

# Research Article

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## Assessment of *Eucalyptus Globulus* Coppice Yield in the Highland Areas of North Shewa, Ethiopia

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### ABSTRACT

One of the old traditional methods of silvicultural management is coppicing. Many woody species produce new shoots successfully after coppicing. Regeneration of forest through coppice can be used for short rotation of tree to produce wood biomass for construction and fuel purposes. There are different levels of coppice practiced in *Eucalyptus globulus* plantation in the highland areas of North Shewa. However, there was no evidence or study which coppice levels can give high yield. Therefore, the objective of this study was to compare yield of *E. globulus* at different coppice level in the highland areas of North Shewa, Ethiopia. Fifty sampled plots were purposively selected for this study. Volume, mean annual increment, stump height and diameter, stem number and harvesting age were determined from sampled plots. The results revealed that there was no yield difference ( $p > 0.05$ ) between zero, first, second and third coppice levels. However, stump diameter and number of shoots per stump, stump height were significantly different among 1, 2, 3 coppice levels ( $p < 0.05$ ). Number of shoots were positively correlated with stump diameter and height ( $r = 0.77$ ,  $r = 0.72$ ) respectively. Farmers mostly coppice *E. globulus* from November to December and from April to June. Although statistically there was no yield difference between coppice levels, as farmers described the first coppice has higher yield than other coppice levels. The numbers of shoots per stump were higher in the second and third coppice and this could affect stem quality especially at early stage. Altogether the mean number of stems per hectare was 10812 which is higher than previous studies. Therefore, early silvicultural activities like thinning, early coppice management and pruning has to be done to increase wood stem quality and to promote growth as well.

**Keywords:** *Eucalyptus globulus*, coppice levels, plantation, yield, shoots, stump

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### INTRODUCTION

*Eucalyptus* is a genus which has more than 800 species. Even the number grows because of new taxa are described, *Eucalyptus* in general adapt to a wide range of climate and soil conditions. Different gene pool and fast growth behavior enable *Eucalyptus* to be introduced in many countries in the world (Coppen, 2003). This genus is native to Australia, the Malaysian region, and the Philippines but it is planted in different part of the world since 1890s (Dessie, 2011). During the last 100 years *Eucalyptus* plantation rapidly has covered the tropical regions and the Southern hemisphere (Wingfield et al., 2008). *Eucalyptus* plantations done for production of fuel and construction wood, pulp and paper industry, land restoration and for aesthetic purposes (Eldridge et al., 1993).

The early recorded introduction of *Eucalyptus* tree in Africa was in 1828. It was first brought to Africa by government, settlers and missionaries. At present time *Eucalyptus* are widely distributed almost in all African countries. Among the

introduced *Eucalyptus* varieties *E.globulus* was favored tree crop; however its production was decreased due to diseases. Meanwhile the species is grown widely at the Ethiopian highlands where there are enough moisture and rain (Jacovelli, 2003). The first introduction of *Eucalyptus* in Ethiopia was during the era of emperor Menelik II (1868-1907). The aim was to alleviate the shortage of fuel and construction wood material in the capital city Addis Ababa. Since then the distribution of *Eucalyptus* has been increased rapidly to every corner of the country. It uses for fuel wood, industry and construction materials (Pohjonen and Pukkala, 1990; Tolosana *et al.*, 2010). Since the first introduction, 55 and more species of *Eucalyptus* introduced and grown in Ethiopia, of which between five and ten are widely planted (Dessie, 2011). *E.globulus* performed well in terms of growth and survival rate in highlands and *E. camaldulensis* the second most common *Eucalyptus* species primarily grown in lower altitudes (Hailu, 2002).

Coppicing is a traditional method of woodland management, which enables many trees reshoot from the stump or roots if cut down. It depends on the aim and nature of the crop (Karwani *et al.*, 2016). Many countries apply coppice management for many species in different ways (Spinelliet *al.*, 2017). One of the main behaviors of coppice is its ability to regenerate by vegetative reproduction. This system of reproduction occurs in many woody species. It is an important survival mechanism especially in areas where forest fire is usually occurred (Lust and Mohammady, 1973). Tree regeneration through coppicing is frequently used in short-rotation cultures to produce wood biomass for energy or pulp production, and to take atmospheric carbon efficiently into the ecosystem (Luostarinen *et al.*, 2009). Coppice crop often has shorter rotation periods than those of seedling crops, because coppice stems grow faster than seedlings as they grow from large and well established root systems. It is obviously recognized that tree crops developing from coppice have higher yield compared with seedlings of the same age (Mengist, 2011). Coppicing ability varied between tree species with stump surface area, the taller species would have fewer shoots per stump surface area in savanna tree species (Shackleton, 2000). Performance of coppicing also related to parent crop. Good coppicing is important due to its cheap reestablishment costs (Little and Gardner, 2003). Coppicing ability affecting by a number of factors including season of cutting, sites, carbohydrate level and other growth factors like age, height and diameter of stump, subspecies, origin and placement of the sprout injuries (Blake, 1983).

*E. globulus* regenerates rapidly through stump coppice following the removal of the stem and crown at harvesting (Blake, 1983). This ability to coppice and the fact that second rotation establishment costs are avoided have led many plantation managers to assume that the second rotation may be managed as a coppice crop. *E.globulus* plantations are managed as a successive short rotation coppice system for more than a century in the central Ethiopian highlands (Zewdie, 2008). Coppice can provide a cheap alternative to replanting in the second rotation in *E.globulus* plantations (Whitlock *et al.*, 2004). Short rotation coppice method 5 to 7 years cutting age is done for *E.globulus* for many cutting cycles. Even though, regeneration from stump is cheap and suitable and economical for *E.globulus* (Greyer *et al.*, 1985). Meanwhile, the yield of coppice *E.globulus* tree planted in highland area of Ethiopia at different coppice levels not investigated in the past in North Shewa. Thus, the objectives of this study were aimed to investigate and compare the effect of different coppice levels on yield and to assess farmers experience on coppicing time and coppicing ability of *E.globulus* tree planted in highland areas of North Shewa.

## MATERIALS AND METHODS

### Description of the study area

The study was conducted at Basona Worana, Tarma Ber and Ankober districts of North Shewa between 2015 and 2016. The altitude of Basona Werena district ranges from 1300 -3400 m.a.s.l. Rainfall in Basona Werena ranges from 950-1200 mm. Average temperature of the area is 12 °C. Brown, black, and red are the major soil types of this district. The area has two rain fall types main season and short season. Barley, wheat and faba bean are the main crops grown. The main vegetation types found in the district are *Eucalyptus*, natural shrubs, fodder trees and acacia species (Abiro *et al.*, 2016). Tarma Ber district has an altitude from 1450 -3186 m.a.s.l. Annual rainfall reaches from 1100 to 1400 mm. Average temperature is 20 °C. The major soil types of the area are brown, black, and gray. The district receives bimodal rain fall. Cereal and pulse crops are the main crop grown in the district. Barley, tef, wheat, sorghum and mung bean are grown in the area. Vegetations occur in the area are natural and plantation forests. *Eucalyptus* species are the main components of plantation forest. Acacia species also grow in the low land areas of the district (Abiro *et al.*, 2016). Ankober district is found in the eastern edge of central Ethiopian highlands. The district has two main vegetation types. Above 3000 m.a.s.l *Erica arborea* and *Chloris* species occur and the other vegetation is *E.globulus* and diverse vegetation occur on the lower altitude (Kalu and Seid, 2014). The altitude ranges from 2400 to 3300 m.a.s.l (Abiyu, 2016). The rain fall of Ankober is characterised by bimodal type which short rainy period occurs from March to late June. The long rainy periods occurs from June to September. Mean annual rain fall reaches up to 1179 mm. The mean minimum and maximum temperature is 6.47 and 19.99 respectively (Asmamaw *et al.*, 2018).

## Data collection and sampling

The study site was selected based on community experience on *E. globulus* planting. Farmers who had *E. globulus* more than three years after planting or after coppicing which is at harvesting age for small pole size were selected purposively. All coppice levels which were practiced by the farmers selected systematically. Four coppice levels i.e., 0, 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup> were selected with plot size 10 m x 10 m for sample measurement. The selected farmers were interviewed about regeneration capacity of *E. globulus* tree after coppicing, level of coppicing, and season of coppicing. Finally, each farmer's *E. globulus* plot was visited and indicators of plant growth parameters such as, diameter at breast height (DBH), height, number of shoots per stump, stump height and diameter were measured. All stems in the 10 by 10 m plots were measured for height and diameter. Diameter for tree was measured with caliper and height was measured with labeled sticks and height more than the sticks height was estimated by observing the remaining tree height above the stick. Stems greater than 2 centimeters diameter were included in the measurement.

## Volume estimation

Volume of trees was calculated per measured plot and then changed to hectare basis. The following formula was used to calculate the volume of trees.

$$V = \pi * (DBH/200)^2 * H * ff \text{ (Mengist, 2011)}$$

V = is volume (m<sup>3</sup>)

H = tree height

ff = form factor (0.4)

## Data Analysis

Descriptive statistical analysis was done for means, standard deviation and standard errors. To estimate the differences between groups means i.e., between different coppices levels one way analysis of variance (ANOVA) ( $p \leq 0.05$ ) was employed. Multiple comparison among means were evaluated using Tukey's HSD test ( $p \leq 0.05$ ). Pearson correlation coefficients were used to analyze relationships between variables. All statistical analyses were performed with the statistical software R version 3.4.3 (R Development Core Team, 2017).

## RESULTS

### Diameter at breast height (DBH) and tree height

Diameter at breast height (DBH) was significantly different between coppice levels ( $p < 0.05$ ) (Table 1). The overall mean DBH was 5.7 centimeters and the minimum DBH was 4.0 centimeters and the max DBH was 8.8 centimeters. Tree height also significantly different among different coppice levels ( $p < 0.01$ ) (Table 2). The mean tree height was 7.7 meters and the minimum 5.9 meters and the maximum height was 10.2 meters.

Table 1: Summary of mean and standard deviation of diameter at breast height (DBH), minimum and maximum diameter of trees in centimeter and mean separation done using Tukey HSD test ( $p < 0.05$ ).

Coppice level	N	Mean± SD	Min	Max
0	16	6.1±1.1 <sup>a</sup>	4.5	8.8
1	16	5.2±0.6 <sup>b</sup>	4.0	6.3
2	14	5.7±0.8 <sup>ab</sup>	4.2	7.7
3	4	5.3±0.7 <sup>ab</sup>	4.3	6.2
Significance		*		

\*= $p < 0.05$ , SD=Standard deviation, Min = minimum, Max = maximum.

### Volume and mean annual increment (MAI)

One way analysis of variances shows that there was no yield difference between different coppice levels ( $p > 0.05$ ) (Fig. 1a). The overall mean volume per hectare was 125.1m<sup>3</sup>/ha. The minimum yield observed was 42.02 m<sup>3</sup>/ha. The maximum yield was recorded 270.53 m<sup>3</sup>/ha. Mean annual increment (MAI) was not also significantly different among coppice levels ( $p > 0.05$ ) (Fig. 1b). The overall mean of MAI was 26.6 m<sup>3</sup>/ha/yr. The minimum was 8.4 m<sup>3</sup>/ha/year and the maximum was 50.1m<sup>3</sup>/ha/year.

Table 2: Summary of mean and standard deviation of tree height, minimum and maximum height in meter. Mean separation done using Tukey HSD test ( $p < 0.05$ ).

Coppice level	N	Mean± SD	Min	Max
0	16	8.3±0.9 <sup>a</sup>	6.7	10.2
1	16	7.5±0.7 <sup>b</sup>	5.9	8.8
2	14	7.4±0.6 <sup>b</sup>	6.3	8.3
3	4	7.2±0.2 <sup>b</sup>	4.7	7.5

Significance

\*\*

\*\*=  $p < 0.01$ , SD = Standard deviation; Min = minimum, Max=maximum

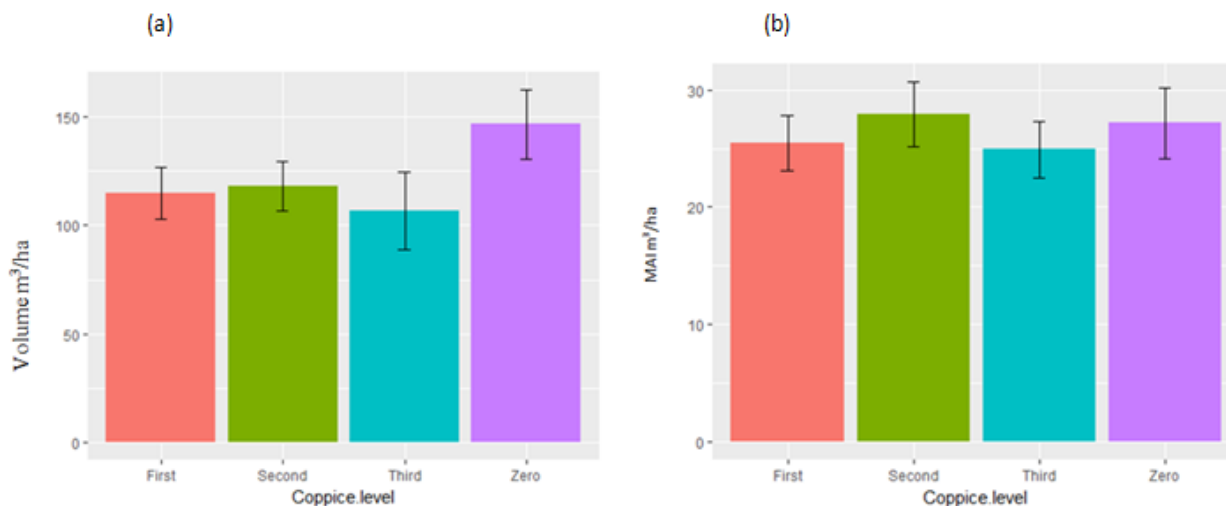


Fig. 1. Yield of *Eucalyptus globulus*: The graphs show the mean yield of *Eucalyptus globulus* per hectare in  $m^3$  at different coppice levels. (a) Mean annual increment (MAI) of *Eucalyptus globulus* per hectare (b). Error bars are standard errors of the mean.

**Coppice performance**

Number of shoots per stump was significantly different ( $p < 0.05$ ). The mean numbers of resprouted shoots were 1.8 at first, 2.3 at second, and 2.1 at third coppice levels (Fig.2). The overall mean shoot number was 2.1 shoots per stump and the minimum shoot number was 1.3 per stump. The maximum number of shoots recorded in this study was 3.5 per stump of *E.globulus* tree.

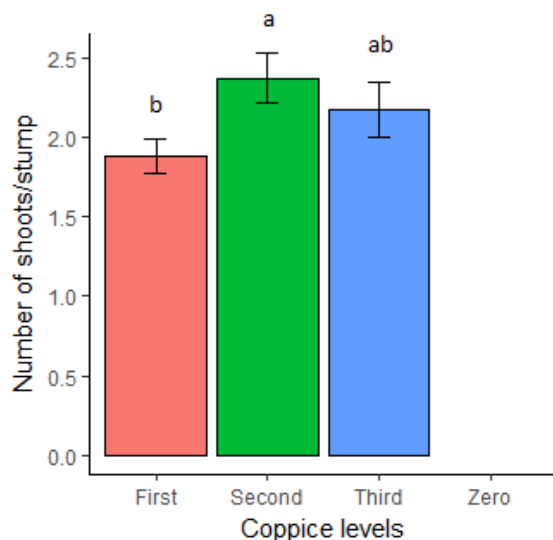


Fig. 2. Mean number of shoots per stump. Groups according to probability of means differences and alpha level ( $p < 0.05$ ) using HSD Test. Error bar indicates the standard error of the mean. Graphs sharing the same letters are not significantly different at the 0.05 significance level.

### Stump height and diameter

There was significant differences between stump height among different coppice levels ( $p < 0.01$ ) (Fig. 3a). The minimum stump height was 8.0 centimeters and the maximum was 40.9 centimeters. Overall mean stump height was 18.4 centimeters. Stump diameter also significantly different at different coppice levels ( $p < 0.01$ ) (Fig. 3 b). The minimum stump diameter was 14.3 centimeters and the maximum stump diameter was 47.6 centimeters. Overall stump diameter was 24.7 centimeters.

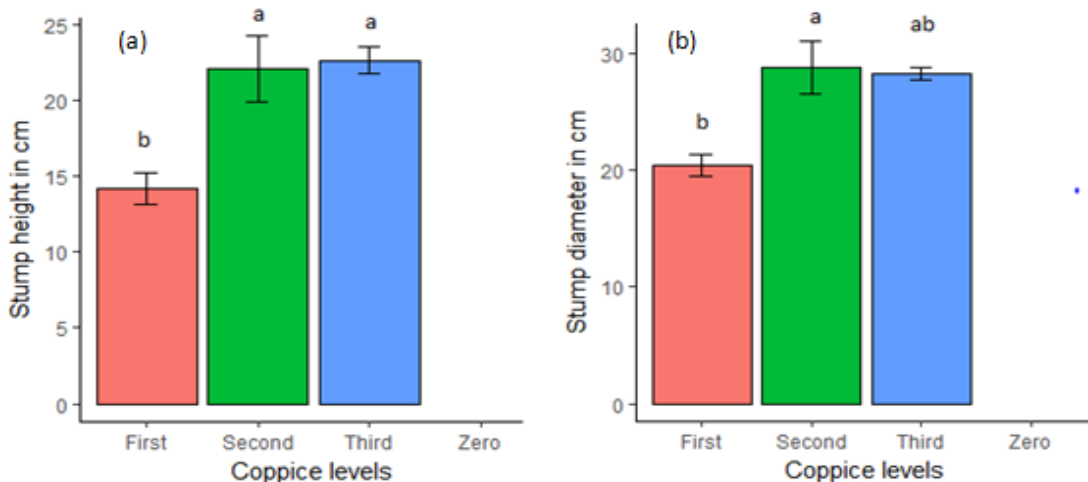


Fig. 3. Stump height (a) and diameter (b) of *Eucalyptus globulus* in centimeters at different coppice levels. Different letters indicate significant differences ( $P < 0.05$ ). Error bar indicates the standard error of the mean.

### Stem number and harvesting age

Stem number per hectare was not significantly different ( $p > 0.05$ ) among all coppice levels. The overall mean stem number per hectare or tree density was 10812 stems/ha. The minimum stem number per hectare was 4900 and the maximum was 17800 stems/ha for all coppice levels.

Harvesting age was significantly different among coppice levels ( $p < 0.01$ ). Zero coppice was taken a little longer for harvesting than the coppice regeneration. Zero coppice was reached for harvest at 5.7 years and first coppice 4.5 years, second and third coppice was taken 4.2 years. Altogether the minimum harvesting age was 3 years and maximum harvesting age was 10 years for *Eucalyptus globulus* tree in the studied areas.

### Correlations

Pearson's product moment correlation was done to estimate the relationship between different variables in the coppice levels. Number of shoots per stump had strong positive correlation with stump diameter and height ( $p < 0.001$ ,  $r = 0.77$ ) and ( $p < 0.001$ ,  $r = 0.72$ ) respectively (Fig. 4 a and b). Number of shoots increases when height and diameter of *Eucalyptus* stump increases. However, correlation between other variables were not strong ( $r < 0.50$ ).

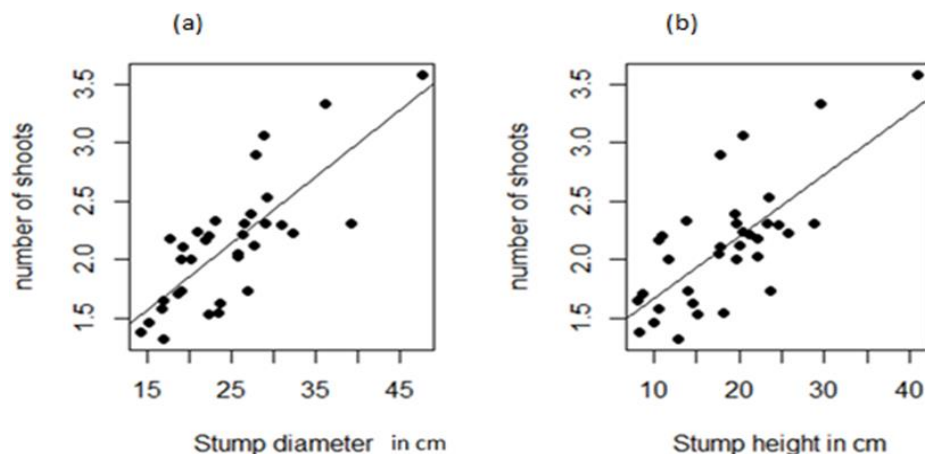


Fig. 4. Shows number of shoots per stump positively correlated with tree stump diameter (a) and height (b)

## Famers' opinion

Farmers which had *Eucalyptus globulus* were interviewed about coppicing seasons, yield difference among different coppice levels and coppicing performance of *Eucalyptus globulus*. Most farmers agreed they coppice *Eucalyptus globulus* from November to December and from end of April to end of May. Most of (88.89) per percent of farmers responded that the first coppice has better yield compared to other coppice levels for *Eucalyptus globulus* although this is not agreed with our statistics result. Among interviewed respondents 11.11 percent of farmers responded zero coppice has better yield advantage. All respondents (100) percent of interviewed farmers agreed that *Eucalyptus globulus* has no problem of regeneration after coppicing. They all agreed *Eucalyptus globulus* coppice well than other tree species in their areas.

## DISCUSSION

This study revealed that there was no significant standing volume or yield difference between different coppice levels of *E. globulus* trees in the highland areas of North Shewa. The overall mean standing volume for all coppice level was 125.1 m<sup>3</sup>/ha. This was lower than the study done at Wondo Genet College at plot levels which was found 165 m<sup>3</sup>/ha at the age of 5 years for non-coppiced origin (Pohjonen and Pukkala, 1991). Our result also not in agreement with Zewdie, (2008 ) he reported that there was a decrease in yield after first coppice in *E.globulus*. In his study, stand biomass production of *E.globulus* was reduced by 14% from the second and third cutting cycles to the sixth and seventh cycles. Yields from coppiced plants are mainly limited by environmental conditions including soil nutrient and moisture factors (Kirby and Watkins, 2015).

Mean annual increment (MAI) was not significant in our study among different coppice levels. The mean MAI was 29.2 m<sup>3</sup>ha<sup>-1</sup> year<sup>-1</sup> and this is between the study done by Pohjonen and Pukkala (1990). They reported that MAI of *E.globulus* in fuelwood plantations varied between 10 and 30 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup>. However, the variation in our study was from 8.4 m<sup>3</sup> m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup> to 50.1 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup>. A model based study done on *E.globulus* in Bolivia by Guzmán *et al.* (2012) also found that the mean annual growth with optimal rotation length is about 13 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup> on medium quality sites and 18 m<sup>3</sup> ha<sup>-1</sup> year<sup>-1</sup> one productive sites. However, our results was higher than the Bolivian study although the study did not based on site productivity classification.

Number of coppice shoots per stump varied among coppice levels. The number of shoots were higher in second and third coppice in this study. The mean number of shoot was 2.1 per stump. This number was recommended for *E.globulus* coppice management for Chilean sites (Geldres *et al.*, 2004). According this report stump thinning in 18 months after harvest to three sprouts per stump could enough for pulp and fuel wood purposes. For sawn wood purpose thinning should be done to one or two sprouts per stump.

Although stump height is not a biological factor, stump height is important factor for better coppice regeneration. The average stump height was 18.5 cm in this study. Higher stumps have large number of epicormic buds and lignotubers and this help to improve the sprouting ability (Stape *et al.*, 1993). The result of our stump height was higher than 12 cm which commonly cut in *Eucalyptus* mentioned by Matthews (1991). In addition our result was between 10 to 20 cm recommended by Turnbull and Pryor (1978). *Eucalytus* do not coppice better from low cut stumps from lignotuber. On the other hand coppice stems from high stump height can be simply break off by wind and other forces due to that the sprouts are on the bark side of the cambium poorly attached. Stump height was higher in the second and third coppice as the same time number of shoots was also higher in second and third coppice. In our study there was positive correlation between number of shoots and stump height. The same results described by Shackleton (2000) that number of shoots per stump often related to cutting height. Stump diameter was also varied in our study. The mean stump diameter was 24.7 cm. Second and third coppice had high stump diameter and as age increases its clear that diameter increases. Number of shoots increases in our study as diameter increases up to 30 centimeter of stump diameter. This is in agreement with Songyuan (2001) which found that sprouting number per stump increases with stump diameter in *Eucalyptus urophylla*. The same study also found that diameter and height of sprouts increased with the increases in stump diameter.

The overall mean stem number per hectare was 10812 in this study. No significant difference observed in stem number or tree density per hectare among different coppice levels. Tree density in our study was much higher than Zewdie (2008) which he found 4548 stems ha<sup>-1</sup> on average in different *Eucalyptus globulus* plantation sites in the central highlands of Ethiopia. Our result also much higher than Mengist (2011) 2631 trees per hectare when data pooled and averaged from three blocks in the highlands of Ethiopia. According to Albaugh *et al.* (2017) study in Chile, low stocking density *Eucalyptus globulus* could give similar amount of biomass yield as high stocking. In similar study there was no biomass yield difference between 5000 or 15000 stems of *E.globulus* per hectare. The author advised to plant the lower initial stocking (5000 trees per hectare) to minimize cost. In a site density yield model development study by Rinehart



and Standiford (1983) on *Eucalyptus globulus* tree showed that, planting densities of 435 trees, 680 and 1210 trees per 0.4 hectare areas was recommended for fire or construction wood from low to high productivity sites.

The purpose of *Eucalyptus globulus* tree in studied area was mainly for house construction component especially for roof construction. At 5.7 cm DBH the stem was cut down as clear cut for all coppice levels. 4.8 years was a harvesting age for zero coppice shoot in the highlands of North Shewa where this study was done. Age of harvest varies depends on site fertility and condition. Harvesting age was significantly different among coppice levels in our study. Zero coppice takes a little longer for harvest than the coppice regeneration in our study and this is supported by Steinbeck (1981) sprouting shoots of *Eucalyptus globulus* grow fast after cut because the root systems established well to take nutrients and water. In addition they store enough carbohydrates which can facilitate fast regrowth.

## CONCLUSION AND RECOMMENDATIONS

Volume, mean annual increment, stump height and diameter, number of shoots and age at first harvest of *Eucalyptus globulus* were described in this study. There was no statistically significant yield difference among different coppice levels up to a third level. However, numbers of shoots per stump were higher in the second and third coppice levels and this increases tree numbers per hectare more than recommended spacing. In addition the study revealed number of *Eucalyptus* stems per hectare farmers maintained and it is higher than other studies. Therefore, this affect the stem quality if the aim is to get larger poles and needs some early silvicultural activities like thinning, early coppice management, stand density control and pruning to increase wood quality and promote growth. Further studies should be done on tree densities to identify appropriate spacing for *Eucalyptus globulus* in North Shewa. This helps to recommend which *Eucalyptus* tree densities per given area are suitable for yield and fast growth in North Shewan highland conditions.

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## AUTHOR CONTRIBUTIONS

L.H. was involved in the field survey, data analysis and writing. G.T. reviewed the paper, data collection and proposal development. M.B. data collection and computerization and participated in proposal development. R.E. and H.F. were involved during data collection and survey in the field. D.A. involved in data collection.

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