Print : ISSN 0970 – 7662
Online : ISSN 2455 – 7129

Journal of Tree Sciences

online available at www.ists.in

Volume 39 No. 1 June, 2020

Performance of *Grevillea robusta* A. Cunn.Ex R.Br. Under Different Farming and Spacing Regimes

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DOI: 10.5958/2455-7129.2020.00007.2

ABSTRACT

Silver oak (*Grevillea robusta*) is one of the important tree species in Agroforests of Kodagu, India.The present study generated information on growth performance and yield of the species in different farming situations at different spacing and ages. The results indicated that the spacing and farming situation has a pronounced effect on growth (diameter at breast height, height, basal area and volume of individual trees) of silver oak at different ages. At the age of five, the average diameter at breast height (DBH) varied significantly under different farming situations with values ranging from 12.74 cm (monoculture) to 13.69 cm (silver oak with coffee). The effect of spacing and farming situations was not found to be significant on survival rate in most of the ages. The influence of farming systems on yield was observed at the age of five years, where there was significant variation on average volume per hectare with highest yield under monoculture (10.44 m^3ha^{-1}) followed by silver oak with coffee and pepper (9.75 m^3ha^{-1}) and silver oak with coffee (7.01 m^3ha^{-1}).

Key Words:

Age, Diameter at breast height, *Grevillea robusta,* Growth performance, Spacing

INTRODUCTION

Kodagu located in the Western Ghats, a world biodiversity hotspot, has high conservation significance because of its agroforestry-dominated landscape and the current priority is to prevent depletion of existing diversity. Local farmers appear conscious of the biodiversity value of their plantations, which may be linked to their traditional cultural practices of conserving sacred forests and species (Bhagwat et al. 2005). However, international coffee price fluctuations and public policies are driving

them away from traditional land management practices towards modern practices favouring shade tree monocultures and sun-intensive cultivation (Garcia et al. 2010).

Grevillea robusta A. Cunn.ex R.Br. commonly known as silver oak is a medium to large tree, native to Coastal Eastern Australia from the Clarence River, New South Wales, to Mary Borough, Queensland. It is commonly planted as an ornamental tree in many warm-temperate and tropical climates. *G. robusta* is extensively planted in India as shade tree in coffee, tea and cinchona plantations. It was the earliest shade tree to be introduced in India. The tree grows well in moderate elevation from 1000 m– 2300 m MSL. Silver oak in the coffee based agroforestry perform several roles such as shade tree for the coffee plantation, standard for pepper vine, providing timber and fuel wood etc. In addition, *G. robusta* is considered as the best support for black pepper (*Piper nigrum*) vines (Elouard et al. 2000). In the recent years, Silver oak is being cultivated as monoculture and with different crop combinations in the region *viz.,* silver oak with coffee alone, with pepper and coffee etc. In spite of all these, little information is available on growth performance of the species under different farming situations and spacing regimes. In the present study, attempts were made to assess the growth and yield of silver oak under different farming situations and spacing regimes at different ages.

MATERIALS AND METHODS

The study was carried out at different plantations of *G. robusta* in and around Kodagu district, Karnataka within Central Western Ghats region between 12°42'08"N and 75°73'97"E. The study locations were chosen by considering the farming situations, spacing and the different ages. Based on the existing dominant farming situations, the sample plots were selected for the study. In all, four dominant situations v*iz.*, silver oak alone (monoculture), silver oak with coffee, silver oak with coffee and pepper, and silver oak with coffee and teak were identified. For the purpose of the study, stratified random sampling technique was adopted by considering age, farming situation and spacing. Stands of representative age classes of 5, 10, 15 and 20 years were selected with the appropriate spacing in different farming situations for the study. In each strata, plots were laid out with a minimum of 30 trees. Diameter at breast height and total height (m) were recorded. By considering the diameter at breast height, basal area of the individual tree was obtained. The form factor for tree were developed by adopting destructive method of sampling of trees and finally, the volume of individual tree was calculated by multiplying total height of the tree, basal area and form factor. The wood volume for each plot, was calculated by summing up the volumes calculated for individual tree.

$$\mathbf{Plotwoodvolume}\left(\mathbf{m^3}\right) = \mathbf{\Sigma\ individual\ tree\ volume\ intheplot}$$

Further, the wood volume per plot was extrapolated into per hectare basis and mean annual increment ($m^3\ ha^{-1}\ yr^{-1}$) on the basis of wood volume was calculated using the following formulae.

$$\text{Wood Volume}(m^3 ha^{-1}) = \frac{\text{Survial percent} \times \text{Plotwood volume} \times 10{,}000}{\text{Area of sample plot} \times 100}$$

Mean annual increment (MAI) was calculated using the formulae

$$\text{Mean Annual Increment}\ (m^3 ha^{-1} yr^{-1}) = \frac{\text{Woodvolume}}{\text{Stand age}}$$

Statistical analysis

General Analysis of variance (without blocking) of the data was carried out as described by Williams and Matheson (1994) in Genstat Software (Genstat5 Release 3.2), after angular transformation of per cent values was done.

RESULTS AND DISCUSSIONS

Growth performance of G. robusta under different farming system

The growth parameters such as height, basal area and volume of individual trees were differing significantly under different cropping systems (Table 1). The results revealed that, the average DBH and height under silver oak + coffee farming was 25.57 cm and 14.55 m respectively that accounts with the individual tree volume of 0.443 m^3. The results of variation of DBH and height at the age of five years are in line with results of Xu et al. (2008) who reported that the nutrient management increased tree height and diameter growth over a period of time and also close spacings resulted in smaller DBH than wider spacing at the same age (Land et al. 2004).The findings pertained to the growth of ten years can be concurred with the relationship of tree size to age and increments to age are important, particularly in predicting future growth (Brack and Wood 1996).

In the stands of 15 year old trees (Table 2), effect of farming situation was not evident for all the estimated growth parameters. In the fifteen year old trees, generally growth of a tree is influenced by site where it grows, spacing adopted, competition, *etc*. The results can be attributed to the site that decides the growth and development of a particular tree. The trees of same age are found to have similar growth within the region. Also the tree growth might not have been influenced by the growth and development of the associated crop. Further, in 20 year old trees showed that the average survival rate was 92.50 per cent (Table 2). In the same farming situation, the average DBH and height recorded was 34.58 cm and 24.67 m respectively. The form factor recorded for the 20 year silver oak trees was 0.48 which was lower when compared to the trees in younger age classes. The lower form factor at the age of 20 could be due to the fact that the during young age tree cannot withstand the prevailing wind, so as the tree age increases the tree itself reinforces at the base in order to withstand the wind. This results in wideness of the stem at the base when compared to the top portion. Hence, the form of a tree decreases with increase in age. The result can be concurred with findings of Swamy et al. 2011, who revealed that the form factor varied from 0.3 to 0.69 in *Pongamia pinnata* and *Azadirachta indica* respectively at the age of five years and the reason for this was, increased age and height of the tree found to decrease the form factor.

Growth performance of G. robusta under different spacing

The average survival rate was found to be on par in the entire spacing regime with the values ranging from 92.87 per cent (6 m x 6 m) to 95.71 per cent (4 m x 4 m) (Table 3). The average DBH and height of the trees showed significant difference under different spacing regimes (Table 3). Effect of spacing on the basal area of individual tree and average volume of individual trees was evident in the study. These results of variation in diameter growth and average individual tree volume are in accordance with the findings of Kalinganire (1995), where the study revealed that, the spacing had profound influence on diameter growth and tree volume production in silver oak. Clara Manasa (2012) stated that the volume production increases with the spacing in *Eualyptus urophylla,* with the values ranging from 0.12 (2 m x 3 m) to 0.15 m^3 (3 m x 3 m). The growth of ten year old trees in different spacings showed that, effect of spacing on survival and the height was not evident in the study (Table 3). Significant difference was observed in DBH and basal area under different spacing regime (Table 3). The volume was found to be maximum under 5 m X 5 m (0.503 m^3) and least in 6 m X 6 m (0.383 m^3). Normally, wider spacing favours the diameter growth but at the age of ten years, the diameter growth in the spacing 5 m X 5 m was significantly higher when compared to 6 m X 6 m which could be due to prevailing management practices or site conditions such as intense competition from the associate crops in 6 m X 6 m spacing.

Table 1. Growth performance of five and ten year old trees in different farming situations

AGE	Farming situation	Survival (%)	DBH (cm)	Height (m)	Form Factor	Basal Area (m^2)	Volume (m^3)
5 year	Silver oak with coffee	94.26 (76.15) $^{\Delta}$	13.69^{c}	9.10 ^{b}	0.69	0.017 ^{c}	0.094 ^{c}
	Silver oak with coffee and pepper	94.06 (76.57)	13.34^{b}	8.67 ^{a}	0.69	0.014 ^{b}	0.086^{b}
	Monoculture	96.33 (78.97)	12.74 ^{a}	8.78 ^{a}	0.51	0.010 ^{a}	0.057^{a}
	S.Em(±)	1.237	0.1001	0.0886	-	0.0009	0.0016
	LSD (0.05)	NS	0.3057	0.2706	-	0.0028	0.0049
10 year	Silver oak with coffee and pepper	99.80±2.30	25.57±2.58	14.55±0.95	0.57	0.053±0.01	0.443±0.09
	Coefficient of Variation (%)	2.30	10.08	6.52	-	18.90	20.31

$^{\Delta}$ *Parenthetical values are arc sine transformed; Figures with similar superscript do not differ significantly ; LSD- Least Significance Difference ; NS-Not-Significant*

Table 2. Growth performance of 15 and 20 year old silver oak tree under different farming situations

Age	Farming situation	Survival (%)	DBH (cm)	Height (m)	Form Factor	Basal Area (m^2)	Volume (m^3)
15 year	Silver oak with coffee and pepper	97.13 (80.26) $^{\Delta}$	31.37	22.42	0.55	0.0778	0.983
	Silver oak with coffee, pepper and teak	99.96 (88.93)	29.96	19.75	0.55	0.0712	0.792
	S.Em(±)	3.061	2.613	0.548	-	0.012	0.173
	LSD(0.05)	NS	NS	NS	-	NS	NS
20 year	Silver oak with coffee and pepper	92.50 ±7.35	34.58±3.59	24.67±2.14	0.48	0.098±0.02	1.190±0.28
	Coefficient of Variation (%)	7.94	10.38	8.67	-	20.40	23.52

$^{\Delta}$ *Parenthetical values are arc sine transformed; Figures with similar superscript do not differ significantly; LSD- Least Significance Difference; NS- Not-Significant*

The estimated growth of 15 year old trees under different spacing revealed that, average survival rate, DBH, basal area and average volume of individual trees did not differ significantly (Table 4). However, the height growth of trees under different spacing regime showed significant variation with an average value of 22.46 m for 6 m x6 m and 21.39 m for 5 m x5 m. Normally, the height growth of trees in monoculture or in single species stand is least influenced by the spacing as compared to diameter growth. Further, the competition for light make the trees grow taller in closer spacing. The findings of 15 year old trees contradicted the perception on spacing and height which could be because the stand had combination of coffee and pepper or even with teak and the intense competition for light from the associated crops like pepper in widely spaced trees would have resulted in more allocation of biomass for height growth in 6 m x 6 m.. The average survival rate among different spacing

showed a significance difference for twenty years old trees (Table 4). The average DBH was not differing significantly with values ranging from 34.31 cm under 5 m x 5 m to 36.65 cm under 6 m x 6 m. Interestingly, the effect of spacing on height growth, basal area and volume of individual trees was not evident in the study. Survival rate in any stand is governed mainly by the site conditions and availability of growth resources at the site. Existence of significant difference in the survival rate under different spacing at the age of 20 years could be ascribed to the intense competition which would have limited the growth resources or the trees at closer spacing (5 m x 5 m) as compared to wider spacing (6 m x 6 m). Existence of similar growth in diameter, height and other related parameters could be ascribed to site conditions which were having more or less similar number of trees per unit area due to low survival rate in the closer spacing (5 m x 5 m).

Table 3. Growth performance of five and ten year old trees under different spacing

AGE	Spacing	Survival (%)	DBH (cm)	Height (m)	Basal Area (m^2)	Volume (m^3)
5 year	4 m x 4 m	95.71 (78.97) $^{\Delta}$	12.73^{a}	8.77 ^{a}	0.010 ^{a}	0.057 ^{a}
	5 m x 5 m	94.05 (76.57)	13.33 ^{b}	8.67 ^{a}	0.014 ^{b}	0.086 ^{b}
	6 m x 6 m	92.87 (76.15)	13.69 ^{c}	9.10 ^{b}	0.017 ^{c}	0.094 ^{c}
	S.Em(±)	0.980	0.100	0.088	0.0009	0.001
	LSD (0.05)	NS	0.305	0.270	0.002	0.004
10 year	5 m x 5 m	99.97 (89.10) $^{\Delta}$	27.55 ^{b}	14.29	0.060 ^{b}	0.503 ^{b}
	6 m x 6 m	99.46 (85.80)	23.59 ^{a}	14.81	0.045 ^{a}	0.383 ^{a}
	S.Em(±)	1.57	0.670	0.260	0.001	0.020
	LSD(0.05)	NS	1.476	NS	0.005	0.063

$^{\Delta}$ *Parenthetical values are arc sine transformed; Figures with similar superscript do not differ significantly; LSD- Least Significance Difference; NS- Not-Significant*

Table 4. Growth performance of 15 and 20 year old trees under different spacing

AGE	Spacing	Survival (%)	DBH (cm)	Height (m)	Basal Area (m^2)	Volume (m^3)
15 year	5 m x 5 m	99.14 (84.70)$^{\Delta}$	30.51	21.39 ^{a}	0.075	0.891
	6 m x 6 m	96.74 (79.60)	31.91	22.46^{b}	0.080	1.016
	S.Em(±)	2.27	0.650	0.375	0.003	0.046
	LSD (0.05)	NS	NS	0.835	NS	NS
20 year	5 m x 5 m	90.45 ^{a} (72)$^{\Delta}$	34.31	24.82	0.097	1.186
	6 m x 6 m	100 ^{b} (90)	36.65	23.53	0.105	1.219
	S.Em(±)	4.74	2.087	1.248	0.011	0.164
	LSD (0.05)	9.81	NS	NS	NS	NS

$^{\Delta}$ *Parenthetical values are arc sine transformed; Figures with similar superscript do not differ significantly; LSD- Least Significance Difference; NS- Not-Significant*

Yield of G. robusta under different farming situations

The influence of farming systems on yield at the age of five years (Table 5) revealed that, significant variation was observed in average volume per hectare. Considerably, highest yield was recorded under monoculture (10.44 m^3ha^{-1}) followed by silver oak with coffee and pepper (9.75 m^3ha^{-1}) and silver oak with coffee (7.01 m^3ha^{-1}). In pure plantation, yield is more productive than the multiple-species stands. Significant variation of both the estimated parameters can be concurred with the findings that monoculture plantation showed higher in volume or the biomass production than the mixed crops (Petit and Montagnini 2006).The influence of farming systems on yield at the age of five years (Table 5) revealed that, significant variation was observed in average volume per hectare. Considerably, highest yield was recorded under monoculture (10.44 m^3 ha^{-1}) followed by silver oak with coffee and pepper (9.75 m^3ha^{-1}); and silver oak with coffee (7.01 m^3ha^{-1}). There was also significance difference in average mean annual increment (MAI) and the maximum mean value was recorded for monoculture (2.08 $m^3ha^{-1}yr^{-1}$) and minimum was found for silver oak with coffee (1.40 $m^3ha^{-1}yr^{-1}$). The yields under farming situation of silver oak with coffee and pepper at the age of 10 years revealed that, the average volume per hectare and MAI recorded was 152.3m^3ha^{-1} and 15.23 $m^3ha^{-1}yr^{-1}$ respectively (Table 5). The production of high volume per hectare can be attributed to the increased diameter and height over a period of time. The MAI for the stand with coffee and pepper was 15.23 $m^3ha^{-1}yr^{-1}$ which is much higher than the similar cropping situation at five year age (1.40 $m^3ha^{-1}yr^{-1}$).

Yield at the age of 15 years under different cropping situations (Table 5) revealed that, significant variation on average volume per hectare was not evident in the study under various cropping situations with the values ranging from 293 m^3ha^{-1} (silver oak with coffee and pepper) to 359 m^3ha^{-1} (silver oak with coffee, pepper and teak). Similarly, significant difference was not evident for average mean annual increment (MAI) in various cropping situations. The average MAI was found to be 19.60 $m^3ha^{-1}yr^{-1}$ for silver oak with coffee and pepper and 23.19 $m^3ha^{-1}yr^{-1}$ for silver oak with coffee, pepper and teak. Growth rate increases rapidly during young ages and declining with tree maturity. Inter-rotation site management practices have critical impacts on productivity. Harvesting operations, site preparation and silviculture from planting to canopy closure can have strong influences on the soil and site environment and in turn on productivity of successive plantations (Mackensen and Folster 1999). The yield under farming situation of silver oak with coffee and pepper at the age of twenty years revealed that, the average volume per hectare and MAI recorded was 408 m^3ha^{-1} and 20.38 $m^3ha^{-1}yr^{-1}$ respectively (Table 5). Mean annual increment which is an indicator of average growth of the stand can be used to determine the rotation age. Based on the MAI it can be inferred that the MAI of silver oak at 20 year old stand is much lower than the stands of 15 year old implying that the rotation age of the species under specific farming system is between 15 - 20 years. This needs further detailed investigation by laying out suitable experiments.

Yield of G. robusta under different spacing

The data on yield of 5 year old silver oak trees under different spacing regime is presented in the Table 6. The results revealed that, the effect of spacing on volume per hectare was evident and maximum value was recorded for 4 m x 4 m spacing (10.44 m^3ha^{-1}) and least under 6 m x 6 m spacing (7.01 m^3ha^{-1}). Existence of spacing effect on mean annual increment was evident and the maximum value was recorded under 4 m x 4 m spacing (2.08 $m^3ha^{-1}yr^{-1}$) which was found to be superior over other spacing regimes. In general, when the spacing declines the number of

trees accommodated per hectare is more. The result are in line to the findings of Penner et al. (2001), who reported that closer spacing (2.1 m) had the highest merchantable volume of all the plots and the highest total volume production per unit area. The data on Table 6 reveal the yield of 10 year old trees under different spacing regimes. Significant difference on the average volume per hectare was evident under different spacing regime with the values ranging from 200.50 m^3ha^{-1} (5 m x 5 m) and 104.20 m^3ha^{-1} (6 m x 6 m). The study on effect of spacing on stand volume of 8.8 year *Ailanthus tryphysa* revealed that the stand volume at closer spacing was more than twice the stand volume at wider spacing (Shujauddin and Kumar 2003). Thakur et al. 2019 and Singh et al. 2019 also reported higher height of *Melia dubia* at closer spacing. Similar observations on effect of spacing on pulp wood production was also reported by Clara Manasa (2012) in *Eucalyptus urophylla* wherein the trees under closer spacing (2 m x 2 m) produced maximum pulp wood and MAI, when compared to the wider spacing (2.75 m x 3.00 m). Thus, the findings in the present study are in accordance with the findings of other works carried in the similar conditions.

Yield of 15 year old silver oak trees was maximum value for 5 m x 5 m spacing (347 m^3ha^{-1}) which was found to be superior over other spacing regimes (Table 6). Significant difference in mean annual increment was observed with the values ranging from 17.90 $m^3ha^{-1}yr^{-1}$(6 m x 6 m) to 23.11 $m^3ha^{-1}yr^{-1}$ (5 m x 5 m). The result can be concurred with the findings of Whyte and Woollons (1990), who reported that the yield from a stand thinned to 300 stems ha^{-1} was much greater than that of stand at 200 stems ha^{-1}, that volumes of the largest 200 trees ha^{-1} in the 300 stems ha^{-1} plots were almost as great as the entire yield from plots thinned to 200 stems ha^{-1}. The data on yield of 20 year old trees under different spacing regimes (Table 6) revealed that, the average volume per hectare was on par in different spacing with values ranging from 339 m^3ha^{-1} (6 m x 6 m) spacing to 416 m^3ha^{-1} (5 m x 5 m). Effect of spacing in MAI was not evident under different spacing regimes with the values ranging from 16.94 $m^3ha^{-1}yr^{-1}$ (6 m x 6 m) to20.82 $m^3ha^{-1}yr^{-1}$ (5 m x 5 m). Effect of spacing on MAI was not evident under different spacing regimes with the values ranging from 16.94 $m^3ha^{-1}yr^{-1}$ (6 m x 6 m) to 20.82 $m^3ha^{-1}yr^{-1}$ (5 m x 5 m). Both the yield and MAI for both the spacing were on par which could be due to reduced growth or stagnated growth after 15 years of planting in silver oak which can further be evidenced by the reduced MAI at the age of 20 years.

Table 5. Yield parameters in different farming situations

AGE	FARMING SITUATIONS	Volume (m^3)	MAI ($m^3ha^{-1}yr^{-1}$)
5 year	Silver with coffee	7.01[a]	1.40[a]
	Silver oak with coffee and pepper	9.75 [b]	1.95 [b]
	Monoculture	10.44 [c]	2.08[c]
	S.Em(±)	0.216	0.039
	LSD (0.05)	0.659	0.121
10 year	Silver oak with coffee and pepper	152.3	15.23
	Coefficient of Variation (%)	34.64	34.6
15 year	Silver oak with coffee and pepper	293	19.6
	Silver oak with coffee, pepper and teak	359	23.19
	S.Em(±)	60.2	4.01
	LSD (0.05)	NS	NS
20 year	Silver oak with coffee and pepper	408	20.38
	Coefficient of Variation (%)	65.82	32.89

Table 6. Yield parameters in different spacing

Age (Year)	Parameter	Spacing			Mean	S.Em (±)	LSD. (0.05)
		4 m x 4 m	5 m x 5 m	6 m x 6 m			
5	Volume/ha (m^3ha^{-1})	10.44[c]	9.75[b]	7.01[a]	10.35	0.216	0.659
	MAI ($m^3ha^{-1}yr^{-1}$)	2.08[c]	1.95[b]	1.40[a]	1.81	0.003	0.121
10	Volume/ha (m^3ha^{-1})	-	200.50[b]	104.20[a]	152.30	5.882	18.310
	MAI ($m^3ha^{-1}yr^{-1}$)	-	20.05[b]	10.42[a]	15.23	0.588	1.831
15	Volume/ha (m^3ha^{-1})	-	347[b]	269[a]	308	17.700	55.90
	MAI ($m^3ha^{-1}yr^{-1}$)	-	23.11[b]	17.90[a]	20.51	1.183	3.728
20	Volume/ha (m^3ha^{-1})	-	416	339	408	57.70	NS
	MAI ($m^3ha^{-1}yr^{-1}$)	-	20.82	16.94	20.38	2.887	NS

Figures with similar letters as superscript do not differ significantly; CD- Critical Difference; NS- Not-Significant.

CONCLUSIONS

The study revealed that at the age of five years, significant difference was observed for the yield parameters in various cropping situations and it was found to be better under monoculture. If the objective is for timber production preferring monoculture is of more importance. The increased diameter over the time has been attributed to the more volume at the age of 10 years under silver oak with coffee and pepper farming situation. However, the trees at the age of 15 years did not show any significant differences in yield parameters as the growth in young age increases more rapidly than at maturity. Further, the study also highlights the variation in growth and yield parameters at different spacing regimes revealing that 4 m x 4 m spacing is superior at the age of five years and 5 m x 5 m at the age of 10 and 15 years for the tree growth and yield parameters.

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