Original Research Article

Response of Timber Yield, Biomass, CAI and Carbon Sequestration to Varied Pruning Intensities of *Dalbergia sissoo* Roxb. in Agrisilviculture System

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Abstract

In Central India, an experiment was carried out on a 22 year old *Dalbergia sissoo*-based agrisilviculture model in 2020-21 to investigate the response of different pruning intensities on Rabi seasonal diameter growth, timber production, CAI of total biomass, and carbon sequestration potential. Each year, paddy followed by wheat is grown under trees spaced at 5m × 5m continuously being treated with four different pruning intensities, *i.e.*, 0% (P_0: No pruning), 25% (P_{25}: Light pruning), 50% (P_{50}: Moderate pruning) and 75% (P_{75}: Heavy pruning) of the total tree height. It was reported that different rates of pruning had a significant effect. Maximum Rabi seasonal D.B.H. increment was recorded in P_0 (0.68 cm) and minimum in P_{75} (0.49 cm). Maximum seasonal yield of large-sized timber, small-sized timber, and fuelwood (5.80 m^3 ha^{-1}, 0.62 m^3 ha^{-1} and 7.48 q ha^{-1}, respectively) were recorded under light pruning treatment (P_{25}). However, the minimum seasonal yield of large-sized timber and fuelwood (5.80 m^3 ha^{-1} and 5.14 q ha^{-1}, respectively) were under heavy pruning (P_{75}) and the minimum seasonal yield of small-sized timber (0.32 m^3 ha^{-1}) under moderate pruning (P_{50}). Maximum annual above-ground biomass, annual below-ground biomass and current annual increment of total biomass (171.63 q ha^{-1} yr^{-1}, 34.33 q ha^{-1} $yr^{-1,}$ and 205.95 t ha^{-1} respectively) were recorded under light pruning treatment (P_{25}), while minimum (84.50 q ha^{-1} yr^{-1}, 16.90 q ha^{-1} yr^{-1} and 101.40 t ha^{-1} respectively) under heavy pruning (P_{75}). Carbon sequestration potential was reported to be higher with light pruning (92.68 q ha^{-1} yr^{-1}), followed by moderate pruning (63.69 q ha^{-1} yr^{-1}), while minimum under heavy pruning (45.63 q ha^{-1} yr^{-1}) and no pruning (46.91 q ha^{-1} yr^{-1}) at all. It was concluded that light pruning of 25% was best among the four treatments in terms of timber and biomass yield.

Keywords: Agrisilviculture, Carbon sequestration, Current Annual Increment, *Dalbergia sissoo*.

Introduction

Dalbergia sissoo Roxb. belongs to the Leguminosae family and the Papilionioideae subfamily and is often known as North Indian rosewood or Shisham. It is indigenous to the Indian subcontinent as well as southern Iran. In India, the species can be found in the Sub-Himalayan and outer Himalayan valleys from the Indus to Assam, at up to 900 meters and occasionally up to 1500 meters. It is a unique species of the Khair-Sissoo primary seral forest (Champion and Seth, 1968). It is a deciduous tree that proliferates, is hardy, and may reach a height of up to 30 meters. It's a multifunctional tree that produces high-quality lumber, high-calorie fuelwood, protein-rich feed, shade, and has nitrogen-fixing abilities (Singh and Sharma, 2007; Jackson, 1987). Shisham is great fuelwood, with sapwood and heartwood calorific values of 4908 and 5181 kcal/kg, respectively (Anon., 1952). Because of its hardness, endurance, and characteristic dark coloured heartwood with a specific gravity of 0.62 - 0.82, it is one of India's most popular timber species, used for a variety of uses (Orwa et al., 2009). These benefits and its rapid growth rate make it ideal for use in agroforestry systems (Bhargava and Rai, 2019; Patel et al., 2017). Farmers are increasingly integrating fast-growing trees on their property near agricultural crops due to rising demand and high prices for wood (fuel, lumber, pulp) (Kumar et al.,2018). There are many different forms of interactions between the components of an agroforestry system, the most common of which is competition for light, water, nutrients, and other precious resources (Kar et. al., 2019a; Kar et. al., 2019b). Regulating and minimizing competition for scarce resources between the tree and the agriculture component (Frank and Eduaro, 2003; Dhillon et al., 2010; Kar et al., 2019a; Kar et al., 2019b; Kar et al., 2019c; Upadhyaya and Nema, 2003) Pruning is a canopy management technique used primarily in agroforestry systems to allow more light into lower strata crops, reduce competition, improve tree shape and wood quality, provide intermediate yields of small timbers and fuelwood, reduce tree taper, and increase overall biomass productivity. (Sinclair and Luther, 1998; Chandrashekara, 2007; Nutto et al., 2006; Pradhan et al., 2003; Viquez and Perez, 2005; Newaj and Dar, 2007; Rai et al., 2008; Newaj et al., 2010; Takiya et al., 2010; Takiya et al., 2011; Manhas et al., 2011; Sah Estimating the volume of timber and fuelwood is necessary for calculating the cost-benefit ratio of an agroforestry system, which is necessary for comparing the benefits of various agroforestry systems (Sahu et al., 2015). To compensate for the delay in return from the tree component, the intermediate yield from the tree component in the agroforestry system is critical. However, only a few studies have been done to measure the influence of Shisham pruning on seasonal timber production, seasonal fuelwood yield, yearly biomass increment, and carbon sequestration potential in an agroforestry system; hence the current study was undertaken.

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Materials and Methods

Experimental location, topography, and climate- The field experiment at the Dusty Acre Research Farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya in Jabalpur (MP). The site is located at 23o 12' 50" North latitude and 79o 57' 56" East longitude, and it is in the Kymore Plateau and Satpura hill agroclimatic zone, with medium-deep black soil. Nature is simple to slightly sloppy in this location (0-1 percent). The climate is subtropical, with hot, dry summers and chilly, dry winters. In May and June, the temperature reaches 46°C, while in December and January, it drops to 2°C. The average annual rainfall in the area is 1350 mm, with most of it falling between June and September.

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Experimental details- The research was conducted out in a Dalbergia sissoo-based agroforestry model that was nearing the conclusion of its rotation. In subsequent years, the model was built in 1998 with a planting geometry of 5m x 5m spacing and intercropped with paddy – wheat cycle. Each year, trees were subjected to four distinct pruning regimes: no pruning (0 percent of total tree height), light pruning (25 percent of total tree height), moderate pruning (50 percent of total tree height), and heavy pruning (100 percent of total tree height) (75 percent of the total tree height). A total of 64 trees were investigated, with 16 trees being subjected to each pruning procedure. Seasonal (Rabi) and yearly tree development parameters under various pruning intensity treatments were measured and enumerated using non-destructive methods in April 2020, November 2020, and lastly in April 2021 (at the age of 22 years). According to Gomez & Gomez, the data gathered were submitted for statistical analysis of variance (Randomised Block Design) (1984).

Volume calculations- The volume of Shisham tree was categorized as large-sized timber, small-sized timber, and fuelwood. Estimation of volume of large size timber (diameter ≥ 10 cm), the volume of small size timber (7 cm ≥ diameter < 10 cm), and weight of fuelwood (diameter 4 cm ≥ diameter < 7 cm) was done using allometric models developed by Sahu *et al*. (2015) from the same experimental plot (Table 1). Mean wood density derived from laboratory analysis was 750 kg/m^3, used for biomass estimation.

Table 1: Allometric equations for estimating timber volume, fuelwood biomass under different pruning intensities

Pruning Intensities	large-sized timber volume estimation (m^3)	small-timber volume estimation (m^3)	fuel wood weight estimation (Kg)
P_0: No pruning (0%)	$\sqrt{v}$ = 0.0517 + 0.0159D	$\sqrt{v}$ = 0.0393 + 0.0054D	$\sqrt{w}$ = 1.6664 + 0.1680D
P_{25}: Light pruning (25%)	$\sqrt{v}$ = - 0.2817 + 0.0317D	$\sqrt{v}$ = - 0.0661 + 0.0092D	$\sqrt{w}$ = - 0.5306 + 0.2184D
P_{50}: Moderate pruning (50%)	$\sqrt{v}$ = - 0.1547 + 0.0275D	$\sqrt{v}$ = - 0.0105 + 0.0069D	$\sqrt{w}$ = - 0.5306 + 0.2184D
P_{75}: Heavy pruning (75%)	$\sqrt{v}$ = - 0.1312 + 0.0276D	$\sqrt{v}$ = - 0.1987 + 0.0165D	$\sqrt{w}$ = - 2.2383 + 0.2999D

Above and below-ground biomass-
Stem biomass of trees was obtained by multiplying stem volume with wood density.

Stem biomass = Stem volume (VOB) × Wood density (WD)
Where VOB is the volume over bark and
WD is the average wood density.

Aboveground biomass of a tree was calculated following IPCC (2006) by multiplying stem biomass with a biomass expansion factor. The biomass expansion factor for hardwood species and conifers are given by Brown and Schroeder (1999) and particularly of Shisham by Lodhiyal and Lodhiyal (2003) *i.e.* 1.86.

Aboveground biomass = stem biomass × BEF
Where, BEF is the biomass expansion factor.

Belowground biomass was calculated by multiplying above ground biomass with root shoot ratio following IPCC (2006). Root shoot ratio for *Dalbergia sissoo* (0.2) was given by Sharma *et al.* (1988). Aboveground biomass and belowground biomass were added to work out the total biomass of tree.

Carbon content-
The total carbon content in the tree was determined by multiplying the biomass of the tree with a conversion factor of 0.45 (Magnussen and Reed, 2004).

RESULTS-

Information on the effect of different pruning intensities on varied growth and yield parameters of *Dalbergia sissoo* so gathered after proper statistical analysis of data are presented as follows-

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Seasonal increment of diameter at breast height (cm)-

Differential pruning of *D. sissoo* had a significant effect on d.b.h. Increment in Rabi season decreased with an increase in pruning intensity (Table 2). Maximum d.b.h. increment (26.33 cm) was in trees where pruning was not practiced (P_0) and minimum (16.65 cm) under heavy pruning (P_{75}).

Seasonal large-sized timber yield (m^3 ha^{-1})-

Pruning treatments significantly affected the seasonal yield of large-sized timber (Table 2). Maximum quantity of Rabi seasonal large-sized timber (5.80 m^3 ha^{-1}) was yielded under light pruning (P_{25}), followed by heavy pruning (P_{75}); whereas minimum seasonal small-sized timber (2.86 m^3 ha^{-1}) was recorded under heavy pruning (P_{75}), which was at par with no pruning (P_0).

Seasonal small-sized timber yield (m^3 ha^{-1})-

The effect of different pruning intensities on the seasonal yield of small-sized timber was statistically significant (Table 2). Maximum quantity of Rabi seasonal small-sized timber (0.62 m^3 ha^{-1}) was yielded under light pruning (P_{25}), followed by moderate pruning (P_{50}); whereas minimum seasonal large-sized timber (0.32 m^3 ha^{-1}) was recorded under moderate pruning (P_{50}), which was at par with no pruning (P_0).

Seasonal Fuelwood yield (q ha^{-1})-

Pruning had a very significant effect on the fuelwood production (Table 2), where Rabi seasonal fuelwood production was recorded under light pruning (7.48 q ha^{-1}), and no pruning treatment (7.01 q ha^{-1}) were significantly higher than seasonal fuelwood production under heavy pruning (5.14 q ha^{-1}) and moderate pruning treatment (5.29 q ha^{-1}).

Table 2: Effect of pruning intensities on seasonal d.b.h. increment, large size timber, small size timber, and fuelwood yield of *D. sissoo* in agrisilviculture system.

Pruning Intensities	Seasonal D.B.H increment (cm)	Seasonal Large-sized timber yield (m^3 ha^{-1})	Seasonal Small-sized timber yield (m^3 ha^{-1})	Seasonal Fuelwood yield (q ha^{-1})
No pruning (0%)	0.68	2.94	0.37	7.01
Light pruning (25%)	0.60	5.80	0.62	7.48
Moderate pruning (50%)	0.52	3.99	0.32	5.29
Heavy pruning (75%)	0.49	2.86	0.48	5.14
CD (0.05)	0.02	0.32	0.10	1.47
SEm±	0.01	0.10	0.03	0.47

Biomass increment of the tree [Above Ground Biomass (AGB), Below Ground Biomass (BGB), and Current annual increment of biomass (CAI)]-

Pruning intensities treatment had a significant effect on the above-ground biomass increment, below-ground biomass increment, and current annual increment of the total biomass of Shisham tree in agrisilviculture system (Table 3). Maximum AGB increment, BGB increment and CAI (171.63 q ha^{-1} yr^{-1}, 34.33 q ha^{-1} yr^{-1}, 205.95 q ha^{-1} $yr^{-1,}$ respectively) were recorded under light pruning (P_{25}), followed by moderate pruning (P_{50}). However, AGB increment, BGB increment and CAI (84.50 q ha^{-1} yr^{-1}, 16.90 q ha^{-1} yr^{-1}, 101.40 q ha^{-1} $yr^{-1,}$ respectively) were recorded under heavy pruning ($P_{75)}$, which were at par with that (86.88 q ha^{-1} yr^{-1}, 17.37 q ha^{-1} yr^{-1}, 104.25 q ha^{-1} yr^{-1} respectively) under no pruning treatment (P_0).

Carbon sequestration potential-

Carbon sequestration was significantly varied under the variable pruning regime of *D. sissoo* under agrisilviculture system (Table 3); where maximum carbon was sequestered (92.68 q ha^{-1} yr^{-1}) under light pruning (P_{25}), followed by moderate pruning (P_{50}). However, minimum carbon were sequestrated under heavy pruning (45.63 q ha^{-1} yr^{-1}) and no pruning treatment (46.91 q ha^{-1} yr^{-1}), statistically at par.

Table 3: Effect of pruning intensities on annual AGB increment, BGB increment, CAI and Carbon sequestration of *D. sissoo* in agrisilviculture system.

Pruning Intensities	AG Biomass increment (q ha^{-1} yr^{-1})	BG Biomass increment (q ha^{-1} yr^{-1})	CAI of total biomass (q ha^{-1} yr^{-1})	Annual carbon sequestration (q ha^{-1} yr^{-1})
No pruning (0%)	86.88	17.37	104.25	46.91
Light pruning (25%)	171.63	34.33	205.95	92.68
Moderate pruning (50%)	117.95	23.59	141.54	63.69
Heavy pruning (75%)	84.50	16.90	101.40	45.63
CD (0.05)	9.49	1.90	11.40	5.13
SEm±	3.05	0.61	3.66	1.65

Discussion

This study aimed to see how pruning intensities affected the seasonal and yearly yield characteristics of Dalbergia sissoo in an agrisilviculture system. With increasing pruning intensities from P0 to P75, the diameter at breast height was observed to exhibit a declining tendency. Newaj et al. (2010) found a similar pattern in an Albizzia procera-based agrisilviculture system, with d.b.h. being greater in trees with no pruning than 50 percent and 75 percent trimming. In a study of the effect of pruning intensities (0, 25 percent, 50 percent, and 75 percent) on the growth of Pinus brutia, Erkan et al. (2016) discovered that 50 percent and 75 percent pruning resulted in decreased d.b.h. growth, whereas 0 percent and 25 percent pruning resulted in the highest d.b.h. growth. Lower branches provide relatively little to photosynthesis, and their respirational losses are not compensated; therefore their removal in a 25% pruning treatment has less effect than 50 percent and 75 percent pruning. Montagu et al., 2003; Chandrashekara, 2007; Erkan et al., 2016; Singh et al., 2020; Savill et al., 1997; Kozlowski and Pallardy, 1990; Montagu et al., 2003; Chandrashekara, 2007; Erkan et al., 2016; Singh et al., 2020). Uotila and Mustonen (1994) found that pruning 40 percent or more of the live crown of Scots pine (Pinus sylvestris L.) resulted in a considerable decrease in growth. In both moderate and intensive pruning, photosynthetic portions of the tree crown (direct contributors to growth) are removed for a portion of the year, resulting in the remaining crown dedicating its energy to replace crown loss, resulting in a reduced diameter increase. Erkan et al. (2016), Alcorn et al. (2008), Alcorn et al. (2008), Alcorn et al. (2008), Alcorn et al. (2008), Alcorn e Pruning intensities had a considerable impact on wood volume output in terms of large and small-sized timber. The maximum timber volume was measured in 25% pruning intensities near the end of the rotation and the lowest in 75% pruning. This was since trees are often trimmed by removing leaves and branches from the lower portion of the crown, resulting in a more cylindrical stem shape and increased precise bole length, resulting in higher biomass allocation in the bole than other components. (Kumar et al., 2018; Muhairwe, 1994; Shepherd, 1986); Kumar et al., 2018; Muhairwe, 1994; Shepherd, 1986). Savill as al. (1997), citing Wang et al. (1980)'s research on Chryptomeria japonica, found that eliminating 10% or somewhat more of the live crown really promoted growth. The CAI of total biomass of the tree was highest at 25% pruning intensity, followed by 50% and 75 percent pruning intensity. This tendency was also found in above-ground biomass increment, below-ground biomass increment, and carbon sequestration; however, fuelwood decreased as pruning intensity increased. This might be owing to reduced photosynthesis caused by branch pruning, which reduces the amount of surviving leaf area and the number of buds from which new branches and leaves can be formed. A similar set of findings was also published by (Patel et al., 2017; Kumar et al., 2018; Bhargava R and Rai N, 2019; Pinkard et al., 1999; Palai et al. 2021; Sahoo et al. 2020; Kar et al. 2020). Erkan et al. (2016) found comparable findings in a Pinus brutia trial, reporting that 75 percent pruning decreases standing volume by 18-21 percent.

Conclusion

The basic goal of management in an agroforestry system is to maximize the total return from all of the components. In an agrisilviculture system, this may be accomplished by locating an optimal state of tree management in which food production and the production of high-quality wood in large quantities can be achieved while also delivering a high economic return. This study aimed to standardize different pruning intensities in an agrisilviculture system to maximize the quality and amount of wood produced. Maximum wood output, biomass, and carbon sequestration were observed in 25% pruning intensity near the end of the rotation; however, this must be in agreement with the system's maximum crop production.

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