Managing rubber plantations for advancing climate change mitigation strategy

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Storing atmospheric carbon dioxide (CO_2) in a long–term reservoir is one of the viable strategies to decelerate the climate change phenomenon. Terrestrial vegetation, especially forestry and agroforestry systems have been prioritized to stock CO_2 through phototropic sequestration. Rubber tree (*Hevea brasiliensis*), primarily managed for latex production, is explored in this contribution for its role in vegetation carbon stock management and climate change mitigation. The present study was carried out in selected *Hevea* stands aged between 5 and 40 years from Barak Valley, part of North East India. A total of 67 trees were harvested to estimate the biomass carbon stock in above- and below-ground components in plantations of different age groups. The study revealed that plantation density of 688–784 trees ha^{-1} is managed under plantations of different age groups. Total biomass (above and below ground) increased from 41 kg $tree^{-1}$ under 5–10 years to 307 kg $tree^{-1}$ under 30–40 years age group of plantations. Total vegetation carbon stock (Mg ha^{-1}; above and below ground) ranged from 16.00 (5–10 years) to 105.73 (30–40 years), which is more than many tropical forestry and agroforestry systems across the world. Vegetation carbon sequestration rate revealed that 2.56 mg C ha^{-1} $year^{-1}$ organic carbon is being accumulated in *Hevea* plantations. Considering the economic profitability from *Hevea* plantation management (through latex production) and its capability to stock high-biomass carbon, restoring degraded and secondary forests through this species will improve livelihood security and advance climate change mitigation strategies.

Keywords: Agroforestry systems, carbon sequestration, climate change mitigation, rubber plantations.

MANAGING carbon pools (terrestrial, oceanic, etc.) is crucial to mitigate the increasing concentration of atmospheric carbon dioxide (CO_2)[1]. Various pools of carbon sinks are being associated with CO_2 absorption by the oceans (2.4 Gt C $year^{-1}$)[2] and terrestrial uptake (3.6 Gt C $year^{-1}$)[3,4]. Global carbon stocks in terrestrial vegetation (466 Gt C) appear quite limited compared to 39,000 Gt C in the ocean and 760 Gt C in the atmosphere[5]. However, better management of terrestrial vegetation can enhance its carbon sink capability[1]. Global ecological and environmental studies and political demands are focusing on reducing the concentration of atmospheric CO_2 level. The goal of the first commitment period of the Kyoto Protocol has only remained as text in the file[6]. However, after this unsuccessful completion of the first commitment period of the Kyoto Protocol, the Doha amendment has fixed its goal to be achieved by the Annex I parties of the United Nations Framework Convention on Climate Change (UNFCCC) to reduce at least 18% of carbon emission below their 1990s level during the period 2013–2020 (ref. 6). To achieve this goal in a cost-effective way, the evaluation and accounting of carbon stocks as well as management of carbon sink reservoirs are crucial[6,7]. Since enhancing forest carbon stock and its management could play a vital role to achieve the goal[8], maintaining the desired carbon stocks into the vegetative pools for a long period is the urgent research need.

Rubber tree (*Hevea brasiliensis*), although originated in Amazon basin, is now cultivated across the tropical world for natural rubber production. Due to the increasing demands of natural rubber and its commercial consistency, it has attracted the interests of policy makers and cultivators in secondary and degraded forests restoration[9]. Total land cover under rubber plantations around the world is ~10 million hectare (m ha)[10], of which India contributes 0.68 m ha. Since long-term and purposeful agroforestry systems possess greatest capacity in carbon sink[11], and Clean Development Mechanism (CDM) of the Kyoto Protocol[8], encourages the role of biomass in carbon stock management through afforestation and reforestation, management of *Hevea* plantations can offer an excellent opportunity in enhancing vegetative carbon sink management. With this background, the present communication is aimed at exploring the standing organic carbon stock in a chronosequence of *Hevea* plantations and to discuss its implication for climate change mitigation.

The present study was carried out in Bazarghat area of Karimganj district, Assam, North East India (Figure 1). The study area falls within the range of the Himalayan foothills and Barak river basin, with an average annual precipitation of 3538 mm, temperature between 13°C and 37°C and relative humidity of 93.5% (ref. 12).

Hevea plantations of different age groups ranging from 5 to 38 years were considered for the present study. Depending on the age of the plantations, four specific age groups were considered, viz. 5–10, 10–20, 20–30 and 30–40 years. Under each age group of *Hevea* plantations, two stands with 25 m × 25 m were considered for biomass sampling. All the trees present within every sampling stand were counted to compute the plantation density for each age class. Each plantation has been managed with 3–6 m planting space between two consecutive trees in a single row, depending on the topography of the area.

Trunk circumference at 200 cm (C200) above the ground level was measured for all the trees under different age groups of the plantations. Circumference at 200 cm

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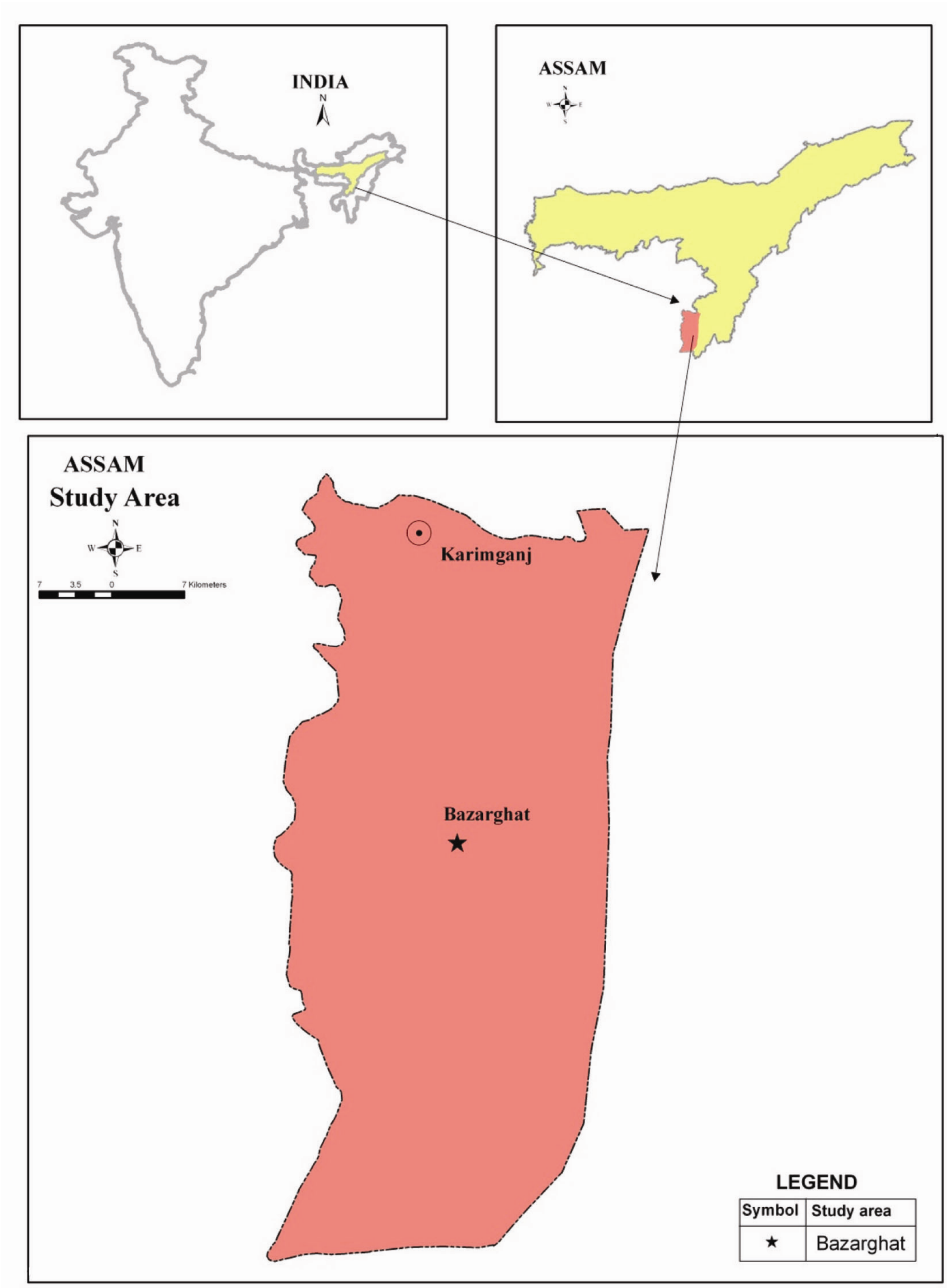

Figure 1. Locations of the study area.

was taken to avoid any artefact due to tapping cuts. Field-obtained dataset revealed C200 ranges from 10 to 110 cm (including all the age groups). Based on C200 distribution, 5–6 girth classes were considered. Depending on the availability of trees under each girth classes for different age groups of stands, 2–3 of *Hevea* trees were harvested. A total of 15, 19, 15 and 18 trees were harvested from stands of 5–10, 10–20, 20–30 and 30–40 years age respectively. Harvested trees were separated into leaf, branch and log. Branch with greater than 30 cm circumference was considered as log. Coarse root (>2.5 mm diameter) was extracted from 1 m radius with 1 m depth area from the main tree stem. Fresh weight of the extracted coarse roots was measured after carefully removing soil. Sub-samples (500 g) of each part of the felled tree were taken to determine the corresponding dry to fresh weight ratio (65°C). Once the sample was dried, the ratio of fresh to dry weight ($R_{dw/fw}$) of all the plant parts was computed. Total dry weight of each plant part of the felled tree was computed as

Dry weight of each part of the tree (PDW) (kg) = $R_{dw/fw}$x fresh weight of the plant part (kg).

Total dry weight (TDW) or total biomass of the felled tree was estimated after computing the PDW values for all the tree parts, by adding all the calculated PDW values of the respective tree. Total carbon stock was estimated assuming 50% of the dry biomass[13]. Vegetation carbon sequestration rate was calculated as follows: (mean carbon stock at 40-year-old stand – mean carbon stock at 5-year-old stand)/difference in the stand age, i.e. 40–5 = 35.

The average stand density of *Hevea* plantations was: 49(±1), 45(±1), 43(±1) and 43(±1) per 25 m × 25 m area for 5–10, 10–20, 20–30 and 30–40 years age class respectively. The respective plantation densities were computed as 784, 720, 688 and 688 trees ha^{-1}. Figure 2 shows an increasing trend in above- and below-ground biomass stock with increase in age of the tree. Total biomass increased from 41 kg tree^{-1} (5–10 years) to 307 kg tree^{-1} (30–40 years; Table 1). Biomass density (Mg ha^{-1}) ranged from 32.01 (5–10 years) to 211.46 (30–40 years). Biomass allocation pattern revealed that log component contributed the highest proportion (42–74%), followed by branch (17–35%), coarse root (7–17%) and leaf (2–6%, Figure 3). Except for log component, proportion of other plant parts decreased with increase in age of the tree (Figure 3).

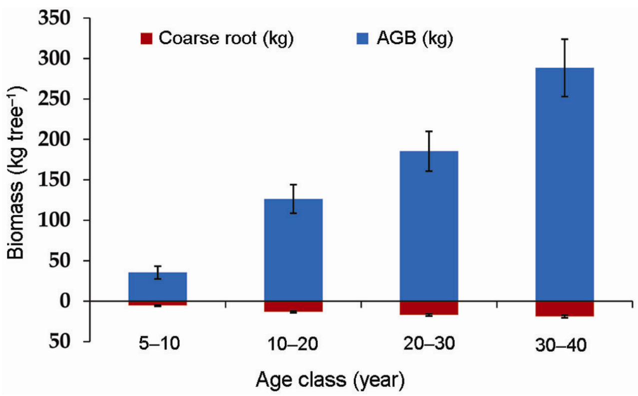

Figure 2. Average biomass (kg tree^{-1}) for coarse root and above-ground biomass (AGB) of *Hevea* trees. Values are mean ± standard error.

Figure 3. Average biomass allocation (%) of different parts of *Hevea* trees.

Total vegetation carbon stock (Mg ha^{-1}, above and below ground) ranged from 16.00 (5–10 years) to 105.73 (30–40 years; Figure 4). Contribution of above and below ground biomass to total vegetation carbon stock was 13.88–99.25 and 2.12–6.47 Mg C ha^{-1} respectively (5–10 to 30–40 years) (Figure 4). Analysis of vegetation carbon sequestration rate revealed that annually 2.56 Mg C ha^{-1} year^{-1} organic carbon is being accumulated in *Hevea* plantations.

Estimated stand density of the chronosequence of *Hevea* plantations revealed that tree density decreases with the increase in the age of the plantations. Since all the plantations were managed with 3–6 m spacing between two consecutive trees, natural storms are the chief reason for breaking down of the trees. Total biomass and carbon stock of *Hevea* plantations in the present study were positively related to the age of the stand. Such a relationship has also been reported for *Hevea* trees from other parts of the world[14,15]. Total biomass stock of a 7-year-old agrisilviculture system was 52 Mg ha^{-1} (ref. 16). Biomass stocks under different agroforestry systems like multi-storey systems, taungya agroforestry system and coffee multi-storey systems of the Philippines were 78, 28 and 15 Mg ha^{-1} (ref. 17). A similar study conducted on *Grewia optiva* in the Western Himalaya showed biomass stock of 7–47 Mg ha^{-1} for 4–23 year of plantations[18]. Biomass stocks in 4–20 year Costa Rican secondary forests range from 45 to 103 Mg ha^{-1} (ref. 19). In the tropical rain forests of Sri Lanka and Thailand, the biomass values range from 153 to 275 Mg ha^{-1} (refs 20, 21). Therefore, the observed biomass stock is comparable and even more than many of the tropical forestry and agroforestry systems across the world. However,

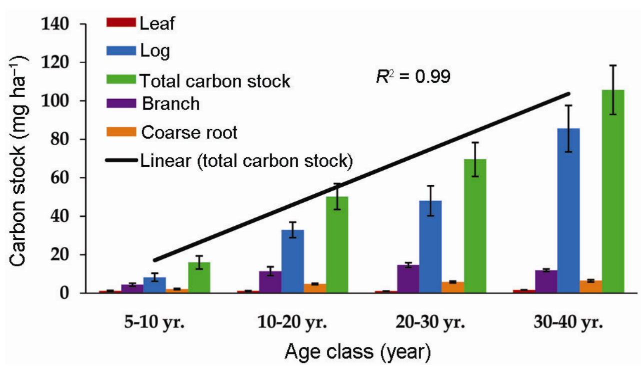

Figure 4. Carbon stock (Mg ha^{-1}) under *Hevea* plantations. Values are mean ± standard error.

Table 1. Average tree biomass (kg tree^{-1}) and biomass density (Mg ha^{-1}) under *Hevea* plantations

Age class (year)	Leaf (kg tree^{-1}) (±SE)	Branch (kg tree^{-1}) (±SE)	Logs (kg tree^{-1}) (±SE)	Coarse root (kg tree^{-1}) (±SE)	Tree biomass (kg tree^{-1}) (±SE)	Total biomass (Mg ha^{-1}) (±SE)
5–10	2.95 (0.66)	11.31 (1.96)	21.15 (5.43)	5.41 (0.82)	40.83 (8.62)	32.01 (6.76)
10–20	3.13 (0.53)	31.83 (6.28)	91.50 (11.14)	13.25 (1.09)	139.70 (18.69)	100.58 (13.46)
20–30	3.06 (0.24)	42.58 (3.55)	139.73 (22.71)	16.92 (1.35)	202.30 (25.68)	139.18 (17.67)
30–40	5.01 (0.22)	34.66 (1.99)	248.86 (35.18)	18.82 (1.59)	307.35 (36.95)	211.46 (25.42)

Values are mean ± standard error.

Hevea biomass stock is lower than the assessed biomass values for tropical forests of NE India (324–406 Mg ha^{-1})[22]. The present study revealed the biomass contribution of different plant components to the total biomass of *Hevea* trees follow the trend: log > branch > coarse root > leaf in all the age classes (Figure 3). Similar sequence of biomass contribution has been reported from China[23,24]. Total carbon stock of *Hevea* plantations for 5–10, 10–20, 20–30 and 30–40 years was estimated as 16.00 (±3.38), 50.29 (±6.73), 69.59 (±8.84) and 105.73 (±12.71) respectively. This has been supported by other reports[14,15,23–25]: 12–22 Mg C ha^{-1} for <10 year, 35–76 Mg C ha^{-1} for 10–20 year, 66–78 Mg C ha^{-1} for 20–30 year and 86–170 Mg C ha^{-1} for >30-year-old *Hevea* plantations[14,15,23–25]. Estimated carbon stock under <10-year-old *Hevea* plantations was lower than the reported carbon stock of 8-year-old *Populus deltoids*-based agroforestry (96 Mg C ha^{-1})[26] and 10-year-old cocoa (*Theobroma cacao*)-based agroforestry (58 Mg C ha^{-1})[27]. However, carbon stock under the 20–30 year age class of *Hevea* plantations was higher than that of semiarid, sub-humid, humid and temperate regions agroforestry systems[28]. Moreover, carbon stock for >30-year-old *Hevea* plantations falls within the range of tropical forests of NE India (97–149 Mg C ha^{-1})[29] and mango (*Mangifera indica*) agroforestry systems of Indonesia (121 Mg C ha^{-1})[30]. Mean vegetation carbon sequestration rate (across all the *Hevea* plantations) was 2.56 Mg C ha^{-1} year^{-1}, which is lower than 5.6–7.6 Mg C ha^{-1} year^{-1} for 14–38-year-old *Hevea* plantations of Brazil and China[14,23,25]. However, carbon accumulation rate in the present study is comparable with the community-based teak forests of Madhya Pradesh, India (3.4 Mg C ha^{-1} year^{-1})[31], but lower than many tropical agroforestry and forestry systems[32]. Although carbon sequestration rate in *Hevea* plantations is comparatively low, nevertheless, the economic profitability from latex production assures its long-term management and therefore, acts as a permanent sink of atmospheric CO_2.

Analytical data presented here support the following conclusions: (i) more than 80% of vegetation organic carbon is stored in the above-ground part. (ii) Biomass carbon stock in *Hevea* plantations is comparable or even more than many tropical and subtropical forestry and agroforestry systems. (iii) Adopting best management practices may further enhance carbon sequestration rate in *Hevea* plantations. (iv) Expansion of *Hevea* plantations can offer ecological stability over the increasingly practised traditional slash and burn agricultural system in NE India, concurrently uplifting the socio-economic conditions of local people through generating income stream from carbon trading.

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Correction

Preface: Special section on 'Soil and water management'

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The following sentence in the Preface was inadvertently omitted in the final print. 'We also thank Dr M. Velayutham for editing these papers at the behest of *Current Science*.'

We regret the omission.

– Editor