Growth and Yield of Maize in Eucalyptus Tree Alley Cropping Agroforestry Practice in Kafa Zone, Ethiopia

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Abstract

Background and Objective: Recently, the agenda of Eucalyptus has been debatable because of its both positive and negative arguments. And different research results and scientific literature on the environmental impact of Eucalyptus trees show complex, inconsistent, and site-specific results. The objective of the study was to evaluate the growth and yield of maize in Eucalyptus hedgerow agroforestry practice in Decha Woreda southwest Ethiopia.

Materials and Methods: Randomized Complete Block Design with three replication was employed for this study. Plant height, the number of cobs, cob weight, 100 seed weight, biomass and grain yield parameters for maize growth performance and diameter at breast height (DBH) and height data were measured to evaluate the effect of eucalyptus tree species on the intercropped plants/maize. Analysis of variance (ANOVA) was performed and treatment separation was made by using Least Significance Difference (LSD) at a 95% probability level.

Results: Maize grain yield variation within the treatment was not significant in the first year cropping season, however, yield advantage was obtained under Eucalyptus camaldulensis hedgerow. In the second and third-year cropping seasons, grain yield variations were significant (P≤0.05) and consistently declined under the hedge row of Eucalyptus species as compared to sole cropping. Among the four eucalyptus tree species evaluated in hedge row arrangement, *Eucalyptus grandis* and *Eucalyptus saligna*significantly (P≤0.05) affected the maize grain yield in the second and third cropping seasons. In the case of tree growth performance, *Eucalyptus saligna*and *Eucalyptus grandis* attained higher height and diameter at breast height. Whereas the reduced growth performance in height and diameter at breast height as compared to the treatment but not in annual growth reference level was recorded in *eucalyptus camaldulensis* and *eucalyptus citriodora*. Also, this study reveals the non-significance effect of the eucalyptus species on soil moisture near the hedgerows. Even though, the advantage of soil moisture under eucalyptus camaldulensis was recorded for three consecutive years.

Conclusion: Therefore, farmers who planted *Eucalyptus camaldulensis* with maize intercropping, in a hedge row arrangement with enough space (8m) between hedgerows could obtain both wood and food products from a unit land area. However, as a precaution, it is important to set management options which may reduce competition between trees and annual crops since both products are vital for farmers.

Introduction

In Ethiopia Eucalyptus was introduced during the reign of Emperor Menilek II (1868–1907) in 1894/95[1]. The purpose was to supply fuel wood and construction timber to the new and growing capital city, Addis Ababa. In the 1970s, the plantation area around Addis Ababa was about 15,000 ha while in other parts of the country approximately 76,000 ha of plantations had been established. Between 1975 and 1994, further new plantations were established mainly in urban areas with aid from international donors such as UNSO, SIDA, WFP, and WB[2]. About 55 species of Eucalyptus have been grown in Ethiopia, of which the

most widespread Eucalyptus species include *E. camaldulensis, E. citriodora, E. globulus subsp., globulus, E. regnans, E. saligna and E. tereticornis*. *E. globulus* and *E. camaldulensis* are the major species planted in the highlands of Ethiopia[3].

Recently, however, planting Eucalyptus has become a subject for argument because of its both positive and negative ecological effects. The main potential negative impacts focused on its severe competition of growth resources with companion plants particularly the extraction of water resources and soil nutrients. The detrimental effect of *Eucalyptus* plantation on soil total nitrogen, exchangeable Calcium and soil moisture content[4], and P stocks[4, 5] were reported. Studies conducted in the central highlands of Ethiopia also reported that *E. globulus* depleted soil nutrients.[6, 7] Furthermore, Schlo¨nvoigt and Beer[8] reported that *Eucalyptus deglupta* reduced maize yields by 15 and 58% during the second and the third maize harvests in Costa Rica, respectively. An average of 20–25% yield reduction per unit land area for maize intercropped between up to 10 tree species was reported in Canada when compared to the yield recorded in conventional mono-cropping[9] Research results on boundary planting of *E. globulus* in Ethiopian Nitosols showed a significant reduction of wheat yield in the first 8 to 12m across the tree crop interface[10]. Other studies suggested that Eucalyptus released toxic allele chemicals into the soil system mainly through litter decomposition products [6,11] and reduced germination and radical growth of chickpeas, field pea, maize, and teff.[6]

On the contrary, other studies showed that light, moisture and minerals under the canopy of Eucalyptus are adequate to support other plant growth.[12,13] Several research results revealed that Eucalyptus species are efficient water users, i.e., they consume less water per unit of biomass produced than other crops, conifers, acacias, and broad-leaved tree species.[14,12] Under both moisture and nutrient stress *Eucalyptus globulus* and *E. camaldulensis* showed to grow better as compared to deciduous tree species in Ethiopia.[15, 16, 17,18]Another study in Ethiopia showed that land-use change from agriculture to *E. globulus* and *E. camaldulensis* plantation had no adverse impact on exchangeable potassium, total soil nitrogen, phosphorus, and sulphur at least up to the age of 14.5 years [19] Although people believe that the species would not serve agroforestry purposes, Eucalyptus has given the best results when planted as an agroforestry tree with 6 x1 m spacing under rainfed conditions.[20] Good results were recorded when coffee was inter-cropped in spacing 8*8meter spacing of Eucalyptus plantations in Costa Rica.[21] Furthermore, no adverse effects were noted when agricultural and horticultural crops grew with Eucalyptus in India, Nepal and Thailand.[22] The use of some Eucalyptus trees in agro-forestry is also common in Nigeria and Thailand[23]. In Philippines, widley spaced tree rows intecroping is more profitable and feasible to smallholders than mono cropping.[24]

The aforementioned research results and scientific literature on the overall impact of Eucalyptus trees show complex, inconsistent, and site-specific results. Generally, the effect of Eucalyptus may vary within different geographical areas, rainfall regimes and management employed. In recent years, rows of *Eucalyptus* species planted along field borders have become a dominant feature of south and southwest

Ethiopia, and maize farming is the dominant agricultural system and is widely grown as a major food and cash crop. Therefore, information on the effect of Eucalyptus on the surrounding environment and the level of maize yield reduction in systems with Eucalyptus trees is very important for increased awareness and improved land management intervention in the study area. With this context, the present study was aimed at i) assessing the effect of four Eucalyptus tree species viz *Eucalyptus camaldulensis, Eucalyptus citrodora, Eucalyptus grandis* and *Eucalyptus saligna* planted in hedgerow arrangement on the grain yield of intercropped maize ii) evaluating the allelopathic effect of the species on maize seedling growth in Decha district of Kaffa zone, southwest Ethiopia.

Materials and Methods

Description of the study area

The study was conducted at Modiyo kebele in Decha district Kaffa zone, southwest Ethiopia. The district is located within the latitude of 07^{0}8'-07^{o}26' North and longitude of 35^{o}53'-36^{o}36' East. The altitude of the study area ranges from 500 to2300 masl consisting of a highly dissected plateau with flat and undulating terrain.

According to the harmonized soil map of Africa[25], the major soil groups are Nitisols, Acrisols, Leptosols, Regosols, Cambisols, and Vertisols. Nitisols are agriculturally the most important and dominant type of soil. Some physical and chemical characteristics of the soil at the study site are indicated in Table 1. The study area experienced one long rainy season, lasting for 8 months from March to October and the wettest months are between May and August. The mean annual rainfall ranges from 1710 mm at Bonga station to 1892 mm at Wushwush station. Over 85% of the total annual rainfall, with mean monthly values in the range of 125–250 mm occurs in the 8 months long rainy season. The mean temperature is 19.4°C at Bonga and 18.1°C at Wushwush station.[26] The vegetation of the area belongs to the Afro-montane rain forest. [27]

Table 1
Some soil physicochemical properties of the studied site in the Decha district of Kaffa zone, southwest Ethiopia.

Soil properties	Values	Soil rating[28]
% OC	3.76	High
% OM	6.48	High
%TN	0.32	High
Av.P (Ppm)	12.06	Low
pH soil H_2o 1:2.5	5.2	Strongly acidic
Textural class	clay	
Note: *OC-Organic carbon, OM-Organic matter, TN-Total nitrogen, Av.P- Available phosphorus*,		

Plant Material and Nursery Management

Seeds of Eucalyptus species were obtained from Forest Research Center, Addis Ababa. Seedlings for the trials were raised at the Keyakela nursery site in the Kaffa zone between December–June 2012 close to the study sites. Nursery sowing of the multipurpose species was done on seedbeds and after germination, the seedlings were pricked out into white polythene tubes. A bamboo shed was set up immediately after pricking out to provide shade and was removed as necessary. While in the nursery the seedlings were watered twice per day during the morning and evening except on days when it rained. This was, however, reduced to once every other day three weeks before planting. Weeds were removed on detection and root pruning was done whenever roots outgrew the polythene.

Experimental design and approach: Two separate experiments were conducted both in the field and nursery. The first experiment was conducted from 2013 to 2016 to evaluate the effect of Eucalyptus tree species on the grain yield of intercropped maize laid out in a randomized complete block design with five treatments and three replications. Treatments were; T_1 (control): maize mono-cropping, sown at 30 cm within-row spacing and 75 cm between rows spacing, T_2 (trees of *Eucalyptus camaldulensis* on hedgerows at 0.5 m x 10 m, with maize inter-planted in the 10 meter wide alleys), T_3 (trees of *Eucalyptus citriodora* on hedgerows at 0.5 m x 10 m, with maize inter-planted in the 10 meter wide alleys), T_4 (trees *Eucalyptus grandis* on hedgerows at 0.5 m x 10 m, with maize inter-planted in the 10 meter wide alleys) and T_5 (trees of *Eucalyptus saligna* on hedgerows at 0.5 m x 10 m, with maize inter-planted in the 10 meter wide alleys). Plots having the size of 300 m^2, (15 m along the contour line and 20 m along the maximum slope gradient) consisting of three rows of Eucalyptus with thirty-one trees per line were established at the trial site. The plots were separated by guard areas of 8 m to avoid the influence on adjacent plots. The first maize cropping was carried out after nine months of tree planting and was continued for two consecutive cropping years. All other maize farming operations were performed manually following local practices. Every cropping season, maize variety, BH660, was sown into furrows

at a spacing of 30 cm b/n plant and 75 cm b/n rows. The maize crop was fertilized at the recommended rate (100 kg DAP and 100 kg Urea). Fertilizer was applied only to the crop but trees might have probably benefited from the fertilizer applied to the maize. Ring weeding around tree seedlings was conducted for one year.

The second pot experiment was conducted in a nursery at Bonga Agricultural Research centre. Leaf biomass was collected from established eucalyptus hedgerows at 24 and 36 months after planting to evaluate the allelopathic potential of *Eucalyptus* species on germination and early growth of maize crops. The fresh green leaves of four Eucalyptus tree species (*E. camaldulensis, E. citriodora, E. saligna* and *E. grandis*) were collected from the experimental site and washed with water, and chopped manually. 500g of the chopped leaf was soaked in 2 litres of water using plastic tubes for 24 hours and stirred frequently. The extract was filtered through a double-layered cloth. Soil samples were taken from different spots under a canopy of four Eucalyptus tree species except for the control which was taken from outside the canopy and was filled to the respective pots. Five treatments were replicated four times in a completely randomized design. Five seeds of maize variety BH660 were sown in each pot. The aqueous extracts of four Eucalyptus species were applied to the respective and one control pot was irrigated with tape water. The soils in pots were kept moist throughout the experiment by applying aqueous extract and water to the respective pots. The number of seeds germination was counted daily till the completion of germination. To assess the growth of the maize plant, seven days after seeding the plants were thinned and only three healthy plants were kept in each bag. After 14 days, the plants were harvested for fresh weights of shoots and roots. They were then kept in paper bags and tagged properly and air-dried for two weeks for taking the dry weight of shoots and roots.

Data collection and Analysis

To evaluate the effects of *Eucalyptus* tree species on the growth and yield of maize, plant height, and the number of cobs, cob weight, 100 seed weight, and grain yield data were measured and two plant samples were also taken from each of the upper, middle and lower alley zones to measure total biomass of maize.

To evaluate the annual growth performance of eucalyptus trees diameter at breast height (DBH) and tree height were recorded until the age of 36 months. To estimate the wood resource from Eucalyptus trees, the basal area was also calculated as $BA = \pi d^2/4$, where d = diameter at the breast height.

For allelochemical effect evaluation; germination rate, plant height, collar diameter, number of leaves per plant, fresh biomass, root & shoot length, root & shoot fresh weight, and root & shoot dry weight data were calculated. The germination percentage was calculated following[29] as:

GC (%) = (No of germinated seeds/Total No of seeds sown) x 100.

Shoot length (cm) was measured with a meter rod and the measurements were taken from the stem joint to the tip of the terminal leaf. Root length (cm) was measured with a meter rod and the

measurements were taken from the root joint to the tip of the tap/main root. Collar diameters (mm) of the crops were determined using a calliper. After the different organs were separated to shoot and root biomass, they were kept in paper bags and tagged properly. Wet and dry weights of the biomass were measured using scientific electrical balance.

Statistical Analysis:

The collected data were subjected to statistical analysis software (SAS version 9), analysis of variance (ANOVA) was used to analyze variations among the treatments and a 95% probability level was considered for significance declaration. The least significant difference (LSD) tests were used to identify mean differences.

Results and Discussion

The effect of Eucalyptus tree species on Maize grain yield

Maize grain yield variation among the treatment was not significant in the first cropping season (2014). Significant ($p \leq 0.05$) yield reduction was recorded in the second (2015) and third year (2016) of intercropping. The highest reduction of maize grain yields was recorded by plots with *E. saligna* ranging from 49% in the second cropping season to 72% in the third cropping season, followed by *E. grandis* ranging from 30.5% in the second cropping season to 57% in the third cropping season compared to mono-cropping (Table 2). Similar effects of *Eucalyptus saligna* were reported in Southern Rwanda maize grain yield reduced from 2.5 t/ha in open fields to 0.5 t/ha within 10.5 m of the woodlots.[30] Onyewotu *et al.*[31] also revealed the competitive effects of Eucalyptus shelterbelt on an adjacent millet (*Pennisetum typhoides*) that crop grown very close to the belt was reduced because of competition with the trees for light, soil moisture and nutrients, and shading. Plots with *Eucalyptus saligna* and *Eucalyptus grandis* significantly reduced maize biomass yield in the third year of intercropping as compared to other treatments (Table 3).

No significant effect of *E.camaldulensis* on grain and biomass yield was recorded across all studied seasons. A similar result was reported by Alebachew *et al.*[32] that *E. camaldulensis* is well suited for growing in arable fields intercropping maize with trees planted at 5 x 5 m gave satisfactory yields. Ceccon[33] has also reported positive results when intercropping *E.camaldulensis* with crops. However, maize yield and yield parameters suppression were recorded up to a distance of 20 m away from *E.camaldulensis* stand in Western Amhara, Ethiopia.[34]

After the third year of cropping, maize intercropping was no longer possible in all Eucalyptus species, due to canopy closure. In the first year cropping season, grain yield, biomass and other growth parameters were not significantly affected ($p \leq 0.05$). This may be due to the stage of the tree to compete above and below ground plant growth resources. Laclau *et al.*[35] studied the dynamics of nutrients in short rotational eucalyptus and found that there are two growth periods. The first one is the

juvenile phase up to canopy closure, during which the uptake of nutrients from the soil meets the requirements. The second phase involves intense nutrient recycling. The second and third cropping season shows a significant difference among the treatments in both maize yield and yield component ($p \leq 0.05$). Particularly, in the third year cropping season, maize grain yield in the monoculture system was significantly higher than intercropped maize yield.

Table 2
Grain yield and hundred seed weight of maize under Eucalyptus species in consecutive three years of the study period in Decha district of Kaffa zone, south-west Ethiopia.

Treatments	**Grain Yield (t/ha) (Mean ± SD)**			**Hundred Seed Weight (g) (Mean ± SD)**		
	Year			**Year**		
	2014	**2015**	**2016**	**2014**	**2015**	**2016**
T_1 (Sole maize)	2.46 ± .35	4.33 ± .79a	4.66 ± .67a	40.1 ± 1.1	47.5 ± 3.4	34 ± 2.9
T_2 (*E. citrodora* with maize)	1.93 ± .77	3.67 ± .95ab	2.45 ± 1.1bc	40.3 ± 2.2	51.2 ± 1.3	34.2 ± 4.7
T_3 (E. camaldulensis with maize)	2.98 ± .17	4.78 ± .26a	3.6 ± 1.2ab	39.4 ± 1.1	47.8 ± 1.8	34.1 ± 2.8
T_4 (E. grandis with maize)	2.32 ± .32	3.01 ± .26bc	2.01 ± 1.2bc	41 ± .88	45.7 ± 3.9	35.8 ± 2.3
T_5 (E. saligna with maize)	1.78 ± .99	2.22 ± .22c	1.29 ± .34c	39 ± 2.2	42.9 ± 3.3	37.2 ± 2.1
CV (%)	34	18.1	39	4.1	6.2	8.8
LSD($p_{=.05}$)	NS	1.184	2.01	NS	NS	NS

Note: *Mean values with different letters are statistically different at α = 0.05*

Table 3
Biomass yield and plant height of maize under Eucalyptus species in consecutive three years of the study period in Decha district of Kaffa zone, south-west Ethiopia.

	Biomass Yield (t/ha) (Mean ± SD)			Plant height (m) (Mean ± SD)		
	Year			Year		
	2014	2015	2016	2014	2015	2016
T_1 (Sole maize)	59.6 ± 9.7	80.3 ± 5.9	33.2 ± 7.2a	2.2 ± .25	2.7 ± .26	2.2 ± .16a
T_2 (*E. citrodora* with maize)	59.4 ± 5.4	69.3 ± 14.3	25 ± 7.8bc	2.3 ± .22	2.7 ± .28	2.1 ± .16ab
T_3 (E. camaldulensis with maize)	70.9 ± 1.4	84.6 ± 9.8	29.6 ± 1.6ab	2.4 ± .14	2.8 ± .16	1.8 ± .1b
T_4 (E. grandis with maize)	55.3 ± 6.0	71.7 ± 10.9	23.6 ± 6.6bc	2.2 ± .20	2.7 ± .17	2 ± .19ab
T_5 (E. saligna with maize)	50.3 ± 7.9	47.4 ± 9.4	22.6 ± 8.9c	2.2 ± .31	2.4 ± .22	1.9 ± .29b
CV (%)	14.9	19.5	14	8.7	8.8	7.3
LSD($p_{=.05}$)	NS	NS	6.8	NS	NS	0.26
Note: *Mean values with different letters are statistically different at α = 0.05*						

Tree growth performance in the hedgerow agroforestry practice

The statistical comparison showed that DBH and height growth of *Eucalyptus saligna* and *Eucalyptus grandis* were significantly ($p < 0.05$) higher than *Eucalyptus camaldulensis* and *Eucalyptus citriodora* across all years (Table 4 **and** Fig. 1).

Table 4
Height and diameter at breast height of Eucalyptus species with the consecutive three years of study

Eucalyptus species	Tree height (m) (Mean ± SD)			DBH (cm) (Mean ± SD)		
	Year			Year		
	2014	2015	2016	2014	2015	2016
E.saligna	4.7 ± .21a	10.5 ± .92a	15.1 ± 1.4a	3.5 ± .2a	8.8 ± .4a	13.9 ± .52a
E.grandis	4.5 ± .62a	9.8 ± .71a	14.6 ± .65a	3.3 ± .59a	8.5 ± .19a	13.6 ± 1.1a
E.citrodora	3.3 ± .28b	7.5 ± .59b	10.5 ± .57b	2.5 ± .23b	7.1 ± .11b	11.3 ± .31b
E.camandulnesi	2.9 ± .25b	7.4 ± .64b	10.4 ± .73b	2.2 ± .22b	7.1 ± .63b	11.3 ± .44b
CV (%)	9.7	8.2	7.1	12	4.9	5.2
LSD($p_{=.05}$)	0.7	1.4	1.7	0.6	0.7	1.2

Note: *DBH = diameter at breast height in centimetres, Mean values with different letters are statistically different at α 0.05*

Table 5
Basal area of Eucalyptus species with the consecutive three years of study

Eucalyptus species	Basal area (m^2/ha) (Mean ± SD)		
	Year		
	2014	2015	2016
E.saligna	343 ± 30.8a	2017 ± 181.4a	5107 ± 383.4a
E.grandis	323 ± 109.3a	1893 ± 84.7a	4830 ± 776.3a
E.citrodora	190 ± 34.9b	1320 ± 42.4b	3340 ± 180.3b
E.camandulnesi	143 ± 44.7b	1337 ± 235.7b	3310 ± 261.8b
CV (%)	25.2	9.5	11.1
LSD($p_{=.05}$)	117	293	870

Note: *Mean values with different letters are statistically different at α 0.05*

The highest mean annual diameter and height increment was observed for *Eucalyptus saligna* (3.48 cm and 3.78 m) followed by *Eucalyptus grandis* (3.44cm and 3.65m). The lowest values were recorded by *Eucalyptus camaldulensis* and *Eucalyptus citriodora* (Fig. 1). A consistent result with the present study

was reported by Delgado-Matas and Pukkala[36] that both *E.grandis* and *E.saligna* showed excellent performance among six studied eucalyptus species in Angola.

Tree basal area and intercrop yield

The results of Nissen and Midmore[37] have suggested using the stand basal area as a simple parameter to evaluate competitiveness in intercropping systems and to provide an estimation of the economic value of the tree component. Analysis of Pearson Correlation in the present study revealed that basal area and maize grain yield were negatively correlated (Fig. 2). Maize intercropped between *E.saligna* experienced a rapid yield decline as basal area increased from 343.3 m^2 ha^{-1} in the first year of intercropping to 2016.7 m^2 ha^{-1} in the second year (Table 5), indicating stronger competition for above- and below-ground resources. Similar results were reported by Bertomeu[38] that the increment in the basal area of *Eucalyptus deglupta* resulted in a reduction of maize grain yield by 40%.

Effect of Eucalyptus leaf extract on seed germination and seedling growth of maize

The effect of these Eucalyptus trees' leaf extracts on germination percentage, fresh weight, and dry weight of maize was recorded and summarized (Table 6). The results of each tree species were discussed separately.

Germination percentage

Germination was determined by counting the number of germinated seeds at hour intervals until there had been no further germination for more than three days. Seed germination is considered to be the most critical stage, especially under stressful conditions. During germination, biochemical changes take place, which provides the basic framework for subsequent growth and development. The results revealed that Eucalyptus aqueous extract application significantly stimulated seed germination over water-applied treatment (Table 6). The increase in germination percentage was found from 18–39% as compared to the control and the more stimulating effect was recorded on the pot irrigated by *Eucalyptus citriodora* leaf extract followed by *Eucalyptus saligna*. Whereas a significantly lower germination percentage was recorded on the pot irrigated with water (Table 6). Inconsistent study results were reported by different scholars. Similar to the present study, the stimulatory effect of eucalyptus tree species was reported by Nadir *et al.*[39] that a higher germination percentage of crops was recorded under eucalyptus trees than in open land. Furthermore, the beneficial effect of eucalyptus on the germination of wheat and cowpea was also reported by Blaise *et al.*[40]. On the other hand, Espinosa *et al.*[41] and Abugre *et al.*[42] revealed that *Eucalyptus grandis* had no allelopathic effect on germination of maize. On the contrary, various studies revealed that extracts of eucalyptus inhibited the germination of some crops.[43,44,45]

Shoot and root fresh weight

The study result revealed that the effect of aqueous extracts of all studied Eucalyptus was found to be stimulatory regarding the shoot fresh weight of maize seedlings as compared to the control (Table 6). The results regarding root fresh weight showed that aqueous extract of *Eucalyptus saligna* and *Eucalyptus grandis* induced inhibitory effects on the root fresh weight of maize plant as compared to the control.

Shoot and Root dry weight

The effect of aqueous extract was found to be non-significant regarding to shoot and root dry weight (Table 6). Contrary to this study, Khan *et al.*[46] reported the inhibitory effect of *Eucalyptus camaldulensis* on the root dry weight of maize.

Table 6
Effect of *Eucalyptus* leaf extract on seed germination and seedling growth of maize in Decha district of Kaffa zone, south-west Ethiopia

Treatment	G (%)	SL (cm)	RL (cm)	SFW (g)	RFW (g)	SDW (g)	RDW (g)	CD (cm)
Control	58 ± 3.1e	22.5 ± 1.8c	67.1 ± 3.8b	3.0 ± .6b	4.0 ± .9a	0.41 ± .2	0.38 ± .2	0.22 ± .08b
E.citrodora	97 ± 2.9a	26.8 ± 3.6b	78.2 ± 2a	4.5 ± .5a	3.3 ± .4ab	0.63 ± .2	0.28 ± .1	0.42 ± .18a
E.camandulensis	76 ± 2.5d	29.3 ± 2ab	61.9 ± 1.4c	4.8 ± .9a	3.2 ± .5ab	0.59 ± .3	0.26 ± .1	0.32 ± .08ab
E.grandis	82 ± 2.5c	32.1 ± 2.9a	51.5 ± 3.2d	4.1 ± .5a	2.3 ± 1b	0.49 ± .2	0.29 ± .1	0.28 ± .15ab
E.saligna	89 ± 4.1b	30.4 ± 2.3a	41.5 ± 2.8e	4.9 ± .9a	2.2 ± .4b	0.80 ± .5	0.29 ± .1	0.42 ± .1a
CV (%)	**30**	**9.88**	**4.8**	**18.58**	**24.35**	**33.07**	**32.05**	**30.5**
$LSD_{(P=.05)}$	**5.008**	**4.3**	**4.45**	**1.17**	**1.11**	**NS**	**NS**	**0.16**

Note: SL = shoot length in cm, RL = root length in cm, SFW = shoot fresh weight in gram, RFW = root fresh weight in gram, SDW = Shoot dry weight in gram, RDW = root dry weight in gram, CD = collar diameter in cm

Shoot and Root growth

The aqueous extract of Eucalyptus was found to be stimulatory regarding shoot growth (Table 6). Similarly, the application of leaf extract of *Eucalyptus citriodora* induced a stimulatory effect on root length and collar diameter growth of maize seedlings. This may be due to the nature of chemicals in the extract which might have stimulated the production and synthesis of growth hormones such as auxins.[42]The allelochemicals at low concentrations may act as plant growth regulators.[47,48] The

remaining three eucalyptus tree species Vis *E.camandulensis, E.grandis* and *E.saligna* induced the inhibitory effect on the root length growth of maize seedlings as compared to the control. Similar to the present study Abugre *et al*.[42] observed the inhibitory effect of *E. grandis* (leaf and root extract) on the root growth of maize seedlings as compared to the control. Phenolic acids and volatile oils released from the leaves, bark and roots of certain Eucalyptus spp. have deleterious effects on other plant species.[44, 49].

Even though, the yield of maize was higher in monocropping as compared to intercropping with Eucalyptus tree species, in the concept of agroforestry there is the possibility to produce maize crops in a eucalyptus plantation in the early stage of the tree growth. In addition to this if the interest of the smallholder farmers is to produce more wood products from the unit area it is important to intercrop maize with *Eucalyptus grandis* and *Eucalyptus saligna* than others. Also from this research, we found that the extract of Eucalyptus species has no inhibitory effect on the germination of maize seed, which directs unnecessary of using additional seed to compensate the effect of allelopathic problems of Eucalyptus species than the recommended amount of seed per hectare.

Conclusions

The overall yield of maize grown under *Eucalyptus camaldulensis* revealed better product next to mono-cropping than other Eucalyptus species. Yield reduction was noticed on maize grown under *Eucalyptus saligna* and *Eucalyptus grandis* hedgerow. While *Eucalyptus saligna* and *Eucalyptus grandis* showed a better growth performance than *Eucalyptus citriodora* and *Eucalyptus camaldulensis*. Maize grain yield was affected by tree age and size of the Eucalyptus species which tends to decrease with increasing the basal area. Evaluation of the allelopathic effect of eucalyptus tree species on maize seedling growth revealed a stimulatory effect on germination percentage, shoot length, and shoot fresh weight, while an inhibitory effect on root length and fresh weight. Therefore, growing *Eucalyptus camaldulensis* with maize intercropping, in hedge row arrangement with enough spacing between hedgerows can provide both wood and food products from a unit land area for short rotation. But if the objective of the farmer is to get high volume of wood than maize yields, it is advisable to grow maize crops in the hedgerow of *Eucalyptus saligna* and *Eucalyptus grandis* with different tree management measures that are expected to minimize above and below-ground competition to annual crops. The costs and benefits of planting need to be a careful assessment based on detailed studies giving due consideration to both ecological and socio-economic needs.

Declarations

Significance Statement

This study can be an additional resource for the controversial decision of different scholars that has been divided into two sides on Eucalyptus, especially whether it is possible or not to use Eucalyptus trees with annual crops in humid areas. According to this, the results of our study indicate that planting

maize in the first three years together with eucalyptus helps to get the yield of crops and wood from a certain area and it is understood that the effect of eucalyptus is less. In addition to this, it was understood that the allelopathic effect test shows that the germination of maize and the growth of seedlings are better as compared to the control. Therefore, the result of our research has confirmed that planting Eucalyptus with maize in the same and above the spacing used in this study has a positive side.

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Figures

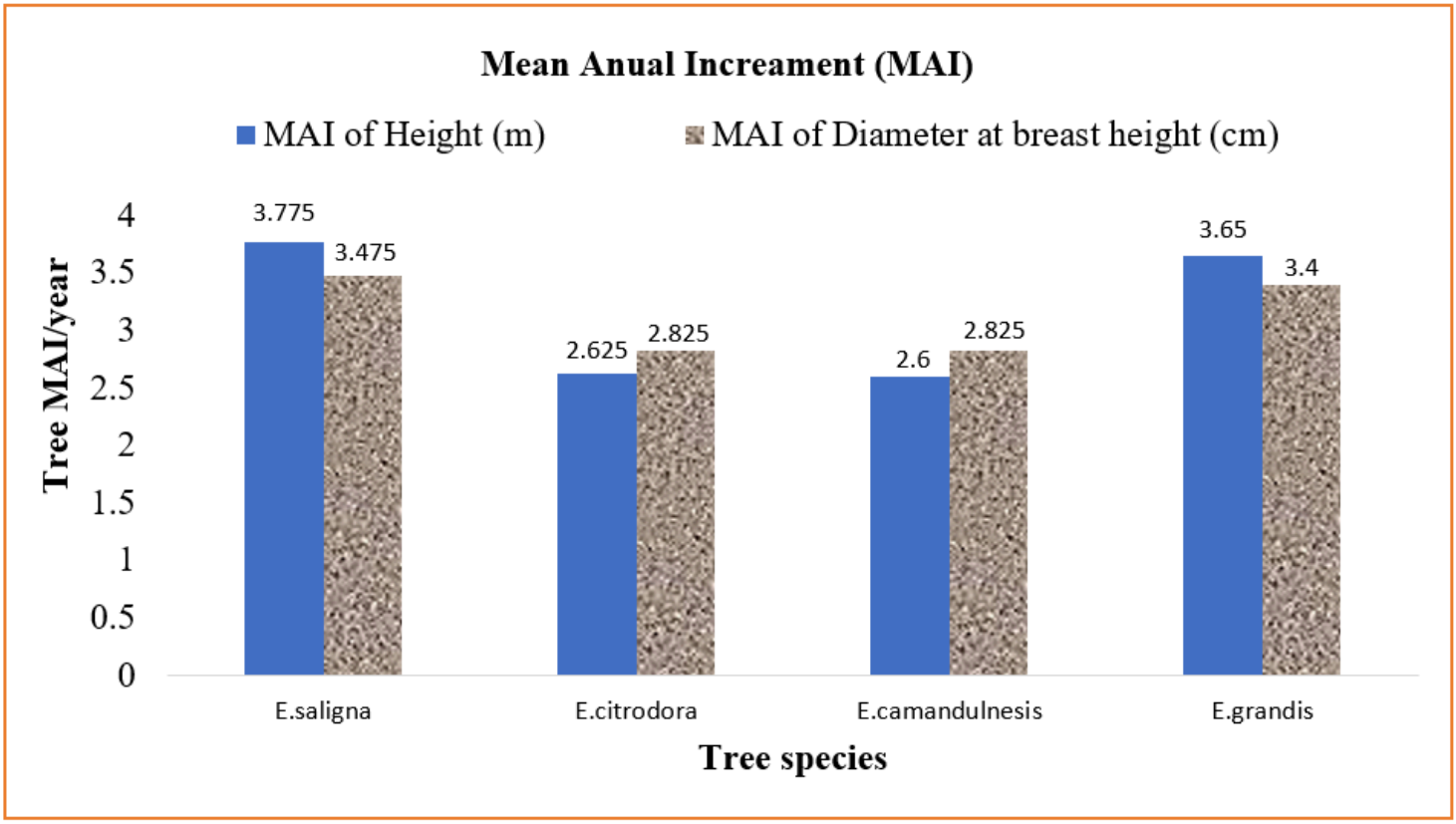

Figure 1

Mean annual height and diameter increment of Eucalyptus species planted on hedgerow in Decha district of Kaffa zone, southwest Ethiopia.

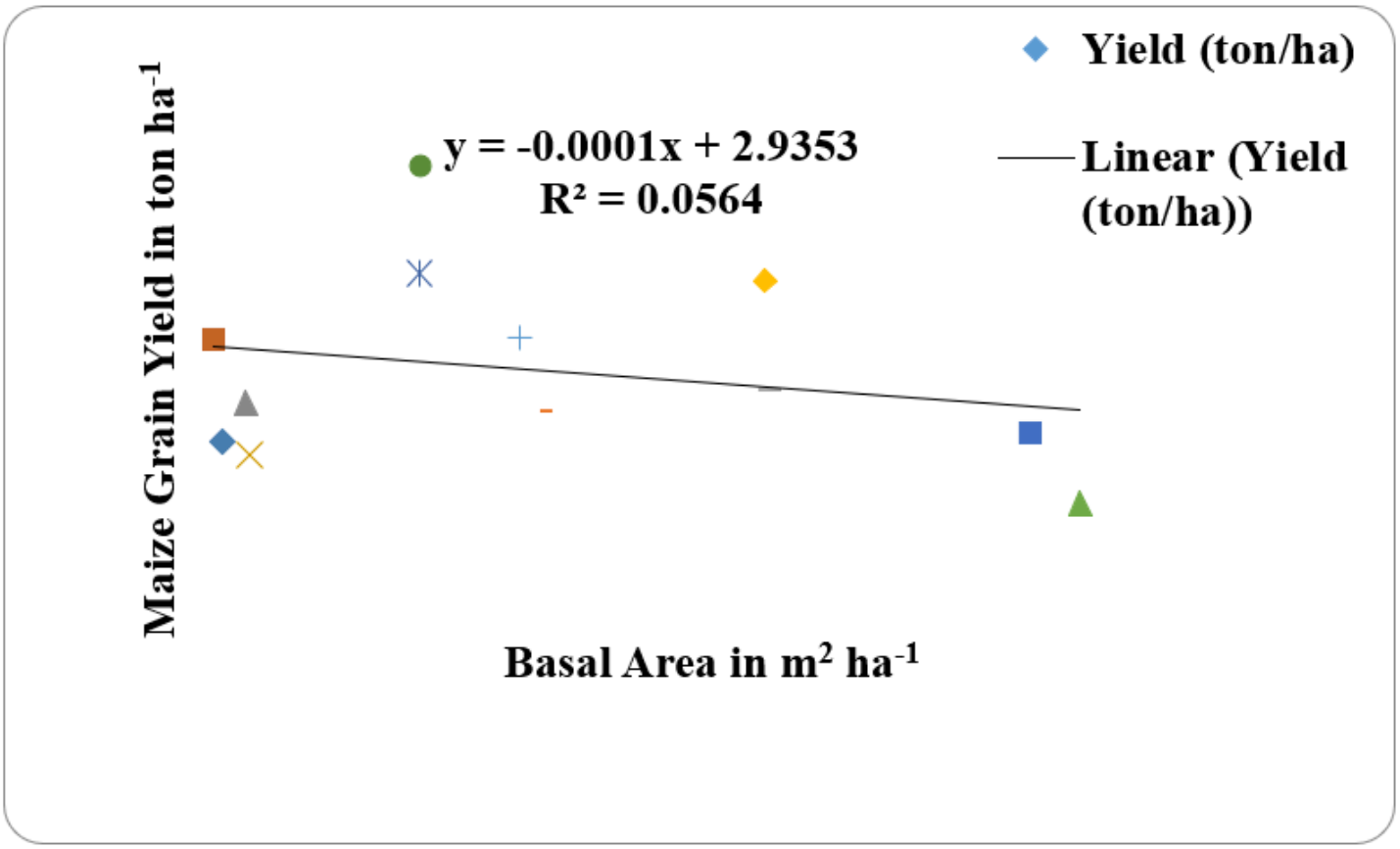

Figure 2

Correlation between Eucalyptus tree basal area and maize grain yield planted on hedgerow in Decha district of Kaffa zone, southwest Ethiopia.

Supplementary Files

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