



Growth, Biomass and Carbon Sequestration Potential of Broad Leaf Forest in North-West Himalayas

Rupinder Kaur¹, Versha Upadhyay², Shikha Bhagta³, Kanchan Chatterjee⁴,
Tanuja⁵, Krishan Pal Singh Rana⁶, Simrat Kaur⁷

10.18805/ag.D-6380

ABSTRACT

Background: Quantifying the growth patterns, biomass production and carbon storage capability of different forest types has gained more attention in recent decades due to the global focus on climate change and carbon budgeting. Depending on their condition, age, species makeup and management techniques, forests can be both generators and sinks of carbon. Significant carbon reservoirs can be found in the North-Western Himalayan broadleaf forests, which are frequently distinguished by their multi-layered canopies and abundant understory vegetation.

Methods: The current investigation was carried out in the broad leaf forest of Solan district in Himachal Pradesh from 2020-21 to 2021-22. The study region belongs to subtropical to sub temperate climatic zone. The identified research area was split into five replicates of 10 × 10 m each. All of the trees in each replication were chosen and counted. A total of 41 trees from the broad leaf forest were chosen and the tree species included. *Bauhinia variegata*, *Grewia optiva*, *Pinus roxburghii*, *Toona ciliata* and *Quercus leucotrichophora*. Tree biomass and growth at the study site were counted. The following growth metrics were measured: total tree height, crown length, crown spread, crown index and Dbh. Volume equations were used to estimate biomass. Growth and biomass metrics were averaged (Mean+S.E.).

Result: Present study provided the information about growth of broad leaf forest, its biomass and capacity to sequester carbon in the mid-hill Himalayas. With a height of 18.33 metres, *Pinus roxburghii* dominated the forest tree stand while *Bauhinia variegata* had height and crown spread of 5.06 m and 0.57 m, respectively. The calculated total biomass of broad leaf forest was 407.48 Mg/ha/year, that might have contributed to the total carbon stock of 183.36 Mg/ha/year. Carbon was sequestered by broad leaf forest at a rate of 672.95 Mg/ha/year. The findings indicated that excellent management methods are necessary for such forests to have improved soil and carbon-storing capacity.

Key words: Biomass, Broad leaf forest, Carbon allocation, Carbon sequestration.

INTRODUCTION

The Himalayan forest's vegetation varies from timberline to tropical dry deciduous woodlands on the slopes. Forests are the primary source of income for individuals living in the Himalayan foothills. The mid-hill forest is dominated by *P. roxburghii* and *Q. leucotrichophora*. Temperate forests of the Western and Central Himalaya range in elevation from 1200 to 3000 metres above sea level and are distinguished by large oak and coniferous woods (Kumar and Bhatt, 2006). The peasants rely heavily on *Q. leucotrichophora* for fuel, fodder and other necessities. Because it is primarily used for fuel, fodder and small timber, oak is the most preferred tree species in the temperate region. Without a doubt, forests are the primary land-based CO₂ sinks (Houghton *et al.*, 2001). Forest ecosystems are crucial to regional and global terrestrial carbon cycles because they store a lot of carbon in vegetation, detritus and soil and exchange a lot of carbon with the atmosphere through respiration and photosynthesis. Since carbon makes up over half of the dry biomass weight of a forest, the amount of carbon that the forest sequesters (or loses) can be estimated from biomass accumulation (FAO, 2005).

¹Department of Agriculture Tula's institute, Dehradun-248 001, Uttarakhand, India.

²Department of Botany, Maya Devi University, Dehradun-248 001, Uttarakhand, India.

³Department of Tree Improvement and Genetic Resources, Krishi Vigyan Kendra, Shimla-171 207, Himachal Pradesh, India.

⁴Department of Zoology, Dev Bhoomi Uttarakhand University, Dehradun-248 001, Uttarakhand, India.

⁵Department of Applied Science and Humanities, Tula's institute, Dehradun-248 001, Uttarakhand, India.

⁶Department of Agriculture, Uttaranchal College of Science and Technology, Dehradun-248 001, Uttarakhand, India.

⁷Department of Chemistry, Mata Gujri College, Fatehgarh Sahib-140 406, Punjab, India.

Corresponding Author: Rupinder Kaur, Department of Agriculture Tula's institute, Dehradun-248 001, Uttarakhand, India. Email: roopnarang@gmail.com

How to cite this article: Kaur, R., Upadhyay, V., Bhagta, S., Chatterjee, K., Tanuja, Rana, K.P.S. and Kaur, S. (2025). Growth, Biomass and Carbon Sequestration Potential of Broad Leaf Forest in North-West Himalayas. *Agricultural Science Digest*. 1-5. doi: 10.18805/ag.D-6380.

Submitted: 31-05-2025 **Accepted:** 21-07-2025 **Online:** 22-08-2025

Forests play a vital role in regulating the global carbon balance. Increased forest biomass promotes atmospheric carbon sequestration, whereas decreased forest biomass adds to CO₂ emissions. To calculate the entire carbon content stored in a forest ecosystem, the aboveground biomass content must be estimated. As trees get bigger and their biomass rises, they take in more carbon from the environment and store it in their tissues, which causes different portions to develop (Matthews *et al.*, 2000). When forests are managed to fulfil emission objectives, the quantity of carbon that may be emitted to the atmosphere or sequestered on the land is determined by the amount of biomass in the forest. The assumption that 50% of biomass contains carbon (on a dry weight basis) is widely accepted (Hamburg, 2000; Brown, 2001).

SOC dynamics and carbon flow are greatly influenced by land use and soil management practises (Tian *et al.*, 2002 and Rasse *et al.*, 2006). According to Brown (1997), roughly 50% of tree biomass is carbon. However, these ecosystems are increasingly threatened by anthropogenic pressures such as deforestation, land-use change, grazing and the impacts of climate variability. The forest and agro-forestry ecosystem contribute significantly to carbon cycling and helps to mitigate climate change because it is dominated by perennial vegetation, which has a larger capacity to store carbon (Sarkar *et al.*, 2021; Nthebere *et al.*, 2022; Jayara *et al.*, 2023 and Namitha *et al.*, 2025). Nonetheless, the dynamics of nutrients in the terrestrial ecosystem were altered by increasing urbanization and human activities (loss of biodiversity, altered land use, degradation of forests and deforestation). It is impossible to undervalue the contribution that trees outside of forests provide to improving lifestyles and providing ecological benefits.

The main objective of this study is to estimate tree biomass and carbon sequestration rates in broadleaf forests. Data were based on tree species measurements in broadleaf forests collected in the years 2020-21 and 2021-22. Forests play an important role in development, livelihoods and climate. They provide wood and non-wood products and agricultural tools to mountain people, as well as improving soil fertility and controlling erosion. The forest composition in the mountain area varies according to altitude, climate, aspect, slope and soil characteristics.

MATERIALS AND METHODS

Study area

The current investigation was carried out in the broadleaf forest of Solan district in Himachal Pradesh. The region is

bounded by latitudes of 30°50'30" N-30°52'0" N and longitudes of 77°8'30" E-77°11'30" E. The study was conducted from 2020-21 and 202-22. The soil is gravel, sandy with loam texture and it is classified as an inceptisols. The research area was split into five replicates of 10 × 10 m each. All of the trees in each replication were chosen and counted. Each replication had all of the trees picked and counted. In total, 41 trees from the broad leaf forest were chosen. *Bauhinia variegata*, *Grewia optiva*, *Pinus roxburghii*, *Toona ciliata* and *Quercus leucotrichophora* were the tree species.

Biomass estimation of tree species

Five sample plots (10 × 10 m) were established in the broadleaf forest and diameter at breast height (DBH at 1.37 m) was measured for every standing tree (Feldpausch *et al.*, 2011) in the sample plots (total 41 trees). Growth and above ground biomass of trees falling in these sample plots were enumerated. All trees were counted in order to calculate height, clear bole, crown spread, crown length and crown index. Diameter at breast height (dbh), crown length and crown diameter were measured with measuring tape. Total height of the tree was measured using Clinometer. The crown spread was established for each tree by measuring the length and breadth of the crown. The area (LxB) to first place of decimal was taken as the crown spread. Crown length is the height of the tree up to the point where the crown branches started was measured and subtracted from the actual height of the tree to know crown length of a tree. Crown Index is the ratio of crown length to the crown width (crown spread).

$$\text{Crown Index} = \frac{\text{Crown length (m)}}{\text{Crown spread (m)}}$$

The allometric volume equations approach was used to determine the biomass of the trees. The biomass of tree species was determined by measuring their diameter and height and applying the volumetric formulae provided by the Forest Survey of India (FSI, 1996), as shown in Table 1. Above ground biomass of tree species was estimated using following equation:

$$\text{AGB} = \text{Volume} \times \text{Specific gravity}$$

Below ground biomass of tree sp. present in broad leaf forest was estimated by multiplying aboveground biomass with a factor of 0.26 (IPCC, 2003). Total biomass per tree was obtained by summing AGB and BGB for each sample tree and averaging the samples. The average tree biomass was multiplied by a factor of 0.45 to determine

Table 1: Volume equations and specific gravity values used for biomass estimation.

Tree name	Volume equations of tree species	Specific gravity value
<i>Bauhinia variegata</i>	$V/D^2 = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454 D$	0.67
<i>Toona ciliata</i>	$V/D^2 = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454 D$	0.42
<i>Grewia optiva</i> / <i>G. oppositifolia</i>	$V/D^2 = 0.007602/D^2 - 0.033037/D + 1.868567 + 4.483454 D$	0.64
<i>Pinus roxburghii</i>	$V/D^2 = 0.167095/D^2 - 2.085944/D + 9.929936$	0.49
<i>Quercus leucotrichophora</i>	$\sqrt{V} = 0.240157 + 3.820069 D - 1.394520 \sqrt{D}$	0.82

the carbon stock of the broadleaf forest (Sheikh *et al.*, 2011b).

Biomass estimation of under storey vegetation and litter

The biomass of shrubs and herbs was also calculated using the destructive harvest approach. In total 15 quadrates (50 × 50 cm) were laid out for herbs and shrubs, respectively. All of the species found in each quadrate were harvested. The total number of shrubs of each species was counted in a quadrate. Shrubs falling in the quadrate were uprooted and brought to laboratory. They were separated in to shoot, branches and leaves and their fresh weight was taken. Samples were stored in paper bags and oven dried at 70°C until the weight is stable for biomass estimation. After that, the biomass values were multiplied by the expansion factor to get an area of one hectare. Similarly, litter biomass was estimated.

$$\text{Moisture Content \%} = \frac{(\text{Fresh weight} - \text{Dry weight})}{\text{Dry weight}} \times 100$$

Biomass was calculated as follow:

$$\text{Biomass} = \frac{100 \times \text{Fresh weight}}{100 + \text{Moisture content}}$$

Carbon sequestration

For the estimation the carbon stock of the forest system the aboveground and belowground tree biomass was added and multiplied with a co-efficient of 0.45 (Sheikh *et al.*, 2011b). By including the carbon stocks of trees, shrubs, herbs and litter, the carbon stock of a broadleaf forest was calculated. Utilizing the following formula, the carbon inventory of the broadleaf forest was determined. Carbon sequestered=Biomass carbon stock × 3.67 (Rajput, 2010).

RESULTS AND DISCUSSION

Trees morphology, biomass and carbon sequestered

Trees present in the study area were *B. variegata*, *T. ciliata*, *P. roxburghii* and *Q. leucotricophora*. Among these *Pinus* dominated the forest stand with a mean height of 18.33 m and dbh of 27.45 cm. Average height and crown spread in *B. variegata* was 5.06 m and 0.57 m and in *Q. leucotricophora* mean height and crown spread were 17.62 m and 1.51 m, respectively (Table 2). *Q. leucotricophora* showed highest dbh, crown spread, crown length and crown index. Nautiyal and Singh, (2013) also reported that the dbh and height in *Rhododendron arboreum*, *Myrica esculenta* and *Quercus leucotricophora* in oak dominated forest of Gopeshwar was 20.46 cm, 28 cm and 150.57 cm and 2.83 m, 6.37 m and 14.75 m, respectively.

Total mean tree biomass of individual species in the present study was in order: *B. variegata* (24.93 Mg/ha) < *T. ciliata* (26.65 Mg/ha) < *P. roxburghii* (151.48 Mg/ha) < *Q. leucotricophora* (172.31 Mg/ha) as given in the Table 3. Both aboveground and belowground biomass followed the same pattern. The maximum above ground biomass was recorded for *Q. leucotricophora* (136.75 Mg/ha) and minimum for *Bauhinia variegata* (19.79 Mg/ha). The maximum and minimum above ground carbon stock was 61.54 Mg/ha for *Q. leucotricophora* and 8.90 Mg/ha for *B. variegata*. The total tree carbon stock was recorded maximum (77.54 Mg/ha) for *Q. leucotricophora* and minimum (11.21 Mg/ha) for *B. variegata*. Present study's findings are in line with those of Rawat and Singh, (1988), who also documented above-ground biomass in oak forests (291.4 Mg/ha) and mixed oak-pine forests (325.8 Mg/ha). Compared to other Indian oak and mixed forests,

Table 2: Morphological attributes of trees under broad leaf forest during study period.

Tree species	Dbh (cm)	Height (m)	Clear bole (m)	Number of branches	Crown spread (m)	Crown length (m)	Crown index (m)
<i>Bauhinia variegata</i>	12.22±2.28	5.06±0.41	3.19±0.41	10.3±2.73	0.57±0.07	1.87±0.24	3.33±0.41
<i>Toona ciliata</i>	35.62±5.91	14.77±1.89	8.26±1.00	15.0±1.53	1.23±0.05	6.51±0.89	5.10±0.91
<i>Pinus roxburghii</i>	27.45±1.71	18.33±1.56	12.73±1.41	33.0±1.53	1.09±0.08	5.61±0.39	4.54±0.29
<i>Quercus leucotricophora</i>	132.58±28.37	17.62±1.18	7.73±0.50	20.0±0.58	1.51±0.22	14.0±1.08	9.50±0.73

Values are Mean ± standard error.

Table 3: Biomass and carbon stocks in trees under Broad leaf forest during study period.

Tree species	Average tree above ground biomass (Mg/ha/year)	Average tree below ground biomass (Mg/ha/year)	Total tree biomass (Mg/ha/year)	Average above ground carbon stock (Mg/ha/year)	Average below ground carbon stock (Mg/ha/year)	Total carbon stock (Mg/ha/year)
<i>Bauhinia variegata</i>	19.79±2.56	5.14±0.67	24.93±3.23	8.90±1.15	2.31±0.30	11.21±1.45
<i>Toona ciliata</i>	21.16±2.78	5.50±0.72	26.65±3.50	9.51±1.25	2.47±0.32	11.98±1.57
<i>Pinus roxburghii</i>	126.24±6.90	25.24±1.38	151.48±8.28	56.80±3.11	11.36±0.62	53.16±18.57
<i>Quercus leucotricophora</i>	136.75±5.55	35.56±1.44	172.31±6.99	61.54±2.50	16.0±0.65	77.54±3.15

Values are Mean±standard error.

many broadleaf forests have higher above-ground biomass (Rawat and Singh, 1988 and Sharma *et al.*, 2010). Total carbon stock of broadleaf forest was 183.36 Mg/ha/year and it sequestered 672.93 Mg/ha/year carbon (Table 3).

Total biomass of land use system is 407.48 Mg/ha/year which is sum total of tree biomass (375.38 Mg/ha/year), shrubs biomass (12.63 Mg/ha/year), herbs biomass (7.84 Mg/ha/year) and litter biomass (11.23 Mg/ha/year). Total carbon stock of broad leaf forest was 183.36 Mg/ha/year and carbon sequestered was 672.95 Mg/ha/year which is comparable with outcomes of studies by Siddiqui and Lodhiyal, 2023, Lodhiyal *et al.*, 2013; Kothai and Geetha, 2025. According to present study, broadleaf forests dominated by oak trees were rich in stocked carbon. Other tree sp. can freely flourish in the microclimate that oak forest stands provide. Oak woods (*Q. leucotricophora*) are more potent and promising in terms of storing carbon (77.54 Mg/ha/year) and so reducing the effects of climate change.

CONCLUSION

The current survey leads to the following conclusions: broad leaf forests with better management inputs and lower usufruct extraction show better health than forest areas with higher anthropogenic pressure, poorer management inputs and less usufruct extraction from neighbouring villages. In addition to these factors, the current soil and climate are believed to have contributed to the vegetation structure and abundance of the region's broadleaf forests. Therefore, more management and scientific input is needed to preserve those forests that are under anthropogenic stress and are deteriorating. To allow these trees to continue storing atmospheric carbon and thus to help preserve a significant amount of carbon sequestered.

ACKNOWLEDGEMENT

Authors are grateful to Department of biological and environmental sciences and also to Vice-Chancellor, Shoolini University, H.P., for providing necessary facilities and co-operation throughout for conducting the present study.

Conflict of interest

The authors say that there is no conflict of interest.

REFERENCES

- Brown, S. (1997). Estimating Biomass and Biomass Change of Tropical Forests. FAO Forestry Paper. 134. A Forest Resources Assessment Publication. Rome.
- Brown, S. (2001). Measuring and monitoring carbon benefits for forest-based projects: Experience from pilot projects, can carbon sinks be operational? Resources for the Future (RFF) workshop proceedings. Washington DC. pp 1-19.
- FAO (Food and Agriculture Organization) (2005). Land Cover Classification System: Classification Concepts and user Manual. Editors Gregorio A.D. and Louisa J.M.J. Environment and Natural Resources. Rome, Italy 8.
- Feldpausch, T. R., Banin, L., Phillips, O. L., Baker, T. R., Lewis, S. L. *et al.* (2011). Height-diameter allometry of tropical forest trees. *Biogeosciences*. **8**(5): 1081-1106.
- Forest Survey of India. (1996). Volume Equations for Forests of India, Nepal and Bhutan, Forest Survey of India Ministry of Environment and Forests, Govt. of India.
- Hamburg, S.P. (2000). Simple rules for measuring changes in ecosystem carbon in forestry-offset projects. *Mitigation and Adaptation Strategies for Global Change*. **5**: 25-37.
- Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., Vander, L.P.J., Dai, X., Maskell, K. and Johnson, C.A. (2001). Climate Change: The Scientific Basis, Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge.
- IPCC (2003). Intergovernmental Panel on Climate Change. Good Practice Guidance for Land use, Land use Change and Forestry. Published by the Institute for Global Environmental Strategies for the IPCC. Publishers Institute for Global Environmental Strategies, Japan.
- Jayara, A.S., Pandey, S., Bhatt, M.K. (2023). Carbon Sequestration as Influenced by Cropping Practices: A Review. *Agricultural Reviews*. **44**(4): 477-484. doi: 10.18805/ag.R-2253.
- Kothai, S. and Geetha, S. (2025). Carbon sequestration through miyawaki plantation. *Agricultural Science Digest*. 1-9. doi: 10.18805/ag.D-6338.
- Kumar, M. and Bhatt, V.P. (2006). Plant biodiversity and conservation of forests in foot hills of Garhwal Himalaya. *J. of Ecology and Application*. **11**(2): 43-59.
- Lodhiyal, L.S., Lodhiyal, N. and Kapkoti, B. (2013). Structure and diversity of tree species in natural forest of Kumaun Himalaya in Uttarakhand. *Journal of plant Development science*. **5**(2): 97-105.
- Matthews, E., Payne, R., Rohweder, M. and Murray, S. (2000). Forest ecosystem: Carbon storage sequestration and carbon sequestration in soil. *Global Climatic Change Digest*. **12**(2).
- Namitha, V.V., Raj K., Sheeja and Prathapan, K. (2025). Carbon sequestration potential in coconut based cropping system: A review. *Agricultural Reviews*. **46**(1): 143-146. doi: 10.18805/ag.R-2553.
- Nautiyal, N. and Singh, V. (2013). Carbon Stock Potential of Oak and Pine Forests in Garhwal Region in Indian Central Himalayas. **2**(1): 43-48.
- Nthebere, K., Sharma, S.H.K., Kumari, P.C. and Qureshi, A.A. (2022). Long-term effect of different cropping systems on carbon sequestration in a sandy loam soil of Telangana. *Agricultural Reviews*. **43**(2): 249-254. doi: 10.18805/ag.R-2301.
- Rajput, B.S. (2010). Bio-economic appraisal and carbon sequestration potential of different land use systems in temperate north-western Himalayas (Ph.D Thesis). Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.) India.
- Rasse, D.P., Dignac, M.F., Bahri, H., Rumpel, C., Mariotti, A. and Chenu, C. (2006). Lignin turnover in an agricultural field: from plant residues to soil-protected fractions. *European Journal of Soil Science*. **57**: 530-538.
- Rawat, Y.S. and Singh, J.S. (1988). Structure and function of oak forests in central himalaya II. nutrient dynamics. *Annals of Botany*. **62**: 413-427.

- Sarkar, P.K., Sarkar, P., Kumar, A., Pala, N.A. and Kumar, M. (2021). Carbon storage potential of water-logged agroforestry system of Tripura, India. *Water, Air, Soil Pollution*. **232**: 151.
- Sharma, M.C., Badunu, P., Narendra, Gairola, S., Ghildiyal, S.K. and Suyal, S. (2010). Tree diversity and carbon stocks for some major forest types of Garhwal Himalaya, India. *Forest Ecology and Management*. **260**: 2170-2179.
- Sheikh, M.A., Kumar, M., Bussman, R.W. and Todaria, N.P. (2011b). Forest carbon stocks and fluxes in physiographic zones of India. *Carbon Balance and Management*. **6**: 15.
- Siddiqui, F. and Lodhiyal, L.S. (2023). Tree Structure Analysis, Biomass and Carbon Stock of Sal Forests in Central Himalayan Region. **18(1)**: 107-115.
- Tian, H., Melillo, J.M. and Kicklighter, D.W. (2002). Regional carbon dynamics in monsoon Asia and implications for the global carbon cycle. *Global Planet Change*. **37**: 201-217.