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Tree Diversity and the Improved Estimate of Carbon Storage for Traditional Agroforestry Systems in North East India

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Abstract Studies across the world suggest agricultural intensification has been responsible for net gains in human well-being and economic development, but with an increasing cost of degradation of natural resources. The traditional agroforestry systems have been increasingly recognized for its contributions to the sustainable intensification of food production while providing several additional benefits to society. The lack of standard protocol for precise estimation of biomass and carbon storage of traditional agroforestry systems might have undermined the actual potential of such systems in climate change adaptation and mitigation. Therefore, the present study was conducted in an age-old traditionally managed *Piper betle* agroforestry system (PAS) from North East India. The study aimed (i) to estimate the specific gravity (SG) and carbon content (CC) of dominant tree species, and (ii) to establish the relationship of SG, CC, and biomass increment rates for dominant tree species in PAS. A total of 44 tree species with a stem density of 1255 stems ha^{-1} was recorded under the PAS. The diversity index of 3.75 estimated for PAS indicate the traditionally managed agro-ecosystem is more diverse than much tropical and sub-tropical agroforestry and forest ecosystems across the world. The estimated SG and CC ranged from 0.35-0.83 g cm^{-3}, 42.7-48.9% respectively. A positive correlation between SG and CC for dominant tree species may facilitate future prediction of CC for other tree species using the allometric model. The present study suggests a preference for median growth rate tree species for incorporation in future agroforestry expansion or social forestry program may enhance provisioning ecosystem services and nature conservancy.

Keywords: *piper betle agroforestry, specific gravity, carbon content, non-destructive approach, dominant trees*

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1. Introduction

The year 2015 emerged as a pivotal year for climate management when the Parties at COP 21 reached an agreement to limit the average global temperature increase to well below 2°C above preindustrial levels and to pursue efforts to limit warming to 1.5°C [1]. Carbon dioxide removal options have become a common feature in climate change mitigation scenarios that are consistent with the goals of the Paris Agreement [2,3,4]. Given that carbon budgets are tight and rapidly being depleted [5,6] carbon dioxide removal options are more widely used to compensate for temporary budget overshoot [7].

Agroforestry practices entail the integration of trees into agricultural systems, in combination with crops, livestock, or both. Afforestation and reforestation and agroforestry projects form part of several voluntary and mandatory carbon-offset trading schemes worldwide [8,9]. In most documented cases of successful agroforestry, tree-based systems are more productive, more sustainable, and more attuned to people's cultural or material needs than treeless alternatives. Agroforestry also provides significant mitigation benefits by sequestering carbon from the atmosphere in the tree biomass [7]. Among the land-based carbon dioxide removal options, a greater emphasis has been given to forests. Agroforestry systems have been managed by humans since millennia, offer opportunities to meet other global sustainability goals [10] such as improved water quality, ecosystem restoration, biodiversity preservation, food and nutrition security, job creation and improved crop yields have received little attention as a strategy for climate change adaptation and mitigation.

Despite the potential of agroforestry systems to sequester and store carbon, inconsistent methodologies and lack of previous quantitative reviews have held back the implementation of reward schemes for farmers and communities [11]. Some authors [12] call for additional research with improved estimates of biomass carbon stock across geographic regions, to determine the regional potential for development of agroforestry systems, and to assess the potential atmospheric greenhouse gas emission (GHG) reduction at regional and national scales.

Different direct and indirect methods are available for the estimation of biomass of trees [13]. The immediate process involves harvesting the desired number of trees for the development of biomass estimation models while in the indirect one weight or volume of the desired species is calculated from the value of wood specific gravity (SG) and carbon content (CC) [14]. The SG and CC values are limited or not available for the various scales of agroforestry systems [15]. Therefore, limited information on SG and CC for agroforestry tree species may undermine their actual biomass and carbon storage potential.

In the present paper, we aimed to explore the SG and CC for dominant agroforestry tree species managed under the traditional *Piper betle* based agroforestry systems (PAS) in North East India. *Piper betle* locally ‘Paan’ is a perennial creeper cultivated for its leaf. In PAS, *Piper* is managed for commercial benefit and planted as a subordinate crop mixed with different trees. Slash and mulching of woody tree leaves are practiced annually [16] as a strategy for soil nutrient management in PAS. The objective of this paper is (i) to estimate the SG and CC of dominant tree species in PAS, and (ii) to establish the relationship of SG, CC, and biomass increment rate for dominant tree species in PAS.

2. Materials and Methods

2.1. Study Area

The study site (24 48.755 N, 092 33.595 E) was located in Hailakandi district in the state of Assam (Figure 1). The site is located in North East India within the range of the Himalayan foothills and Barak river basin. Hailakandi district occupies an area of 1326.10 km^2. The district has an inter-state border with Mizoram on its south, having a length of 76 km and inter-district borders on other sides with Karimganj and Cachar districts. The average annual temperature in Hailakandi is 24.9°C. The mean annual precipitation is about 3075 mm (https://en.climate-data.org/). Temperatures vary from 13 to 37°C, while mean relative humidity is 93.5% [17]. The North-eastern part of India has a long tradition of agroforestry practices [18] and the state of Assam is one of the states that also practices *Piper betle* based agroforestry. In the present study area, *Piper betle* based agroforestry system is maintained by the Khasi tribe of the district. Soils of the study area are classified as fine loamy, mixed, hyperthermic family of Fluvaquentic Endoaquepts [19].

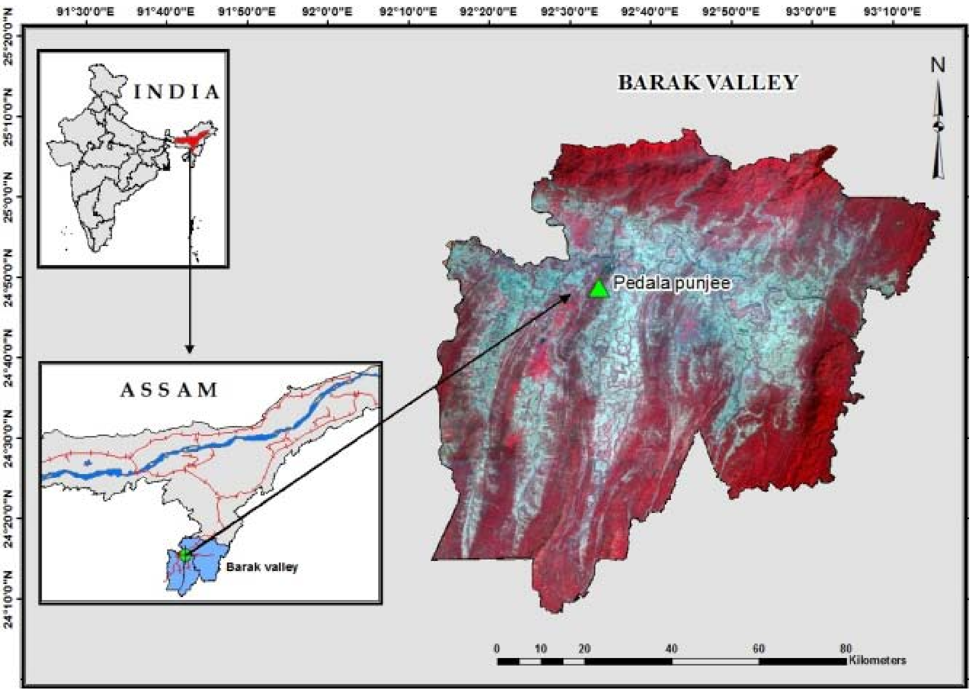

Figure 1a. Map of the study location (Standard False Color Composite image of IRS-P6 LISS4 data)

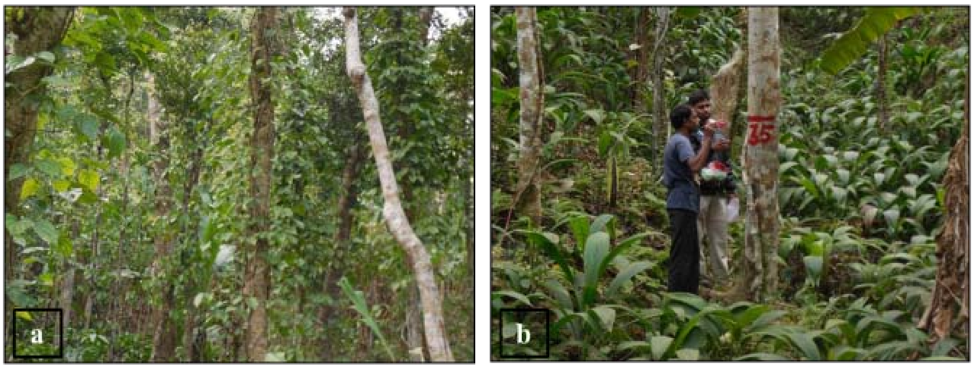

Figure 1b. Traditional Piper betel agroforestry system (PAS) in the study area (a), dendrometric measurement of the tree species in PAS (b)

2.2. About the *Piper betle* Based Agroforestry Systems

Among the different types of agricultural practices, PAS is traditionally practiced by '*khasi*' people an indigenous tribe of North East India. The fresh leaves of betle vine are popularly known as Paan in India, which are consumed by about 15-20 million people in the country and provide an excellent opportunity for livelihood security to the hill farmers [20,21,22]. PAS is a unique example of a traditional farming practice which was adopted by the conventional society as a livelihood security and biodiversity conservation [21,23]. PAS offers viable options for combining biodiversity conservation and management for human benefits. Consequently, the PAS might increasingly become a component of a forested landscape that is valued for contributing towards both resource production and biodiversity conservation [21]. PAS is mainly practiced in hilly terrains.

2.3. Plot Selection for Vegetation Sampling

In the present study, four 250 × 250 m quadrats were selected following the ISRO-GBP/NCP-VCP protocol [24]. In each 250 × 250 m quadrat, four 0.1 ha plots (31.62 × 31.62 m) were laid out at four corners of the quadrat. In each plot, all trees >10 cm girth at the breast height (at 1.37 m from the base) were measured. Thus, all observations were made on a total of 16 plots, each of 0.1 ha area. Tree density (ha^{-1}) was calculated from the expanded values of each 0.1 ha plots by multiplying with 10 and averaged. The basal area (m^2 ha^{-1}) of each plot was derived from the inflated values of each stem into hectare by multiplying the stem density and averaged. The height of each tree was measured using Nikon Laser Forestry Pro (Serial No. 080753). The following methodologies were used to evaluate the different diversity indices, Shannon-Wiener diversity index [25], species richness [26], species evenness [27] and species dominance [28,29,30].

Importance Value Index or IVI of the species was calculated by the following formula [31] as:

$$IVI = Relative\ density + Relative\ frequency + Relative\ dominance$$

2.4. Measuring SG and CC

Two wood cores were extracted from 10 individuals of each tree species at circumference at breast height (CBH) using an increment borer with a sharpened point (inner diameter 5 mm, length 500 mm, Haglof Inc., Sweden). Therefore, 20 wood cores were collected for each species. The wood cores collected were brought to the laboratory and dried in oven for 72 hrs at 65°C. SG was computed following the methods of Perez and Kanninen [32]. Core sub-samples for the 20 tree species that were taken to the laboratory during the SG estimation were powdered and analyzed for the determination of CC. A total of 50% of the ash-free mass was calculated as the CC. The ash content was determined by igniting 1 g of powdered litter sample at 550°C for 6 h in a muffle furnace [33].

3. Results

A total of 44 tree species was encountered in PAS. The stand density and basal area of PAS was 1255 stem ha^{-1} and 29.33 m^2 ha^{-1} respectively. Based on IVI values for the top twenty tree species, the dominant species of PAS was selected. Shannon-Weaver diversity index for PAS was estimated at 3.75. Shimpson diversity, Margalef's species richness and Pielou's species evenness was recorded at 0.03, 7.34, and 0.91, respectively.

Table 1. Annual girth increment, wood specific gravity and carbon content for dominant tree species under traditional *Piper betle* agroforestry system in North East India

Dominant tree species	Girth increment rate (cm yr^{-1})	IPCC Wood specific gravity (g cm^{-3})	Estimated wood specific gravity (g cm^{-3})	Carbon content (%)
Artocarpus lacucha Buch.-Ham.	1.21	0.580	0.556	45.3
Artocarpus chama Buch.-Ham.	1.35	0.580	0.592	46.8
Artocarpus heterophyllus Lam.	0.85	0.580	0.636	46.5
Dysoxylum gobara (Buch.-Ham.) Merr.	1.09	0.570	0.614	45.9
Elaeocarpus serratus L.	1.48	0.400	0.471	43.6
Ficus hispida L.	1.76	0.413	0.398	44.5
Mesua ferrea L.	1.39	0.660	0.711	47.8
Litsea salicifolia (J. Roxb. ex Nees.) Hook. f.	1.10	0.400	0.432	45.2
Litsea sp.	2.28	0.400	0.452	44.8
Memecylon celastrinum Kurz.	0.84	0.900	0.825	48.9
Oroxylum indicum (L.) Vent.	1.71	0.320	0.353	42.7
Semicarpus anacardium L. f.	1.40	0.640	0.581	45.2
Shorea robusta Gaertn.	0.68	0.720	0.656	48.8
Spondias pinnata (L.) Kurz.	1.16	0.358	0.412	43.5
Sterculia villosa Roxb.	1.63	0.255	0.362	43.6
Stereospermum sp.	0.77	0.710	0.688	47.2
Symplocos sp.	1.67	0.593	0.541	44.8
Syzygium cuminii (L.) Skeels	1.34	0.760	0.682	47.6
Terminalia chebula Retz.	1.03	0.880	0.736	46.6
Vitex sp.	1.00	0.650	0.682	47.7

The annual girth increment rate varies from 0.68 (*Shorea robusta*) to 2.28 (*Litsea sp*) (Table 1). The SG ranges from 0.353 (*Oroxylum indicum*) to 0.825 (*Memecylon celastrinum*). The lowest and the highest CC was estimated at 42.7% and 48.9% for *Oroxylum indicum*, and *Memecylon celastrinum* respectively (Table 1). The median values for annual girth increment, SG and CC is presented in Table 2. It was also observed that the SG reported by IPCC differs from that estimated in the present study.

Table 2. Summary statistics for girth increment rate, wood specific gravity and carbon content for dominant agroforestry tree species in North East India

Parameter	Girth increment rate (cm $year^{-1}$)	Wood specific gravity (g cm^{-3})	Carbon content (%)
Min	0.68	0.35	42.7
Max	2.28	0.83	48.9
Mean	1.29	0.57	45.9
Median	1.28	0.59	45.6

The girth increment rate for the 20 dominant trees for the three-year study period is presented in Figure 2. It was found the SG was positively correlated with CC (R^2= 0.82) (Figure 3) and negatively with annual girth increment (R^2= -0.41) (Figure 4). The annual girth increment rate was negatively correlated with CC (R^2= -0.40) (Figure 5).

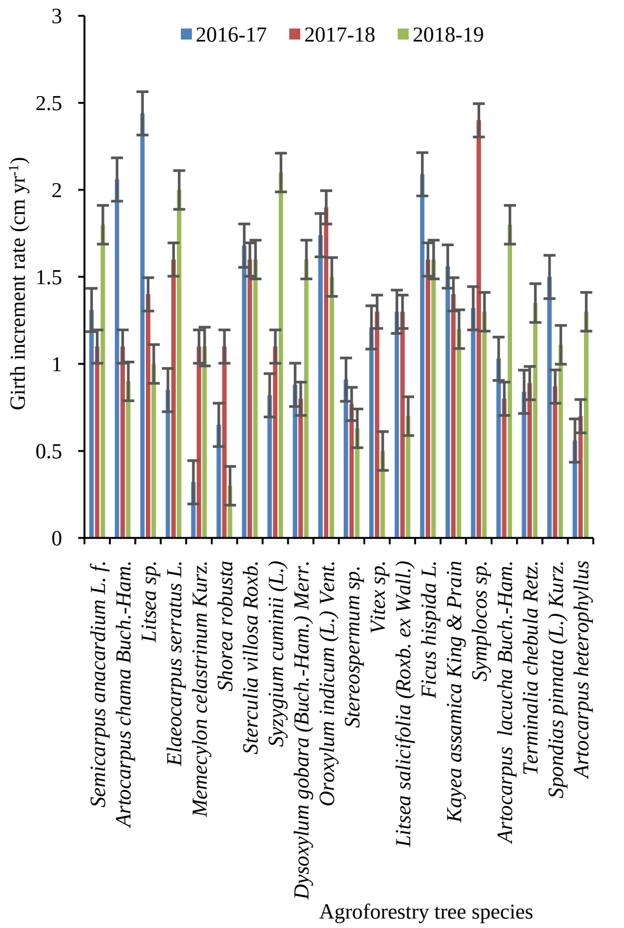

Figure 2. Girth increment rate for dominant agroforestry tree species over three years' study period

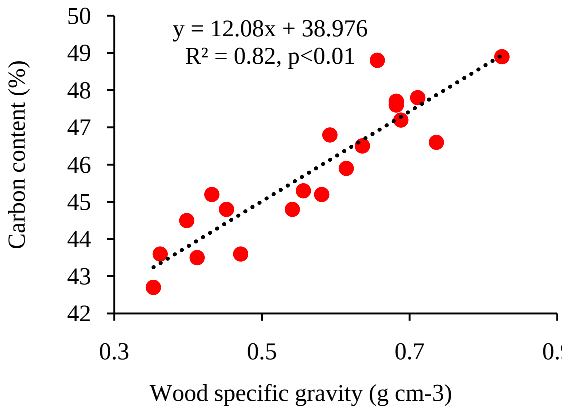

Figure 3. Co-relationship of wood specific gravity with carbon content for dominant agroforestry tree species

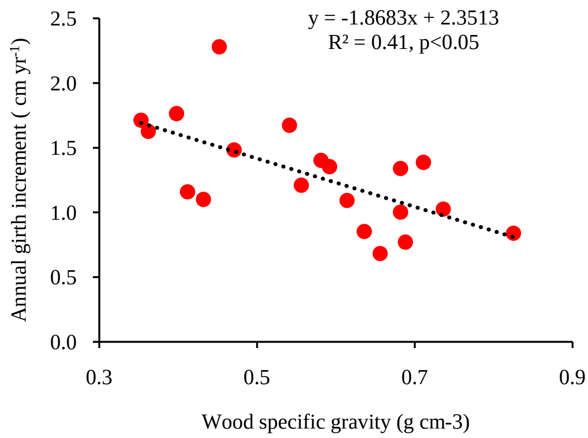

Figure 4. Co-relationship of wood specific gravity with annual girth increment for dominant agroforestry tree species

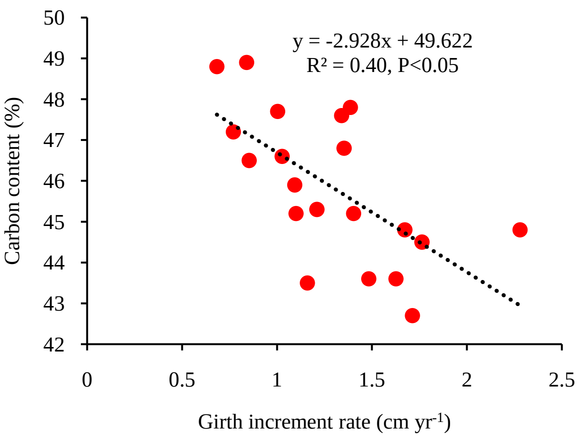

Figure 5. Co-relationship of annual girth increment with carbon content for dominant agroforestry tree species

4. Discussions

Composition of the tree species in the PAS complies with the earlier reports from the traditional agroforestry systems the same region [21,34] and other parts of the country [35,36,37]. However, it was more than the other sugarcane (*Saccharum officinarum*), sweet potato (*Ipomoea batatas*), and pineapple (*Ananas comosus*) based agroforestry systems of elsewhere [38,39]. Tree density of the present study was observed to be more than the earlier reported density values of agri-horticulture, agri-horti-silviculture and agri-silviculture of North Western Himalayas of India [37] and PAS of North East India [21] and similar to the study reports of Wari et al [40] in homegarden and grazing lands of South-western Ethiopia.

In comparison to the earlier report on PAS [21] diversity index was found to be more in the present study. Shannon index was found in compliance with the reports from homegardens of Assam [41], tropical forest of Eastern Ghats, India [42], agroforestry systems of Uttar Pradesh, India [36] and more than that from Agri-horticulture, Agri-silviculture and Agri-horti-silviculture systems of North-western Himalayas [37] and tropical moist forest of Mizoram [43]. PAS is calculated to have more evenness index than the studies conducted on different systems elsewhere around the globe [40,42,43]. Data presented indicates PAS in the present study is more diverse and characterize with high tree density. Therefore, this age-old agroforestry system provides essential ecosystem services and plays a crucial role in the conservation of biological diversity in addition to economic benefits to the farmers.

Annual girth increment varied among the tree species over the three-year study periods. Annual girth increment in *S. anacardium*, *Litsea* sp., *Sterculia villosa*, *Oroxylum indicum, Ficus hispida* and *Symplocos sp.* were found in conformity with the reported increase of *Albizia lebbeck* and *Albizia odoratissima* from tea agroforestry systems of North East India [44], but, more than many tropical forest tree species [45].

The positive correlation between the estimated SG with CC of the dominant trees in PAS may facilitate species-specific measurement of CC for other tree species from a similar geographical region through allometric models in the absence of their actual estimated values. The differences in estimated and reported SG may be due to differences in the geographic area and their respective edaphic and microclimatic conditions. The differences in the reported SG with that of estimated one suggest the need of region-specific SG data bank to improve the precision in the estimation of biomass storage and the carbon stock while advancing the mitigation potential of traditional agroforestry systems under the scenario of anthropogenic climate change. Additionally, the estimated SG of the dominant tree species is higher than many of the tropical forest trees from Asia and Africa [46,47], suggesting the potential PAS in high biomass and carbon storage. The variations in the CC among the dominant tree species are consistent with the previous literature from other parts of the world [48,49,50,51].

5. Conclusions and Recommendations

The present study provides valuable insights into the differences in SG and CC between the previously reported and the currently estimated one. We suggest for region-specific measurement of SG and CC for non-destructively precise estimation of biomass and carbon storage for agroforestry systems. Such accurate estimation may facilitate consideration of PAS for incentive-based programs such as REDD+. It is evident from the study that species with high growth rates either have reduced SG or CC. Therefore, we would argue the selection of PAS tree for any social forestry or future agroforestry program to emphasize species with median values of annual girth increment, SG, and CC for maximizing the provisioning ecosystem services. The approach of PAS to secure livelihood and to generate income also ensures the continued provision of ecosystem services for nature conservancy and to help hill farmers adapt to climate change.

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Statement of Competing Interests

The authors have no competing interests.

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