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Research paper

The effect of spacing and high planting density on yield of *Eucalyptus globulus*

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Production and marketing of Eucalyptus wood products play a significant poverty alleviation role; as a source of regular income and construction materials in turn improving the livelihoods of the rural community in Ethiopia. The study was conducted in Sidama region (Gorche district), South Central Ethiopia. The aim of study was to see the effect of spacing regimes (selected from the most common spacing practices in community) on yield of *Eucalyptus globulus* woodlots. Twenty five sample household's woodlot from each spacing regime with a total of 100 woodlot plantations were sampled from two kebeles. Measurements of all DBH and height of standing *E. globulus* woodlot tree were made. Yield was significantly affected by the initial spacing regimes. With decreasing spacing, mean volume per tree was decreasing while volume per hectare was increasing. Within 1m x 0.75m, 0.75m x 0.5m, 0.5 x 0.5m and 0.5m x 0.25m spacing regimes, 0.031, 0.024, 0.0185 and 0.0116 m^3/tree and 407.75, 637.82, 737.35 and 930.07m^3/ ha mean volume of woodlot respectively were recorded. A one-way ANOVA revealed that there were a significant difference within; Volume, DBH and height of all spacing regimes. Local construction material /Seregela, Kuami, Weraji, Korkoro mager were the most common assortment poles depending on diameter and height. The study further revealed that highest number of biggest sized diameter construction pole were found from lower density planting, (1m x 0.75m) and the highest number of construction pole assortment were found from closer spacing (0.5m x 0.25m). In conclusion, spacing regimes had seriously affected yield of *E. globulus* woodlots. Finally, woodlot growers' preference for different spacing regimes primarily depends on obtaining better final yield. And 1m x 0.7m and 0.75m x 0.5m spacing was found better in terms of providing proportional pole sizes of each assortment types.

Key words: *assortment, E. globulus, ethiopia, income, soil nutrient, Spacing regime, woodlots*

INTRODUCTION

As one the most widely cultivated exotic tree species, Eucalyptus (Rassaeifaret et al., 2013), Ethiopia has adopted and grown more than 55 of the 500 of globally cultivated Eucalyptus tree species Friis (1995). The reason behind the increased plantation of the species might be associated with the rising human population increase in the country leading to increased demand for construction material and fuel energy to be satisfied by the fastest growing behavior of the species and merely its wider adoption to the different agro-ecological (climate and soil) zone the region/country. due to this mentioned and others unforeseen reasons farm level woodlot plantation has become the most common practice in most part of Ethiopian rural livelihoods to meet both the cash need and household wood demand. The profit derived from Eucalyptus is considerably higher than cultivating crops because they are a source of various uses for rural and urban people such as firewood, construction material, medicinal value, and source of income by selling tree biomass such as stem for construction and twigs, leaves and bark for fire wood purpose (Abebe et al., 2014). Because the fast growth nature of most exotic tree species especially Eucalyptus as compared to the indigenous trees in responding with a quick economic returns to smallholding farmers has led to the conversion of their small cropland to woodlot plantation in addition to expansion of planting on their marginal land. The choice farmers density management is critical factor affecting the future productivity of plantations including the site productivity (soil type, slope), rotation length, management system, costs and the use and final value of timber Nyland (2002). Numerous farmers cash and feed demand were satisfied from planting *Eucalyptus in* various spatial patterns in the sub-catchment and homegarden woodlot like fuel wood, building construction, timber, electricity poles, water conservation, charcoal production and erosion control, and also as a cushion for farmers when their agricultural produce fail or are low. As long in many studies trees spaced under high competition, mean yield from the tree was recorded lower. Similarly, woodlot growers in the study area suffers for shortage of land and smallholding farmers fail to incur better volume of logs as well as income from these woodlots plantations. In adequate fuel wood and tree log supply from *Eucalyptus* dense stocking has led some amount of dissatisfaction either in home or market. Insufficient proportion of this construction pole has also raised the cost in the district as well as the country as a whole. Eucalyptus is planted at high density (≤ 250,000 trees/hectare) for repeated density management and thinning operation in the study area. On the other hand, even if farmers plant *Eucalyptus* trees with different planting densities in the study area, the ultimate number of trees to be harvested at certain defined time and volume is not known. And woodlots planted in the district are not objectively matched to reach appropriate size and those plantation are inconvenient to produce poles of a desired size assortments. Furthermore, limited information is available in this regard and limited biophysical research to fill this gap and improve *E. globulus* productivity. Thus, knowledge of this nature would help to align spacing with desired plantation objectives. Hence, this study is designed to fill the knowledge gap and contribute to the productive management of plantations; especially with respect to the final crop productivity objectives of smallholding farmers.

MATERIALS AND METHODS

The study was carried out in two selected kebeles/peasant associations of Gorche district namely (Gorche 01 and 02 kebele) having similar geographic location (Figure 1). The district is one of the highland areas in Sidama region. The region (Sidama) has capital city of Hawassa located about 272 km south of Addis Ababa. The woreda is 44km from Hawassa city and 319km from Addis Ababa, which is situated between 6.41º–6.61'N latitude and 38.44º– 38.98' E longitude (BOFED, 2010).

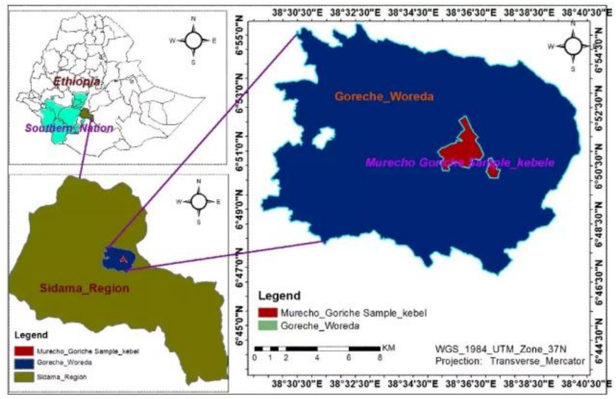

Figure 1. Map of the study area

The study area lies within woyna dega (25%) and dega (75%) agro-ecological zone and the area receives bi- modal rainfall with mean annual rainfall is 1200mm and ranges from 900 mm- 1500 mm. the rain exceeds 5monthswith uneven distribution. The mean annual temperature of the woreda is 19.5 ^{0} c and ranges between 12 – 27 ^{0} c degree (Hawassa metrological station). Concerning the types of the soil, the predominant types of soils are; Nitosols, Andisols and Vertisol. The fertility status of the soil ranges from good to fairly good with acidic and slightly acidic property. The district is somewhat dominated with perennial vegetation. The most dominant tree species in the study area includes; *Eucalyptus* species*, Hagenia abyssinica, Cordial African, Junipers, Erythrina brucii, Cuppressus, bamboo,* and many other indigenous species were the most dominant tree species planted in the district.

The study used *E. globulus* woodlot plantations established on farmer's field from June to August, 2014 (before five years). After assessment of the potential *E. globulus* producing areas in the district; two adjacent kebeles' from Gorche (Gorche 01 and 02 kebele) were selected (Figure 1). As the basic concern of the study were evaluating effect of spacing on yield, most spacing regimes with equal age were assessed to select representative samples with RCBD design systematically. Because of that the plantation were an agroforestry with farmers spacing experience; complete homogeneity were not expected rather reducing biasness to minimum level as much as possible is mandatory. The most important factors to be considered for sample selection as to made selection nearly similar and reduce biasness were;

- Slope of the area
- Age of plantation should be equal to or approximately five years/ 51-61 months only
- Disturbance (sampled on those which were directly planted and do not include any coppice or mixed plantations).
- Similarity of the management system was also considered

After all; four most frequent (Table 1) and commonly used spacing regimes in the district (1m x 0.75m, 0.75m x 0.5m, 0.5m x 0.5m and 0.5m x 0.25m) were selected and 25 farmers' woodlot from each selected spacing regimes (as a replication) and a total of 100 sample woodlots were taken randomly whose age were between 59 to 61 months old from two kebeles. The Table (1) showed *E. globulus* woodlot trees plantation densities used for the study and their corresponding spacing.

The age of woodlot (5 year) in the study were selected purposefully because it was important time to differentiate the potential growth performance of trees in early growing time (before the first thinning and harvest). The growth parameters of each tree DBH and height were recorded on farmer's woodlots for total volume and mean volume estimations. During inventory some selected woodlots for sampling prior to data collection were harvested (selective and total clear) by farmers: because of the aim was to quantify the effect of tree spacing, only trees in fully stock were considered and missed woodlots were replaced by the same others.

Then all stems from the woodlot trees were measured for DBH (at 1.3m from the ground) with caliper and height measurement were also taken using Hypsometer. From each spacing regimes a total of 1109 trees and total sample population of (4 spacing regimes × 25 plots of each replicated farmers woodlots = 4 x 1109 sample trees = 4436 trees) were taken for volume estimation excluding trees on borders to avoid the edge effect. Diameter assessment were formed the basis for determining the stand growth and yield. The collected data interms of DBH and height from the woodlot stands were entered in to excel sheet used by the software that are to be used for analysis and to calibrate stand basal area which were calculated as the sum per hectare of cross-sectional areas of all trees estimated at DBH. This used to calculate volume of standing *E. globulus* woodlot plantation in terms of individual and stand basis. SPSS software version 20 was also employed to see descriptive statistical values.

The formula used for calculating yield/ productivity were as follows;

$V = BHF$

$B = \frac{1}{4} \times \pi \times (DBH)^2$

$V\ stand = mean\ V\ tree^{-1} \times N\ ha^{-1}$

Where V- volume of standing tree, DBH - diameter at breast height, H - height of a standing tree, B - basal area of a tree, F - form factor (0.4, Pucaba, F of Eucalyptus for tropics), N - total number of trees in hectare

Multiple linear regression analysis from the STATA software were employed to determine the significance of different variables affecting productivity. Linear relationship between the height and diameter of different spacing factors on yield and soil characteristics of *Eucalyptus globulus* tree growth were also tested.

The linear model were used to elaborate the linear relationship between tree productivity and factor of productions. Analysis of variance (ANOVA) was also employed to exploit the significant difference within factors of productivities/ height, DBH and volume variations within different spacing regimes of *E. globulus* woodlot plantation.

Table 1. Density of *E. globulus* woodlot in each spacing regimes

Density (Tree/ha)	Spacing (m)
13,334	1m x 0.75m
26,667	0.75m x 0.5m
40,000	0.5m x 0.5m

Finally, the yield values and observations were analyzed and organized by using descriptive statistical method in summaries.

RESULTS AND DISCUSSION

E. globulus woodlot and yield

(i). Spacing Vs Volume growth of E. globulus woodlot plantation

The finding (Table 2) revealed that the volume of standing *E. globulus* has a positive and direct correlation (r = + 0.889 and r = + 0.399) with diameter and total tree height, on the contrary, it correlated negatively and inverse with density (r = - 0.31), this was an indication for wider spacing in Eucalyptus globulus has direct and higher effect in increasing dimeter and height growth of E. globulus woodlot stand. The volume of *E. globulus* woodlots were significantly affected by height and DBH. (Adj R-squared = 0.866), tells a strong correlation between the independent variable (spacing, DBH and height) and the dependent variable (volume). Volume were significantly different within all spacings (one- way ANOVA) and most found to be the result of diameter and height, in which spacing regimes were determinant factors. Moreover, these parameters were significantly affecting volume of woodlot plantation. The statistical comparison (Table 2*)* showed that total volume of *E. globulus* woodlot tree was significantly influenced by different spacing regimes; increased with wider spacing. At, 1×0.75m, 0.75×0.5m, 0.5×0.5m and 0.5×0.25m spacing regimes, average volume of (00.031, 0.024, 0.0185 and 0.0116 m^3 $tree^{-1}$), respectively was recorded (Table 2). Mean volume $tree^{-1}$ (directly correlated with spacing) was decreasing as stocking were increasing but total volume of woodlots increased as planting density were increased in reverse trend as stated earlier. 407.75, 637.82, 737.35 and 930.07 m^3 ha^{-1}, in 1m x 0.75m, 0.75m x 0.5m, 0.5m x 0.5m and 0.5m x 0.25m spacing were recorded respectively. One-way analysis of variance (at 0.05-significant level) for Volume indicated a significant difference within all spacing regimes (Figure 2& Figure 3).

The regression of factor of production in the woodlot signifies linear relation of volume as a function of diameter and height looks as follows (Table 3); The normality test for all factors attached below signifies sample mean has been normally distributed and spacing, volume, DBH and height has mean distribution around the population mean.

Table 2. Summary of descriptive statistics for (Volume, DBH and Height) and regression of factors from STATA

Spacing	DBH (m)				Height (m)				Volume (m^3)				
	mean tree^{-1}	Stdev	max	min	mean tree^{-1}	stdev	max	min	Mean tree^{-1}	stdev	max	Min	Mean ha^{-1}
1mx0.75m	0.071	0.034	0.18	0.01	15.29	5.07	29	2	0.031	0.045	0.08	$9.4x10^{-6}$	407.75
0.75mx0.5m	0.067	0.027	0.18	0.012	13.88	2.68	24	4	0.024	0.049	0.038	$1.1x10^{-5}$	637.82
0.5mx0.5m	0.056	0.027	0.16	0.02	13.4	3.9	26	2	0.0185	0.024	0.05	$2.9x10^{-5}$	737.35
0.5mx0.25m	0.049	0.023	0.17	0.012	12.46	3.7	25	2	0.0116	0.013	0.039	$4.4x10^{-6}$	930.07
CV	26.4				19.92				14.5				

Table 3. Statistical values of regression coefficients for different spacing regimes of the woodlot

Factors	Regression of volume with Coefficient.	df.(model, residual)	Prob.>F	Sig. lev.	No. of obs.	95% C.I.	Adj -R^2	P>|t	Density Coef.
DBH	8.66		0.000			1.5 - 1.02		0.000	-9.6
HT	$6x10^{-2}$	3, 4432	0.000	5%	4436	$2.6x10^3$ $-3x10^{-3}$	0.898	0.000	-0.07
Cons	$-2x10^{-1}$		0.000			-0.11- (-0.1)		0.00	4.06
Cons.	0.05		0.000					0.00	

Table 4. Major assortment information with DBH class in the district of the study area

Local Eucalyptus product	local names	diameter (m)	length (m)
Pole for roof	Weraji	0.052-0.06	8-10
Pole for well stringer	Gidigida mager	0.024-0.0389	5-8
Pole for purlin	Korkoro mager	0.039-0.0519	5-8
Pole for chariot	Seregela/teshegagari	0.1-0.15	8-10
Pole for stand	Kuami	0.067-0.099	6-8

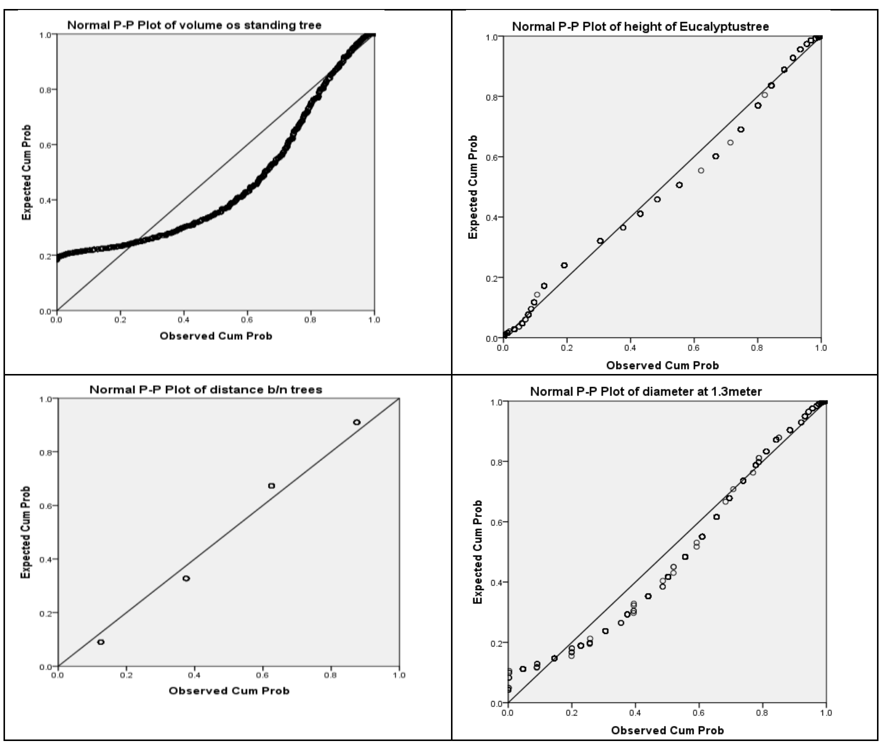

Figure 2. The p-p plot sketch of volume, DBH, height and spacing

The higher production per hectare were in closer spacing (80,000 trees ha^{-1}) and lower in wider spacing (13,334 trees ha^{-1}) (Table 1.). It clearly showed that the number of trees hectare^{-1} plays an important role in total volume production

(Because it is a short rotation crop, otherwise high density decreases volume in the long term as indicated in many research findings). Similar result from Srivastava et al. (1999) investigated the growth of *Terminalia arjuna* under varied plant spacing (10,000, 20,000, 30,000, 40,000 and 50,000 trees ha^{-1}) and found that the mean stand basal area and volume increased with increase in planting density. Studies on other species of Eucalyptus (Chen et al., 2011) in *Eucalyptus urophylla* × *E. grandis* in china revealed that the average individual tree volume increased as initial stocking decreased.

(ii). Diameter Vs volume of E. globulus woodlot

Statistical regression value of volume by DBH from STATA software version 16 signified that (Table 2); volume of *E. globulus* woodlots stand in dense plantation were highly affected by diameter attained at prescribed age (5 year). The volume of the woodlots stand is attributed to 89.8% (Adj R-squared = 0.898) affected by DBH and height. This is evident for competition of trees in the soil and aerial environment (competition for light energy) for the available resources; wider spaced trees can get better resources for their healthy growth and diameter increment, which ascribes for better yield. Volume of the *E. globulus* woodlot plantation as a function of diameter at breast height was seen as (Table 3).

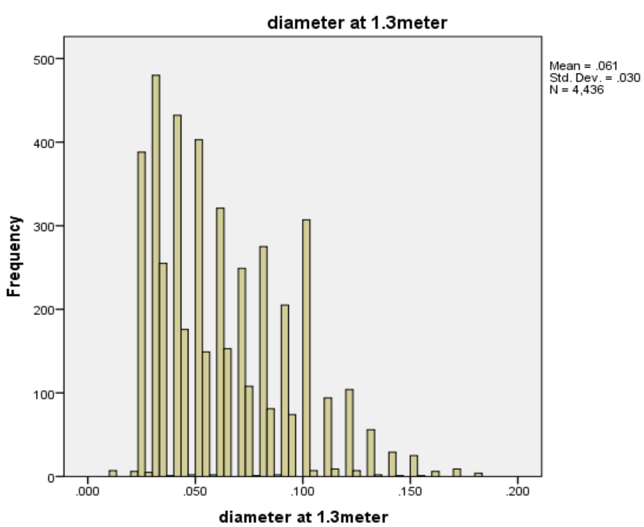

Figure 3. Frequency of DBH of *E. globulus* woodlot in smallholder farmers 5 years after plantation establishment lies between nearly 0.025m to 0.1m

(iii). Initial spacing Vs diameter

Statistical data from sampled from the woodlot plantation also indicated, the inverse correlation of density with diameter and coefficients. (Table 3); The DBH varied significantly within all spacing regimes; increased density were decreasing DBH (Table 2). The maximum and minimum mean DBH (0.071m and 0.049m, were observed in 1m x 0.75m and 0.5m x 0.25m spacings respectively. One-way ANOVA value showed that DBH were significantly different within all spacing regimes of woodlot plantations (Table 2), within increased spacing between trees DBH were seen in increasing trend.

The partial regression of volume (Figure 4) by diameter illustrated the mechanism in which woodlot tree plantation were correlated directly and at early growing period individual growth has been around the mean, but at after some tree diameter was started to deviate as competition was intense and variation of individual tree growth then comes. As a result some values in outlier. DBH were also significantly different between spacing regimes which showed that the diameter varies within planting density and wider spacing regimes were seen better for diameter growth of woodlot stands, which is against the observation of Harris (2007), who reported that planting density had no significant effect on DBH of *Eucalyptus grandis* at early period of rotation and mean diameter decreases as planting density increased in *Eucalyptus grandis*. Similarly, other studies revealed that mean diameter at breast height (Dbh; 1.30 m) has increased with a reduction in stocking, and that this relationship was influenced by age, species and site (Opie et al., 1984). This has been further confirmed by other earlier researchers finding like; Van Laar (1988) for E. grandis stand densities between 600 and 1600, Schönau (1974) for those between 1200 and 1700, and (Meskimen & Franklin, 1978) for those between 800 and 3000 trees ha^{-1}.

(iv). Initial spacing Vs height

Statistical value signifies (Table 2) that, height of *E. globulus* woodlots plantation were affected by spacing; decreased spacing between trees were decreasing total height of woodlot stand. The tree height varied significantly different in all spacing regimes. The mean height after 5 years woodlot plantation were recorded as; 15.97m ± 5.07, 13.9m ± 2.6, 13.4m ± 3.9 and 12.47m ± 3.7 in 1m x 0.75m, 0.75m x 0.5m, 0.5m x 0.5m, and 0.5m x 0.25m spacing regimes respectively.
The height of woodlot trees were averaged mostly in between

Table 5. The amount (number) of construction pole assorted in each diameter class in the woodlot

Local assortment category	DBH class(m)	1mx0.75m	0.75mx0.5m	0.5mx0.5m	0.5mx0.25m
Teshagari	0.10-0.15	3007	3754	3352	3256
Kuami	0.067-0.099	2940	6424	8724	10612
Weraji	0.052-0.066	1693	4035	4720	10156
Korkoro Mager	0.039-0.0519	2246	5120	8203	21550
Gidigida Mager	0.024-0.0389	2148	4732	11101	26628
Total		12034	24065	36100	72202

Table 6. The (100%) distribution of material production from woodlots plantation (DBH base)

Local assortment	DBH class	1x0.75 (%)	0.75x0.5 (%)	0.5x0.5 (%)	0.5x0.25 (%)
Teshagari	0.10-0.15	25	15.6	9.8	4.5
Kuami	0.067-0.099	24	26.7	24.2	14.5
Weraji	0.052-0.066	14	16.8	14	14
Korkoro Mager	0.039-0.052	19	21.3	22	30
Gidigida Mager	0.024-0.039	18	19.6	30	37

10m and 18m and the maximum number of trees height recorded were highest in between 13m and 18m (Figure 5). From the finding, it was apparently evident that total height of woodlot tree as a function of spacing and volume were seen in a direct correlation (Table 3).

The direct correlation of height with individual tree yield in terms of diameter as well as spacing was evident in the study even if some outlier values in graph were an indicator of some most highest trees available in the woodlot whose values are significantly higher than the mean height recorded in the early canopy closure as competition were intense. But their effect was not pronounced as that of the diameter does (Figure 6).

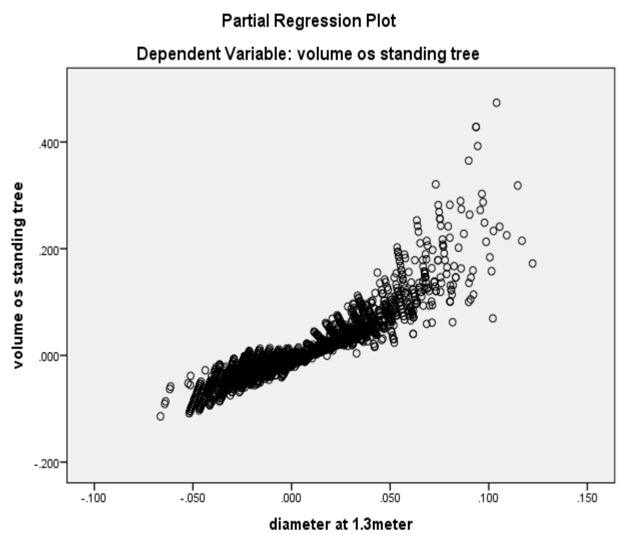

Figure 4. The DBH of woodlot plantation certainty Vs volume increment illustrating a linear relationship between diameter and volume

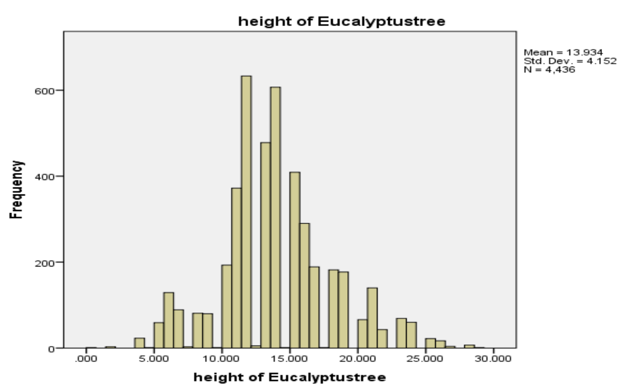

Figure 5. Frequency of sample woodlot trees taken for height growth estimation which were averaged between 10m and 18m

The maximum mean height (15.97m ± 5.07) was observed in 1m x 0.75m and minimum height (12.47m ± 3.7) in 0.5m x 0.25m spacing (*Table 2.*). This can be explained by; increasing in height with decreasing in spacing regimes. I.e. change in density is simply a result of exploiting same available belowground resources (water and nutrient) by less number of trees. The correlation analysis (from STATA version 16.) also indicated height as positive and direct (r = + 0.141 and r = + 0.399) correlation with DBH and volume but negative (r = - 0.292) with density). One-way ANOVA Comparison of height resulted in significant difference between all spacing regimes; illustrating the growth and competition for early canopy closure in the available space by densities. Wider planting favored height growth than narrow planting; providing better allocation of nutrients and sunlight for their vertical growth.

This finding were similar with other studies like; (Opie et al., 1984) who reported a generalization of a reduction in spacing for *Eucalyptus,* i.e. an increase in initial stand density, usually reduced mean height but not necessarily mean dominant or top height. Other authors showed reduced top of height as stand density exceeded 5000 trees ha $^{-1}$ in 11 years old *E. regnans*, but unchanging top height of E. pilularis with stockings between 121 and 1249 trees ha $^{-1}$ in a CCT experiment . For similar study in the already mentioned CCT experiment the top height of 22.5 years E. grandis increased with decreasing from 1800 to 124 trees ha^{-1} actual stand density (Bredenkamp, 1977; Van Laar & Bredenkamp, 1979). But, this study contradicts with few studies (Gilbert et al., 1995; Knowe & Stein, 1995; Ritchie et al., 2007) which dictates; height increases with increase in planting density.

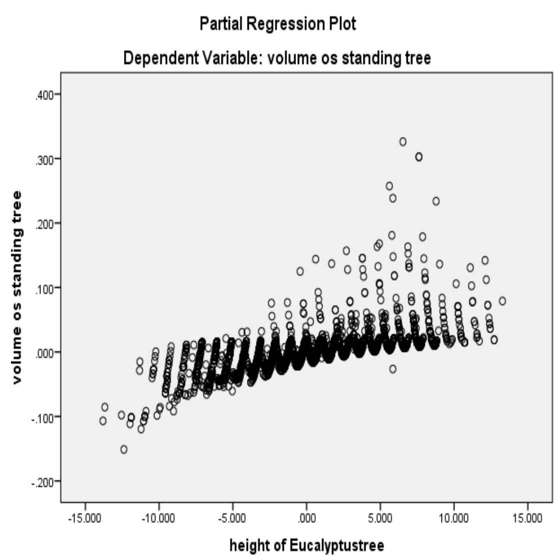

Figure 6. The partial regression plot of height growth with volume growth at 5 years/ yield.

Spacing of E. globulus woodlot plantation and construction pole

(i). Local construction pole and assortments

Farmers' plant *E. globulus* woodlots tree in different spacing regimes with different ultimate objectives. Most of the woodlots plantations in the district are established for immediate cash returns so that farmers prefer to establish over stocked in their small plot of farmland. The density of *E. globulus* trees used in these highland areas are nearly similar/common in management including the spacing regime. And after some time the stand reaches time of initial harvesting; farmers use thinning operation of their plantation in certain years until the stand is remained with few large trees scattered in their plot. A 59-61 months age (sake of this study) *E. globulus* woodlot plantation established by smallholder farmers can intern produce significantly different assortment types (Table 4).

This assortments were mainly dependent on size of pole (DBH and height) (Table 6). This assortment excludes small tree sized fuel wood bundles extracted from branch and leaves wood products of *Eucalyptus* growers during the research age. As this is only to notify how much volume of construction round wood log can be harvested at specified spacing regimes defined in the objectives of the study (Figure 7).

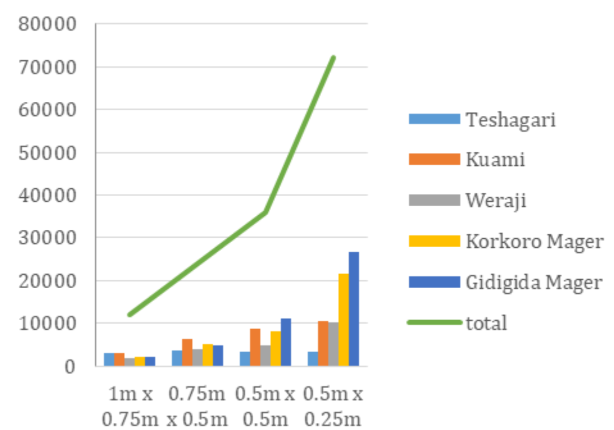

Figure 7. Total number of construction pole/ ha harvested from local assortments in each spacings.

(ii). E. globulus spacing and production of construction poles in the district

Large diameter round local assortment types like teshegagari and Kuami can be more accumulated in sparse spacing regimes while small sized round wood assortment like Weraji and Mager can be mass harvested in very narrow spacing regimes. The total number of *E. globulus* logs at certain age and place may vary in number and size to reach the desired assortment class (Table 5). Based on the sampled trees data from woodlot farm plantations, total number of logs that can be gained in hectare of land in each spacing regimes and local *E. globulus* market assortment, a (10%) loss or salvage were assumed in total yield analysis (Table 5). The proportion of these assortments (*Table 5.)* can be seen decreasing in round wood log sizes as spacing regimes were decreasing. The largest number of large sized round wood log (Seregela and Kuami) were found in 1m x 0.75m and 0.75m x 0.5m and the smallest sized round wood log assortment (Weraji , Korkoro Mager and Gidigida Mager;) in 0.5m x 0.5m and 0.5m x 0.25m spacing regimes respectively. This trend of size allocation may be due to the resource competition induced growth that pretends to a narrowly planted trees tend to suffer a resource limitation and distance planting allows better radial and vertical growth of trees in space.

(iii). Spacing in E. globulus and construction pole production

From (Table 5) 1m x 0.75m, 0.75m x 0.5m, 0.5m x 0.5m and 0.5m x0.25m spacing regimes; a total number of round pole: Seregela (Teshegagari); 3165, 3952, 3529 and 3427, Kuami; 3095, 6762,9183 and 11170 , Weraji; 1782, 4248, 4968 and 10690; Korkoro Mager; 2364, 5390, 8635 and 22684 and Gidigida mager; 2261, 4982, 11685 and 28029 can harvested respectively. The local round wood assortment in spacing regimes showed consistent difference in size class distribution. The research distinguished the clear spacing effect on diameter of *E. globulus* logs and round wood assortments locally used by smallholder farm families. Total percentage (%) share of larger diameter size class distribution (Table 6) were decreasing as initial planting densities was increasing. But the percentages of small sized construction pole harvested from production of high density of plantation in assortments were increasing in number. Even if small sized logs (Korkoro and Gidigida Mager) are less harvested in wider spacings compared to large sized round wood logs (teshegagari and Kuami), more yield were compensated from large number of round logs supplied/harvested in closer spacings. There were a positive and linear relationship between spacing regime and average diameter increment, which decreased as initial spacing were decreasing, but total volume yield from the woodlot plantation were increased as spacing regimes decreased. Farmers in their small farm preferred dense stocking were due to the fact that they could produce/supply more number of trees. The study was similar to the report of (Zerga et al. (2016)); (Dessie et al., 2019).

CONCLUSION

In general, the maximum tree height, DBH and volume tree^{-1} were recorded maximum in wider spacing and minimum in closer spacing. However, total volume production ha^{-1} was observed higher in closer spacing, due to more number of trees present in closer spacing as compared to wider spacing. The statistical comparison from STATA version 16, Showed that the total volume of *E. globulus* woodlot plantation were significantly influenced by spacing regimes. Moreover, it has increased with wider spacing. However, total volume increased as planting density was increasing in reverse trend. The correlation of planting density were also seen negative and reverse (r = -0.31, r = -0.296 and r = -0.292) with mean volume, DBH and total height respectively. The analysis of the data revealed that DBH varied significantly with spacing regimes and were increased as spacing were increasing. A 59-61 months age *E. globulus* woodlot plantation established by smallholder farmers were producing significantly different sized round wood assortment. The proportion of these assortments in size classes were seen decreasing as spacing regimes were decreasing. This trend of size allocation may be due to the resource competition induced growth. Total productions were increased as the more trees were planted per plot area in smallholding families' woodlot farm. Even if the research were concerned only on narrow spacing regimes commonly used in the district of the study rea; farmers under their small plot of land could choose producing Eucalyptus globules poles for immediate cash sale in the early growing size class and large number of poles for local market should be under closer (0.25m x 0.50m) spacing regime, but, where all pole size class in the assortment could be available at medium spacings. On the other hand farmers to supply large poles for the local or regional pole market should choose wider (1m x 0.75 m) spacings. But, the finding clarified that land size were farmers' bottle neck in their choice of spacing distance between E. globules seedlings. Finally it could be better to look at effect of E. globules spacing regime on growth perspectives (information of different time interval) to provide a more concrete prediction of production and productivity.

AUTHOR CONTRIBUTIONS

Abebe Chane – Involved in this original research work from designing to data generation and writeup and reproduced the overall manuscript. Tefera Belay - Involved in this original research work from proposing the field design to analysis of statistical result and write up and supervisory works. Yemiru Tesfaye - Involved in this original research work from proposing the field design to analysis of statistical result and write up and supervisory works.

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COMPETING INTERESTS

The authors have no conflict of interests.

ETHICS APPROVAL

Not applicable

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