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Article

Evaluation of Eucalyptus Globulus for Mixed Tree Plantation with Some Indigenous and Exotic Tree Species In central Ethiopia highlands

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Abstract: Mono-crop plantation widely found in the world and dominated by few species such as Eucalyptus, Pinus and Tectona. While they lack diversified product, negative to environmental service and limited forest product for local use. The experiment was designed to evaluate the impact of mixed plantings on the early growth performance of the E. globulus tree species. The treatments included one monoculture of E. globulus and a combination of the plant with three other native and one foreign tree species. In four consecutive years after plantation, height, root collar diameter, DBH and leaf/branch count were measured. Following two years of out planting, the survival rates of seedlings were determined. Destructive sampling was applied to measure biomass of E. globulus. The growth performance of E. globulus in mixed plantations was compared to that of trees produced in pure plantations. The findings showed that there were no significant variations in growth parameters across the treatments. Following two years of out planting, the survival rates of seedlings were determined. The growth performance of E. globulus in mixed plantations was compared to that of trees produced in pure plantations. The findings showed that there were no significant variations in growth parameters across the treatments. The survival rate of E. globulus was good, ranging from 75 to 96.8%. Similarly, the growth performance of E. globulus's root collar diameter was larger even if the trial did not reveal a significant difference between the treatments for height. In comparison to other treatments, the one that included junipers and E. globulus had a higher mean height throughout the course of three years (1.28, 2.53, and 6.12 meters, respectively), as well as a lower RCD in the first and third years (1.3 and 5.34 cm). At year four, E. globulus attain higher in Height and DBH with high growth rate in mixed plantations compared to pure stands. The relative yield of E. globulus in pure stands compare to mixed stands greater than 1. Above and below ground biomass and carbon density of E, globulus is comparable in all treatment. Overall, the study's findings confirm that planting E. globulus improves its mingling with the examined tree species. Such studies ought to be conducted again over a longer time frame in order to examine the effects at a later stage and recommend technologies for broader implementation.

Keywords: Biomass *E. globulus*; Climate change; growth performance; mixed plantation; tree productivity

Introduction

Most of the world's plantations are monocultures, with just a small number of tree genera (e.g. Eucalyptus, Pinus, and Tectona) is widely used [1], [2]. Such plantations have been criticized for having negative impacts on local environments and its services [3], [4] and not providing many traditional forest goods used by local people, especially for biodiversity conservation [5].

Researches demonstrating that mixed-species plantations can increase stand level productivity relative to monocultures. However, such comparative advantages has not led to their commercial uptake; mixed species plantations are limited to less than 0.1% of industrial plantations in the globe [6]. Commercial and experimental mixed species plantations rarely offer data on financial analyses, and small landholders appear to be the main innovators in establishing and demonstrating mixed species plantations [6]. Mixed-species plantations preferable as result of: increased yield, provide better environmental protection, biodiversity conservation and restoration [7].

Among the different monoculture plantations, monoculture plantation with *Eucalyptus* criticized most [1]. *Eucalyptus* species mainly suppresses ground vegetation, results less undergrowth, has an impact on biodiversity conservation [8]. On the other hand mixed plantation had diversity of component and products. For example, [9] recorded 39 woody plants regenerated in a 20-year-old *E. camaldulensis* plantation in North Eastern Zimbabwe. [10] recorded under *E. globulus* plantations in dry afro-mountain areas of Ethiopia: 16 species in a 13 year old stand, 13 species in a 16-year-old stand and 17 species in a 22-year-old plantation. [11] recorded 46 woody species in a 31-year *E. grandis* plantation in Southwestern Ethiopia, 37 woody plants were identified in a 27-year-old monoculture *E. camaldulensis* plantation in semi-arid areas of Ethiopia. However, these studies on mixed plantations of *Eucalyptus* were focused only on the growth and productivity of the plantation species. Therefore, this research is design to evaluate the effect of some selected tree species on the growth of *Eucalyptus globulus* in early stage. Despite our limited understanding of how to design, select species for, and manage mixed-species plantations in Australia, they are commonly promoted as more environmentally preferable to monocultures [4], [12], [13]. Therefore this research was design to identify most compatible tree species with *Eucalyptus globulus* for Gummer wereda.

Material and Methods

Site Description

The study was conducted in Gummer district, Gurage zone, southern Ethiopia. It is one of the woredas in the central Ethiopia region. Gummer is bordered on the southeast by the Silt'e Zone, on the southwest by Geta, on the northwest by Cheha, and on the north by Ezha. Water bodies in this woreda include Lake Arek'it, after which the town was named. Based on the 2007 Census conducted by the central statistical agency, the district had a total population of 80,178, of whom 37,495 are men and 42,683 women; 2,923 or 3.65% of its population are urban dwellers.

Like most farmers in Ethiopia, the farmers in Gummer wereda produce both crops and livestock. The major crops in the grown in the Woredas are Barley, Faba Bean, Wheat, Potato, Enset and Field Pea. Wheat, Potato and Barley are also the top three contributors to farmers' income. Sheep, Cow, and Horses constituted the largest proportion of total livestock in the wereda. The largest contributor to the livestock population in the Kebele was sheep (38.99%) followed by cows (24.93%), horses (15.03%), calves (6.98%) and heifers (6.76%). These top five accounted for 92.69% of the livestock population ([14].

The major vegetation grown in the wereda are exotic tree species like *Eucalyptus globulus*, *Cupressus lusitanica* *Chamythesis palimnesis* and *Gravellia robusta* and indigenous tree species such as *Juniporus procera*, *Hygenia abyssinica* *podocarpus falcatus*, *Bundelija polystachyus*. *Eucalyptus globulus*, *Juniporus procera*, *Hygenia abyssinica* and *Cupressus lusitanica* are dominantly grown tree species (personal observation). *Eucalyptus globulus*, *Gravellia robusta*, *Chamythesis palminesis*, apple and prim is preferred species by farmers in wereda. The bases of preference are their products and services such as wood products environmental services. Bamboo is the only and an important non-timber forest product in the wereda (SARI Quick survey).

Treatments, Experimental Design and Management

The treatments used for the study were

- *Eucalyptus globulus* monoculture,
- *Eucalyptus globulus* + *Hygenia abyssinica*,
- *Eucalyptus globulus* + *Podocarpus falcatus*,
- *Eucalyptus globulus* + *Cupressus lusitanica* and
- *Eucalyptus globulus* + *Juniporus procera*.

Seedlings of the tree were raised in Gummer wereda agriculture office nursery site, the nearby nursery to the study area. Then, field preparation began one month before planting. Planting holes were dug 50*40 cm deep and wid. The size of the plot was 5m X 5m. A plot consisted of six rows of trees that had six trees one line. One plots had a total of 36 seedlings. Distance between trees in the same row and between in row was 1m. The distance between plots and blocks was 4 m. In mixed

plantation mixed species were planted alternative line, that means the line next to other line that plot contain other mixed species with in a plot.



Figure 1. field design of the experiment containing all treatments with three replications; Where: Eg= Mono-crop *Eucalyptus globulus*; Eg+Jp= *Eucalyptus globulus* mixed with *Juniporus procera*; Eg+H= *Eucalyptus globulus* mixed with *Haygenia abysinica*; Eg+P= *Eucalyptus globulus* mixed with *Podocarpus falcatus*; Eg+C= *Eucalyptus globulus* mixed.

Treatments were laid out in a Randomized Complete Block Design (RCBD) with three replications. Weeding and hoeing were applied after planting uniformly two times in a year to the entire plot in the first and second year of the growing period.



Figure 2. field status of *Eucalyptus globulus* in mixed the left side and mono-crop in the right side.



Figure 3. harvesting tree for measurement of volume of log at the left; the middle and right side are wood samples collected to drive wood density for biomass estimation, these all piece of wood are collected from *E. globulus* by destructive method and labeled.



Figure 4. measuring of the dry weight and volume of sampled wood using sensitive balance and graduated bicker in water displacement method respectively in laboratory.

Data collection

Measurements were taken on 6 trees in each of two lines (6 trees), each located in a different line alternatively in the interior of each plot. For most treatments, there were two rows of buffer trees between measurement trees and trees in other treatments. Early growth data were recorded like height, DBH, RCD, in each year for four year. Survival count was made in the second measurement season, 12 months after out-planting, and was constant when each tree was compared at >12 months of growing periods. Height was measured using Ruler during the first two year and Epyso-meter at year three and four when the trees are beyond to measurable height by ruler. RCD was measured by small caliper and DBH was measured caliper.

Distractive method was used to measure the log length of tree at different position. Wood density of the sample was measured using graduated cylinder by water displacement method.

Data Analysis

Dendrometric measurements were made for all trees for *Eucalyptus globulus* tree in the plot. Basal area (BA) (m² ha⁻¹) and volume (Vt) (m³ ha⁻¹) for the planted tree were calculated using inventory data. Total volume was calculated using the conventional volume equation because local volume equations were not available for these species: [15]

$$RGR = \frac{\ln(V_4) - \ln(V_1)}{T_4 - T_1} \dots \dots \dots 1$$

[16]

Where ln= natural logarism; V4= tree Volume at year four (4th year); V1= tree Volume at year one (1st year); T4=year four (the 4th year) T1= year one (the 1st year)

$$V = \pi \left(\frac{DBH^2}{4} \right) X h. f \dots \dots \dots 2$$

[15]

Where V= tree volume, DBH= tree diameter at breast height, h= tree height and f=form factor (0.42)

Basal area was calculated using the formula

$$BA = \pi DBH^2 / 4 \dots \dots \dots 3$$

Where, BA= basal area, DBH= tree diameter at breast height

To calculate Volume and basal Area increment

$$VI = V_{yr1} - V_{yr4} \dots\dots\dots 4$$
$$BAI = BA_{yr1} - BA_{yr4} \dots\dots\dots 5$$

Where VI= tree volume increment, Vyr1= tree volume in year one, Vyr4= tree volume in year four, BAI= tree basal area increment, BAyr1= tree basal area in year one, BAyr4= tree basal area in year four.

Relative yield

The relative height, DBH, basal area and volume of *E. globulus* was calculated using *E. globulus* under mixed plantation Vs pure *E. globulus* plantation. This parameter is used as land equivalent ratio of *E. globulus*. Those were calculated using the following formulas

$$RH = \frac{Hemix - Hem}{Hem} \dots\dots\dots 5$$

Where RH= Relative Height, Hem= Height of Eucalyptus globulus in mono crop plantation, Hemix= height of Eucalyptus globulus in mixed plantation

Above ground biomass

Aboveground biomass was calculated using [17] (Eq. 4) because this equation is the most recent and important predictive variable for estimation using diameter at breast height (DBH), total height (H), basic wood density (ρ).

$$AGBest = 0.0673(pHD^2)^{0.976} \dots\dots\dots 5$$

Where AGBest = aboveground biomass (kg),D= DBH (cm), H= height (m), and ρ= basic wood density (gcm⁻³). Accumulated aboveground and belowground carbon density was calculated [18].

$$ACD = AGBX0.47 \dots\dots\dots 6$$

[19], [20]

$$BCD = ACDX0.24 \dots\dots\dots 7$$

Where ACD = aboveground carbon density, BCD = belowground carbon density

Generally R software was used to analyzed the collected and manipulated data to determine significance difference at level of α=0.05. Mean separations was done using liner model (LM) and GLM to show the effect of year and treatment on the growth and yield of the *E. globulus*. The ggplot2 package from R soft ware was used to demonstrate some parameter in graphic way.

Result and Discussion

The results demonstrated that the growth performance of *E. globules* was not affected by mixing with different indigenous and exotics species in early growth period at field level. Height, Root collar diameter and number of branches in first two consecutive years have no showed significant difference.

Survival

The survival percent *E. globulus* was generally good, being greater than 75% for most of the tree species on all experimental plots in the study area. The highest survival was registered for *Eucalyptus globulus* mixed with *Juniporous procera* (96.27%) followed by *Eucalyptus globulus* mixed with *Cupressus lusitanica* (92.57%) and *Eucalyptus globulus* mixed with *Podocarpus falcatus* (88.87%). The lower survival count was recorded for pure plantation and *Eucalyptus globulus* with *Hygenia abysinica* (85% and 75.9%). Several studies have found that mixed-species plantations are more productive in comparison with monocultures [21]. Similar studies reported that survival percent of *Eucalyptus* is greater in mixed plantation than pure stand[22]Table 1: The growth performance of *E. globulus* mixed planting with selected tree species in year one

treatment	Height(m)	RCD(cm)	Survival	Branch
<i>E. globulus</i> + <i>Cupressus lusitanica</i>	1.16	1.53	92.57	16.87
<i>E. globulus</i> + <i>Podocarpus falcatus</i>	1.02	1.73	88.87	14.57
<i>E. globulus</i> + <i>Juniporous procera</i>	1.28	1.93	96.27	20.33
<i>E. globulus</i> + <i>Hygenia abysinica</i>	0.94	1.7	75.9	15.87

<i>E. globulus</i> only	1.04	1.53	85	16.6
CV	22.73	26.29	13.8	19.37
LSD	NS	NS	NS	NS

Height

The height of *E. globulus* ranged from 5.52 to 6.12 m in three years. The highest height of (6.12m) *E. globulus* was recorded on plots *E. globulus* mixed with *Juniporous procera*, while the lowest height was recorded in plots *E. globulus* mixed with *Hygenia abyssinica*. This may be the growth performance of *Hygenia abyssinica* was higher than other tree species mixed with *E. globulus*, which may be have higher resource competition than other. Another field observation in this study was height growth of *E. globulus* is better when it mixed with the tree species those have lower growth performance like *Juniporous procera* and *Podocarpus falcatus* (table 2).

Root Collar Diameter (RCD)

RCD measurements made consecutively for three years to all the planted trees. Significant differences between treatment in RCD and DBH were not detected. However, in this study Plots treated with *Eucalyptus globulus* mixed with *Cupressus lusitanica* recorded the highest RCD, while plots treated with *E. globulus* mixed with *Juniporous procera* had higher m the highest DBH. Generally RCD growth for all the trees showed an increasing trend and no-significant differences along the growing periods are provided.

Table 2. The growth performance of *E. globulus* mixed planting with selected tree species in year two.

Treatment	Height	DBH	Basal Area	Log volume
<i>E.globulus</i> + <i>C. lustranica</i>	5.24a	4.93	26.84	289.48a
<i>E. globulus</i> + <i>P. falcatus</i>	4.83ab	4.77	24.08	213.39ab
<i>E. globulus</i> + <i>J. procera</i>	4.82ab	4.82	23.89	146.8b
<i>E. Globulus</i> + <i>H. abyssinica</i>	4.57b	4.77	25.11	185.79b
<i>E. globulus</i> Mono	4.56b	4.6	22.76	136.85
CV	14.67	11.75	26.73	49.95
LSD	0.58	NS	NS	80.28

According to the present study all parameter measured from *E. globulus* have no shows significant difference (table 3). This may be the tree those mixed with *E. globulus* were not be effect at their early growth stage rather than *E. globulus* is fast growing tree and have more resource consumption. In line with my study, the study at Hamakua coast reported that early height growth of *Eucalyptus* was very rapid than other mixed tree during the first 4 yr after out planting averaging nearly 4 m/yr and there is no significant difference among treatment [23]. Similar results were reported that competition from *E. robusta* planted with *C. equisetifolia* did not have any significant effect on the quantity of N fixed or by *C. equisetifolia* at early growing stage (between 6-24 months of age) [24]. However, this may be due to less intense competition in the plantation when compared to the pots. In addition, the competition for resource during at early growth stage at plantation site *E. globulus* is higher than other species. While *E. globulus* may have competed for N, the net effect of competition for all resources from *E. globulus* on *C. cunninghamiana* must have been less than the competition from other *C. cunninghamiana* [24].

Year Effect on Growth and yield of *E. Globulus*

According to the table below the height of *E. globulus* was affected by the interaction between years and mixed (table 4). *E. globulus* mixed with *Juniporous procera* had attained higher height than other in the three year; on the other hand the height of *E. globulus* was higher in the third than the first year. It shows a very fast growth rate of the species. In addition monoculture *E. globulus* had recorded lower height growth rate than in mixed. In line with this research result the research done

in Banglادish show that the initial growth performance of *A. auriculiformis* and *G. arborea* performed better in combinations than in pure plantations [25].

Table 3. Effect of year and planting system the growth performance and yield *E. globulus*.

treatment				Basal Area	Log Volume
Year	Planting system	Height	DBH	m2/ ha	ton/ ha
Yea one	<i>E. globulus</i> + <i>C. lustanica</i>	1.15fg	1.55e	1.99f	2.59d
	<i>E. globulus</i> + <i>P. falcatus</i>	1.02g	1.71e	2.41f	2.76d
	<i>E. globulus</i> + <i>J. procera</i>	1.28efg	1.92e	3.11f	3.38d
	<i>E. Globulus</i> + <i>H. abysinica</i>	0.94g	1.68e	2.25f	2.04d
	<i>E. globulus</i> Mono	1.04g	1.55e	1.95f	1d
year two	<i>E. globulus</i> + <i>C. lustanica</i>	2.38de	3.23d	8.26ef	22.27d
	<i>E. globulus</i> + <i>P. falcatus</i>	2.45d	3.17d	7.98ef	20.74d
	<i>E. globulus</i> + <i>J. procera</i>	2.53d	3.16d	8.04ef	16.68d
	<i>E. Globulus</i> + <i>H. abysinica</i>	2.25def	2.94d	6.81f	14.02d
	<i>E. globulus</i> Mono	2.35de	3.01d	7.22f	13.34d
year three	<i>E. globulus</i> + <i>C. lustanica</i>	5.84c	5.06c	20.13d	131.9d
	<i>E. globulus</i> + <i>P. falcatus</i>	5.58c	5.22c	21.47d	125.25d
	<i>E. globulus</i> + <i>J. procera</i>	6.12c	5.34c	22.46d	109.84d
	<i>E. Globulus</i> + <i>H. abysinica</i>	5.52c	4.82c	18.37de	93.78d
	<i>E. globulus</i> Mono	5.65c	3.01c	19.83d	86.91d
year Four	<i>E. globulus</i> + <i>C. lustanica</i>	11.57a	9.89a	76.98a	100.17a
	<i>E. globulus</i> + <i>P. falcatus</i>	10.27b	8.97ab	64.48bc	704.45b
	<i>E. globulus</i> + <i>J. procera</i>	9.35b	8.88b	61.95c	457.31c
	<i>E. Globulus</i> + <i>H. abysinica</i>	9.53b	9.64ab	73ab	633.35b
	<i>E. globulus</i> Mono	9.23b	8.85b	62.05c	445.56c
CV		14.67	11.75	26.73	49.95
LSD		1.17	0.92	10.84	160.56

Year effect on the relative growth performance and yield of E. globulus

The relative yield of *Eucalyptus globulus* under mixed were compared with mono-crop one. Height and log volume were declare significance difference on their relative growth where as there is no significant difference between DBH and basal area of the tree. As shown the table below except *E. globulus* mixed with *H. abysinica* and *P. falcatus* the relative yield of the tree is ≥ 1 . In all planting system at year 4 the relative yield is greater than one which means the year increase the relative yield of *E. globulus* is greater in mixed than mono-crop. However, uncertainty remains about mixtures achieving greater productivity than monocultures[26], [27]. According to Hossain many slow growing and shade demanding tropical trees are synecology is not suitable for growing in the open plantation areas. They suffer from weed competition and often need special micro-climates which do not exist in a plantation environment[28].

Table 4. the relative yields of *E. globulus* under mixed plantation compared to mono-crop system in height, DBH, basal-area and log-volume.

Treatment				Basal Area	Log Volume
year	Planting system	Height	DBH	m2/ha	ton/ha
Yea one	<i>E. globulus</i> + <i>C. lustanica</i>	1.12ab	105	1.27	2.16ab
	<i>E. globulus</i> + <i>P. falcatus</i>	0.98ab	1.11	1.22	1.68ab
	<i>E. globulus</i> + <i>J. procera</i>	1.22ab	1.22	1.5	1.91ab
	<i>E. Globulus</i> + <i>H. abysinica</i>	0.94b	1.15	1.4	1.87ab
	<i>E. globulus</i> Mono	1ab	1	1	1b
year two	<i>E. globulus</i> + <i>C. lustanica</i>	1.01ab	1.08	1.16	1.71ab

year three	<i>E. globulus</i> + <i>P. falcatus</i>	1.05ab	1.05	1.12	1.58ab
	<i>E. globulus</i> + <i>J. procera</i>	1.08ab	1.05	1.09	1.2b
	<i>E. Globulus</i> + <i>H. abyssinica</i>	1.17ab	0.99	0.99	1.14b
	<i>E. globulus</i> Mono	1ab	1	1	1b
	<i>E. globulus</i> + <i>C. lustanica</i>	1.03ab	1.02	1.05	1.57ab
year Four	<i>E. globulus</i> + <i>P. falcatus</i>	0.98ab	1.05	1.11	1.47ab
	<i>E. globulus</i> + <i>J. procera</i>	1.08ab	1.07	1.14	1.27ab
	<i>E. Globulus</i> + <i>H. abyssinica</i>	0.97ab	0.97	0.94	1.1b
	<i>E. globulus</i> Mono	1ab	1	1	1b
	<i>E. globulus</i> + <i>C. lustanica</i>	1.26a	1.13	1.303	2.45a
	<i>E. globulus</i> + <i>P. falcatus</i>	1.13ab	1.04	1.13	1.85ab
	<i>E. globulus</i> + <i>J. procera</i>	1.01ab	1.01	1.04	1.07b
	<i>E. Globulus</i> + <i>H. abyssinica</i>	1.03ab	1.09	1.22	1.52b
	<i>E. globulus</i> Mono	1ab	1	1	1b
	CV	16.72	15.3	32.14	49.95
	LSD	0.291	NS	NS	1.21

Growth Rate of Height and RCD

The growth rate of *E. globulus* was analyzed by using year one and year three measurements in height and root collar diameter. Even though *E. globulus* statically significance difference was on declare, the highest mean growth rate of height was measured on *E. globulus* mixed with *Juniporus procera* (242.4%) and lower was recorded on *E. globulus* mixed with *Hygenia abyssinica* (229.1%) (fig.3). Similarly, in DBH highest means is recorded on treatment *Cupressus lustanica* with *E. globulus* (175.83%) and lower is recorded on *E. globulus* mixed with *Juniporus procera*(170.83) (fig.4). Mixtures with stratification can also enhance individual-tree growth rates and stem quality of species in upper canopies, whilst minimizing the proportion of taller species that can reach the highest production[29], [30].

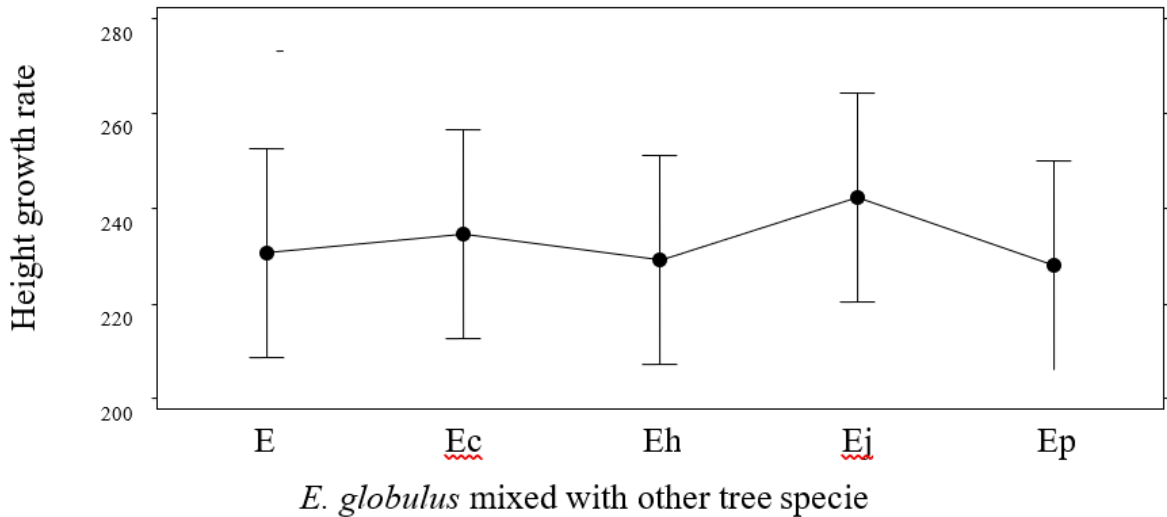


Figure 5. Means and 95% C.I. of height growth rate for *E. Globulus* mixed with one type of exotics and three indigenous tree species in early growth.

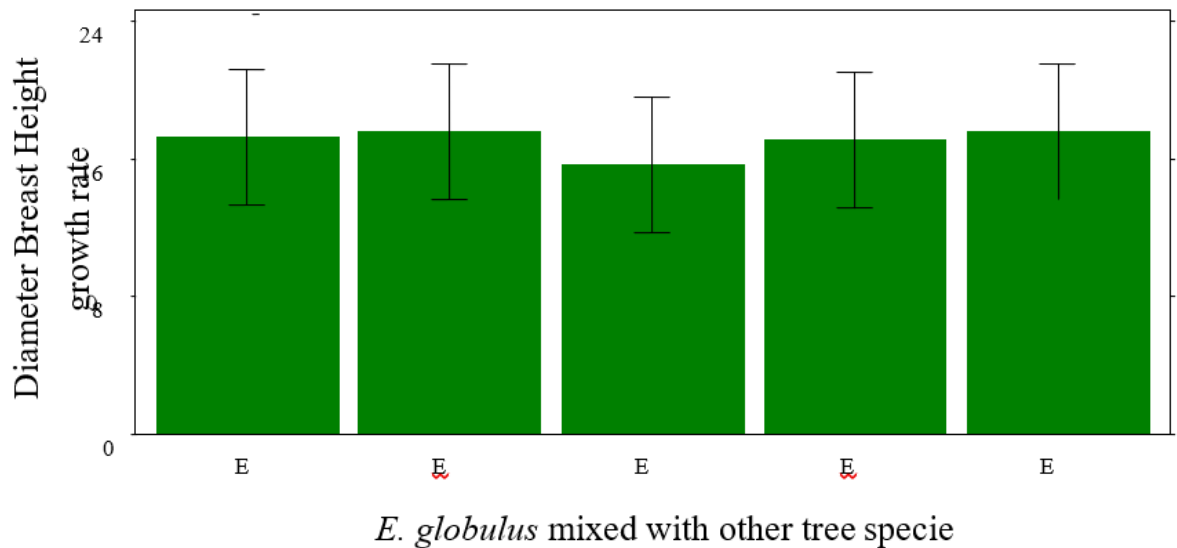


Figure 6. Means and 95% C.I. of Root Collar Diameter for *E. globulus* mixed with one type of exotics and three indigenous tree species in early growth. Where E= *E. globulus* only; E_c= *E. globulus* + *Cupressus lustanica*; E_h= *E. globulus* + *Hygenia abysinica*; E_j= *E. globulus*+ *Juniporus procera*; E_p= *E. globulus*+*Podocarpus falcatus*.

Similarly, the study done at Hawaii showed that, eucalyptus diameters grown in stands with 50% Albania averaged nearly 20 cm at 10 yr and were significantly greater than those in pure, fertilized stands and mixed stands with lower amounts of Albania. Diameters of Eucalyptus in the 66% Albania treatment were larger yet (23.5 cm) and differed significantly from those of all other treatments[22].

Growth rate of Tree Volume

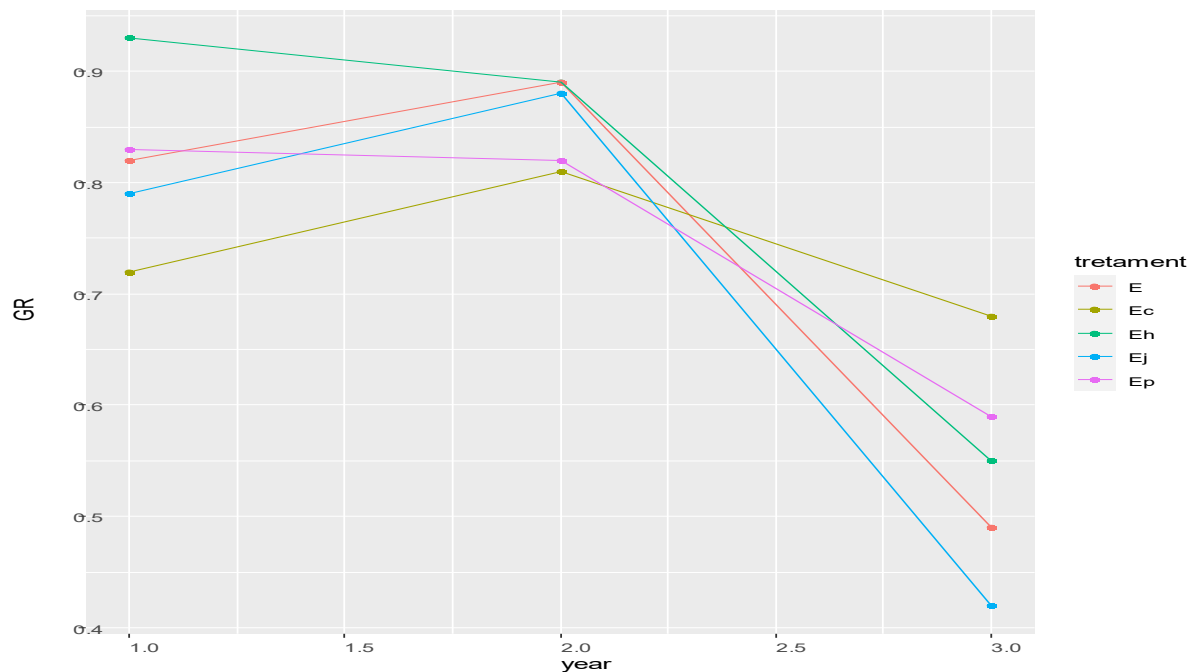


Figure 7. Trend of the rate of yield increment in volume through four year growth of *E. globulus*; E= pure *E. globulus*; E_c=*E. globulus* mixed with *C. lustanica*; E_h=*E. globulus* mixed with *Hygenia abysinica*; E_j= *E. globulus* mixed with *Juniporus procera*; E_p= *E. globulus* mixed with *Podocarpus falcatus*;

Relative yield

The annual yield increment of *E. globulus* in mixed plantation was analyzed relative to the mono-crop *E. globulus* in terms of tree height, DBH, basal area and volume of logs. Generally, there is the fluctuation of parameters from year to year. As shown below the table relative height increment and relative DBH increment of *E. globulus* declare significance difference between mixed plantation and mono-crop. The highest relative height increment and DBH increment *E. globulus* was recorded at the mixed with *Juniporus procera* where as the lowest was recorded at mono-crop (table 5). On the other hand basal area increment was not shows significant difference among the treatments.

Table 5. the relative Height, DBH and Basal area increment of *E. globulus* under mixed plantation and mono-crop.

Treatment	yield		
	relative height	relative DBH	Basal area
<i>E. globulus</i> with <i>Juniporus procera</i>	1.3a	1.11a	10.9
<i>E. globulus</i> with <i>Cupressus lustanica</i>	1.06ab	1.05ab	10.23
<i>E. globulus</i> with <i>Hygenia abyssinica</i>	1.03ab	1.03ab	9.89
<i>E. globulus</i> with <i>Podocarpus falcatus</i>	1.01b	1.07ab	10.61
<i>E. globulus</i> only	1b	1b	10.1
LSD	0.28	0.09	ns
CV	10.96	8.9	46.44

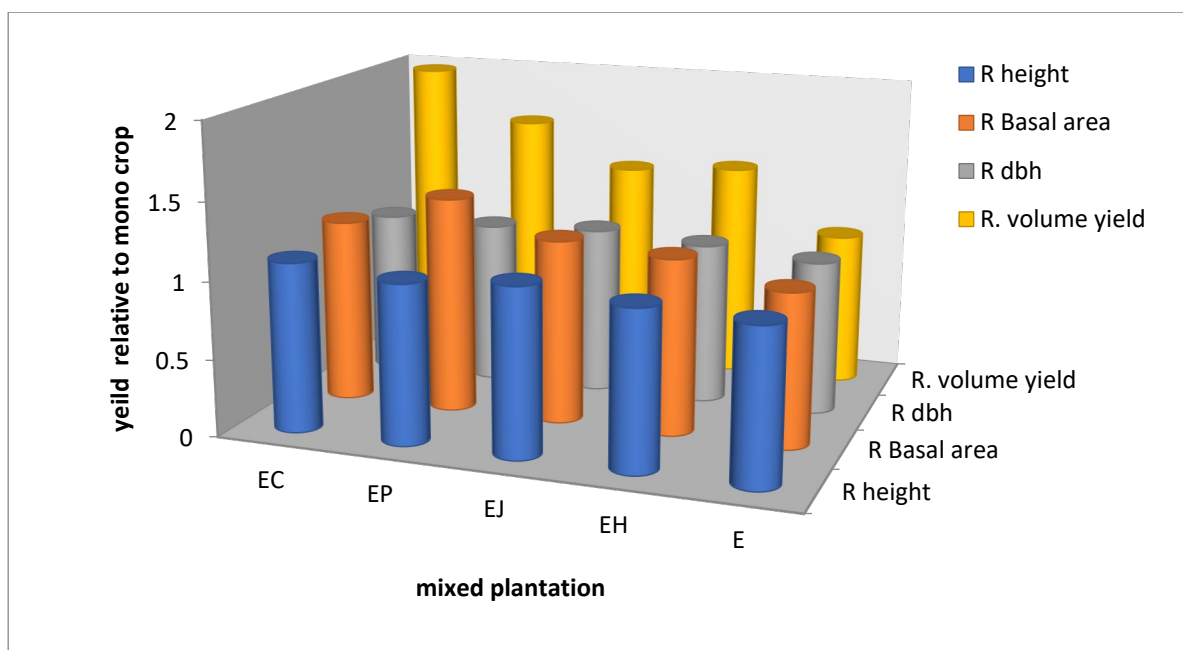


Figure 8. Relative growth performance and yield of *Eucalyptus globulus* when mixed with other species compared to mono crops.

Relative Yield increment of *E. globulus* under mixed plantation compared to mono-crop at different year

Yield increment of *E. globulus* was evaluated under mixed plantation and mono-crop. Even though there was no significance yield increment difference on *E. globulus* under mixed and mono-crop but there was relative yield increment of *E. globulus* under mixed plantation than mono crop. According to the trend of yield increment there may be significant different in yield increment of *E. globulus* between in the two plantation system.

Relative Height and Diameter at Brest Height (DBH) Increment

The height of *E. globulus* tree mixed with *Cupressus lusitanica* and *Juniporus procera* had showed that better growth increment under mixed plantation relative to the mono-crop in the first year. While, *E. globulus* tree mixed *Podocarpus falcatus* and *Hygenia abyssinica* were had lower height growth in the same year relative to the mono-crop. On the other hand, in the second year even though they were not lower growth rate relative to the mono crop but there were the decline of height growth rate relative to the first year except *E. globulus* mixed with *Hygenia abyssinica* and *Podocarpus falcatus*. Generally the height growth increment of *Eucalyptus globulus* was better in mixed than mono crop plantation (fig.4).

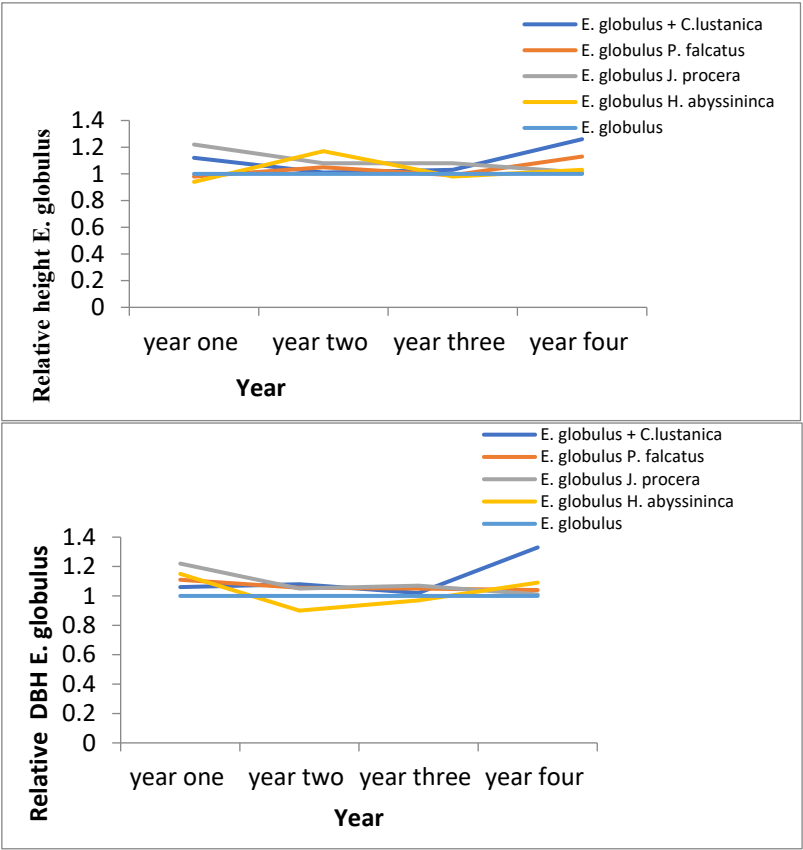
This study implies that when *E. globulus* planted mixed with some selected tree species like *Cupressus lusitanica*, *Podocarpus falcatus*, *Juniporus procera* and *Hygenia abyssinica* had relatively better DBH than mono-crop. While in the second year the DBH increment of *E. globulus* mixed with *Hygenia abyssinica* was lower than the mono-crop.

Pattern of relative growth and yield

Mixing *E. globulus* with different tree species have effect on relative increment on growth parameters (height, DBH and basal area) and yield (volume) of the tree. Trend of relative increment on height and DBH shows that corresponding trend between *E. globulus* in mono and *E. globulus* mixed with other species from year one to year three. Whereas at year for relative height of *E. globulus* mixed with *Cupressus lusitanica* and *Hygenia abyssinica* had shows increasing trend. Similarly relative DBH of *E. globulus* mixed with *Cupressus lusitanica* had shows increasing trend than mono and other mixed plantations.

As shown the figure below, except *E. globulus* mixed with *Hygenia abyssinica* in second and third year, all other mixed plantation had better increment of basal area. Therefore, based on this study to get better basal area increment mixed plantation with selected tree species is better than mono-crops. Log volume increment of the *E. globulus* under mixed plantation was recorded compared with mono-crop plantation. According to our study, *E. globulus* under mixed plantation had shows more log volume annual increment than under mono-crop plantation.

This study was agree with the study done at the diluvial north of Germany that reports the relative yield of tree on mixed stand had higher relative volume than pure stand [31]. In addition the growth of *C. lusitanica* and *E. camaldulensis* in the mixed plantation is significantly higher than pure plantations by DBH ($p = 0.0001$ and $p = 0.0076$). Similarly *C. lusitanica* declare significance difference between pure and mixed stand on the DBH growth ($p = 0.001$) [32].



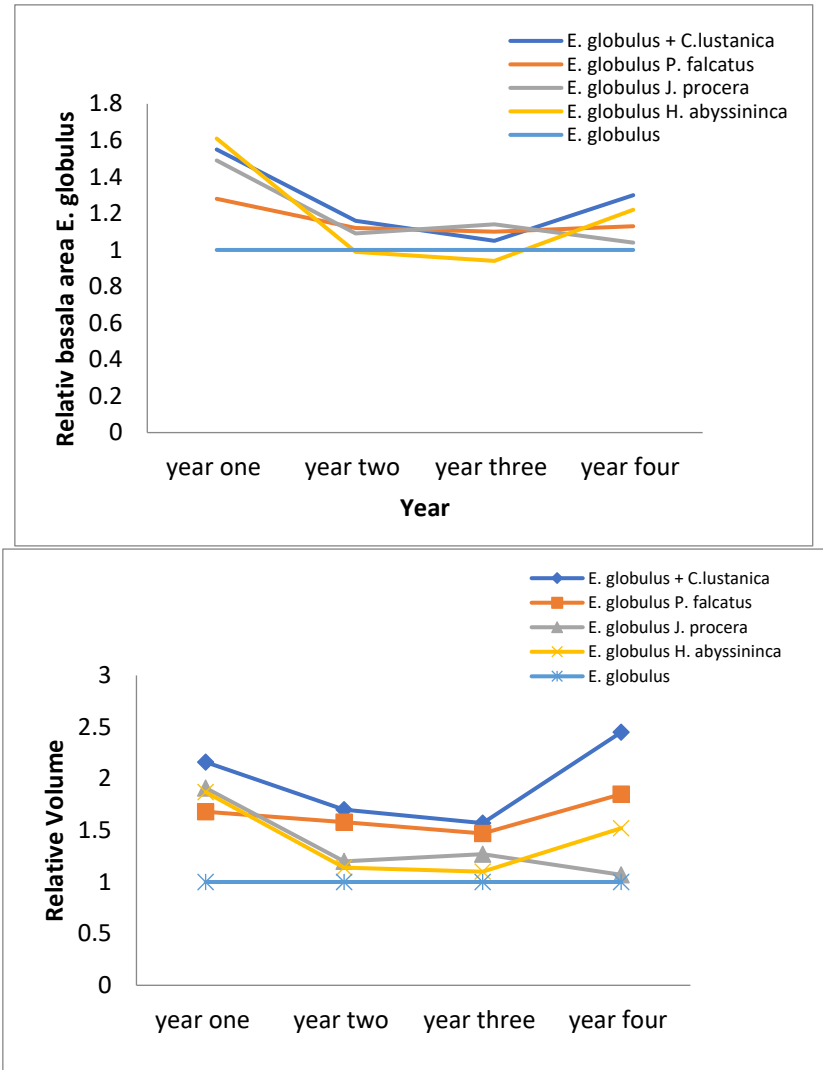


Figure 9. Trend of relative yield increment of *E. globulus* mixed with other species relative to mono-crop plantation in four year.

Carbon Density

According to the present study the biomass yield of *E. globulus* under different cropping system was evaluated. Above ground biomass above and below ground carbon density of *E. globulus* have no significance different in mono crop and mixed plantation. While *E. globulus* mixed with *H. abyssinica* declare significant difference from *E. globulus* mixed with *Podocarpus falcatus*. Therefore, mixing of *E. globulus* with those the above species will not have negative effect on the biomass yield of *E. globulus*. An example from [33] demonstrated that mixing hybrid poplar and white spruce increased wood production of poplar and sequestrated more carbon than monocultures of either poplar or white spruce.

Table 6. the effect mixed plantation on above ground biomass and carbon density of *E. globulus*.

Treatment	Above ground biomass (ton)	Above ground carbon Density (ton)	Below ground carbon density (ton)
<i>E. globulus</i> + <i>C. lustanica</i>	28.3ab	13.3ab	3.19ab
<i>E. globulus</i> + <i>P. falcatus</i>	31.4a	14.76a	3.54a
<i>E. globulus</i> + <i>J. procera</i>	21.3 ab	10.03ab	2.41ab
<i>E. Globulus</i> + <i>H. abyssinica</i>	19.2 b	9.02b	2.16b
<i>E. globulus</i> mono	29.3 ab	13.74ab	3.29ab

CV	21.99	22.01	22.04
LSD	10.3	4.87	1.17

Conclusions and Recommendations

The results support that mixing eucalyptus with indigenous and exotic species did not affect the growth performance of *E. globulus*. This, in turn, suggests that *E. globulus* can be planted mixed with the tested plant species. Such studies should be conducted for longer period to see effects at latter stage and provide conclusive suggestion for wider adoption of the technologies.

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