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Impact of Amide Fertilizer on Carbon Sequestration under the Agroforestry System in the Eastern Plateau Region of India

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Abstract: Carbon sequestration is an important aspect of expelling greenhouse gases from the atmosphere and decelerating the rate of global warming. Agroforestry plays an important role in carbon sequestration. Keeping this in mind, the current study was carried out between 2017 and 2021 to assess the effect of integrated nutrient management on biomass production, carbon sequestration, and carbon credit in a mango and turmeric agroforestry system. The study used randomized block design (RBD) with four treatments and five replications. According to the findings of this study, the rate of fertilizer application has a significant impact on the growth of turmeric and mango crops. The physiochemical characteristics of soil show an improvement in soil composition with the application of urea ($CO(NH_2)_2$), single super phosphate [$Ca(H_2PO_4)_2.2H_2O$] 226 kg ha^{-1}, MOP [KCl] 309 kg ha^{-1} 100 kg ha^{-1}. The carbon density of the agrihorticulture land use system was six to seven times higher than that of the open agriculture-based land use system. The highest turmeric production (8.98 t ha^{-1}) was reported under the mango-turmeric system rather than turmeric alone (6.36 t ha^{-1}) in the T_2-N100kg treatment. Total biomass production (61.2 t ha^{-1} and 64.6 t ha^{-1}), carbon stock (38.6 t ha^{-1} and 41.06 t ha^{-1}), carbon sequestration (246.5 t ha^{-1} and 299.5 t ha^{-1}), and carbon credit (246.57 credits and 299.5 credits) were found to be highest in mango and turmeric-based agroforestry land use system treatments T_{2}-N100 kg and T_{3}-N80 Kg, respectively. The net additional profit from the agrihorticulture land use system was 299.5 carbon credits, which is equivalent to 4,49,250 INR.

Keywords: biomass; carbon sequestration; carbon credit; turmeric; mango; agroforestry

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1. Introduction

Agriculture is one of the most sensitive industries to climate change globally. Due to the vast population reliant on agriculture and the low coping capacity of small and marginal farmers, this vulnerability is considerably higher in India. Climate change might be a major disaster unless we increase our efforts to improve farmers' ability to cope with severe changes in temperature, precipitation, and sea level by adopting a climate-smart agricultural approach.

Climate change is a major environmental issue that has a significant impact on the economy, livelihood, and ecosystem functions through extreme events such as increased flash floods, droughts, land inundation in coastal areas, significant fluctuations in seasonal, daytime, and nighttime temperatures, and biodiversity loss [1]. From the preindustrial age, the temperature of the earth's surface has nearly doubled. Climate change has been shown to have a negative influence on terrestrial ecosystems, food security, and has considerably contributed to land degradation and desertification [2–5]. The increased greenhouse efflux has exacerbated the rate of the harmful effects of climate change [6–8]. Many agricultural operations emit considerable amounts of greenhouse gases such as CO_2, N_2O, and CH_4. On a 100-year time period, one kg of N_2O and CH_4 has a higher global warming potential (GWP) than CO_2 [9–11]. In 2018, global agriculture supplied over 9.3 Gt CO_2 eq, with non-CO_2 contributions totaling 5.3 Gt CO_2 eq. Agricultural soils and enteric fermentation give about similar amounts, 39.5 and 39.2%, respectively. Agricultural soils provide over 70% of worldwide N_2O emissions [3]. Owing to the increasing GHG emissions, the global mean annual temperature increased by 0.40 to 0.76°C in the late twentieth century [12]. Every nation's key area for halting the speed of climate change is to reduce greenhouse gas (GHG) effluxes through optimal GHG mitigation techniques. In this context, a low-carbon economy is one of the most promising options for lowering GHG emissions. Since it is an ecologically supportive, dynamic, and multifunctional natural resource management system at both temporal and geographical scales, agroforestry can be particularly effective in slowing the rate of climate change [13].

Agroforestry provides economic, sociocultural, and environmental advantages in the agricultural landscape, such as reduced erosion, higher soil fertility and water quality, increased biodiversity, greater aesthetics, and carbon sequestration [14]. It is particularly critical for marginal farmers since it may increase their food supply, income, and health. Due to its immense potential as a long-term carbon sink, the agroforestry system is promising [15]. Agroforestry can be a critical answer to climate change by providing ecosystem services and increasing profits through multifunctional forests [16]. However, the full financial examination of the clean development mechanism (CDM) through agroforestry-based carbon sequestration and social commitment to surviving ecological services is still in the works.

Several agroforestry systems have been used in various locations of the world, but only three to five major agroforestry systems have been practiced region-wise that are based on the grower's key objectives. Many efforts on land use systems in various regions of the world had been completed by [17–19]. In this context, one of the agroforestry systems developed according to different types and methods of fertilizer application for examining the biomass increment that directly affect the carbon sequestration potential has high expectations as a carbon sequestration strategy in developed and developing countries. Nitrogen is an essential component of vegetative growth and has been found to increase the productivity of commercial stocks of *Pseudotsuga menziesii* in warm climates in general [20,21]. It is possible to increase biomass storage in aboveground trees by adding N to the ecosystem. However, it is not known how the addition of nitrogen affects the degradation rate of litter in soil and undergrowth. Urea $[CH(NH_2)_2]$ is an amide fertilizer with a high nitrogen content (46%) that is quickly assimilated and responsive to plant growth. Keeping these in view, the present investigation undertakes to understand: (i) the effect of amid fertilizer (only N) for producing more utilizable biomass; (ii) carbon sequestration potential; and (iii) carbon credit and trading in the mango-turmeric agroforestry system.

2. Materials and Methods

2.1. Study Site

The experiment was conducted in a horticultural field at Birsa Agricultural University (BAU), Ranchi. The test location is at 23°26′4.3764″ N and 85°19′14.5272″ E and at an average height of 611 m above sea level (Figure 1). Most of the lands in East India belong to the Alfisols. The soil has a mountainous orography and is reddish, acidic (5.0–5.6), shallow to moderately deep, having little fertility, low alkaline exchange capacity, is naturally drained, prone to erosion, and has high permeability and low water retention.

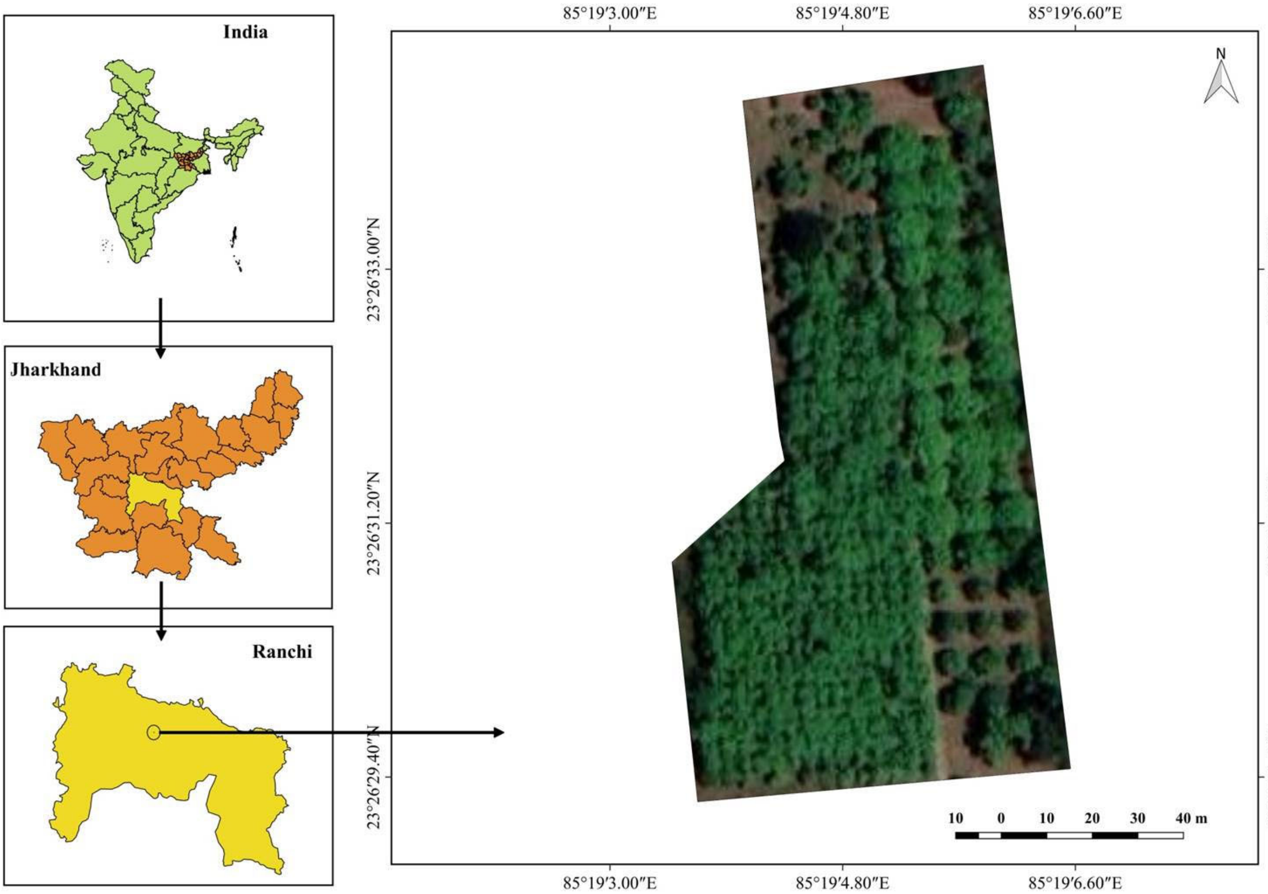

Figure 1. Location map of the study area, including the state boundary of district Ranchi.

2.2. Experimental Layout

The experiment was planned for years (2017–2021) in the randomized block design (RBD) system with four treatments (T_1-$N_0P_{60}K_{60}$, T_2-$N_{100}P_{60}K_{60}$, T_3-$N_{80}P_{60}K_{60}$, T_4-$N_{60}P_{60}K_{60}$) and five replicates (plot size 100×25 m^2) within an agroforestry system based on mango trees associated with turmeric. The source of nitrogen, phosphorus, and potash fertilizers were urea ($CO(NH_2)_2$), SSP ($Ca(H_2PO_4)_2 \cdot {}_2H_2O$) and potassium muriate (KCl), respectively.

2.3. Estimation of Standing Tree Biomass

2.3.1. Aboveground Biomass of Trees

The tree height was measured from the base of the trunk to the tip of the apical bud of the tree by measuring tape to work out the average height. The diameter at breast height (DBH) 1.37 m was measured by tape. The girth was recorded to the nearest centimeter. The crown spread of the individual tree was recorded from N-S and E-W direction by measuring tape in meter. Total number of branches account for more crown diameter and hence more photosynthesis, which will allow the tree to absorb more carbon from the atmosphere.

The aboveground biomass was determined by a nondestructive method. The non-destructive estimation of the C stock can be calculated through allometric equations. An allometric equation, i.e., [$Y = a + b (D) + c (H)$], is used in the present investigation, where Y is aboveground biomass (kg), a, b, and c are the empirical constant, D is diameter at breast height (cm), and H is the total height of the tree (m). Allometry equations based on the regression coefficient were used to estimate the aboveground biomass of *Mangifera indica*.

The estimated volume was converted into biomass by multiplying with specific gravity. Biomass of all the nine trees of per plot was summed and taken as an average to be obtained for one hectare.

$$\text{Aboveground biomass} = \text{Volume } (m^3) \times \text{Specific gravity } (gcm^{-3}) \times \text{BEF (Biomass expansion factor)} \quad (1)$$

Total volume was calculated in the standing position by using the below equation:

$$\text{Total volume } (m^3/\text{tree}) = \text{Basal area} \times \text{Height (H)} \quad (2)$$

$$\text{Basal area} = (\text{Girth})2/(\pi \times 4) \quad (3)$$

where girth = πd, π = 3.14, d = DBH (cm) and H = Height (m).

Specific gravity of the *Mangifera Indica* was calculated as per Rajput et al. [22] and Chavan and Rasal [23].

$$\text{Specific gravity} = (\text{Oven dry mass})/(\text{Green Volume}) \quad (4)$$

where oven dry mass = sample of stem cut from tree, then oven dry weight and green volume = volume of cylindrical stem. Biomass expansion factor expands merchantable volume to total aboveground biomass volume to account for the nonmerchantable components of tree, stand, and forest. BEF is 1.5 dimensionless [24].

2.3.2. Belowground Biomass of Tree

Belowground biomass was estimated by using a factor of 0.26 as the root to shoot ratio [25,26]

$$\text{Belowground biomass} = \text{Aboveground biomass} \times 0.26 \quad (5)$$

2.3.3. Total Tree Biomass

Total tree biomass is the sum of aboveground and belowground biomasses of tree, calculated as per the Equation (6).

$$\text{Total biomass} = \text{Total above biomass} + \text{Total below biomass} \quad (6)$$

2.3.4. Estimation of Crop Biomass

In turmeric, the aboveground biomass (leaf and stem) and belowground biomass (root) was estimated by cutting and excavation method respectively. Three quadrates of equal size (1 × 1 m) were laid down randomly in each plot for estimating the biomass. Dry biomass is estimated at 65°C.

$$\text{Total biomass of crop} = \text{Aboveground biomass (stem, branches. and leaves)} + \text{Belowground biomass (root)} \quad (7)$$

2.4. Estimation of Total Carbon Stock

2.4.1. Carbon Stock in Tree

Biomass C Stock was estimated by converting dry biomass into the C as per Rajput [27].

$$\text{Carbon stock} = \text{Dry Biomass} \times \text{Carbon Content} \quad (8)$$

The carbon stock in tree biomass was determined as per Allen et al. [28]:

$$\text{Ash\%} = W3 - W1/W2 - W1 \quad (9)$$

where W1 = weight of crucibles, W2 = Weight of oven-dried samples with crucibles, and W3 = Weight of ash with crucibles

$$\text{Carbon content} = (100 - \text{Ash\%}) \times 0.58 \text{ (considering 58\% carbon in ash-free litter material)} \quad (10)$$

2.4.2. Carbon Stock in Crop

The carbon stock in herbs and shrub species was determined by multiplying total biomass (aboveground + belowground biomass) with a carbon conversion factor of 0.45 [29–31].

$$\text{Carbon stock of crop} = \text{Total dry biomass} \times 0.45 \quad (11)$$

2.4.3. Carbon Stock in Soil

The carbon stock in soil was calculated as per the Equation (12)

$$\text{Soil carbon stock (t ha}^{-1}\text{)} = \text{Soil organic carbon \%} \times \text{Soil sampling depth (cm)} \times \text{Bulk density (g cm}^{-3}\text{)} \quad (12)$$

The total carbon stock was estimated by adding all the components (tree + crop + soil).

$$\text{Total C stock} = \text{Total tree C stock} + \text{Total crop C stock} + \text{Total soil carbon stock} \quad (13)$$

2.4.4. Estimation of Total Carbon Sequestration

Total C sequestration was obtained by addition of CO_2 sequestrated by total carbon stock (total tree carbon stock + total intercrops carbon stock + total soil carbon stock). The estimated total carbon stocks were converted into carbon sequestration, multiplied by 44/12 or 3.67 [32].

$$\text{Carbon sequestration} = \text{Total carbon stock} \times 3.67 \quad (14)$$

2.5. Estimation of Total Carbon Credit

The carbon credit or certified emission reduction (CER) is the unit related to the reduction of one ton of CO_2 emission. One ton of CO_2 mitigation in the form of plant biomass is equal to one C credit. Thus, the total C credits were calculated from the CO_2 eq. values of retained biomass. The C credit value was adopted from the global market (1 C credit = 1500 INR = 20 $) [33,34].

3. Results

3.1. Germination, Plant Height, and Leaf Area Index of Turmeric (Curcuma longa)

Germination, plant height, and leaf area index of turmeric were affected under different treatments and the agroforestry system in comparison to an open system. Germination of turmeric was delayed by eight to days in an open system. Germination, plant height, and leaf area index are the key indicators which affect crop duration and leafiness, thus affecting total carbon sequestration by the crop. The present information confirms that the open system is not suitable for the optimum growth of turmeric, thus the C sequestration potential is becoming affected under an open system. The results are in conformity with the findings of Gill et al. [35], Bhadoria [36], and Rahangdale [37]. They also investigated and observed that the germination of ginger/turmeric in an agroforestry system was better than in an open system with the application of different levels of fertilizer.

3.1.1. Yield of Turmeric Crop (*Curcuma longa*)

The average dry weight yield (t ha^{-1}) of turmeric in an agroforestry system was between seven to nine t ha^{-1} (Table 1). The effect of nitrogen management and environmental conditions on fresh turmeric output was found to be considerably greater with the application of $N_{100}P_{60}K_{60}$ than $N_{80}P_{60}K_{60}$. Turmeric rhizome yield was greatest when 100 kg nitrogen was treated in three splits. In the open system, the highest rhizome production of turmeric was 6.3 t ha^{-1} and the minimum was 5.18 t ha^{-1} (Table 1), which was statistically superior to $T_1(N_0P_{60}K_{60})$.

Table 1. Mean yield of turmeric (*Curcuma longa*) (t ha^{-1}) under silvihorticulture practices of the agroforestry system and the open system (2017–2021).

Treatment	2017	2018	2019	2020	2021	Mean
Mean dry yield (t ha^{-1}) of turmeric (*Curcuma longa*) under Agroforestry						
T_1-$N_0P_{60}K_{60}$	6.4	7.1	7.2	6.3	7.9	7.0
T_2-$N_{100}P_{60}K_{60}$	7.8	10.3	8.3	9.1	9.4	9.0
T_3-$N_{80}K_{60}P_{60}$	6.9	10.0	7.2	8.2	8.7	8.2
T_4-$N_{60}P_{60}K_{60}$	6.7	5.7	5.9	7.5	7.8	6.7
CD (0.05) [Critical difference]	0.4	0.2	0.3	0.4	0.8	1.1
CV% [Coefficient of variance]	4.2	2.2	3.0	3.5	6.6	10.6
SE (M) [Standard error of mean]	0.1	0.1	0.1	0.1	0.2	0.4
SD (Standard deviation)	0.8	2.1	1.0	1.3	1.0	1.3
Mean dry yield (t ha^{-1}) of turmeric (*Curcuma longa*) under Open System						
Treatment	**2017**	**2018**	**2019**	**2020**	**2021**	**Mean**
T_1-$N_0P_{60}K_{60}$	5.2	5.3	5.7	5.2	4.6	5.2
T_2-$N_{100}P_{60}K_{60}$	6.3	6.4	6.2	6.7	6.3	6.4
T_3-$N_{80}K_{60}P_{60}$	6.2	6.3	6.5	6.4	5.9	6.3
T_4-$N_{60}P_{60}K_{60}$	6.0	4.8	6.3	5.9	5.2	5.7
CD (0.05)	1.0	1.3	1.0	1.3	1.6	1.0
CV%	12.6	16.6	11.4	15.6	21.5	12.0
SE (M)	0.3	0.4	0.3	0.4	0.5	0.3
SD	1.1	1.3	1.3	1.4	1.3	0.6

3.1.2. Biomass of Turmeric (*Curcuma longa*)

Turmeric biomass was overwhelmed by the application of different doses of nitrogen, phosphorus, and potassium. Turmeric biomass under the conditions of the agroforestry system ranged from 8.12 to 10.59 t ha^{-1}, while in the "treeless" open system, turmeric biomass ranged from 6.1 to 7.5 t ha^{-1} (Table 2). The highest turmeric biomass production was found in an agroforestry system compared to an open "treeless" system.

Table 2. Biomass, carbon stock, and carbon sequestration of turmeric (t ha^{-1}) under the agroforestry system and the open system (2017–2021).

Treatment	Biomass Mean				Carbon Stock Means				Carbon Sequestration			
	Agroforestry System		Open System		Agroforestry System		Open System		Agroforestry System		Open System	
	2017	2021	2017	2021	2017	2021	2017	2021	2017	2021	2017	2021
T_1-$N_0P_{60}K_{60}$	7.5	8.1	6.2	6.1	3.4	3.7	2.8	2.7	12.4	13.4	10.2	10.0
T_2-$N_{100}P_{60}K_{60}$	10.5	10.6	7.3	7.5	4.7	4.8	3.3	3.4	17.3	17.5	12.0	12.4
T_3-$N_{80}K_{60}P_{60}$	8.1	10.1	7.1	7.2	3.6	4.6	3.2	3.2	13.4	16.7	11.7	11.9
T_4-$N_{60}P_{60}K_{60}$	7.7	8.4	6.7	6.6	3.5	3.8	3.0	3.0	12.7	13.9	11.0	10.8
CD (0.05)	1.6		0.7		0.7		0.3		2.6		1.2	
CV%	12.2		7.8		12.2		7.8		12.2		7.8	
SE (M)	0.5		0.2		0.2		0.1		0.8		0.4	

3.1.3. Carbon Stock in Turmeric (*Curcuma longa*)

The carbon stock in the turmeric crop was influenced by fertilizer application found in the range of 3.6 to 4.7 t ha^{-1} in the agroforestry system, while it varied from 2.7 to 3.4 t ha^{-1}

in the open system (Table 2). The maximum carbon stock under an agroforestry system was 4.7 t ha^{-1} when $N_{100}P_{60}K_{60}$ was used, however it was comparable to T_3 ($N_{80}P_{60}K_{60}$). The crop's carbon stock is determined by biomass output. The optimum carbon stock was observed since there was a higher biomass production of 10.6 t ha^{-1} with the application of 100 kg nitrogen. Soil fertility and rigorous management help to get the most profitable output. Hence, the rate of C stock depends directly on crop type, intercultural operation, fertilizer inputs, soil type, and fertility. Rajput [27] also observed that the different land use systems have significant influences on the production of aboveground biomass and belowground biomass, as well as total biomass, carbon stock, and CO_2 mitigation potential.

3.1.4. Carbon Sequestration by Turmeric (*Curcuma longa*)

Turmeric sequestration ranged from 13.4 to 17.5 t ha^{-1} (Table 2). Carbon sequestration was evaluated under the agroforestry system due to different treatments. The immense carbon sequestration in the crop under the agroforestry system was 17.5 t ha^{-1} with the regime of 100 kg nitrogen per hectare in the order $N_{100} > N_{80} > N_{60} > N_0$. In an open environment (no trees), carbon sequestration in turmeric ranged from 10 to 12.41 t ha^{-1} (Table 2). In the open system, the minimum carbon sequestration was 10 t ha^{-1}, but in the agroforestry system, it was 13.4 t ha^{-1}.

3.2. Biomass of Mango (Mangifera indica)

3.2.1. Aboveground Biomass of Mango (*Mangifera indica*)

The aboveground biomass of *Mangifera indica* under a silvihorticultural land-use system was measured (Volume × Sp.gravity × Biomass expansion factor 1.5) during the turmeric planting in 2017, which ranged from 23.9 to 28.9 t ha^{-1}, and the mean value after five years was 28.7–43.2 t ha^{-1}. The nutritional response varied from 21 to 48%. Data analysis revealed that the valency of biomass was nonsignificant. Nonetheless, the final value of the aforesaid biomass evidenced a considerable effect of all treatments over $N_0P_{60}K_{60}$, but N_{80}, N_{60}, and N_{100} were at par with each other.

3.2.2. Belowground Biomass of Mango (*Mangifera indica*)

The belowground biomass of *Mangifera indica* was examined (Above biomass × 0.26) and ranged from 6.2–8.4 t ha^{-1} (Table 3), and after five years of successive harvesting of the turmeric, (the belowground) biomass ranged from 7.5–11.2 t ha^{-1} and followed the order $N_{80} > N_{60} > N_{100} > N_0$. The initial measurements of belowground biomass were statistically insignificant. Nevertheless, the final values of belowground biomass displayed a considerable effect over $N_0P_{60}K_{60}$, but N_{80}, N_{60}, and N_{100} were at par with each other.

Table 3. Aboveground biomass, belowground biomass, total biomass, carbon stock, and carbon sequestration of *Mangifera indica* (t ha^{-1}) under an agroforestry system (2017–2021).

Treatment	Aboveground Biomass		Belowground Biomass		Total Biomass		Carbon Stock		Carbon Sequestration	
	2017	2021	2017	2021	2017	2021	2017	2021	2017	2021
T_1-$N_0P_{60}K_{60}$	23.9	28.7	6.2	7.5	30.1	36.2	20.2	24.1	74.1	88.9
T_2-$N_{100}P_{60}K_{60}$	32.2	40.1	8.4	10.4	40.5	50.5	27.2	33.7	99.6	124.1
T_3-$N_{80}K_{60}P_{60}$	29.7	43.2	7.7	11.2	37.4	54.5	25.1	36.3	91.9	133.8
T_4-$N_{60}P_{60}K_{60}$	28.9	40.6	7.5	10.6	36.4	51.1	24.4	34.1	89.4	125.7
CD (0.05)	3.0		0.8		3.8		2.6		9.4	
CV%	5.8		5.8		5.8		5.8		5.8	
SE (M)	1.0		0.3		1.2		0.8		3.1	

3.2.3. Carbon Stock of Mango (*Mangifera indica*)

The initial mean carbon stock ranged from 20.2 to 27.2 t ha^{-1} (Table 3). This was followed by $N_{100} > N_{80} > N_{60} > N_0$. Yet, after five years, the tree's carbon inventory rose from 24.2 to 36.3 t ha^{-1}, with the trend being $N_{80} > N_{60} > N_{100} > N_0$. The beginning (2017) value recorded was statistically insignificant, however the end carbon stock value had a substantial influence on the T_1 control plots, and the other treatments were the same. According to the research, the structural component has an indirect influence on the variable C stocks under different treatments since it directly impacts the ash level in the tree biomass. Furthermore, it can influence tree planting age, functional component, and management intensity.

3.2.4. Carbon Sequestration by Mango (*Mangifera indica*)

The carbon sequestration of the tree varied from 74.1 to 92.0 t ha^{-1} (Table 3) and followed the pattern $N_{100} > N_{80} > N_{60} > N_0$. After five years, the highest mean values were found in N_{80} (133.8 t ha^{-1}) and the lowest in N_0 (88.8 t ha^{-1}) in the following order: $N_{80} > N_{60} > N_{100} > N_0$. Statistically, the early values of carbon sequestration by the tree were nonsignificant, but the subsequent data revealed a significant influence of fertilizer N_{100}, N_{80}, and N_{60} application was at par.

3.3. Soil Organic Carbon Content (SOCs)

The baseline organic carbon values of the open system (without trees) and the agroforestry system ranged from 4.4 to 5.8 g kg^{-1}, and following turmeric harvesting, the organic carbon content of the agroforestry field ranged from 8.83 to 9.66 g kg^{-1}. After five years, organic carbon concentrations in the open and agroforestry systems varied from 4.5 to 5.7 g kg^{-1} and 9.5 to 10.4 g kg^{-1}, respectively. Kumar et al. [38,39] found that among soil chemical characteristics, organic carbon concentration was greater in the agroforestry system than in the open agricultural system.

3.4. Carbon Sequestration by Soil

Carbon sequestration, calculated by multiplying soil organic carbon content, bulk density, and soil sampling depth, ranged from 61.6 to 68.5 t ha^{-1} and 144.2 to 157.9 t ha^{-1} without trees (open system) and with trees (agroforestry), respectively (Table 4). Soil carbon storage was highest in the agroforestry system and lowest in the open "treeless" system. In the agroforestry system, tree leaf mulch contributes directly and repeatedly to soil organic matter.

Table 4. Soil organic content (g kg^{-1}) and soil carbon sequestration (t ha^{-1}) under the agroforestry system and the open system (2017–2021).

Treatment	Soil Organic Carbon of Agroforestry System		Soil Organic Carbon of Open System		Carbon Sequestration by Agroforestry System		Carbon Sequestration by Open System	
	2017	2021	2017	2021	2017	2021	2017	2021
T_1-$N_0P_{60}K_{60}$	8.8	9.5	4.4	4.5	126.3	144.2	62.9	64.8
T_2-$N_{100}P_{60}K_{60}$	9.7	10.4	4.8	5.0	138.2	157.9	57.2	68.5
T_3-$N_{80}K_{60}P_{60}$	8.6	9.2	5.2	5.2	122.6	144.2	67.2	61.6
T_4-$N_{60}P_{60}K_{60}$	8.0	8.7	5.8	5.8	114.6	135.2	48.6	59.2
CD (0.05)	0.2		0.2		2.5		10.4	
CV%	1.4		3.3		1.4		11.8	
SE (M)	0.1		0.1		15.0		61.3	

3.5. Carbon Sequestration by Agroforestry System and Open System

Carbon sequestration in an agroforestry system varied significantly (246.5–299.5 t ha^{-1}) depending on the treatment (Table 5). In contrast, total carbon sequestration in open systems ranged from 70.0 to 80.9 t ha^{-1} (Table 6). When the two treatments and land use systems were compared, it was discovered that the tree grew faster owing to fertilizer application, which was perceptible over the nitrogen-omitted patch. In this experiment, no significant variations among the treatments applied were observed in either of the studied years, 2017 and 2021. The detailed data pertaining to the effect of different treatments applied are presented in Table 7. The observed data were tested for Levene's test for homogeneity of variances at $p > 0.01$ and it was found that the data are significantly homogenous. The Analysis of Variance (ANOVA) among the treatments suggested that there is no significant difference between them (Table 8). Perusal of the data through Tukey's HSD post hoc test (at $\alpha = 0.05$) also supported the ANOVA results, as no significantly different subsets were observed due to the variation in treatments. However, significant differences between agroforestry and the open system were observed in both of the studied years, 2017 and 2021. The detailed data pertaining to the effects of two different systems on carbon sequestration are presented in Table 9. The Analysis of Variance (ANOVA) between the systems suggested that there is significant variation between the level of carbon sequestration by these two systems (Table 10). Perusal of the data through Tukey's HSD post hoc test (at $\alpha = 0.05$) also supported the ANOVA results, as significantly different subsets were observed due to the difference in systems.

Table 5. Carbon sequestration t ha^{-1} by (Crop +Tree+ Soil) under an agroforestry system (2017–2021).

Treatment	Carbon Sequestration by Crop		Carbon Sequestration by Tree		Carbon Sequestration by Soil		Total	
	2017	2021	2017	2021	2017	2021	2017	2021
T_1-$N_0P_{60}K_{60}$	12.4	13.4	74.1	88.9	126.3	144.2	212.8	246.5
T_2-$N_{100}P_{60}K_{60}$	17.3	17.5	99.6	124.1	138.2	157.9	255.1	299.5
T_3-$N_{80}K_{60}P_{60}$	13.4	16.7	91.9	133.8	122.6	144.2	227.9	294.7
T_4-$N_{60}P_{60}K_{60}$	12.7	13.9	89.4	125.7	114.6	135.2	216.7	274.8

Table 6. Carbon sequestration t ha^{-1} by (Crop + Soil) under open system (2017–2021).

Treatment	Carbon Sequestration by Crop		Carbon Sequestration by Soil		Mean Total	
	2017	2021	2017	2021	2017	2021
T_1-$N_0P_{60}K_{60}$	10.2	10.0	62.9	64.8	73.1	74.8
T_2-$N_{100}P_{60}K_{60}$	12.0	12.4	57.2	68.5	69.2	80.9
T_3-$N_{80}K_{60}P_{60}$	11.7	11.9	67.2	61.6	78.9	73.5
T_4-$N_{60}P_{60}K_{60}$	11.0	10.8	48.6	59.2	59.6	70.0

Table 7. Levene's test for homogeneity of variances among different rate of fertilizer (T_1-$N_0P_{60}K_{60}$, T_2-$N_{100}P_{60}K_{60}$, T_3-$N_{80}K_{60}P_{60}$, T_4-$N_{60}P_{60}K_{60}$) treatments.

Treatments	Year	Carbon Sequestration by Crop	Carbon Sequestration by Tree	Carbon Sequestration by Soil	Total Carbon Sequestration
T_1-$N_0P_{60}K_{60}$	2017	12.400 ^{a}	74.100 ^{b}	126.309 ^{c}	212.809 ^{d}
	2021	13.400 ^{a}	88.900 ^{b}	144.157 ^{c}	246.457 ^{d}
T_2-$N_{100}P_{60}K_{60}$	2017	17.300 ^{a}	99.600 ^{b}	138.208 ^{c}	255.108 ^{d}
	2021	17.500 ^{a}	124.100 ^{b}	157.886 ^{c}	299.486 ^{d}
T_3-$N_{80}K_{60}P_{60}$	2017	13.400 ^{a}	91.900 ^{b}	122.648 ^{c}	227.948 ^{d}
	2021	16.700 ^{a}	133.800 ^{b}	144.157 ^{c}	294.657 ^{d}
T_4-$N_{60}P_{60}K_{60}$	2017	12.700 ^{a}	89.400 ^{b}	114.639 ^{c}	216.739 ^{d}
	2021	13.900 ^{a}	125.700 ^{b}	135.233 ^{c}	274.833 ^{d}

Means followed by the same letters in each column are not significantly different based on the Tukey's HSD post hoc test at $\alpha = 0.05$.

Table 8. Analysis of Variance among different rates of fertiliser (T_1-$N_0P_{60}K_{60}$, T_2-$N_{100}P_{60}K_{60}$, T_3-$N_{80}K_{60}P_{60}$, T_4-$N_{60}P_{60}K_{60}$) treatments (2017–2021).

Source of Variation	*d.f.*	Sum of Squares			
		Carbon Sequestration by Crop	Carbon Sequestration by Tree	Carbon Sequestration by Soil	Total Carbon Sequestration
Between Groups	3	25.214	1315.064	546.919	2512.631
Within Groups	4	6.685	1946.295	796.262	5463.299
Total	7	31.899	3261.359	1343.182	7975.930
F-value		5.029 (NS)	0.901 (NS)	0.915 (NS)	0.613 (NS)

NS: Not significant.

Table 9. Levene's test for homogeneity of variances between agroforestry and the open system (2017–2021).

Systems	Year	Treatments	Carbon Sequestration by Crop	Carbon Sequestration by Soil	Total Carbon Sequestration
Agroforestry System	2017	T_1-$N_0P_{60}K_{60}$	12.400 [a]	126.309 [a]	212.809 [a]
		T_2-$N_{100}P_{60}K_{60}$	17.300 [a]	138.208 [a]	255.108 [a]
		T_3-$N_{80}K_{60}P_{60}$	13.400 [a]	122.648 [a]	227.948 [a]
		T_4-$N_{60}P_{60}K_{60}$	12.700 [a]	114.639 [a]	216.739 [a]
	2021	T_1-$N_0P_{60}K_{60}$	13.400 [a]	144.157 [a]	246.457 [a]
		T_2-$N_{100}P_{60}K_{60}$	17.500 [a]	157.886 [a]	299.486 [a]
		T_3-$N_{80}K_{60}P_{60}$	16.700 [a]	144.157 [a]	294.657 [a]
		T_4-$N_{60}P_{60}K_{60}$	13.900 [a]	135.233 [a]	274.833 [a]
Open System	2017	T_1-$N_0P_{60}K_{60}$	10.200 [b]	62.926 [b]	73.126 [b]
		T_2-$N_{100}P_{60}K_{60}$	12.000 [b]	57.205 [b]	69.205 [b]
		T_3-$N_{80}K_{60}P_{60}$	11.700 [b]	67.216 [b]	78.916 [b]
		T_4-$N_{60}P_{60}K_{60}$	11.000 [b]	48.624 [b]	59.624 [b]
	2021	T_1-$N_0P_{60}K_{60}$	10.000 [b]	64.848 [b]	74.848 [b]
		T_2-$N_{100}P_{60}K_{60}$	12.400 [b]	68.509 [b]	80.909 [b]
		T_3-$N_{80}K_{60}P_{60}$	11.900 [b]	61.587 [b]	73.487 [b]
		T_4-$N_{60}P_{60}K_{60}$	10.800 [b]	59.207 [b]	70.007 [b]

Means followed by the same letters in each column are not significantly different based on the Tukey's HSD post hoc test at $\alpha = 0.05$.

Table 10. Analysis of Variance between agroforestry and the open system (2017–2021).

Source of Variation	*d.f.*	Sum of Squares		
		Carbon Sequestration by Crop	Carbon Sequestration by Soil	Total Carbon Sequestration
Between Groups	46.58	21,986.59	131,028.62	46.58
Within Groups	37.34	1627.29	8277.55	37.34
Total	83.92	23,613.87	139,306.16	83.92
F-value		17.465 **	189.157 ***	221.612 ***

** Significantly different at $p < 0.01$; *** Significantly different at $p < 0.001$.

3.6. Carbon Credit and Carbon Trading

The total carbon credit estimated (1 metric tonne carbon = 1 credit) was 299.5 credits under the agroforestry system, whereas 80.9 credits were recorded using the open system T_2-$N_{100}P_{60}K_{60}$, implying that the value of carbon credit gained under the open system was approximately 218.6 credits greater (Table 11). With the agroforestry system, the possible profit from selling carbon in stock/on the open market will be INR 3,27,886.6 (4098 $).

Table 11. Mean value of carbon credits and carbon trading from agroforestry and the open system, 2017–2021.

Treatment	Carbon Credits by Agroforestry			Carbon Credits by Open Field			
	Carbon Sequestration Agroforestry (t ha^{-1})	Carbon Credits	Carbon Pricing for Trading (INR)	Carbon Sequestration Open Field (t ha^{-1})	Carbon Credits	Carbon Pricing for Trading (INR)	Benefits over Open System (INR)
T_1-$N_0P_{60}K_{60}$	246.5	246.5	369,750	74.8	74.8	112,271.7	257,478.3 (3218 $)
T_2-$N_{100}P_{60}K_{60}$	299.5	299.5	449,250	80.9	80.9	121,363.4	327,886.6 (4098 $)
T_3-$N_{80}K_{60}P_{60}$	294.7	294.7	442,050	73.5	73.5	110,230.7	331,819.3 (4414 $)
T_4-$N_{60}P_{60}K_{60}$	274.8	274.8	412,200	70.0	70.0	105,011.1	307,188.9 (3839 $)

Note- INR: Indian Rupees.

3.7. Multiple Regression Equation

The Table 12 demonstrated that if the tree girth is less than 30 cm, the equation biomass (kg) = −12.641 + 1.787D + −0.715H can be used to estimate the aboveground biomass of *Mangifera indica* in their native environment, and if the girth class is between 30–35 cm, the equation biomass (kg) = −33.197 + 2.734D + −1.868H can be used. The biomass equations for *Mangifera indica* were derived on the basis of diameter classes 30 cm and >30–35 cm. Ravindranath and Ostwald [26] and Chavan and Rasal [40] also used the same allometric equation for their respective studies.

Table 12. Allometry equations based on the regression coefficient to estimate the aboveground biomass of *Mangifera indica*.

Girth Class	a	b	c
<30 cm	−12.641	1.787	−0.715
>30 cm–35 cm	−33.197	2.734	−1.868
Girth class	Equation		R^2
<30 cm	Biomass (kg) = −12.641 + 1.787D + −0.715H		94.23%
>30–35 cm	Biomass (kg) = −33.197 + 2.734D + −1.868H		97.40%

4. Discussion

4.1. Effects of Shade and Fertilizer on the Growth, Yield, Biomass Production, and Carbon Sequestration of Turmeric

The vast majority of biomass yield and carbon sequestration interacted with fertilizer rate in this research. Turmeric's crop output, biomass gain, and carbon sequestration potential improved when cultivated in shady environments, resulting in a shade-loving niche through an agroforestry system, compared to open conditions where the plants were grown in full sunlight. Prior research found that shade-grown turmeric plants increased in plant height, leaf size, and fresh rhizome weight [41]. *Curcuma longa* is a shade-loving plant that emerges in low-light environments similar to its natural gloomy habitats. Turmeric leaves are susceptible to high concentrations of radiation. Increased amounts of radiation would degrade photosynthesis and pigments, as well as diminish forage, resulting in a leaf site that was lower than the original field circumstances. All development aspects were taken into account by applying the fertilizer at four distinct rates. Higher fertilizer rates may have resulted in larger rhizome yields since NPK treatment rates quadrupled plant nutrient absorption. The usage of fertilizers has resulted in an increase in turmeric output.

Singh et al. [42] also observed that varying fertilizer dosages increased the production of turmeric rhizomes. According to the current study, the biomass in the agroforestry system was between 8.12 and 10.59 t ha^{-1}, but the turmeric biomass in the "treeless" open system was between 6.1 and 7 t ha^{-1} lay. 5 t ha^{-1} (Table 2). With 100 kg of nitrogen depending on plant biomass output, the maximum carbon resources were calculated to be 10.6 t ha^{-1} (Table 2). Since C stocks are closely tied to crop yields, it is critical to understand the rate at which C may be created from various crops. Understanding how much C a single farmer may potentially generate from a certain crop species is therefore critical to determining its total yield potential. The degree of carbon sequestration in the open system was 10 t ha^{-1} and 13.4 t ha^{-1} [Table 2] in the agroforestry system. Biomass production and carbon stocks are interconnected, with vegetative growth and crop output influencing both. Carbon sequestration may be accomplished in a variety of methods, including agricultural techniques and other sorts of energy sources. [26].

4.2. Effects of Fertilizer on Mangifera Indica Growth, Biomass Output, and Carbon Sequestration, as Well as Carbon Trading in Agroforestry

Carbon storage in aboveground biomass showed a wide range of differences in this study; in 2017 it was 23.9–28.9 t ha^{-1} and after another five years of fertilization and nutrient enrichment by decomposition of the litter it shows an increase of five units, that is, from 28.7 to 43.2 t ha^{-1} in 2021 (Table 3), comparable to various studies reported by others in tropical India, Chavan et al. [23] (32.31, 8.40 and 40.71 t ha^{-1}). According to Deri et al. [43], a mango tree plantation sequestered 3,591 t ha^{-1} of aboveground carbon, which was expected to increase with altitude and DHB. Ganeshamurthy et al. [44] used an allometric equation developed for grafted mangoes to investigate the carbon sequestration potential of Alphonso mangoes in the Konkan region of India. Soil carbon storage was 157.2 t ha^{-1}, implying that decomposition of leaf litter improves soil aggregates and contributes to soil fertility. However, the litter supply in an open system is relatively low because most of the biomass is removed from the field [26,45]. The OC content was higher in the agroforestry system than in the open system among the soil chemical properties. Among the soil chemical properties studied, the OC content in the agroforestry system was higher than in the open system. This is most likely due to the increased production of organic matter by trees and other plants, which can be used as a source of nutrients for the soil. In an open agroecosystem, low SOC can be attributed to intensive farming [46]. Kumar et al. [38,39] discovered that the OC content was higher in the agroforest system than in the open system among soil chemical properties. It is possible that the variability of carbon sequestration potential varies directly with species genetics, lifespan, structural and functional components, and so on. [26,44]. Kumar et al. [11] investigated wheat in agroforestry and open source and discovered that agroforestry had a much higher carbon credit ($42,049) and economic price ($744,270). In the wheat agroforestry system, Kumar et al. [11] found higher biomass (25,702 t ha^{-1}) and higher carbon stock (1146 t ha^{-1}).

5. Conclusions

Fertilizers improve agroforestry soil fertility by enhancing N-based carbon absorption, which may lead to an increase in rhizosphere C deposition and increase soil organic carbon. This enhanced soil organic carbon may be beneficial in boosting the bioavailability of other nutrients. As indicated by the considerable positive link between biomass increases and fertilizer rates, appropriate fertilizer rates also assist achieve optimal plant production and improve biomass carbon content within the mango-turmeric agroecosystem. The growth of the wood component in the agroforestry system will also be favorably correlated with nutrient management. It is also economically beneficial to collect more C from the atmosphere by raising photosynthetic rates and net primary output. With proper nutrient application rates, the carbon credit created in the turmeric-mango agroforestry system rises. This means that the investigated agroforestry system not only produces a greater yield with an appropriate fertilizer dose, but it may also create additional cash for the farmer in the form of carbon credits. In accordance with the findings, cultivating turmeric in mango plantations with optimal fertilizers is both cheap and ecologically benign, and it should be employed to accelerate the rate of atmospheric C reduction.

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