) ^{f}	16.03(±3.68) ^{cd}
E. pilularis	5.37(±2.41) ^{c}	8.48(±2.00) ^{d}	10.16(±2.72) ^{de}	13.95(±3.11) ^{bc}
P. patula	3.04(±0.92) ^{a}	5.32(±1.59) ^{a}	7.25(±2.20) ^{a}	-
T. grandis	4.94(±1.80) ^{bc}	6.46(±2.37) ^{b}	8.35(±2.53) ^{b}	-
T. ivorensis	5.61(±1.52) ^{c}	7.59(±2.69) ^{d}	8.69(±2.61) ^{bc}	10.18(±3.43) ^{a}
Total Mean	4.94(±1.80)	7.97(±2.69)	9.57(±3.07)	13.19(±4.09)
P-value	0.001	0.004	0.006	0.017

Values with different letters in a column differed significantly ($p < 0.05$)

Five years after planting, the growth data revealed that the total mean dbh was 13.19 (± 4.09) cm, and *E. deglupta* and *E. grandis* had significantly higher dbh than the other species (Table 3). At all years, *E. grandis* maintained significantly higher height over the other timber species. In contrast, *P. patula* attained the smallest height at all years from age one up to age 5 (Table 4).

Table 4: Mean (± SD) height (m) of the eight planted tree species at Tepi, South-western Ethiopia

Species	During planting	Height				
		Age 1	Age 2	Age 3	Age 4	Age 5
C. alliodora	0.60 (±0.13) ^{d}	2.05(±0.35) ^{b}	6.00(±0.69) ^{d}	8.83(±1.54) ^{d}	14.68 (±3.34) ^{cd}	16.16(±3.34) ^{b}
C. torulosa	0.50 (±0.07) ^{c}	1.81(±0.46) ^{b}	3.82(±0.87) ^{a}	5.47(±1.01) ^{a}	8.27(±5.76) ^{b}	10.50(±5.44) ^{a}
E. deglupta	0.51(±0.13) ^{c}	2.44(±0.79) ^{b}	6.94(±2.19) ^{e}	10.36(±3.16) ^{e}	17.58(±5.90) ^{d}	19.19(±6.64) ^{c}
E. grandis	0.76(±0.20) ^{e}	3.07(±0.92) ^{b}	7.80(±1.72) ^{e}	11.97(±1.73) ^{f}	22.05(±4.27) ^{e}	26.12(±5.03) ^{d}
E. pilularis	0.49(±0.10) ^{c}	2.08(±0.88) ^{b}	5.15(±1.66) ^{c}	8.12(±1.32) ^{cd}	13.92(±3.95) ^{c}	16.52(±2.39) ^{bc}
P. patula	0.20(±0.03) ^{b}	1.04(±0.32) ^{a}	3.57(±0.78) ^{a}	5.20(±1.41) ^{a}	7.38(±1.60) ^{a}	-
T. grandis	0.11(±0.03) ^{a}	1.31(±0.74) ^{a}	4.11(±1.43) ^{ab}	6.49(±0.70) ^{b}	8.01(±1.57) ^{a}	-
T. ivorensis	0.61(±0.24) ^{d}	1.49(±0.39) ^{b}	4.75(±1.11) ^{bc}	7.76(±1.75) ^{c}	11.65(±4.42) ^{b}	12.92(±4.75) ^{a}
Total Mean	0.48(±0.24)	1.85(±0.88)	5.09(±1.91)	7.76(±2.52)	12.25(±5.89)	16.36(±6.58)
P-value	0.00	0.005	0.003	0.00	0.00	0.00

Values with different letters in a column differed significantly ($p < 0.05$)

The age 4 data show that *E. grandis* had significantly the highest height of all the species. At this same age, the species had also one of the best diameters. The mean height of *E. grandis* at age 5 at this site (26.1 m) was taller than the one reported for the species at age of 8 (23.2 m) at Wondo Genet, southern Ethiopia (Hunde et al., 2003). This species was also reported as the most productive eucalyptus species in the world (Eldridge et al., 1994). When comparing the mean annual height increment of *E. grandis* with the other timber species in the experimental site such as *P. patula*, the mean annual growth rate of the former was nearly threefold of that of the latter.

3.1.3 Combined growth and survival scores

According to the growth and survival combined scores, *E. grandis* and *C. alliodora* are the most promising species (with relatively high growth and high survival) scoring 8 out of 10. Three species (*T. ivorensis*, *T. grandis* and *P. patula*) with respective scores of 6, 5.5 and 5 exhibited high survival but low growth whereas *E. deglupta* with a score of 4.5 showed low survival but high growth conditions. *E. pilularis* and *C. torulosa* with respective scores of 3.5 and 3 were the least promising species with relatively low survival and low growth rates (Figure 2).

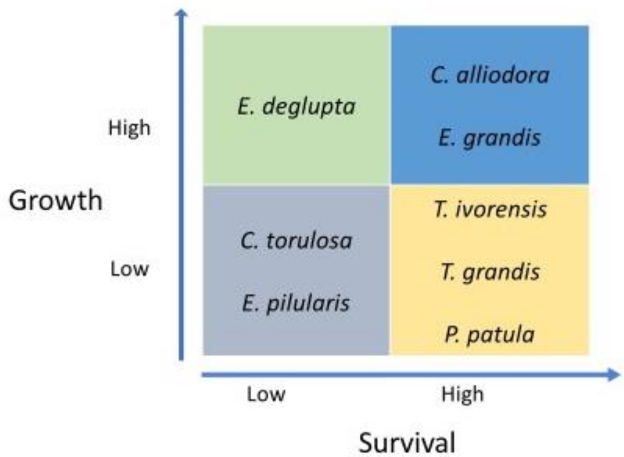

Figure 2: Survival and growth category of the planted tree species at the age of four at Tepi, South-western Ethiopia

4. Conclusions and implications

The two species *E. grandis* and *C. alliodora* deserve the highest attention especially when considering the promotion of fast and high-volume timber production. The high growth but low survival species, *E. deglupta* can also be an important candidate for similar initiative assisted with replanting to compensate for the low survival. The high survival but low growth species *T. ivorensis, T. grandis* and *P. patula,* could still be promoted further for future planting in the region for their timber quality by forest companies. Such a study ideally should be replicated over sites for robust evaluation of the performance of the timber species under different environmental conditions. Based on the findings, smallholders in moist southwestern region should consider *E. grandis* and *C. alliodora* as good plantation species options and the extension should promote the planting of the two species. Forest companies should make wise use of the six species (*E. grandis*, *C. alliodora, E. deglupta, T. ivorensis, T. grandis* and *P. patula*) in short- and long-term plantation schemes in the moist southwestern region of Ethiopia. However, tree growers interested in *C. torulosa* and *E. pilularis* should be aware of their relatively low performances. More data should be generated on the long-term performance of the species.

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