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Carbon-Sequestration Potential of Bamboo-based Farming Systems in Peri-Urban Landscapes

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***Abstract*:** The study is built upon the importance of bamboo as a component in the land-use in the peri-urban areas of Tripura West, Tripura as this area is known for bamboo in their homestead along with cultivation of crops. The study accounted bamboos as woody components in the land-use and estimated the carbon sequestration along with other woody tree components in the system. The total emission from crops was 100,086.53kg CO_2e, while the sequestration by woody species of trees and bamboos was 362629.68 kg CO_2e which ultimately gave net positive carbon emission value of 262543.15 kg CO_2e. The highest emitter was lowland rice (4454.87 kg CO_2e/ha) and the highest sequestration potential was seen in *Bambusa tulda* (48030.89 kg CO_2e/ha).

***Keywords*:** Agriculture Land-use, Bamboo-based Agroforestry, Climate change, Emissions, Mitigation

Agriculture is responsible for fifty percent of the earth's methane and nitrous oxide emission having more global warming potentials 28 and 265 times more than carbon-di-oxide respectively (Carlson et al 2016, IPCC 2018). The main challenge is overcoming growing food needs due to growing population, while minimizing the bad environmental impact of agriculture especially GHGs emission (Pathak et al 2014, Sapkota et al 2015, Ram et al 2016, Vetter et al 2019). Estimating greenhouse gas emissions from agriculture and allied activities is crucial for evolving mitigation strategies (Carlson et al 2016, Jat et al 2016, Kim et al 2016, Fagodiya et al 2017, Fagodiya et al 2020, Barreto et al 2024). The main elements of reducing carbon stocks and increasing amount of greenhouse gas in the environment are forest conversion, land-use changes and various agricultural practices (Hergoualc'h et al 2012, Luedeling et al 2014, Sharma et al 2016, Ajit et al 2013, Ajit et al 2017). Agroforestry can play the role (Jose and Bardhan 2012, Thangata and Hildebrand 2012, Majumdar et al 2013) by adopting ethnic community based traditional techniques in agriculture that uses less machinery and input of FYM and tilling modifications in place of fertilizers (Selvan and Kumar 2016). Bamboo is an important yet overlooked rich biomass resource that can stock carbon (Scurlock et al 2000, Ben-zhi et al 2005). Bamboo-centred agroforestry setups have demonstrated considerable promise in lessening GHG emissions and promoting global carbon absorption. Inclusion of bamboo in land use can bring sustainable climate change solutions to the farmers by sequestering carbon (Tu et al 2013) while giving attractive livelihood opportunities and food security to resource poor farmers (Basumatary et al 2015 and Panmei and Selvan 2024).Research indicates that bamboo species in our country can accumulate carbon at rates between 1-2.3 Mg per ha per year in AGB and 0.14-0.39 Mg per ha per year in soil, illustrating their importance in carbon agriculture and market (Subbanna and Viswanath 2021 and Debnath et al 2022). There is limited exploration of bamboo's capacity for carbon capture across the country. The current work was undertaken to know the quantum of emissions from crops in bamboo-based agroforestry systems and understand the carbon sequestration potential of the prevalent bamboo-based agroforestry systems.

MATERIALS AND METHODS

The primary field-work was performed in West Tripura district of Tripura, a North-Eastern state of India. It lies between 23°42′N - 24°5′N and 91°15′E – 91°35′E occupying an area of 10,486 km^2 at an average altitude of 12.80 msl. The state is charactered by warm and humid tropical climate with five different seasons viz., spring, summer, monsoon, autumn, and winter (https://tripura.gov.in/geographical-profile). Temperature varies from 20-36° C in summer and in winter, it ranges from 7-27° C. Rainy season is from June-September.

Data collection: Tripura have 21 species of bamboo among 130 species available in India bearing area of 3246 km^2 among 6294 km^2 of total RFA of the state. The bamboos are spread in wild, rural as well as peri-urban areas. In five peri-urban sites a total of fifty bamboo-based agroforestry farms were selected and an interaction was conducted (with their consent) on farmers/owners to collect information pertaining to greenhouse gas emission from their farm (Table 1).

Emission estimation: The GHG emissions of these farmlands were calculated by using “Cool Farm Calculator”. It is a web-based AI application designed for crops, or crop products providing unique results (Hillier et al 2011 and Jabbour et al 2021). This tool has been raised with the collaboration between University of Aberdeen, Unilever, and sustainable food lab in 2008 (Cool Farm Alliance 2020). This tool efficiently evaluates each system by examining the conditions that have the greatest impact on GHG emission. It is not only a calculator for GHG emission but also encourages management and helps to make action plans by creating "what if" situation (https://coolfarm.org/releasenotes).

Sequestration estimation: Sequestration was calculated for woody components i.e., for trees and bamboos. AGB of woody components was estimated.

AGB = 0.0509 x ρD^2H (Chave et al 2005).

AGC was calculated as:

AGC = AGB x 0.47 (Mcgroddy et al 2004).

This was estimated by using the default conversion factor of 47% of the overall biomass (Andreae and Merlet 2001 and Mcgroddy et al 2004). From AGB and AGC, the quantity of carbon-sequestered was calculated by using the following equation:

CO_2sequestered = AGC x 3.67

RESULTS AND DISCUSSION

Total emission from different crops in bamboo-based agroforestry: Emission (in kgCO_2e) from crops were estimated by input of primary data of land-use area, crops cultivated, management regime, energy and water use, volume of crop harvested, into the web-based AI tool "Cool Farm Calculator". The main sources of emission included application of nitrogen fertilizers, machinery use, land preparation practices etc. Emission across the 50 locations in the 5 sites are given in Table 2.

Total emission from each crop (27 species) in all the 5 sites (50 plots) are summed as 100,086.53kg CO_2e. The emissions varied significantly from crop-to-crop (Table 3). Among them, lowland rice had the highest emissions (total of 44828.98 kg CO_2e @ 4454.87kg CO_2e/ha) because of anaerobic conditions. This is due to release of methane and nitrous oxide in anaerobic situations in paddy cultivation (IPCC 2018). The lowland rice exhibited maximum emission levels in all sites, surpassing all other crops. This outcome also aligns with Mboyerwa et al (2022). Modification in management of fertilizer application at 100% NPK+Zn+FYM showed highest sequestration (Yaseen et al 2023) which indicate that incorporation of this technique may be able to curtail the emission from rice cultivation in the study sites. The other highGHG emitter varied across different locations and majorly included brinjal-*Solanum melongena*, green amaranth- *Amarathus cruentus*, bottle gourd-*Lagenaria siceraria*, pumpkin-*Cucurbita pepo*and chilli-*Capsicum*

Table 1. Site of bamboo-based agroforestry farms selected for greenhouse gas emission in West Tripura, India

Location	Name of the village	Latitude	Longitude
Suryamaninagar	Bellavpur	23.770242º	91.254464º
Suryamaninagar	Madhupur	23.764919º	91.260034º
Amtali	Kopali para	23.771156º	91.258954º
Amtali	Madhyapara	23.770181º	91.259074º
Barjala	Chandinamura	23.853835º	91.264413º

Table 2. Total emissions from all crops across the five study sites of bamboo-based agroforestry farms in West Tripura, India

Location code	Name of the location	Total emissions (kg Co_{2e})
S1	Bellavpur	14455.11
S2	Kopalipara	18533.17
S3	Madhyapara	20941.67
S4	Madhupur	32638.61
S5	Chandinamura	13517.97
Total		100,086.53

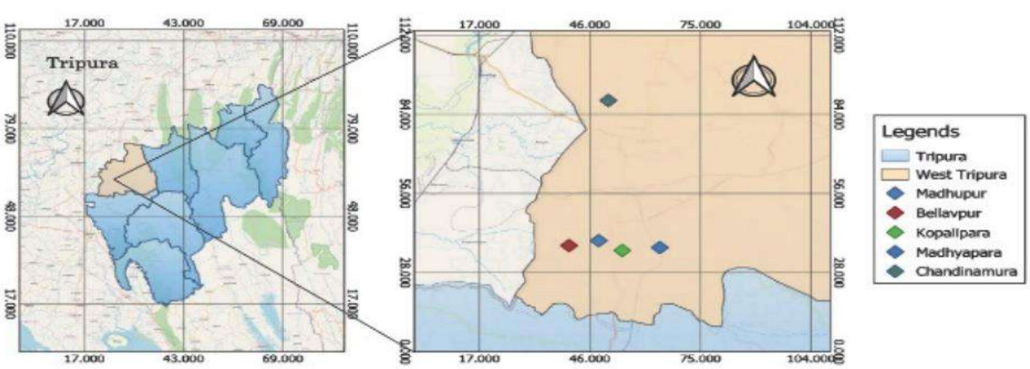

Fig. 1. Site of bamboo-based agroforestry farms selected for greenhouse gas emission in West Tripura, India

frutescens. Emission from chilli production can be positively controlled by effectively managing nutrient supply through fertigation (Nair et al 2024). The crop with second least emission was French bean-*Phaseolus vulgaris* (361.43 kg CO_2e/ha) showing low emission due to nitrogen fixing ability. Jeuffroy et al (2013) observed that incorporating nitrogen fixing crops in rotation can decrease nitrous oxide emission by 20-25%. Therefore, targeted initiatives must be taken to combine high-emission crops like lowland rice with low-emission crops, to substantially mitigate the environmental impact of agricultural activities (Li et al 2024). This study shows that emissions from various vegetables are also consistent. Fan et al (2021) concluded that proper application of organic fertilizer with appropriate irrigation strategies can reduce field emission. Further the rate of emissions varied from field to field depending on different factors like type of soil, type of crop, management practices.

Carbon sequestration by bamboo and woody trees: During the survey 34 woody species were encountered with 7 bamboo species, and 27 other tree species. A total of 362629.68 kg CO_2e was sequestered within the studied plots in all sites by the bamboos and the other woody tree species. The 7 species of bamboo found across all sites were viz. *Bambusa affinis, B. balcooa, B. polymorpha, B. tulda, B. vulgaris, Dendrocalamus hamiltonii* and *Melocanna baccifera.* Bamboo genetic resources are widely found in agroforestry land use across India (Selvan 2018). The total carbon sequestered by these bamboos stand at 91611.55 kg CO_2e which is 25.26% of the total carbon sequestered within the bamboo-based agroforestry land-use. *Bambusa tulda* has the

Table 3. Emission from crop and land-use management practices of bamboo-based agroforestry farms in West Tripura, India

Species/Crop	S1	S2	S3	S4	S5	Total per crop emission (kg CO_2e)	Emission from each crop (kg CO_2e/ha)
Abelmoschus esculentus	x	2	3	1	1	962.88	850.63
Amaranthus cruentus	2	4	2	2	2	7623.83	2728.96
Amaranthus dubius	x	x	x	x	1	184.25	842.48
Ananas comosus	x	x	x	1	x	2790	2682.69
Benincasa hispida	x	1	1	x	x	327.45	1445.35
Brassica nigra	x	1	1	x	x	797.51	1744.64
Brassica oleracea	x	1	x	x	x	94.56	152.52
Capsicum frutescens	1	4	4	2	x	4678.95	1127.30
Carica papaya	x	2	x	1	1	2856.44	1915.27
Citrus limetta	3	1	x	x	x	1290.67	1831.60
Citrus limon	1	1	x	x	x	662.89	1564.15
Coriandrum sativum	x	x	x	x	1	77.99	916.99
Cucumis sativus	2	x	x	1	x	818.77	2367.88
Cucurbita pepo	3	4	2	4	2	5748.83	1896.64
Cuminum cyminum	x	1	x	x	x	220.66	1050.76
Ipomoea batatas	x	1	x	x	x	155.46	536.07
Lagenaria siceraria	5	6	2	3	5	8751.80	2063.54
Moringa oleifera	x	1	x	x	x	306.3	831.09
Musa paradisiaca	x	5	x	2	x	2148.85	966.52
Oryza sativa	8	5	7	9	6	44828.98	4454.87
Phaseolus vulgaris	x	x	x	x	1	94.56	361.43
Raphanus sativus	x	x	x	x	2	433.23	2067.49
Solanum lycopersicum	2	2	2	x	x	578.76	1578.76
Solanum melongena	3	4	4	7	7	11676.55	1685.90
Vigna unguiculata	1	4	2	1	x	1076.97	582.37
Zea mays	1	x	x	x	x	535.6	2122.74
Zingiber officinale	x	1	x	x	x	363.79	1254.45
Total						100086.53	

The numerical values indicate the presence of the particular species in the n number of plots. X value indicate the absence of the species

Table 4. Carbon Sequestration by woody components including bamboo in the bamboo-based agroforestry land-use in West Tripura, India

Bamboo & other woody tree species	S1	S2	S3	S4	S5	Sequestration ($kgCO_2e$)	Sequestration ($kg\ CO_2e/ha$)
Albizia procera	x	x	x	1	x	2221.65	11594.92
Annona reticulata	1	x	x	x	x	248.32	3050.43
Areca catechu	5	5	6	4	5	33456.11	6065.98
Artocarpus heterophyllus	5	2	1	1	x	20269.33	13017.78
Azadirachta indica	x	x	x	x	2	318.54	1562.55
Bambusa affinis	3	2	5	1	3	23303.80	12107.58
Bambusa balcooa	1	1	x	x	x	2451.55	12537.16
Bambusa polymorpha	1	2	1	2	2	8934.83	11162.34
Bambusa tulda	1	x	2	1	x	23108.58	48030.89
Bambusa vulgaris	8	5	4	7	4	30575.29	9283.91
Borassus flabellifer	x	x	x	1	x	279.60	268.85
Carica papaya	x	x	x	1	1	127.91	252.53
Cocos nucifera	5	4	3	6	7	70390.65	13979.94
Conocarpus lancifolius	x	x	1	x	x	8.70	13.26
Corchorus olitorius	x	x	x	x	2	10.94	17.78
Dendrocalamus hamiltonii	x	x	1		x	6.45	13.16
Dipterocarpus turbinatus	1	x	x		x	5219.28	46025.35
Eucalyptus globulus	x	x	x	1	x	53.26	45.98
Gmelina arborea	3	x	x	x	1	4990.18	9186.01
Hevea brasiliensis	x	x	1	x	x	203.93	2257.94
Litchi chinensis	1	x	x	x	x	786.80	10388.81
Mangifera indica	3	6	9	8	*9*	78569.79	11828.81
Melocana baccifera	x	3	x	x	1	2813.62	3561.67
Mesua ferrea	x	1	x	x	*x*	2025.21	7023.18
Moringa oleifera	x	1	x	x	x	908.94	2466.25
Musa paradisica	x	x	2	5	1	2134.68	1498.21
Polyalthia longifolia	x	2	3	x	1	12009.35	12992.22
Saraca asoca	x	x	1	x	x	116.11	236.94
Shorea robusta	x	x	x	x	1	19.45	74.36
Swietenia macrophylla	x	1		x	x	2640.65	15269.61
Syzygium cumini	1	x	9	6	x	20917.67	4651.92
Tectona grandis	2	1	1	1	1	10901.94	11101.5
Terminalia arjuna	1	x	x	x	x	647.08	4992.93
Vachellia nilotica	x	x	x	x	1	526.52	2012.44
Ziziphus mauritiana	1	x	x	x	1	1085.34	4026
Total						362629.68	
Sequestration from Bamboos						91611.55	

The numerical values indicate the presence of the particular species in the n number of plots. X value indicate the absence of the species

highest carbon sequestration potential (48030.89 CO_2e/ha). High carbon sequestration in this study was in *Artocarpus heterophyllus* (13017.78kg CO_2e/ha) which was also encountered by Jithila and Prasadan (2018). *Areca catechu* and *Cocos nucifera* are excellent in carbon capture despite its slender form, thus can be easily incorporated as boundaries. Sudha et al (2021) observed that coconut in agroforestry systems with other tree components are very effective in carbon sequestration. *Polyalthia longifolia* (12992.22 kg CO_2e) is a good tree for carbon sequestration. Net carbon capture by *Gmelina arborea* based agroforestry has been much more higher than sole cropping system (Kumar et al 2024) which is consistent with the result for *Gmelina arborea* (9186.01kg CO_2e/ha). Ganeshamurthy et al (2019) showed that carbon-sequestration rate by *Magnifera indica* is quite good. *Mangifera indica* had sequestered total of 78569.79 Kg CO_2e (11828.81 kg CO_2e/ha) which is amongst the highest in all the species. This is also due to its presence in all the sites. Leguminous trees-*Moringa oleifera* (2466.25kg CO_2e/ha) and *Albizia procera* (11594.92 kg CO_2e/ha) showed high sequestration rate. Guleria et al (2014) and Rosenstock (2014) also indicated nitrogen-fixing trees positively influences growth in biomass of the plant that ultimately increase the carbon fixation.

Net emission: The net emission is the difference between the sequestration and emission from the land-use 262543.15 kg CO_2e. Positive net emission was observed from the tree component in agroforestry systems due to sequestration upto the tune of 90% (Sudha et al 2021). The net emission was significantly higher in poplar-based wheat agroforestry system as compared to the open farming of wheat (Chauhan et al 2010, Chauhan et al 2010, Kumar et al 2020). Integrating trees and bamboo with agricultural practices can achieve considerable net carbon sequestration, effectively neutralizing the emissions associated with crop farming (Sharma et al 2016, Selvan et al 2023).

CONCLUSIONS

The emission from all crops in cultivation on all sites was 100086.53kg CO_{2e} while the sequestration by bamboos and other woody components in the land-use was 362629.68 kg CO2e. Bamboo accounts for 25.26% of the sequestration with *Bambusa tulda* being the best performer. This study emphasizes the potential of integrated farming system in improving carbon-sequestration and mitigating the overall carbon footprint in agricultural practices. The study also observed that results varied greatly depending upon the management practices/ land-use regimen and the post production transport to market. The advantageous net carbon balance highlights the dual merits of incorporating tree and bamboo cultivation in agricultural practices increasing carbon capture and offering supplementary economic, greater livelihood options and ecological improvements. Therefore, this study encourages the wider application of integrated agricultural systems as a viable solution to attain food security, livelihood generation and carbon neutrality.

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