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Quantifying biomass accretion patterns in *Grewia Optiva* drummond trees across varied spacings in Mid Hills of Himachal Pradesh

Uday Kumar Lodh*, C L Thakur, Subhash Sharma, Praveen Kumar
Department of Silviculture and Agroforestry, Dr Yashwant Singh Parmar University of Horticulture and Forestry, College of Forestry, Nauni, Solan, Himachal Pradesh, India

Abstract

Optimal tree spacing not only enhances yield but also boosts carbon sequestration, a key factor in combating climate change. To optimize tree spacing and assess biomass accretion patterns, a study was conducted to assess the growth and biomass parameters of Grewia optiva trees within an existing agroforestry system under three different tree spacings: S_1 (8 × 1 m), S_2 (8 × 2 m), and S_3 (8 × 3 m) in the mid-hills of Himachal Pradesh during the years 2021-2022 and 2022-2023. The results revealed significant variation under different tree spacings (S_1 to S_3). Growth and biomass parameters values of tree height (6.34 m), diameter at breast height (16.32 cm), crown spread (2.30 m), number of branches (4.82), fodder yield (6.92 kg tree^{-1}), torchwood yield (5.65 kg ha^{-1}), and bast fiber (750 g tree^{-1}) were maximum under spacing S_3 and minimum under S_1. Leaf Area Index (LAI) was maximum (1.22) in spacing $S_{1,}$ and photosynthetic active radiation (PAR) in the understorey was maximum (433 µmol m^{-2}s^{-1}) in spacing S_3. Therefore, trees spaced at spacing S_3 (8 × 3 m), which exhibited the highest growth parameters, can be recommended for different agroforestry models in the mid-hills of Himachal Pradesh.

Keywords: Bast fibre, leaf area index, photosynthetic active radiation, split plot design, torchwood yield

Introduction

Agroforestry is a common practice in the mid-hills of Himachal Pradesh. The present study was carried out in the sub-humid mid-hills of Himachal Pradesh, where *Grewia optiva* is grown abundantly in farm bunds. The cultivation of agricultural crops along with fruit trees (agri-horticulture) is an exclusive and unique practice in the Himalayan region. In the Himalayan region, several indigenous agroforestry systems based on people's needs and site-specific characteristics have been developed over the years. One such traditional agroforestry system is the *Grewia optiva* based agroforestry system.

Among the various trees used in agroforestry, *Grewia optiva* is an important multipurpose tree. It belongs to the family Malvaceae and is one of the most essential fodder trees of the northwestern Himalayas. It is widely distributed throughout the sub-Himalayan tract, up to 1800 meters above mean sea level. It is sparingly found in forest areas and mostly raised along agriculture fields; the tree is heavily lopped for palatable leaf fodder. It is very popular among the farmers of the western Himalayas for feeding their cattle during the winter when no other green fodder is available. It provides sustainable biomass production on a short-rotation basis and enriches the soil by adding leaf litter.

Agroforestry contributes the most to the total farm income, followed by agriculture and livestock in the low hills and mid hills of Himachal Pradesh (Sharma *et al.*, 2020) [10]. Therefore, efforts were made in the present study to estimate the optimum spacing of *Grewia optiva* trees required for obtaining maximum growth and biomass.

Materials and Methods

The present study evaluates the growth parameters of *Grewia optiva* trees that were 17 years old within an existing agroforestry system under three different tree spacings: S_1 (8 × 1 m), S_2 (8 × 2 m), and S_3 (8 × 3 m) during the years 2021-2022 and 2022-2023. The investigation was conducted at the experimental farm of Silviculture and Agroforestry, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan.

Parameters Recorded during study

Tree height (m): Tree height was measured by using a graduated pole. The pole was marked with the measurements from the tape.

Diameter (cm): The stem diameter over bark was measured (mean of two right angle measurements) at 1.37 m above ground level with the help of a tree calliper. The measurements were made before lopping the branches for the fodder and fiber extraction.

Crown spread (m): The crown spread was measured in meters from the tree trunk in east-west and north-south directions by holding the tape beneath the canopy up to the last tip of the branches. The average of the two was taken as a crown spread. The measurements were made before lopping the branches for the fodder and fiber extraction.

$$CS = \frac{D_1 + D_2}{2}$$

Where, CS = Crown spread
D_1 = Crown spread in north-south direction (m)
D_2 = Crown spread in east-west direction (m)

Number of branches per tree: In each spacing, the primary branches were noted for all the trees. Further, the values were averaged for each spacing.

Fodder yield (kg/tree): Leaves and tender twigs were collected by lopping the branches of each tree in all three spacings, and green weight was measured on a weighing machine.

Bast fiber yield (g/tree): Branches were lopped from each tree spacing of 1m, 2m, and 3m. After lopping, branches were weighed, tied into bundles, and sun-dried for two weeks at each spacing. For two months, these bundles were retted by submerging 20 cm beneath the surface of the water in a horizontal position in gently flowing, fairly deep, clear water. After retting, fibers were extracted using the beat-break-jerk method. The fibers extracted from each bundle were dried and weighed to calculate the bast fiber yield.

Torchwood yield (g/tree): Following retting, fibers were extracted using the beat-break-jerk method. Torchwood was extracted from each bundle, dried, and weighed to determine the torchwood yield.

Photosynthetically active radiation (PAR): The photosynthetically active radiation (PAR) was measured using the ACCUPAR LP-80 Ceptometer, which is equipped with two PAR sensors: the ‘Probe PAR’ sensor with a range of 0 to 2500 µmol $m^{-2}s^{-1}$ and the ‘External PAR’ sensor with a range of 0 to 4000 µmol $m^{-2}s^{-1}$. This instrument was used for the measurement of PAR both above and below the tree canopy. The sensors recorded the incoming PAR through the canopy. These PAR measurements were taken simultaneously in an open field and under three different tree spacings.

Leaf area index (LAI): The leaf area index (LAI) refers to the amount of green leaf area on one side, measured per unit of ground surface area. The measurement was conducted using the ACCUPAR LP-80 Ceptometer instrument on a clear, sunny day. The data was collected under three different tree spacings.

The readings obtained from the instrument were derived using the formula provided below:

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Ground area}}$$

Statistical Analysis: The data obtained was analyzed using MS Excel and OP Stat software, with significance of correlation coefficient values tested against (n-2) degrees of freedom (Gomez and Gomez, 1984) [6].

Results and Discussion

Tree height (m): Between the three tree spacings in 2021–2022 and 2022–2023, the height of *G. optiva* trees ranged from 4.80 to 6.34 meters and from 4.74 to 6.30 meters (Table 1). Compared to other tree spacings, trees in the widest spacing (8×3m) were taller. The efficient usage of belowground resources, such as water and nutrients, by trees in the agroforestry system can be attributed to the maximum tree height at wider spacings. Internode elongation is one of the functional consequences of physiological activity. Increased intra-specific competition for light, space, and nutrients among trees in closer spacing may have limited their height growth (Singh *et al.*, 2007) [11]. The relationship between tree density and height is asymptotic, which means that as tree density increases, so does tree height. However, it becomes non-asymptotic after a certain reasonable level for any biological system. In the early stages of development, narrow spacing improved tree height growth, and as the system progressed, more height growth was observed in many agroforestry systems with wider spacings.

Diameter at breast height (dbh): Table 1 reveals an increasing trend in tree diameter with increasing space between *G. optiva* trees. Among the three tree spacings, tree diameter ranged from 14.08 cm to 16.30 cm in 2021-22 and from 14.14 cm to 16.32 cm in 2022-23. The diameter growth of the trees is mainly governed by their genetic makeup, planting density, management practices, and the microclimatic conditions in which they are allowed to grow. It can be assumed that the larger plasticity of trees in wider spacing, which stimulated cambial cells to produce bigger girth, is the reason why the maximum diameter of trees was recorded in the current investigation during the two consecutive years in spacing S_3 (8×3m) as 12.87 cm and 13.17 cm, respectively. Another factor could be increased intraspecific competition caused by the crown closure of trees, particularly in narrow spacings, which reduces photosynthesis and, eventually, carbon storage and hampers diameter growth, as suggested by Hebert *et al.*, (2016) [7]. Many tree species are more prone to size-symmetric competition. This impedes diameter expansion due to increased struggle for belowground resources (water and nutrients) rather than strife for light, as shown in inter-tree competition in closely spaced trees.

Crown spread (m): Under different tree spacings in a *G. optiva* based agroforestry system, tree crown spread varied from 1.32 m to 2.12 m in 2021-22 and from 1.47 m to 2.30 m in 2022-2023. The findings demonstrated that when the space between trees increased, so did the crown spread of *Grewia* trees (Table 1). The current study found an inverse relationship between tree spacing and crown spread. This might result from close spacing, which limits the ability to acquire resources to achieve optimum crown growth. Insufficient solar influx interception caused by size-symmetric (two-sided) overlapping of tree crowns and increased competition for other resources from neighbouring trees can also contribute to less crown spread under close spacing (Sonmez, 2009) [12]. Another factor could be that trees with close spacing have more vertically oriented branches, which increases inter-tree competition and reduces overall crown width (Nagar *et al.*, 2015) [9].

Number of branches per tree: Among the three spacings, the number of main branches of *Grewia* trees ranged from 3.14 to 4.52 in the years 2021-22 (Table 1). During the year 2022-23, the number of main branches varied from 3.35 to 4.82 under three tree spacings: S_1 (8 × 1 m), S_2 (8 × 2 m), and S_3 (8 × 3 m). More main branches were under the widest tree spacing (S_3) in both years. The availability of more space between trees enabled the branches to grow laterally rather than vertically to harness the sunlight efficiently (Subbulakshmi *et al.*, 2019) [13].

Fodder yield (kg tree $^{-1}$): Data enumerated in Table 2 revealed that among three tree spacings, fodder yield (leaf biomass and tender shoots) of *Grewia* trees ranged from 4.68 kg $tree^{-1}$ to 6.92 kg $tree^{-1}$ in the years 2021-22. During 2022- 23, *Grewia* fodder yield varied from 4.52 kg $tree^{-1}$ to 6.48 kg $tree^{-1}$ under three tree spacings: S_1 (8 × 1 m), S_2 (8 × 2 m), and S_3 (8 × 3 m). In both years, *Grewia* trees accumulated maximum fodder yield under the widest tree spacing (S_3). The production of leaf biomass is a significant tangible benefit of an agroforestry system. The increased fodder yield of *G. optiva* trees in wider spacing (S_3)

compared to the narrowest spacing (S_1) in an agroforestry system could be attributed to increased light availability in wider spacing, which promoted branch development and increased leaf biomass. There is a direct relationship between tree leaf biomass and intercepted photosynthetic active radiation in agroforestry systems (Binkley *et al.*, 2013) [3]. In tree crowding, i.e., closely spaced trees, tree crowns tend to be physically abrasive with each other, causing the loss of foliage buds and reducing overall fodder production. Another factor could be the optimal supply of belowground resources (water and nutrients) for trees with wider spacing, which allocates more nutrients for developing greater leaf biomass than trees with close spacing (Eshete *et al.*, 2022) [5].

Torchwood yield (kg tree $^{-1}$): It is evident from the data presented in Table 2 that, among the three spacings, the torchwood yield of *Grewia* trees ranged from 3.54 kg tree^{-1} to 5.51 kg tree^{-1} in the years 2021-22. During the year 2022-23, the torchwood yield varied from 3.44 kg tree^{-1} to 5.65 kg tree^{-1} under three tree spacings: S_1 (8 × 1 m), S_2 (8 × 2 m), and S_3 (8 × 3 m). The highest torchwood yield was under the widest tree spacing (S_3) in both years, whereas the mean minimum (3.44 kg tree^{-1}) was recorded in S_1. As a result of its more extensive crown spread, more branches, and more leaves, the wider spacing, i.e., 3m spacing, is found to be ideal for producing higher leaf biomass, torchwood, and bast fiber yield. Planting trees at wider spacing increased the proportion of biomass allocated to roots, branches, and leaves for several growing seasons due to the increased volume of soil available to each tree and the space available for individual crown development (Bebre *et al.*, 2022) [2].

Bast fibre (g tree $^{-1}$): It is evident that among different tree spacings (Table 2), the bast fiber content of *Grewia* trees ranged from 510.48 g tree^{-1} to 713.56 g tree^{-1} in the year 2021-22, while during 2022-23, bast fiber per tree varied from 492.34 g tree^{-1} to 722.12 g tree^{-1}. In an agroforestry system, bast fiber accretion per tree increases with increasing tree spacing, i.e., maximum bast fiber production per tree at the widest spacing and vice versa. Bast fiber is a plant fiber extracted through the retting process from the inner bark, i.e., phloem, of *Grewia* branches. Trees with more leaf area are exposed to more sunlight, resulting in optimal photosynthesis and, thus, optimized carbon fixation. This might be the reason for reducing bast fiber per tree under the closest spacing (S_1) to the widest spacing (S_3). Another explanation could be that wider spacing encourages trees to have more active crowns that produce the most juvenile wood fibers. A positive correlation between tree growth and the characteristics of wood fiber was also noted by Doungpet (2005) [4].

Leaf area index (LAI): The observations on the leaf area index presented in Table 3 reflect that during the year 2021-22, among the three tree spacings, the leaf area index ranged from 0.86 to 1.22, and during the year 2022-23, it ranged from 0.80 to 1.20 under the three tree spacings S_1 (8 × 1 m), S_2 (8 × 2 m), and S_3 (8 × 3 m). This dimensionless parameter describes the overall area of leaf tissue per unit of ground surface area. The leaf area index regulates the microclimate beneath the canopy, radiation interception, and the exchange of water and carbon gas, influencing the entire agroforestry ecosystem. The increase in leaf area index under the narrowest spacing (8 × 1m) in both cropping years (2021-22 and 2022-23, respectively) could be attributed to light competition, which resulted in increased canopy density (Li *et al.*, 2014) [8].

Photosynthetic active radiation (μmolm^{-2}s^{-1}): The understorey photosynthetic active radiation ranged from 252.23 (μmolm^{-2}s^{-1}) to 421.23 (μmolm^{-2}s^{-1}) in the years 2021–2022 for the three different tree spacings. Contrarily, between 2022 and 2023, understorey photosynthetic active radiation under various tree spacings varied from 254.22 (μmolm^{-2}s^{-1}) to 433.23 (μmolm^{-2}s^{-1}). In the current situation, wider tree spacing improved the penetration of solar radiation in *G. optiva* based agroforestry and vice versa.

Understorey photosynthetic active radiation, as a micro-meteorological parameter, is the amount of light available for crop photosynthesis and is regulated diurnally. It is also regulated by tree stocking and species in the agroforestry system. The present study found reduced understorey photosynthetic active radiation (PAR) levels in a *G. optiva* based agroforestry system with narrow spaced trees (8 × 1 m). It could be because densely stocked trees have a higher leaf area index (LAI), which reduces understorey photosynthetic active radiation flux more than widely spaced trees.

The variation in understorey photosynthetic active radiation is largely due to differences in crown architecture among different tree spacings. The PAR levels were lower in narrowly spaced *Eucalyptus deglupta* hedgerows than in widely spaced hedgerows (Abas *et al.*, 2015) [1]. The canopy architecture and leaf area index (LAI) of the *Grewia optiva* tree determine PAR underneath the tree. The linear regression analysis between PAR and LAI values was inverse and significant (Fig. 1). LAI was maximum at closer spacing (S_1), thereby obstructing incoming PAR and resulting in lower values of PAR. As the LAI has increased ($S_3 < S_2 < S_1$), the PAR has decreased ($S_3 > S_2 > S_1$) under three tree spacings.

Conclusion

G. optiva reaches its maximum biomass and growth characteristics at an 8 x 3m spacing. Therefore, it can be concluded that the spacing of trees at 8 x 3m in the *Grewia optiva* based agroforestry model can be considered an optimum spacing in the mid-hills of Himachal Pradesh.

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Table 1: Tree height (m), diameter at breast height (cm), and crown spread (m) of *Grewia optiva* trees planted at three spacings in agroforestry system in 2021-22 and 2022-23

Tree	Tree height (m)	D.B.H (cm)	Crown spread (m)	Number of branches

spacings	(Mean ± SEM)		(Mean ± SEM)		(Mean ± SEM)		(Mean ± SEM)	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
S_1 (8 × 1 m)	4.80 ± 0.33	4.74 ± 0.25	14.08 ±0.14	14.14 ± 0.06	1.32 ± 0.03	1.47 ± 0.04	3.14 ± 0.01	3.35 ± 0.02
S_2 (8 × 2 m)	5.51 ± 0.27	5.65 ± 0.14	14.42 ± 0.11	14.92 ± 0.10	1.78 ± 0.02	1.90 ± 0.03	4.24 ± 0.02	4.46 ± 0.01
S_3 (8 × 3 m)	6.34 ± 0.04	6.30 ± 0.21	16.30 ± 016	16.32 ± 0.20	2.12 ± 0.01	2.30 ± 0.01	4.52 ± 0.03	4.82 ± 0.01

Table 2: Fodder yield (kg tree $^{-1}$), torchwood yield (kg tree $^{-1}$), and bast fibre (g tree $^{-1}$) of *Grewia optiva* trees planted at three spacings in agroforestry system in 2021-22 and 2022-23

Tree spacings	Fodder yield (kg tree $^{-1}$) (Mean ± SEM)		Torchwood yield (kg tree $^{-1}$) (Mean ± SEM)		Bast fibre yield (g/tree) (Mean ± SEM)	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
S_1 (8 × 1 m)	4.68 ± 0.03	4.52 ± 0.04	3.54 ± 4.23	3.44 ± 4.10	510.48 ± 4.62	492.34 ± 4.22
S_2 (8 × 2 m)	5.64 ± 0.02	5.50 ± 0.06	4.46 ± 3.26	4.52 ± 5.24	640.36 ± 3.35	620.21 ± 5.92
S_3 (8 × 3 m)	6.92 ± 0.01	6.48 ± 0.06	5.51 ± 2.24	5.65 ± 6.21	750.62 ± 2.56	722.12 ± 5.64

Table 3: Leaf area index (LAI) and photosynthetic active radiation (µmol m^{-2} s^{-1}) of *G. optiva* trees planted at three spacings in the agroforestry system in 2021-22 and 2022-23

Tree spacings	LAI		PAR (µmol m^{-2} s^{-1})	
	2021-22	2022-23	2021-22	2022-23
S_1 (8 x 1 m)	1.22 ±0.02	1.20 ±0.01	252.23 ± 5.21	254.22 ± 4.43
S_2 (8 x 2 m)	1.12 ±0.03	1.10 ±0.03	324.32 ± 4.22	316.32 ± 3.56
S_3 (8 x 3 m)	0.86 ±0.01	0.80 ±0.02	421.23 ± 3.16	433.23 ± 3.26

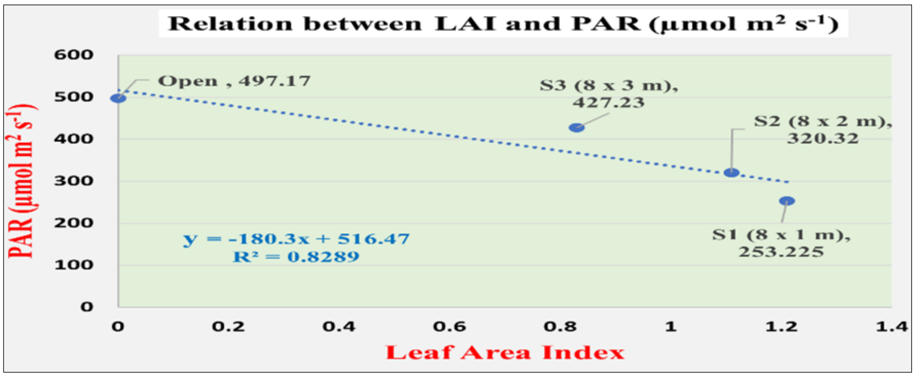

Fig 1: Relation between leaf area index (LAI) and photosynthetic active radiation (PAR) under tree spacings of *Grewia optiva* (Average values of 2021-22 and 2022-23)

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