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RESEARCH ARTICLE

Changes in carbon sequestration with age of trees in guava orchards at different locations in a tropical climate on Alfisols

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Abstract

Understanding changes in carbon (C) fluxes resulting from land-use change patterns is essential for formulating effective climate change mitigation strategies. This study conducted at two different locations focuses on the dynamics of carbon sequestration in guava orchards as a function of tree age, a land-use type that is increasingly prevalent in agricultural regions. Through comprehensive sampling in different agro-climatic zones, the carbon content stored in tree biomass, litter, weeds and soil layers was assessed, the evaluation of which provided insights into carbon levels in different environmental contexts. Carbon sequestration was observed to increase with guava orchard age, with mean carbon stocks of 106.84 t C/ha in Dhenkanal and 114.35 t C/ha in Rayagada. In guava orchards above-ground carbon accounted for 21.22% and 22.38% of total carbon sequestered per hectare at the recommended spacing of 6 × 6 m in Dhenkanal and Rayagada, respectively. Our findings provide critical baseline data on carbon stocks in guava orchards as a function of tree age, contributing to the understanding of the carbon cycle in these cultivated ecosystems. This study highlights the importance of region-specific data, and suggests future research to include guava orchards in other regions with larger sample sizes to comprehensively assess carbon sequestration potential nationwide.

Keywords

carbon sequestration; guava; soil carbon stock; tree biomass

Introduction

Perennial horticulture is gaining momentum, with fruit crops leading the way. These high-value cash crops provide significant income for farmers. In 2021, India produced approximately 102 million tons of fruit. Eight major fruit crops cover over 80% of the fruit-growing area in the country. Among them, guava ranks fourth in cultivation area after mango, citrus, banana and grape (1). Guava is grown on approximately 264.85 thousand hectares across several states, with a total production of about 4053.5 thousand metric tons in 2021. The Gomati River belt district in Uttar Pradesh is the largest guava producer in India.

In 2024, Odisha reported a guava production of 121.290 thousand tons, unchanged from 2023. This data, updated annually, has an average annual production of 104.560 thousand tons from March 2012 to 2024 (Fig. 1). The highest recorded production was 121.290 thousand tons in 2024, while the lowest was 103.440 thousand tons in 2012 (2).

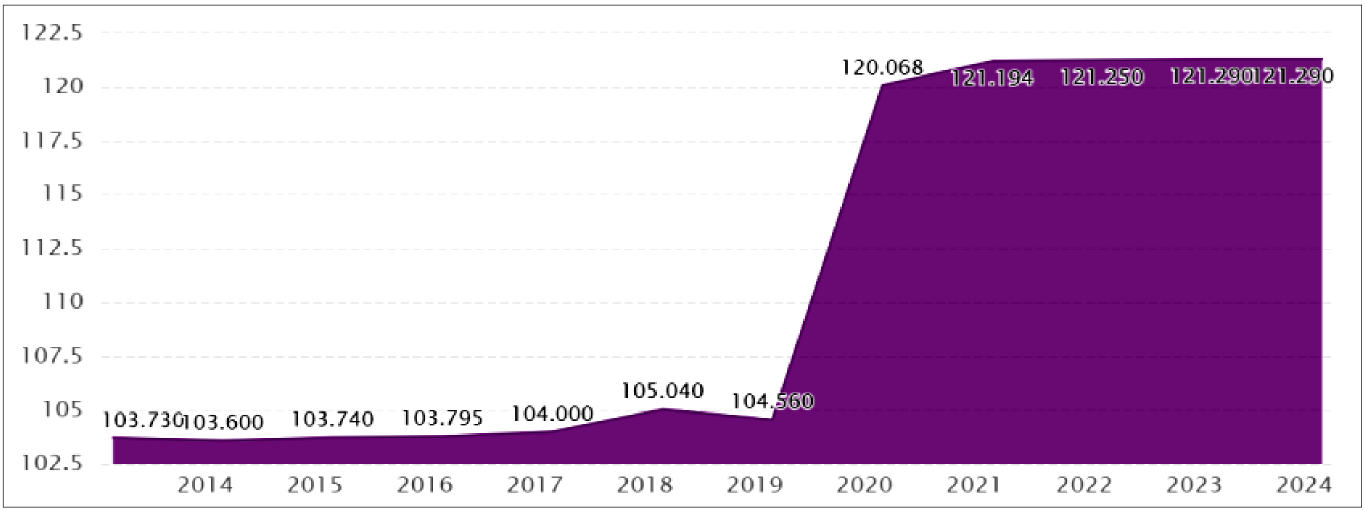

Fig. 1. Trends in guava production in Odisha in the past one decade (DAFW, 2024). X-axis: years and Y-axis: production (in thousand tons).

Guava trees are fast-growing evergreens that reach heights of 3–10 m and have a lifespan of 40–50 years, though productivity stabilizes after 6-7 years and usually declines after 15 years. Annually, each tree can yield between 500–800 fruits. A 10-year-old tree, at a planting density of 277 trees per hectare, produces about 19 metric tons of fruits per hectare. Although yield varies by variety, the average annual yield from a typical farm is 20–25 tons per hectare.

Guava trees produce substantial biomass, playing a crucial role in carbon sequestration. The amount of carbon sequestered increases significantly as the tree ages and matures, stored in both above and below-ground biomass, as well as in both long-lived and short-lived wood products. In ecosystems, major carbon pools include above-ground biomass (AGB), below-ground biomass (BGB), dead wood, litter, and soil organic matter (3-6). Assessing biomass equations to improve carbon budget estimates involves understanding the relationship between individual trees and whole-stand biomass, with the standard assumption being that about 50% of a tree's wood mass is carbon (7). Fruits, transported out of the orchard, are not included in carbon sequestration accounting, making carbon harvest crucial in fruit orchards like guava.

There is limited information on the effect of tree age on carbon sequestration in guava orchards established from grafted or layered seedlings due to a lack of non-destructive methods for estimating tree biomass. The allometric equations for estimating biomass were developed in grafted mango and sapota (6, 8). Using similar methodologies, this paper reports estimates of carbon sequestered by guava orchards of different age groups from two different locations in Odisha state of India.

Materials and Methods

This study was carried out in two different locations viz., Dhenkanal and Rayagada districts of Odisha in farmers' fields in Eastern India. The orchard site is located at an elevation of about 971 m above sea level, spreading between the latitudinal parallel of 26˚N and the longitudinal meridians of 85˚22' E and 86˚ 52' E. The region undergoes four well-defined seasons; from December to February there is a dry season characterized by clear and sunny weather, followed by summer from March to May. The southwest monsoon occurs between June and September, while October and November mark the northeast monsoon or the retreat of the southwest monsoon. In climatological terms, the climate is classified as a 'sub-humid tropical monsoon climate', characterized by four distinct seasons. The key characteristics of the region's climate include an agreeable range of temperatures, with the highest average maximum temperature reaching 40 °C in May-June and the lowest average minimum dropping to 7 °C in January. The region experiences two consecutive rainy seasons, the southwest and northeast monsoons, which are characterized by opposing wind patterns. The southwest monsoon occurs from June to September, followed by the northeast monsoon from October to November.

Selection of orchard

For this study orchards of different age groups viz., 5–10, 10–15 and >15 years old orchard of guava cv. Allahabad Safeda was selected at a farmer's farm on Alfisol. The orchard accommodated 277 trees per hectare at a spacing of 6 × 6 m. Trees received fertilizers as per recommendation. Standard practices recommended by IIHR, Bengaluru, were implemented for orchard management, encompassing both pest and disease control measures.

Estimation of tree biomass

For the estimation of both AGB and BGB, the allometric equation developed for the guava orchard was used (6). In brief, the allometric equation was derived from destructive sampling of 20 guava trees. Measurements taken included allometric parameters such as the number of primary and secondary branches, girth of both primary and secondary branches, tree height, tree volume, basal diameter and diameter below the graft union. The stem diameter below the graft union was measured using a diameter tape. A Spiegel Relaskop was used to measure both the height of the tree and the diameter of the crown. Various statistical models, including multiple linear regression (MLR) model and the power model, were utilized to estimate tree biomass. The power model was chosen for biomass estimation due to its superior fit. Guava power model for estimation of tree biomass:

$$Y = 11.52\ X^{0.839}$$

For BGB estimation, the ratio of 1:0.29 was used (8).

Tree sampling

Mature leaves were collected from 20 randomly selected trees in the orchard to estimate carbon content. These samples were pooled together, washed and dried in a hot air oven at 65 °C until they reached a constant weight. Once dried, the samples were ground for carbon estimation. Similarly, samples from the trunk, as well as twigs representing primary, secondary and tertiary branches, along with other smaller branches, were collected and processed for carbon analysis. Additionally, bark and wood samples were obtained from selected trees using a tree drill and prepared for carbon estimation.

Carbon estimation

The carbon content of the guava tree was assessed by using a CHNS analyzer (Elementar) and expressed as percentage of C in the sample. The litter and weed biomass gathered from the orchard were processed and evaluated for carbon content using CHNS analyzer , and the results were reported as the percentage of C in the sample.

Soil profile samples were drawn up to one meter depth from four random places in the orchard. The soil samples were mixed thoroughly and placed in plastic bags in the laboratory. They were air-dried, passed through a 2-mm sieve, and stored for further analysis. The bulk density of the soil was assessed using the core sampling method with a volumetric cylinder. Soil bulk density was calculated as the ratio of the oven-dry weight of the soil (dried at 105 °C for 24 h) to its total volume. The total soil organic matter was measured using the Walkley-Black method, which involves wet acid digestion (9). Soil carbon stock was determined by multiplying the concentration of total soil organic carbon (TOC) by the soil bulk density of each layer (10), using the equation (1):

$$C\ stock = (TOC \times Ds \times e) / 10$$

Where, TOC represents the total organic carbon at a specific soil depth (thickness of the layer), Ds denotes the soil bulk density at that same soil depth, and e refers to the thickness of the layer.

Results and Discussion

Soil properties

The orchard soil is a typical udic haplustalf (11) and guava performs well in Alfisols. These Alfisol soils exhibit acidity due to the leaching of bases, which occurs as a result of frequent and heavy rainfall during the 6-month monsoon period. The electrical conductivity is very low (<0.528 dS/m). The soil contains a minimal amount of organic matter (0.41%). The available nitrogen content was rated as low, phosphorus was also low, and potassium was at medium level. The available phosphorus was low because in acid soils fixation is high due to a high sesquioxide presence.

Allometric parameters and C capture by guava

The observed average number of primary branches ranged from 2.50 to 3.16 among different age groups of trees in Dhenkanal and from 2.66 to 3.33 in Rayagada, with an overall mean of 2.86 (Table 1, Fig. 2 and 3). The mean diameter of primary branches varied from 5.12 to 11.58 cm in Dhenkanal and 6.51 to 11.27 cm in Rayagada across different age groups, yielding an overall mean of 8.55 cm. These measurements indicate that tree strength increases with age. Using these parameters, the AGB of guava trees was assessed employing the allometric equation developed for orchard guava (6). The mean AGB recorded was 97.85 kg/tree for 5-year-old trees in Dhenkanal and 126.04 kg/tree in Rayagada, rising to 236.12 kg/tree and 241.23 kg/tree, respectively, for trees aged over 15 years (Table 1, Fig. 2 and 3). The BGB was determined based on a root-to-shoot ratio of 0.29 (8). The BGB exhibited a similar trend, with a mean BGB of 49.43 kg/tree (Table 1, Fig. 2 and 3).

Using the mean C content of biomass, the total above-ground and below-ground carbon sequestered by orchard guava trees was calculated. The total C sequestered was 64.08 kg/tree in Dhenkanal and 82.54 kg/tree in Rayagada for 5-year-old trees, increasing to 154.62 kg/tree in Dhenkanal and 157.97 kg/tree in Rayagada for trees over 15 years old, with an overall mean of 111.61 kg/tree (Table 1, Fig. 2 & 3). A 10-year-old mango tree could

Table 1. Allometric parameters and tree C sequestration from guava orchards of different age groups

Location/Tree age group	No. of Primary Branches*	Mean Girth of primary branches (cm)*	Average Value X No. of Primary Branches	AGB Kg/tree	AGB C Kg/tree	BGB Kg/tree	BGB C Kg/tree	Total C Kg/tree
Dhenkanal								
5–10 years	2.5	5.12	12.81	97.85	49.52	28.38	14.55	64.08
10–15 years	2.66	7.92	21.07	148.58	75.20	43.09	22.10	97.30
>15 Years	3.16	11.58	36.59	236.12	119.50	68.48	35.12	154.62
Rayagada								
5–10 years	2.66	6.51	17.32	126.04	63.79	36.55	18.75	82.54
10–15 years	2.83	8.91	25.22	172.76	87.43	50.10	25.70	113.13
>15 Years	3.33	11.27	37.54	241.23	122.09	69.96	35.88	157.97
Mean	2.86	8.55	25.09	170.43	86.26	49.43	25.35	111.61

AGB: above-ground biomass; **BGB**: below-ground biomass; **C**: carbon

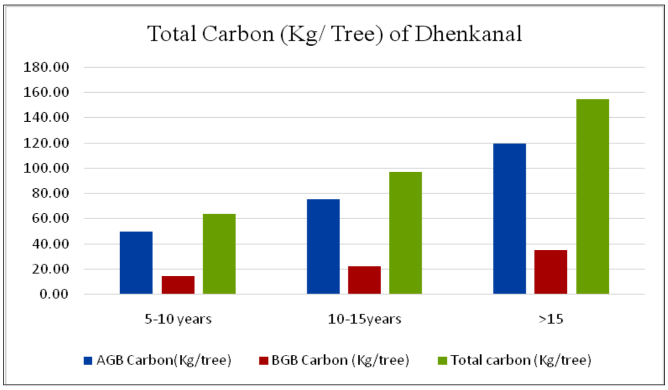

Fig. 2. Diagrammatic representation of the amount of AGB, BGB and total C in Dhenkanal (Table 1).

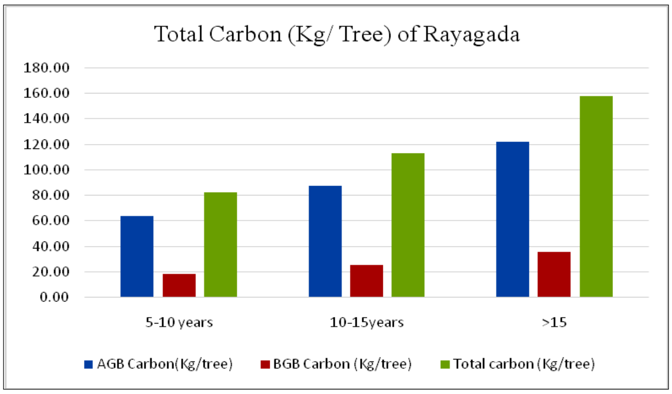

Fig. 3. Diagrammatic representation of the amount of AGB, BGB, and total C in Rayagada (Table 1).

sequester 58 kg C, while a 15-year-old mango tree could sequester about 115 kg C per tree (12). Additionally, a 10-year-old guava tree could sequester 33 kg C, and a 15-year-old guava tree could sequester about 54 kg C per tree. Our results indicate higher values of C sequesteration, likely due to the robust tree growth in the sub-humid tropical monsoonic climate and fertile soils of Dhenkanal and Rayagada compared to other regions in India.

In this study, orchards consisted of trees aged from 5 years to over 15 years. A 5-year-old guava tree sequestered 12.82 kg C/tree/year in Dhenkanal and 16.51 kg C/tree/year in Rayagada, while a 15-year-old tree sequestered 10.31 kg C/tree/year in Dhenkanal and 10.53 kg C/tree/year in Rayagada. The differences between Dhenkanal and Rayagada were more pronounced in younger trees but neutralized as trees aged, with biomass production plateauing after 10 years (6). In sapota tree, 16.72 kg C was sequestered per sapota tree, although the tree age was not specified (13). It was noted that the potential of fruit crops such as apple, mango, guava, sapota, citrus and grape in sequestering C enhances biological yield (13, 14).

Despite our higher values, the robustness of tree growth in the sub-humid tropical climate justifies the findings compared to subtropical regions of India where guava is extensively cultivated (1). This higher productivity further improves the net primary production (NPP), net ecosystem production (NEP), and net ecosystem carbon balance (NECB) of fruit crops. Calculating carbon biomass provides useful information about the quantity and quality of C sequestered in the area, and how it behaves in fruit crops such as guava, where C is eventually trapped in woody biomass, aiding in the mitigation of greenhouse gas emissions and addressing global warming and climate change.

Carbon sequestration in weed and litter biomass

The orchard surface is covered by leaf litter and weed biomass, which contribute to floor-level carbon sequestration. Weeds are predominantly found between tree rows, in the spaces between trees, and along the boundaries. The annual weed biomass was estimated from samples collected in the experimental orchard. Over one year, the estimated weed dry biomass in the experimental orchard was 1191 kg/ha in Dhenkanal and 1198.8 kg/ha in Rayagada for 5-year-old orchards, and 486.6 kg/ha in Dhenkanal and 516 kg/ha in Rayagada for 15-year-old orchards (Table 2, Fig. 4). We observed a decrease in weed biomass in older orchards which is attributed to an increase in shading that reduces the amount of sunlight reaching the ground, limiting the growth of weeds. Also, mature trees have extensive root systems that can outcompete weeds for water and nutrients, making it harder for weeds to grow.

Litter biomass is mainly concentrated within the tree drip circle. Litter biomass was lower than weed biomass due to the larger open areas in the orchard allowing weeds to proliferate. The estimated litter dry biomass was 253.5 kg/ha in Dhenkanal and 287.4 kg/ha in Rayagada for 5-year-old orchards, and 654 kg/ha in Dhenkanal and 684 kg/ha in Rayagada for 15-year-old orchards (Table 2, Fig. 4). The estimated mean carbon content of weeds was 47.59%, while the carbon content of guava litter was 46.46%. Using these values, the C content of weeds and litter was calculated. The share of this fraction in total carbon sequestration is quite small. Generally, in forests, C stored in the forest floor accounts for less than 10% of the total C sequestered (15). This value varies significantly in fruit orchards, depending on the management practices employed. Regular weeding results in a lower proportion of floor carbon.

Table 2. Soil C stock, litter and weed biomass C in the guava orchard

Source	Dhenkanal				Rayagada			
	5–10 years	10–15 years	>15 years	Mean	5–10 years	10 – 15 years	>15 years	Mean
Soil C t/ha	77	77	77	77	81	81	81	81
Weed biomass kg/ha	1191	1086	486.6	921.2	1198.8	1129.2	516	948
Weed C kg/ha	552.62	512.59	234.05	433.09	570.63	540.89	249.33	453.62
Litter biomass kg/ha	253.5	554.4	654	487.3	287.4	615.6	684	529
Litter C kg/ha	114.58	253.47	308.03	225.36	133.21	288.72	324.9	248.94
Total C content (weed+litter) kg/ha	667.21	766.06	542.09	658.45	703.84	829.60	574.23	702.56
Total C other than tree biomass t/ha	77.67	77.77	77.54	77.66	81.70	81.83	81.57	81.70

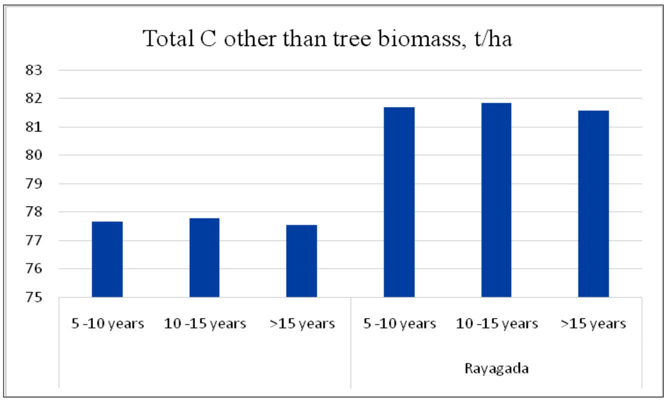

Fig. 4. Diagrammatic representation of total C other than tree biomass (t/ha) (Table 2).

In this study, weed and litter carbon biomass represented 0.63% and 0.62% of the total C sequestered in the orchards in Dhenkanal and Rayagada, respectively (Table 3). This is due to proper weeding practices being maintained in the orchards. Although its contribution to total C is relatively small, litter plays a vital role in the carbon biogeochemical cycle, acting as a link between C in vegetation and C in the soil. Our values are slightly higher than those reported by Ganeshamurthy *et. al.* (6), likely due to the robustness of the trees in our selected orchards compared to those sampled by the Ganeshamurthy group.

Soil carbon stocks

Soil organic carbon (SOC) tends to reach a quasi-equilibrium value (QEV) after approximately 30 years under horticultural systems (16). However, the horticultural systems in these tropical land use conditions achieve QEV in about 25 years (17). The guava orchards examined in this study ranged from 5 to 15 years old, indicating that the soil carbon content in these orchards has likely not yet stabilized. The mean soil carbon stocks recorded in the experimental orchards were 77000 kg/ha in Dhenkanal and 81000 kg/ha in Rayagada (Table 2, Fig. 4). These SOC levels are comparable to those reported for guava orchards, mango orchards and Indian forest soils (6, 18, 19).

Carbon sequestration by one-hectare guava orchard

The experimental guava orchard was planted with a spacing of 6 × 6 m, accommodating 277 trees per hectare (Table 3, Fig. 5). To calculate the total C sequestered by guava trees per hectare, the estimated total carbon sequestered per tree was multiplied by the number of trees per hectare. Carbon sequestration increased with tree age. In 5-year-old orchards, the total C sequestered by guava trees was 95.42 tonnes/ha in Dhenkanal and 104.57 tonnes/ha in Rayagada. This increased to 120.37 tonnes/ha in Dhenkanal and 125.33 tonnes/ha in Rayagada in 15-year-old orchards. The mean C sequestered by guava trees in the experimental orchards was 106.84 tonnes/ha in Dhenkanal and 114.35 tonnes/ha in Rayagada.

In guava orchards, the share of soil carbon in the total carbon sequestered was greater than that of tree carbon. Previous studies show that soil C often exceeds tree biomass C (6, 8, 20). In this report, the proportion of soil C

Table 3. Carbon pool compartment in guava orchard (6 × 6 m = 277 trees)

Source	Carbon quantity				C (%)			
				Dhenkanal				
Age group	**5–10 years**	**10–15 years**	**>15 years**	**Mean**	**5–10 years**	**10–15 years**	**>15 years**	**Mean**
AGB tree C (t/ha)	13.72	20.83	33.10	22.55	14.38	19.89	27.50	20.59
Litter C (t/ha)	0.11	0.25	0.31	0.23	0.12	0.24	0.26	0.21
Weed C (t/ha)	0.55	0.51	0.23	0.43	0.58	0.49	0.19	0.42
Weed+litter C (t/ha)	0.67	0.77	0.54	0.66	0.70	0.73	0.45	0.63
Total above-ground C (t/ha)	14.38	21.59	33.64	23.21	15.08	20.62	27.95	21.22
Root C (t/ha)	4.03	6.12	9.73	6.63	4.22	5.85	8.08	6.05
Total tree C (t/ha)	18.42	27.72	43.37	29.84	19.30	26.47	36.03	27.27
Soil C (t/ha)	77.00	77.00	77.00	77.00	80.70	73.53	63.97	72.73
Total below-ground C (t/ha)	81.03	83.12	86.73	83.63	84.92	79.38	72.05	78.78
Total C sequestered in orchard (t/ha)	95.42	104.72	120.37	106.84	-	-	-	-
				Rayagada				
AGB tree C (t/ha)	17.67	24.22	33.82	25.24	16.90	21.40	26.98	21.76
Litter C (t/ha)	0.13	0.29	0.32	0.25	0.13	0.25	0.26	0.21
Weed C (t/ha)	0.57	0.54	0.25	0.45	0.55	0.48	0.20	0.41
Weed+litter C (t/ha)	0.70	0.83	0.57	0.70	0.67	0.73	0.46	0.62
Total above-ground C (t/ha)	18.37	25.05	34.39	25.94	17.57	22.13	27.44	22.38
Root C (t/ha)	5.19	7.12	9.94	7.42	4.97	6.29	7.93	6.40
Total tree C (t/ha)	23.57	32.17	44.33	33.35	22.54	28.42	35.37	28.78
Soil C (t/ha)	81.00	81.00	81.00	81.00	77.46	71.58	64.63	73.66
Total below-ground C (t/ha)	86.19	88.12	90.94	88.42	82.43	77.87	72.56	77.61
Total C sequestered in orchard (t/ha)	104.57	113.17	125.33	114.35	-	-	-	-

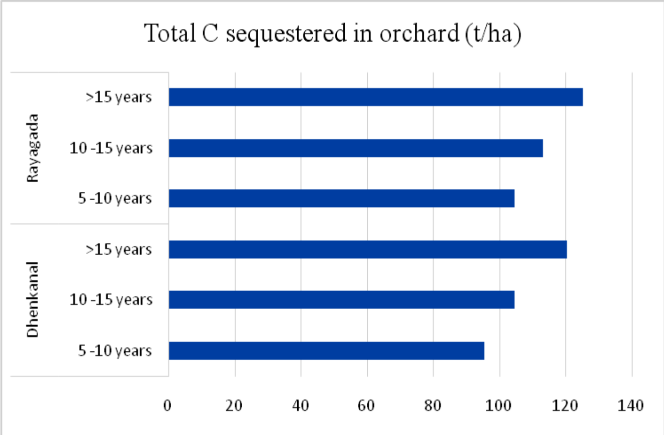

Fig. 5. Diagrammatic representation of total C sequestered in orchard (t/ha) (Table 3).

to total sequestered C was 72.73% in Dhenkanal and 73.66% in Rayagada, while tree C accounted for 27.27% in Dhenkanal and 28.78% in Rayagada. The proportion of soil C decreased from 80.70% in 5-year-old orchards to 63.97% in 15-year-old orchards in Dhenkanal, and from 77.46% to 64.63% in Rayagada (Table 3, Fig. 5).

The soil C stock in mango orchards in Mangalore was 41 tonnes/ha in the 50 cm deep layer (18). It was also noted that soil carbon sequestration in Indian forest soils varied, ranging from 37.5 tonnes per hectare in tropical dry deciduous forests to 92.1 tonnes per hectare in littoral swamp forests (19). Our sites, previously under forest, had fairly good soil organic stocks and the values in our study refer to 100 cm deep soil profiles. Thus, the values found in our study are comparable to those reported for similar climates in the region.

Conclusion

In formulating effective strategies for climate change mitigation, it is crucial to analyze the changes in C fluxes that arise from patterns of land use change. Understanding the dynamics of land use and land-use change in a given region is critical to this examination. Fruit crops increasingly occupy agricultural land, contributing significantly to carbon sequestration. In this study, carbon sequestration increased with orchard age. The mean carbon sequestered was 106.84 t C/ha in Dhenkanal and 114.35 t C/ha in Rayagada. Above-ground carbon in guava orchards accounted for 21.22% and 22.38% of the total carbon sequestered per hectare at the recommended 6 × 6 m spacing in Dhenkanal and Rayagada, respectively. Generating basic information on the carbon content associated with various land-use and land-change classes at the regional level, is a crucial first step toward effective climate change mitigation. Our study provides unique data on carbon stocks in guava orchards as a function of tree age. This information is valuable for boosting our understanding of the carbon cycle in guava farming ecosystems. Future research should encompass guava orchards in various regions of the country with larger sample sizes to more accurately assess the carbon sequestered in cultivated guava orchards across the nation.

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The figure used in this paper was sourced from WWW.CEICDATA.COM |Department of Agriculture & Farmers Welfare.

Authors' contributions

SM and GCA designed the concept of the study. DSK helped in the acquisition of data and sample collection. SM performed the data compilation, sequence alignment and drafted the manuscript. ANG & TRR helped in modifications and coordination. AD helped in the statistical analysis. BKB helped in diagrammatic representations. All the authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author used ChatGPT to improve language and grammar. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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