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BIOMASS ALLOCATION AND CARBON STOCK OF EXISTING AGROFORESTRY SYSTEM IN MID-HILLS OF HIMACHAL PRADESH, INDIA

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ABSTRACT

Carbon is a crucial element in forest ecosystem that trees have to accumulate and use to support their structure as well as to sustain physiological processes. The mid-hill Himalayan agro forestry system includes the essential tree species *Toona ciliata*, *Grewia optiva* and *Bauhinia variegata*. Present study aimed to estimate total biomass and carbon stock of existing agroforestry system of District Solan (H.P.), using biomass equations. This estimation is valuable for sustainable forest management, as it helps to assess changes following interventions and supports the future conservation efforts. *Toona ciliata*, *Grewia optiva* and *Bauhinia variegata* each had a total biomass (AGB+BGB) estimate of 31.29, 30.40, and 25.92 Mg/ha, respectively. *Toona ciliata* had the highest total carbon store (1.02 times greater at 14.08 Mg/ha) than *Grewia optiva* (13.68 Mg/ha). The total biomass of the agroforestry system, which includes both the biomass of the trees (87.6 Mg/ha/year) and the biomass of the crops (2367.64 Mg/ha/year), was 2455.25 Mg/ha/year. The total carbon stock of the land use system was 1104.86 Mg/ha/year. Agroforestry land use system sequestered 4121.64 Mg/ha/year carbon. Our study built upon the idea that vegetation composition and structural characteristics, in addition to climatic and topographic factors, plays a crucial role in determining biomass and carbon stock in agroforestry ecosystem. It also recommends assessing biomass and carbon stocks to prioritize land use practices tailored to specific tree species, thereby supporting climate change mitigation efforts.

Key words : Agro forestry, Biomass, Carbon stock, Carbon allocation, Above ground biomass, Below ground biomass.

Introduction

Himachal Pradesh's primary land use pattern consists of forests and agricultural areas punctuated by trees and perennial plants. Research on the functions of agro forestry systems as land use has developed as a result of a growing interest in how different types of land use systems affect economics and welfare of the society. In Himachal Pradesh, various methods of land use, such as forestry, plantations and agro forestry, have diverse effects particularly on output, nutrient distribution and carbon sequestration. Agroforestry is a management system that incorporates trees into agricultural landscapes and on farms and results in a diverse and sustainable production system that benefits land users at all levels in terms of the environment, society and economy (Fay *et al.*, 1998; Leakey, 1996 and Sanchez, 1995). Crop fallow rotations, complex agro forests, simple agro forests, silvipastoral systems, and urban agro forestry are only a few of the activities included in agro forestry alongside crops increases the biodiversity as well as it reduces the pressure on natural forests for fuel, improves soil fertility, controls water logging, controls and prevents the soil erosion, checks the eutrophication of rivers and provides fodder for livestock. Additionally, it has the capacity to increase the system's resilience to detrimental effects of climate change (Fujisaka *et al*., 1996; Makundi and Sathaye, 2004). To ascertain the standing biomass of the trees, different non-destructive procedures are popular in addition to destructive methods. In general, well-validated allometric connections between the various tree parts are employed to estimate the standing biomass of the standing tree.

The growth of under storey crops is significantly influenced by the tree architecture. Fast-growing, multipurpose tree species must be integrated onto the cropland in order to address the shortage of fuel and fodder. Under certain circumstances, the crop productivity was lower under tree canopies (Puri *et al*., 1994; Kaur and Puri, 2013 and Kaur *et al*., 2016); whereas in other instances productivity was higher (Belsky *et al*., 1989; Puri and Kumar, 1995). Crop productivity was found to be higher under tree canopies due to improved microclimate, soil and moisture conservation, and increased fertility of the soil, whereas crop productivity was found to be lower due to shade and competition for light, moisture, and nutrients (Schroth, 1999; Kaur *et al*., 2017 and Kaur *et al*., 2024).

For the carbon sink or source of atmospheric CO_2, vegetation is crucial. The leaves use the ambient CO_2 produced by the photosynthesis process to produce food. Different species react to the use of carbon in various ways (Korner, 1993). The main cause of the current global climate change, which has clearly increased the mean global temperature by 0.4°C over the past 70 years for the Indian subcontinent (Negi *et al*., 2003) is the increase in atmospheric CO_2 in combination with temperature rise.

Agroforestry is most important global approach to boost the land-use efficiency while lowering economic, environmental hazards for the farmers (Mey and Gore, 2021 and Paul *et al*., 2017). As evidenced by multiple-purpose trees (e.g., fruits, fuelwood, fodder, gums, resins and timber trees) intentionally retained on farm bunds in hilly areas (Semere, 2019 and Chavan *et al*., 2020), agro forestry has been practiced historically since time immemorial and it's necessary for maintaining sustainability in farming systems. Adoption of agro forestry technology is impacted by physical, demographic and institutional variables (Nath *et al*., 2022). Research has demonstrated that climatic variables, such as temperature and precipitation, impact forest biomass both directly and indirectly by affecting species diversity (Mensah *et al*., 2023).

Materials and Methods

Study area

In the years 2020-2021 and 2021-2022, study was carried out in the village Sultanpur of the Solan district (HP) as given in Fig. 1. The area under study was located between latitudes 30^0 50′30" and 30^0 52′0" North and longitudes $77^0$8′30" and $77^0$11′30" East. The region lies in a transitional climate zone between the subtropical and sub temperate zones, with summertime maximum temperatures reaching 37.8^0C. The majority of the annual rainfall, which ranges between 1000 to 1400 mm, falls between mid-July and mid-September during the monsoon season. Agro forestry practices are followed traditionally in hilly areas which is a combined production system including agricultural crops as well as forest/ fruit/ grasses/ and animals. The trees were scattered in the agricultural fields (terraces) and also on the boundaries. The prominent tree species, crops, fruits and vegetables grown in the study area were: *Toona ciliata*, *Grewia optiva*, *Bauhinia variegata*, *Triticum aestivum* (Wheat*)*, *Vigna mungo* (Black gram), *Brassica campestris* (Sarson), *Zea mays* (Maize), *Solanum lycopersicum* (Tomato), *Capsicum annuum* (Shimla - mirch) and *Pisum sativum* (Pea).

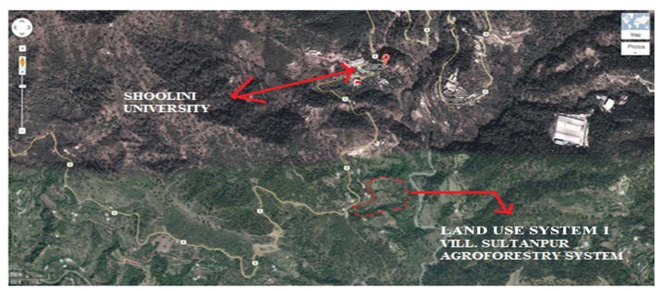

Fig. 1 : Google map showing Land use system (Agro forestry System).

Biomass estimation of tree species

The study area of the agroforestry system was divided equally into five replications of 10×10 m and in each replication all trees were selected and enumerated. A total of 38 trees were found in agroforestry land use systems All the standing trees in the agro forestry system were measured for their diameter at breast height (at 1.3 m) in five sample plots (10×10) that were put up in the system. All trees were counted to determine height, clear bole, crown spread, crown length, and crown index. Utilizing the volumetric formulae provided by Forest Survey of India (FSI, 1996) which is given in Table 1, the biomass of all tree species was estimated. Using biomass equation and specific gravity of tree with the help of allometric model, the biomass and carbon content of each tree were calculated. The above-ground biomass of various tree species was estimated as following:

AGB = Volume × Specific gravity

Below ground biomass of tree sp. present in agro forestry system was estimated by multiplying aboveground biomass with a factor of 0.26 (IPCC, 2003). The total biomass per tree was calculated by adding the AGB and BGB for each sample tree and averaging the samples. The carbon stock of an agroforestry system was determined by multiplying the average tree biomass by a factor of 0.45, as per Woomer (1999) and Sheikh *et al*. (2011b). The data was analysed statistically. Mean values were taken from data available from five sites in triplicates and the standard error of means were determined.

Results and Discussion

The agroforestry system featured dominant tree species such as *Toona ciliata*, *Grewia optiva* and *Bauhinia variegata*, which were assessed for various morphological parameters, biomass, and carbon stock. These three tree species namely *Toona ciliata*, *Grewia optiva* and *Bauhinia variegata* are predominately present in almost all the farms located in midhills of the state (Verma *et al*., 2007). According to Kumar *et al*. (2006), *G. oppositifolia* is favoured by the villagers as a species of fodder because of its high nutritional content, good quality fodder and other characteristics in tropical and sub-tropical communities. In five separate agroforestry systems, according to Kumar and Singh (2009), *G. oppositifolia* was the dominating tree. Studies on the phytosociology of trees in various communities' agricultural systems in temperate zones revealed the species composition that was as follow *Grewia oppositifolia*, *Quercus leucotricophora*, *Celtis australis*, *Melia azedarach* and *Toona serrata* (Sharma *et al*., 2009 and Kala, 2010).

As detailed in Tables 2 and 3, *Toona ciliata* exhibited an average height of 20.0 meters and a crown spread of 1.37 meters. *Grewia optiva* had an average diameter at breast height (DBH) of 15.36 cm, a height of 7.85 meters, a crown spread of 1.08 meters, a crown length of 2.25 meters, and a crown index of 2.75. *Bauhinia variegata* had a DBH of 22.76 cm and a crown spread of 0.87 meters. Notably, *Toona ciliata* had the highest crown index, while *Bauhinia variegata* had the lowest. The species exhibited significant differences in various morphological attributes such as height, crown spread, and DBH. Biomass values were also recorded, with *Toona ciliata* having an average of 31.29 Mg/ha, *Grewia optiva* at 30.40 Mg/ha, and *Bauhinia variegata* at 25.92 Mg/ha. Total biomass contribution by trees (87.61 Mg/ha/year) and crops (2408.1 Mg/ha/year) in agroforestry system was 2495.7 Mg/ha/year. Total carbon stock of land use system was 1123.06 Mg/ha/year and system sequestered 4121.64 Mg/ha/year carbon.

The contribution of biomass depends on various aspects of the tree. The largest biomass in the current study was found in the stem wood, which was followed by branches and leaves. The largest biomass accumulation among the several species examined by Chauhan *et al*. (2009) and Kumar *et al*. (2012) was found in the stem and the smallest was found in the bark. The variation in biomass across various agro forestry trees is an indication that growth is influenced by a variety of elements, including location (environment), management techniques used, age of trees and innate ability (i.e., fast or slow growing tree species). The highest contribution

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

Tree name	Volume equations of tree species	Specific gravity value
Bauhinia variegata	V/D2 = 0.007602/D2-0.033037/D + 1.868567 + 4.483454 D	0.67
Toona ciliata	V/D2 = 0.007602/D2-0.033037/D +1.868567 + 4.483454 D	0.42
Grewia optiva/G. oppositifolia	V/D2 = 0.007602/D2-0.033037/D + 1.868567 + 4.483454 D	0.64

Table 2 : Morphological attributes of trees under agroforestry system during two years of study. Values are Mean ± standard error.

Tree	dbh (cm)	Height (m)	Clear bole (m)	Number of branches	Crown spread (m)	Crown length (m)	Crown index (m)
Toona ciliataa	59.24±6.34	20.00±2.91	15.80±3.05	16.0± 2.52	1.37±0.25	4.20±0.17	3.28±0.61
Grewia optiva	15.36±0.54	7.85± 0.75	3.60±1.20	6.00 ±2.00	1.08±0.10	2.25±0.45	2.75±1.32
Bauhinia variegata	22.76±4.01	4.90± 1.41	3.00 ±0.92	4.00 ±1.15	0.87±0.23	1.90±0.50	2.07±0.24

Table 3 : Biomass and carbon stock in trees under agroforestry system during two years of study. Values are Mean ± standard error.

Tree	Above ground tree biomass (Mg/ha)	Below ground tree biomass (Mg/ha)	Total tree biomass (above+below) Mg/ha	Above ground carbon stock (Mg/ha)	Below ground carbon stock (Mg/ha)	Total carbon stock (above+below) Mg/ha
Toona ciliata	24.85±0.30	6.46±0.08	31.29±0.38	11.18± 0.14	2.90±0.03	14.08±0.17
Grewia optiva	24.13±0.82	6.27± 0.21	30.40±1.03	10.86 ±0.37	2.82±0.10	13.68±0.46
Bauhinia variegata	20.57±2.66	5.34± 0.69	25.92 ±3.35	9.25 ±1.19	2.40±0.31	11.65±1.51

Table 4 : Total Growth, biomass and carbon content in Agro forestry system (Trees and Crops) during two years of study.

Parameters	Agro forestry System
Above ground tree biomass (Mg/ha)	69.55 Mg/ha/year
Below ground tree biomass (Mg/ha)	18.06 Mg/ha/year
Total tree biomass (Mg/ha)	87.6 Mg/ha/year
Total vegetation biomass (trees crops/trees) in Mg/ha/year	2495.7 (87.6 trees+2408.1 crops) Mg/ha/year
Above ground tree carbon stock	31.29
Below ground tree carbon stock	8.12
Total vegetation carbon stock	1123.06 Mg/ha/year
Total vegetation carbon sequestered (Mg/ha/year)	4121.64 Mg/ha/year
Total carbon allocation (leaf + stem + branch + root)	45.95 (trees + crops)

by stem, branches and roots compared to leaves for total biomass was also proved by several workers in young plantations (Puri *et al*., 2002; Swamy *et al*., 2003 and Kumar *et al*., 2021).

Total carbon stock was highest in *Toona ciliata*, at 14.08 Mg/ha, which is 1.02 times greater than that of *Grewia optiva*, which had a total carbon stock of 13.68 Mg/ha. *Bauhinia variegata* had the lowest carbon stock at 11.65 Mg/ha (Table 3). The proportion of above-ground biomass relative to the total biomass was 79.41% for *Toona ciliata*, 79.37% for *Grewia optiva*, and 79.35% for *Bauhinia variegata*, as reported in the present study. The average total carbon stock was highest for *Toona ciliata* (14.08 Mg/ha) and lowest for *Bauhinia variegata* (11.65 Mg/ha). All the species present in agro forestry system showed great potential for C sequestration and CO_2 mitigation. Trees contribute more biomass and consequently store more carbon, but crops in agro forestry still make a major contribution to the production of biomass and carbon stock.

Additionally, agroforestry may offer a natural alternative for resource management that satisfies both forest-based needs and synergizes mitigation and adaptation methods (Komal *et al*., 2022). Based on increased carbon sequestration, agro forestry (Nair, 2007; Birhane *et al*., 2020 and Sarkar *et al*., 2021) has been acknowledged as a GHG mitigation strategy under the Kyoto Protocol (Chandra and Singh, 2018, Yasin *et al*., 2019 and Semere *et al*., 2022). The composition of agro forestry systems is influenced by factors such as temperature, elevation, soil structure, and rainfall patterns (Rajput *et al*., 2017; Birhane *et al*., 2020; Salve and Bhardwaj, 2020; Sharma *et al*., 2023; Nath *et al*., 2022). Because biomass production potential influences how much climate dynamics are influenced at the regional and/or global levels, agro forestry systems are more biologically productive and will become more significant (Rajput *et al*., 2017). Despite the tremendous carbon stock potential of agro forestry systems, further quantitative research at the regional and national levels is necessary (Das *et al*., 2020).

Conclusion

Long-term carbon storage in forest biomass and product pools is greater in forests with longer rotation periods. Significant carbon exchanges between the land and atmosphere are driven by biotic factors and changes in land use. While agroforestry is just one of many potential solutions to address current climate challenges, its implementation can be justified by several additional benefits. These include the positive impact on soil carbon, which enhances agricultural productivity and sustainability. Given that no single mitigation strategy is sufficient on its own, combining various small contributions may be a more practical approach to achieving CO_2 reduction targets. Moreover, agroforestry offers a more cost-effective method of carbon sequestration compared to other CO_2 mitigation strategies. As climate patterns evolve, there is an increasing need to classify plant species based on their effectiveness in responding to elevated CO_2 and climate change. The present study provided valuable data on biomass and carbon stock of agroforestry plant species, thereby accentuating the role of woody plants in carbon sequestration potential. These are baseline data that might attract and help conservation managers, researchers and scientists in understanding the role of agroforestry ecosystems in carbon stocking and sequestration potential.

Consistent with previous studies in the Himalayas, our findings show that a small number of dominant species with large diameters contribute significantly to the carbon stock of these forests. Therefore, it is essential to regulate the harvesting of these species to ensure long-term ecosystem sustainability. Additionally, these findings could aid policymakers and stakeholders in formulating effective management plans and climate change mitigation strategies for the Western Himalayas. Future research is recommended to explore the detailed mechanisms underlying biomass and carbon storage in this region.

Author's contribution

(RK)- Designing of Research Work, Manuscript Preparation and Statistical Analysis; (RK, PH and MC)- Analysis of data and Manuscript Preparation; (RK, KS and SP)- Manuscript Finalization.

Conflict of interest statement

There are no conflicts of interest, according to the authors.

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