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Pure and Mixed Plantations of *Eucalyptus camaldulensis* and *Cupressus lusitanica*: Their Growth Interactions and Effect on Diversity and Density of Undergrowth Woody Plants in Relation to Light

Shiferaw Alem[1*], Jindrich Pavlis[1], Josef Urban[1], Jiri Kucera[2]

[1]Department of Forest Botany, Dendrology and Geobiocenology, Mendel University in Brno, Zemedelska 3/613 00, Brno, Czech Republic
[2]EMS Brno, Turisticka 5 621 00, Brno, Czech Republic
Email: [*]shife19@gmail.com, [*]shife19@yahoo.com

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Abstract

Published results on the growth interactions of non-nitrogen fixing mixed plantations species, and their impact on the regeneration of woody plants are scant. This paper addresses the growth interactions of pure and mixed plantations of *Eucalyptus camaldulensis* and *Cupressus lusitanica* and their impact on the regeneration of woody plants in relation with light. Data on the regenerated woody plants, individual characteristics of the plantation species and light reaching under the canopies were collected using sample plots (n = 4) with a size of 20 m × 20 m for each plantation type. The result showed that, *E. camaldulensis* was suppressing the growth of *C. lusitanica* while its growth was favored when it was mixed with *C. lusitanica* ($p < 0.05$). There were no significant differences between the pure and mixed plantations in their diversity and density of undergrowth woody plants ($p > 0.05$). Density of plantation trees were found not having a significant relationship with diversity of species ($p = 0.801$). There was a significant but not direct relationship between light reached in the understory of the canopies and diversity of species in the plantations ($p = 0.027$). Overall, the result indicated that both the pure and the mixed plantations were favoring the recruitment of woody plants.

Keywords

Diversity, Growth, Light, Mixed Plantation, Pure Plantation, Woody Plants

[*]Corresponding author.

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1. Introduction

The vast majorities of the world's plantations are monocultures, with just a small number of tree genera (*Eucalyptus*, *Pinus*, and *Tectona*) widely used (FAO, 2001; Evans & Turnbull, 2004). However, monocultures have been criticized for having negative impacts on local environments and its services (Lamb et al., 2005; Erskine et al., 2006), and for not providing many traditional forest goods used by local people (Evans, 1999), especially for biodiversity conservation (Camus et al., 2003). As a result, interest in mixed-species plantations instead of monoculture plantations has increased for several reasons: such as increased yield, provide better environmental protection, biodiversity conservation and restoration (Montagnini et al., 1995). Among the most commonly used and widely distributed plantation species throughout the world, monoculture plantations of *Eucalyptus* have attracted by far the most criticism (Evans, 1992; FAO, 2001). Arguing that, the species mainly suppresses ground vegetation and results less undergrowth, and has an impact on biodiversity conservation (Jagger & Pender, 2000).

Different studies on the impacts of monoculture *Eucalyptus* plantations on undergrowth plants are found. To mention some Alem & Pavlis (2012) identified 37 woody plants in a 27-year-old monoculture *E. camaldulensis* plantation in semi-arid areas of Ethiopia. Alem & Woldemariam (2009) recorded 46 woody species in a 31-year *E. grandis* plantation in Southwestern Ethiopia. Kitessa (2010) recorded 31 and 24 woody plants under the canopies of a 28 year-old *E. camaldulensis* and *E. saligna* plantations in South Western Ethiopia, respectively. Tapani (2001) recorded 39 woody plants regenerated in a 20-year-old *E. camaldulensis* plantation in North Eastern Zimbabwe. Feyera et al. (2002) recorded under *E. globulus* plantations in dry afro-montan 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. Different comparative study results on the impact of species mixtures with *Eucalyptus* are also available (Dan et al., 2003; Mila et al., 2006). However, these studies on mixed plantations of *Eucalyptus* were focused only on the growth and productivity of the plantation species. The species mixtures were also nitrogen fixing, in which their results cannot represent the impact of *Eucalyptus* species mixed with non-nitrogen fixing species on productivity and regeneration. Moreover, these studies were specific to *Eucalyptus pellita*, and *Eucalyptus saligna* only. The results of these studies were not showing the impacts of the mixed plantations on the undergrowth vegetation in relation to light reaching in the under storey. Overall, study results on the impacts of non-nitrogen fixing plantation species mixed with *Eucalyptus* on the growth interactions and their impact on undergrowth vegetation in relation with light reaching under the canopies are lacking.

In Bedele district, South Western part of Ethiopia, pure plantations of *E. camaldulensis* and *Cupressus lusitanica* and mixed plantation (*E. camaldulensis/C. lusitanica*), established in 1984, that meet the criteria of mixed plantation were found. These plantations can give an opportunity to explore the impact of non-nitrogen fixing timber species mixed with *Eucalyptus* species on the regeneration of native woody plants and the productivity of the plantation species. Therefore, this study aimed to assess the impacts of pure plantations of *C. lusitanica* and *E. camaldulensis* in comparison with mixed plantation on diversity and density of undergrowth plants in relation to light and on the growth interactions of the plantation species. The hypotheses are 1) *E. camaldulensis* species do not have a negative impact on the growth of *C. lusitanica*; 2) Mixed plantations favor the regeneration of woody plants as compared with the pure monoculture plantations.

2. Materials and Methods

2.1. Site Description

The study was conducted in Bedele (Tulu Mutie plantation forest site), located 500 kms from Addis Ababa, the capital city of Ethiopia, in Illubabor Zone, Bedelewereda, in Southwestern Ethiopia (**Figure 1**). Geographically, the pure *C. lusitanica*, pure *E. camaldulensis* and the mixed plantations were located at 8˚27'N latitude and 36˚21'E longitude at an elevation of 2162 meters above sea level. All of the plantation forests are found in the same area bordering each other.

The climatological data for the site was obtained 2 km away from the plantation site (Bedele meteorological station). The result of fifteen years (1997-2011) of climatic data analysis showed that the plantation area receives a unimodal type of rainfall pattern, with the highest rain occurring between May and September (**Figure 2**). The mean annual precipitation was 197. 4 ± 13.2 cm, with a large inter-annual variability (**Figure 2**). The mean annual minimum and maximum temperature of the area is 12.7˚C and 25.6˚C, respectively (**Figure 2**). The hottest months occur from December to April (maximum 28.9˚C) while the coldest months occur from September to

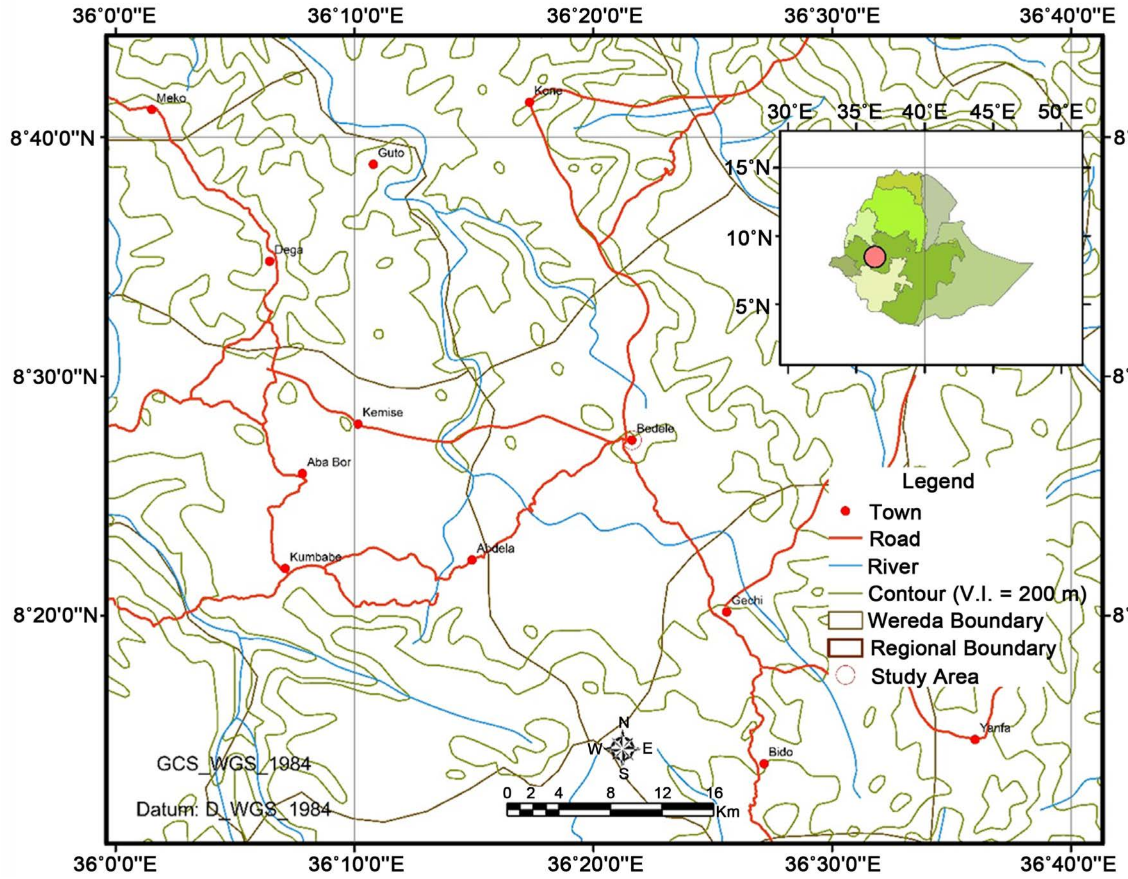

Figure 1. Location Map of the study area.

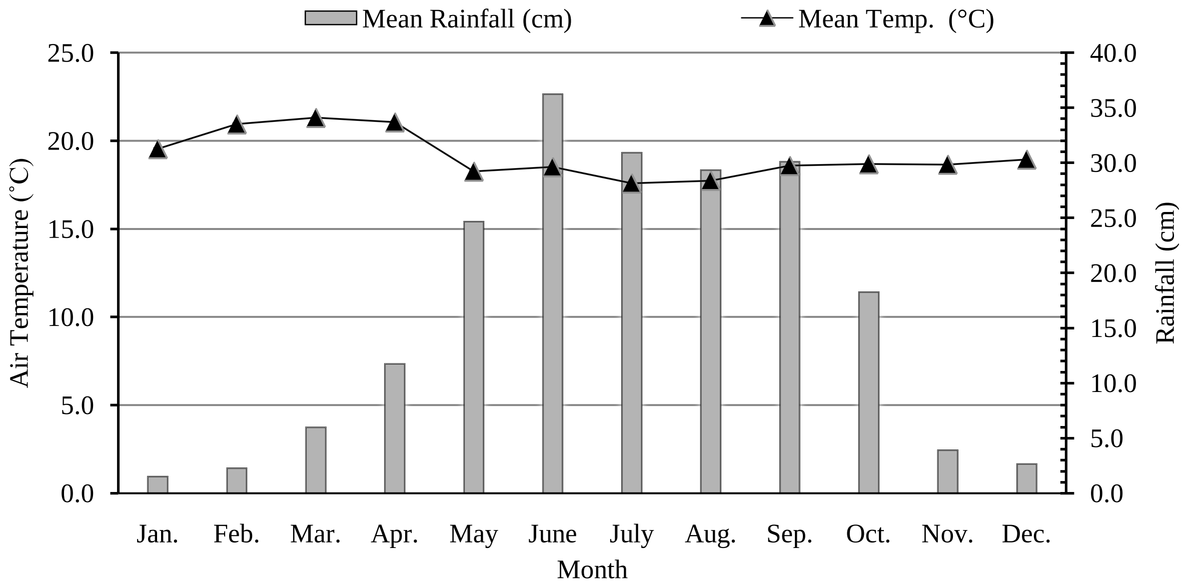

Figure 2. Climatic diagram of Bedele district using 15 years of data (1997-2011) (Source of data: Ethiopian Meteorological Service Agency Badele Branch).

November (minimum 11.7˚C). The physical features of the study area are characterized by a rugged topography dominated by gentle slopes and localized steep slopes, ranging from 2% - 45%.

2.2. History of the Plantation and Stand Characteristics

The study was conducted in pure stands of *C. lusitanica* and *E. camaldulensis* and mixed plantation (*C. lusitanica*/*E. camaldulensis*). The plantations were established at a spacing of 2.5 m × 2.5 m. However, during the data collection, it was observed that the density of each plantation was decreased because of windfall problems and self thining, especially in the pure *C. lusitanica* plantation (**Table 1**). In the mixed plantation the *E. camaldulensis* and *C. lusitanica* species were planted in equal proporation though later their density differs because of different factors. As a result at the time of data collection the proportion of *E. camaldulensis* and *C. lusitanica* were 59.6%, and 40.4%, respectively (**Table 1**). The physical characteristics of the studied plantation species and types are presented in **Table 1**. All of the plantations were established in 1984 in an agricultural land (1970-1983) that was previously natural forest. The plantations were surrounded by natural forest in the northwest direction and agricultural land in the southern part (**Figure 1**). In general, *E. camaldulensis* has broad leaves, whereas *C. lusitanica*, a coniferous species, has needle shaped leaves. *E. camaldulensis* has open crowns and longer straight boles, whereas the *C. lusitanica* had a dense and deep crown.

2.3. Data Collection

2.3.1. Sampling Design

We followed the procedure of Kent and Cooker (1994) for the sampling plot design (nested quadrant), which were used for the vegetation and plantation data collection. For the vegetation data collection in each of the selected plantation species and types, four square plots, each having an area of 0.04 ha (20 m × 20 m) were laid out along line transects following a gradient (upslope-downslope). In each major plot, five subplots (2 m × 2 m) were established at the four corners and centre of the major plots. The distance between the consecutive plots within a transect line was 100 meters. Similarly, the distance between the transect lines was also 100 meters. To avoid an edge effect, the plots were laid out 30 m away from the edges of the stand. A compass was used to align the transect. The number of sampling plots was restricted into four in each plantation forest because of the small area size of the studied plantations, which are between 2 - 2.5 ha (**Table 1**).

2.3.2. Vegetation and Light Data Collection

The understory woody species were identified independently within each plot in each plantation type. All the understory woody plants (trees > 1 m and saplings (0.51 - 1 m)); their diameters were measured with a caliper at 20 cm above the ground. All seedlings (≤0.5 m) were counted and their height were measured with a ruler in each subplot. Understory woody plants taller than 2 m, their total height was measured using hypsometer and trees or saplings shorter than 2.0 m, their total heights measured with a measuring tape. Plant species were identified in the field based on expert knowledge and using field guide manuals (Azene, 2007; Fichtl and Admasu, 1994). In each major plot all the plantation species stands diameters at breast height (dbh), at 1.3 meter, above the ground were measured using a caliper. Their total height were also measured using hypsometer.

A quantum sensor (Minikin QT EMS 12, EMS Brno, http://emsbrno.cz) with a small data logger and built-in sensors were used to collect the photosynthetic photon flux density (PPFD) reaching under the canopies of each plot of the individual plantations. So the measurements were carried out simultaneously in each plot under the forest plantations and in an open area following the method of Eshetu & Olavi (2004). The quantum sensors were

Table 1. Characteristics of the plantation species and descriptions of the locations (the values in parentheses are the standard errors).

Plantation		Age	DBH (cm)	Height (m)	Mean basal area (m^2)	Stems/ha	Area of plantation (ha)	Description of the stand
C .lusitanica		27	31.5 (8.9)	18.6 (3.4)	8.4 (0.1)	444 (83)	2.5	Slope ranging from 2% - 20%, southeast of the natural forest
E. camaldulensis		27	25.1 (7.1)	16.9 (5.3)	5.3 (0.03)	822 (244)	2	Slope 10% - 40%, southeast of the natural forest
Mixed plantation	*C. lusitanica*	27	21.7 (5.1)	12.3 (5)	3.9 (0.02)	211 (149)	2	Slope 4% - 45%, southeast of the natural forest
	E. camaldulensis	27	29.5 (8.2)	17.8 (4.1)	7.4 (0.04)	311 (113)		

programmed to store the measured PPFD value per second intervals in its memory chips, which had the advantage of retrieving the data of different time measurements for a particular period. These instantaneous measurements of PPFD were carried out for six cloudless days at Ethiopian local time (09:00 AM - 15:00 PM), which is GMT + 3.

2.4. Data Analysis

Tree density and mean basal area were calculated for the understory woody plant species in each plantation and for each plot independently. The diversity of species was analyzed following Kent & Cooker (1994), for each plot independently and the average was considered for each individual plantation forests. The Shannon-Wiener Diversity Index (*H'*) was used to determine the species diversity (1).

$$H' = -\sum_{i=1}^{S} p_i \ln p_i \quad (1)$$

where S is the number of species and p_i is the proportion of the individual species to the total, n_i/N.

The equitability (evenness) of species was calculated using H'/H'_{max}, where H_{max} is the ln (natural logarithm) of S (number of species). The vegetation data collected from each plot of the plantation forests were used for the structural analysis.

The dbh and height data on the plantation trees, collected in individual plots, was used for the growth comparison analysis of the different plantation types (pure monocultures and mixed plantation). In this analysis individual plots data were considered as a replication and F-test was used for the comparison.

The PPFD ($\mu mol \cdot m^{-2} \cdot s^{-1}$) data were organized and analyzed using a computer program (Mini32 ver. 40.58) and the light reached in the understorey of each plot of the plantations calculated in percentage, independently. A regression analysis was conducted to evaluate the relationship between the PPFD and diversity and mean basal area of the regenerated woody plant species.

3. Results

3.1. Floristic Composition, Diversity and Density of Species in the Pure and Mixed Plantations

A total of 26 woody species of trees and shrubs were recorded in all of the studied plantation species and types; of which 61.5% were trees and 38.5% were shrubs (**Table 2**). The total number of species recorded in each plantation ranked as *E. camaldulensis* (22) > *C. lusitanica* (20) > mixed plantation (19) (**Table 2**). Out of the total species identified 4 and 2 species were recorded only in *C. lusitanica* and *E. camaldulensis* plantation, respectively. Fifteen species are common to all the studied plantations. The diversity of species (*H'*) under the pure and mixed plantations is presented in **Table 3** and its absolute result indicated that the mixed plantation is more diverse than the pure plantation of *C. lusitanica* and *E. camaldulensis*. However, the ANOVA test result ($F_{cal(2, 9)} = 0.67$, $p = 0.537$) indicated no significant differences in the diversity of species recorded in the pure *E. camaldulensis*, *C. lusitanica* plantations and the mixed plantation ($p > 0.05$).

The absolute woody plant density recorded in the forests ranked as mixed plantation (5889 stems/ha) > *C. lusitanica* (4645 stems/ha) > *E. camaldulensis* (4356 stems/ha) (**Table 3**). However, the statistical analysis result indicated not a significance difference ($F_{Cal(2, 9)} = 0.62$, $p = 0.561$) in the density of woody plants between the pure plantations of *C. lusitanica*, *E. camaldulensis* and the mixed plantation. The absolute number of seedlings/ha in the mixed plantation was higher by 2.4% and 2.6% than the pure plantations of *C. lusitanica* and *E. camaldulensis*, respectively. The absolute number of tree stems/ha (>1 meter) recorded in the pure *E. camaldulensis* > pure *C. lusitanica* > mixed plantation (**Table 3**). The proportion of tree stems/ha (>1 meter) in the *E. camaldulensis*, *C. lusitanica* and mixed plantation was 36.2%, 27%, 10.6%, respectively (**Table 3**). Out of the 15 common species recorded under all the studied plantation species and types *B. antidysenterica*, *C. edulis*, *C. anisata*, *M. ovatus*, *W. uniflora* had relatively higher density of woody stem/ha in the mixed plantation forest as compared with the pure plantations of *C. lusitanica* and *E. camaldulensis* (**Table 2**). Whereas, *C. aurea*, *C. macrostachyus*, *F. indica*, *G. saxifraga*, *M. lanceolata*, *V. thomsoniana* and *Solanum* species had relatively higher number of woody stems/ha in the pure *C. lusitanica* plantation than the pure *E. camaldulensis* and mixed plantation forests (**Table 2**). The frequency distribution of different diameter and height classes of woody plants in the different plantations is presented in **Figure 3** and **Figure 4**. The result showed that pure *E. camaldulensis* and *C. lusitanica* plantations

Table 2. List of naturally regenerated indigenous understory woody plants in the different plantations (the numerical values in the table represent the stem density of the species per hectare).

Species	Family	Life form	Plantation Species		
			CL	EC	MX
Albizia grandibracta	Fabaceae	T	−	11	11
Bersama abyssinica Fres.	Melianthaceae	T	−	256	289
Brucea antidysenterica J.f. Mill	Simaroubaceae	S	33	11	56
Calpurnia aurea (Lam.) Benth.	Fabaceae	S	78	22	33
Carissa edulis (Forsk.) vahl	Apocynaceae	S	100	78	178
Clausena anisata (Willd.) Hook. F. ex Benth	Rutaceae	S	33	122	567
Coffea arabica L.	Rubiaceae	S		22	67
Croton macrostachyus Hochst.ex A. Rich.	Euphorbiaceae	T	122	111	89
Ehretia cymosa Thonn.	Boraginaceae	T	−	22	−
Ekebergia capensis sparrman.	Meliaceae	T	−	22	−
*Ficus vasta*Forsk. Var., glabrescensHutch	Moraceae	T	11	−	−
Flacourtia indica (Burm.f.) Merr	Flacourtiaceae	T	189	56	144
Galiniera saxifraga (Hochst.) Bridson	Rubiaceae	T	100	67	20
Maesa lanceolata Forsk	Myrsinaceae	T	411	11	11
Maytenus ovatus var. argutus (Loes.) Blakelock	Celastraceae	T	378	2022	2267
Millettia ferruginea (Hochst.) Bak	Papilionaceae	T	167	89	167
Prunus africana (Hook. f.) Kalkm.	Rosaceae	T	22	44	44
Pterolobium stellatum (Forsk.) Chiov	Pittosporaceae	S	11	−	−
Solanum species	Solanaceae	S	67	11	11
Veprisdainellii (Pichi-Serm) kokwaro	Rutaceae	T	−	11	11
Vernonia amygdalina Del.	Asteraceae	T	11	−	−
Vernonia thomsoniana oliv. & Hiern	Asteraceae	T	2789	1222	1422
Woodfordia uniflora (A. Rich.) Koehne	Lythraceae	T	56	11	122
Aba bira©		S	33	11	−
Cheyi©		S	11	189	22
kekericho (Afegna)©		S	11	−	−

CL = *Cupressus lusitanica*; EC = *Eucalyptus camaldulensis*; MX = Mixed Plantation; − = indicates absence in the plantation. ©Species with common names only.

Table 3. Diversity and density of species in the plantations (the values in parentheses are the standard deviations).

Plantation	*H'*	Density of seedlings, saplings and trees/ha			
		Seedlings/ha (<0.50 m)	Saplings/ha (0.51 - 1 m)	Trees/ha (>1 m)	Total density of stems/ha
C. lusitanica (CL)	1.52 (0.41)	1400 (28)	1989 (26)	1256 (9)	4645 (55)
E. camaldulensis (EC)	1.64 (0.05)	1278 (11)	1500 (9)	1578 (23)	4356 (39)
Mixed plantation	1.77 (0.3)	3356 (30)	1911 (13)	622 (9)	5889 (43)

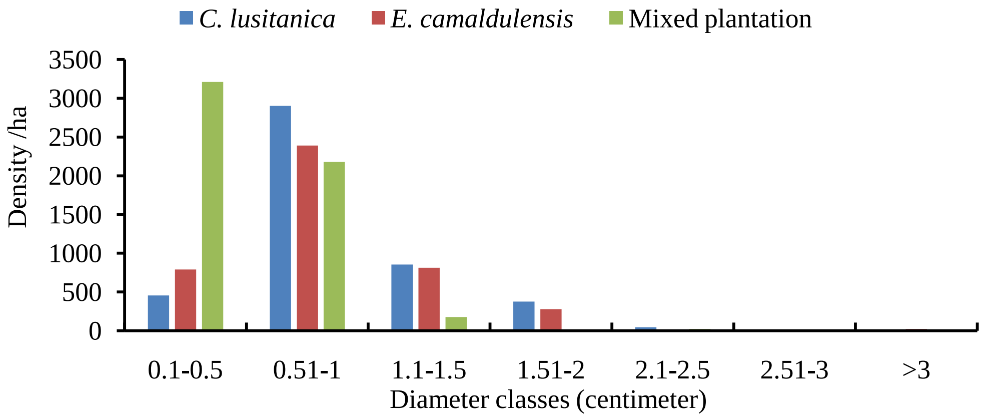

Figure 3. Diameter class distribution of woody plants regenerated under the canopies of the different plantations.

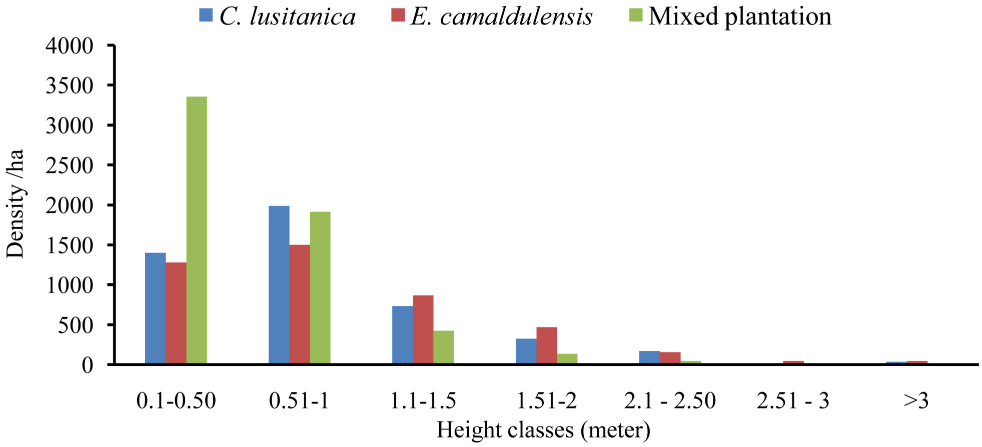

Figure 4. Height class distribution of woody plants regenerated under the canopies of the different plantations.

displayed relatively wider diameters and height class distributions compared with the undergrowths woody plants of the mixed plantation (**Figure 3** and **Figure 4**). However, the statistical test result indicated not a significant difference ($F_{cal(2, 9)} = 3.14$, $p = 0.092$) in the mean basal area of regenerated woody plants under the canopies of the pure and mixed plantations ($p > 0.05$).

3.2. Growth Interactions of the Monoculture and Mixed Plantation Species

The comparative analysis result of the growth of the pure plantations of *C. lusitanica* and *E. camaldulensis* and the mixed plantation is presented in **Figure 5** and **Figure 6**. The statistical test result indicated a significant difference on the mean DBH ($p = 0.0001$, **Figure 5**) and mean height ($p = 0.001$, **Figure 6**) between the pure and mixed plantation of the *C. lusitanica*. Similarly, there was a significance difference in the mean DBH ($p = 0.0076$) between the pure and mixed plantations of the *E. camaldulensis* (**Figure 5**). However, there were no significant differences in the mean height ($p = 0.4935$) between the pure and mixed plantations of the *E. camaldulensis* (**Figure 6**).

3.3. Effect of Light and Density of Plantation Trees on the Understory Woody Plants

The mean percent value of PPFD transmitted in the specified time (09:00 AM - 15:00 PM) and reached in the understory of the plantations for the pure *C. lusitanica*, *E. camaldulensis* and mixed plantations were, 13.7%, 8.3% and 11.3%, respectively. The statistical test result indicated no significant differences in the mean percent values of PPFD recorded under the canopies of the different plantation types ($F_{(2, 9)} = 1.79$, $p = 0.222$). The result

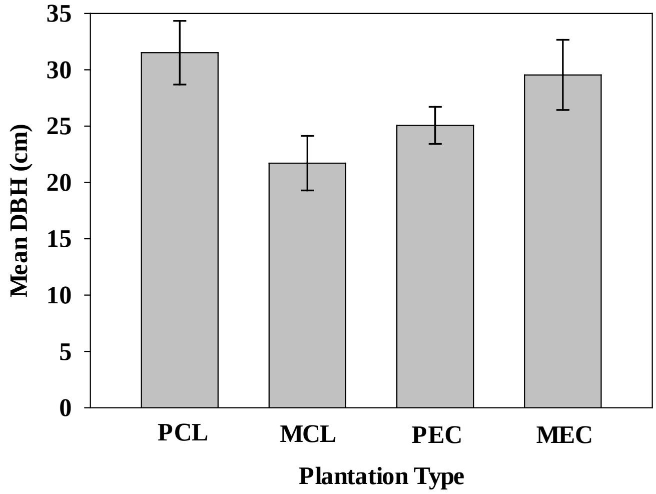

Figure 5. Mean DBH of the pure and mixed plantations ($p = 0.05$). PEC (Pure *E. camaldulensis*), MEC (Mixed *E. camaldulensis*), PCL (Pure *C. lusitanica*), MCL (Mixed *C. lusitanica*).

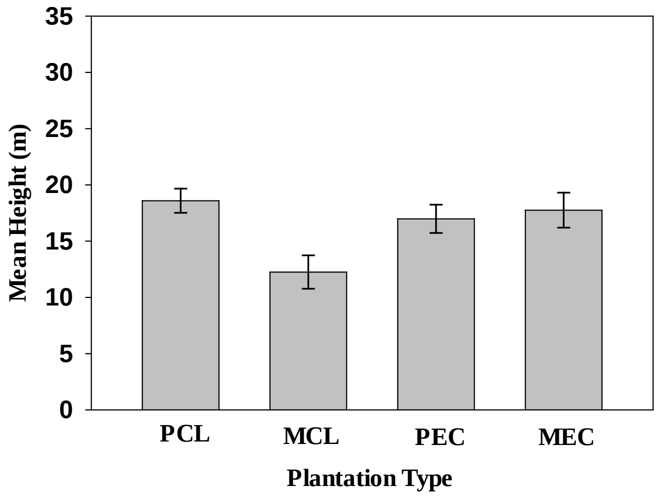

Figure 6. Mean height of the pure and mixed plantations ($p = 0.05$). PEC (Pure *E. camaldulensis*), MEC (Mixed *E. camaldulensis*), PCL (Pure *C. lusitanica*), MCL (Mixed *C. lusitanica*).

also further indicated no significant relationship ($R^2 = 0.15$, $p = 0.212$) between density of plantation trees/plot and the percent PPFD recorded in the understorey of the pure and mixed plantations (**Figure 7(a)**). Statistically, there was a significant relationship ($R^2 = 0.403$, $p = 0.0266$) between PPFD (%) under the studied plantations and diversity of species per plot (**Figure 7(b)**). However, they do have an inverse relationship, that shows high light under the studied plantations does not always result high diversity of species (**Figure 7(a)**). Statistically there was no significant relationship between density of plantation trees/plot and diversity of woody plant species in the studied plantations ($R^2 = 0.012$, $p = 0.801$ **Figure 7(c)**). Also, there was no significant relationship ($R^2 = 0.0095$, $p = 0.776$) between the PPFD under the canopies of the different plantations and the mean basal area of regenerated woody plants, (**Figure 7(d)**).

4. Discussion

4.1. Effect of Pure and Mixed Plantations on Diversity and Plant Density

The absolute number of species recorded in the pure plantations of *E. camaldulensis* and *C. lusitanica* is greater

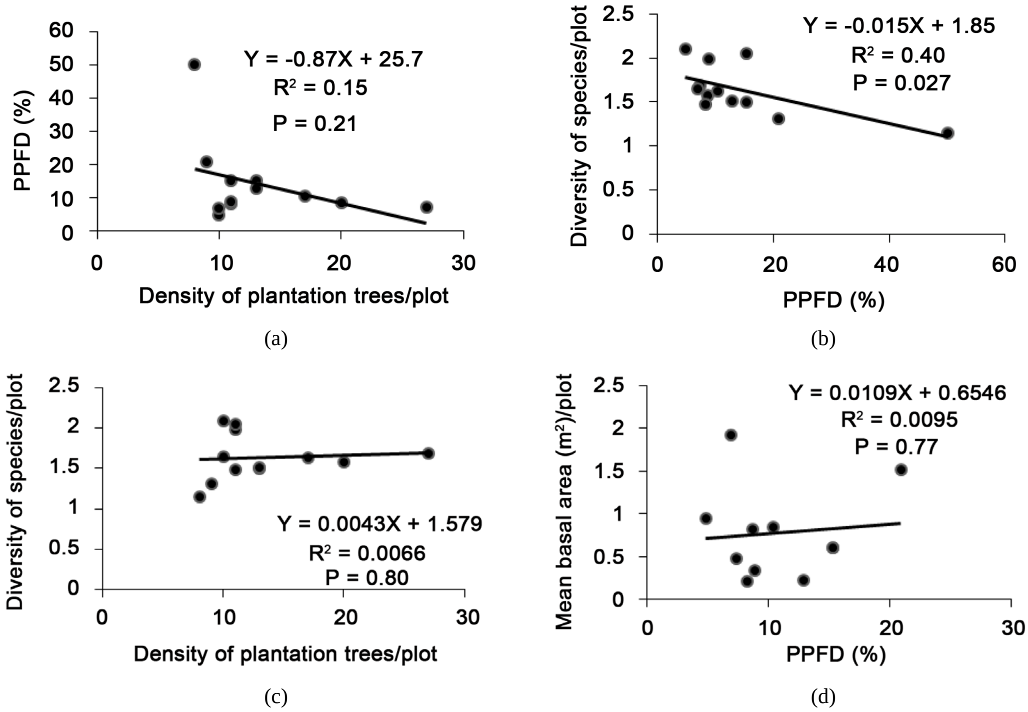

Figure 7. Light as a function of density of plantation trees (a), Diversity (*H´*) of woody plants ((b) and (c)) as a function of light and density of plantation trees, and, mean basal area of woody plants (d) as a function of light.

than the mixed plantation. This could indicate that pure monoculture plantations have the potential to harbor more number of species than the mixed plantations. Out of the total species recorded in all the plantation types 4 and 2 species are recorded only in the pure *E. camaldulensis* and pure *C. lusitanica* plantations, respectively. Which could indicate that the pure monoculture plantations have the potential to harbor and favor the regeneration of certain species much better than the mixed plantation. There were also no significant differences in the diversity of species among the pure *E. camaldulensis*, pure *C. lusitanica* and mixed plantations. This also indicated that the pure plantations are as diverse as the mixed plantations which further indicated their importance for biodiversity conserving.

Overall, the total number of species recorded in the individual pure plantations was relatively comparable with the findings of similar study results of pure monocultures species, in different localities of Ethiopia (Eshetu, 2001; Feyera & Demel, 2001; Feyera et al., 2002). Feyera et al. (2002) recorded under *E. globulus* plantations in dry afro-montan 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. This study also found a total of 18, 23 and 25 native woody species in 11, 22 and 27 years of *E. saligna* plantation. Feyera & Demel (2001) also recorded a total of 18 and 11 naturally regenerated woody species under 14 years and 24 years *C. lusitanica* plantation within the area of the central Ethiopian highlands. In a similar study of uneven aged plantations established in the dry afro-montane areas of Ethiopia, Feyera et al. (2002) recorded more number of species under *C. lusitanica* plantations, a total of 30 woody species in a 9 year old stand, 22 species in a 17 year old stand and 17 species in a 25 year old plantation. The difference in the absolute number of identified species with other study results might be associated with the species pool available in the surrounding area, local climatic conditions, soil seed bank, microclimatic condition under each forest and plantation history.

The absolute number of seedlings/ha in the mixed plantation was much higher than the pure plantations while the absolute number of trees/ha (>1 meter) in the pure plantations were much higher than the mixed plantation (**Table 3**). This could indicate that mixed plantations may favor the recruitment of seedlings but may have a negative impact on the growth of the understory plants. Though there is a difference in the absolute number of seedlings, saplings and tree density in the studied plantation types, the statistical result indicated no significance differences in the density of woody plants/ha among the pure *E. camaldulensis*, *C. lusitanica* and the mixed plantations. This could indicate that the pure plantations are as important as the mixed plantation in the recruitment of native woody plants. The difference on the absolute density of undergrowth woody plants in the different plantations might be because of the plantations tree species attributes (Lugo, 1992; Guariguata et al., 1995; Parrotta, 1995; Fimbel & Fimbel, 1996), site factors, such as substrate quality (Gerontidis, 2000), litters mass and depth (Lugo, 1992; Parrotta, 1995; Harrington & Ewel, 1997).

Some species like, *G. saxifrage*, *M. lanceolata* and *V. thomsoniana* were more favored in the pure plantation of *C. lusitanica* than the pure *E. camaldulensis* plantation and the mixed plantation. Other species like *C. edulis*, *C. anisata* and *M. ovatus* has relatively higher density of trees in the mixed plantation than the pure monoculture plantations of *E. camaldulensis* and *C. lusitanica* plantations (**Table 2**). These results could indicate that certain species were much better favored in the mixed plantation than the monoculture plantations. While others are much better regenerated in the monoculture plantations than the mixed plantation. Though research has shown that there are potential advantages to be gained by using carefully designed species mixtures in place of monocultures (Kelty, 2006; Funayama et al., 2001), this research result indicated that the pure monoculture plantations are equally important in the regeneration of understory woody plants like that of the mixed plantation.

4.2. Productivity of the Monocultures and Mixed Plantation

When some species are mixed and established with different species both may favor or disfavor each other, resulting in either a positive or a negative growth impact. In this study we found that the *E. camaldulensis* mixed with *C. lusitanica* had gained a higher diameter as compared with the pure plantation of *E. camaldulensis*. This could indicate that the productivity of *Eucalyptus* species could be increased when mixed with *Cupressus* species under appropriate management condition than the pure *Eucalyptus* plantation stand. This result is in agreement with the findings of DeBell (1985) that indicated in a 25 months, *Eucalyptus* trees grown in mixture with legumes were larger than *Eucalyptus* trees grown in pure plantings. Our results indicate that when *Euaclyptus* species mixed with non nitrogen species could also have better growths. On the contrary, *C. lusitanica* mixed with *E. camaldulensis* had lower diameter and height as compared with the pure *C. lusitanica* plantation stand. This indicates that *E. camaldulensis* is competent and suppressing the growth of *C. lusitanica* grown with it. Similarly, Yang et al. (2009) in their study find out similar results that in a 2 - 3 year old, *Acacia crassicarpa* mixed and planted with *Eucalyptus* had a retarded growth as compared with the pure *A. crassicarpa* stand. Overall, based on this result *C. lusitanica*, which is an important timber species in the tropical countries, should not be mixed and grown with *E. camaldulensis* species, since it has a negative impact on its productivity.

4.3. Effects of Light and Density of Plantation Trees on the Understory Woody Plants

The result of the woody plant species diversity was related to the PPFD light reaching under the canopies but their relationship is not direct. This indicates that in the studied plantations more light reaching under the canopies does not result higher diversity of species. This result is not in agreement with the findings of Son et al. (2004), who reported an increase in the diversity of species with an increase, in the light in a *Larix leptolepis* plantation. This difference could be attributed because of differences in plantation species, micro-environments under the studied plantations, availability of seed sources, type of regenerated species (shade lover or not). There was no significant relationship between density of plantation trees/plot and diversity of species. Which indicates that density of trees did not affect the diversity of undergrowth plantations.

Also, the PPFD light reaching under the canopy of the pure and mixed plantations have no significant relationship in the mean basal area of regenerated woody plants under the canopies of the studied plantations. This result is not consistent with Son et al. (2004), who showed that more light in the understory vegetation encouraged understory plant production. This difference could be resulted because of differences in the studied plantations and type of regenerated species. Therefore, based on the supportive results of this study, manipulating the density of plantations through optimum thinning which can allow more light to reach under the canopies of the studied plantations, may not always facilitate the growth of indigenous woody plants.

5. Conclusion

The results, which are specific, to the studied pure plantations of *C. lusitanica*, *E. camaldulensis* and mixed plantations (*C. lusitanica*/*E. camaldulensis*) indicate that the pure monoculture plantations are equally facilitating the regeneration of woody plants like that of the mixed plantation. The *E. camaldulensis* species was found affecting the growth of *C. lusitanica*, an important timber species, negatively. As a result we recommend not to mix or grow *C. lusitanica* with *E. camaldulensis* since it causes a retarded growth on it.

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