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RESEARCH ARTICLE

Biomass and carbon stock estimation in different perennial fruit trees of the semi-arid region, Rajasthan, India

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Abstract

Fruit orchards are vital in delivering both economic and environmental services, yet their potential for carbon sequestration remains underexplored. Estimating carbon sequestration is important in semi-arid regions where vegetation cover is sparse; the perennial biomass adds litter inputs that enhance soil carbon storage and improve soil fertility. Quantifying carbon sequestration provides valuable insights into the role of fruit-based orchards in climate change mitigation in fragile ecosystems, thereby contributing to sustainable ecosystem services. The present investigation was carried out in different fruit orchards, viz. *Ficus carica, Cordia myxa, Citrus limon, Citrus jambhiri* and *Aegle marmelos* at ICAR-Central Arid Zone Research Institute, Regional Research Station, Pali Marwar, Rajasthan, India. Since fruit is an economic part, a non-destructive method based on tree dimensions (tree height and diameter) was used for biomass and carbon estimation. The results revealed significant differences among different species of fruit orchard ($p < 0.001$). *C. myxa* (29.28 ± 14.18) and *A. marmelos* (27.04 ± 9.60) recorded total carbon stock (kg tree^{-1}) on par with each other. Pearson correlation coefficient indicates that tree height is positively correlated with above-ground biomass (AGB) and carbon stock (0.98). Among the five fruit orchards, Soil organic carbon (SOC) was highest in *C. myxa* irrespective of depth (8.45 Mg ha^{-1}). *C. myxa* and *A. marmelos* are indigenous fruit tree species that can serve as potential carbon sinks and may be promoted for farmer adoption through supportive policies in the arid and semi-arid regions of Rajasthan.

Keywords: biomass; carbon sequestration rate; carbon stock; fruit orchard; semi-arid region

Introduction

Climate changes, especially future temperature increases and droughts, are projected to negatively affect agriculture (1). The elevated level of greenhouse gases (GHGs), particularly carbon dioxide (CO_2), in the atmosphere highlights the urgency in adopting measures for carbon sequestration to mitigate climate change (2). The total hot arid area in India is 39.54 M ha, with Rajasthan accounting for 31.71 M ha (49.6 %). Variations in climatic patterns, including low and erratic rainfall, soil fertility issues, increasing frequency of droughts and inadequate resources, exacerbate the vulnerability of farming communities in semi-arid tropics (3). Land degradation also affects 67 % of Rajasthan's land, with wind erosion contributing 44.2 %, vegetal degradation 6.25 % and salinisation 1.07 %, posing further threat to the fragile ecosystem (4). Nevertheless, the vast land resources offer greater opportunities for the development of fruit-based systems, which can improve livelihood opportunities and elevate the economic status of the local communities. Numerous initiatives have been taken by national and international government organisations to mitigate climate change while adopting carbon farming practices and co-benefitting other environmental and economic services (5). Perennial fruit trees play an important role in storing carbon in the trunk, bole, branches, leaves, flowers and fruits. These fruit trees are the Trees Outside Forests (TOF), which contribute to carbon sequestration and act as a carbon sink. Fruit-based agroforestry systems have been reported to sequester 1.5–3.5 Mg C ha^{-1} yr^{-1}, equivalent to 5.5–13 Mg of CO_2 eq ha^{-1} yr^{-1} (6). Many studies have reported carbon sequestration; however, few studies have compared biomass and carbon stock across multiple perennial fruit species in semi-arid regions (7, 8). Therefore, the current study aimed to determine carbon stock and soil organic carbon in different fruit orchards of the semi-arid region of Rajasthan.

Materials and methods

The study was carried out in the experimental farm of ICAR-Central Arid Zone Research Institute (CAZRI), Regional Research Station (RRS), Pali Marwar, Rajasthan. The research station is spread over 248 ha of land (25°47'–25°49' E and 73°18'–73°18' N) at 217–220 m above mean sea level in the transitional plain of Luni basin. The area receives rainfall from July to September with an average annual rainfall of 450–500 mm. Summer will start from March and last up to May-June. The mean maximum and minimum temperature ranges from 6–45 °C. The soil was shallow in depth (30–45 cm) with sandy clay loam to sandy loam texture, 1.35–1.5 mg m^{-3} bulk density and 7.7–8.4 pH. The Electrical conductivity (EC) of water ranges from 2.5-4.5 dS m^{-1}. The orchard (*Ficus carica, Cordia myxa, Citrus limon,* *Citrus jambhiri* and *Aegle marmelos*) was established in 2015-2016 (Fig. 1). Since fruit is an economic part of the tree, a non-destructive method was followed for biomass and carbon stock estimation. Data on height, girth and diameter, length of the branch were measured in 2023-2024. Tree height was measured using a height pole in metres and girth was measured with a tailor's tape in centimetre at 1.37 m breast height (All the trees in each orchard were measured). Diameter at breast height (DBH) was determined using the following formula in Equation 1.

$$DBH\ (cm) = \frac{GBH\ (cm)}{\pi} \quad \text{(Eqn.1)}$$

Where, GBH- Girth at breast height, π- 3.14.

For shrubby species, girth was measured at two point's viz. the basal and top side of the branch. The number of branches was counted and the volume was estimated considering each branch as a truncated cone using the following formula.

$$Volume\ of\ branch(m^3) = \frac{1}{3}\pi\,(r_1{}^2 + r_1 r_2 + r_2{}^2)h \quad \text{(Eqn.2)}$$

Where, π- 3.14, r- radius, h- height.

Biomass calculation: Above-ground biomass (kg $tree^{-1}$) was calculated using the formula in Equation 3.

$$AGB\ (kg) = Vol\ (m^3) \times Wood\ specific\ gravity \quad \text{(Eqn.3)}$$

The reported wood specific gravity (WSG) values were taken from literature (Table 1).

Below-ground biomass (Kg $tree^{-1}$) is estimated by multiplying above-ground biomass (AGB) by the root shoot ratio of 0.26. The total carbon stock is determined as

Table 1. Wood specific gravity values of different fruit tree species

Common name	Scientific name	Wood specific gravity values
Anjeer	*Ficus carica*	0.40
Gunda	*Cordia myxa*	0.42
Lemon	*Citrus limon*	0.63
Rough Lemon	*Citrus jambhiri*	0.50
Bael	*Aegle marmelos*	0.70

$$\text{Total carbon sock } (\Sigma TCS) = (\Sigma AGB + \Sigma BGB) \times \text{tree density} \times \text{Carbon content } (\%) \quad \text{(Eqn.4)}$$

The average carbon content is taken as 50 % of the tree volume. The quantity of carbon dioxide is determined by multiplying total carbon stock by 3.67 (Ratio of one molecule of carbon to oxygen).

Soil samples were collected randomly from each orchard at different depths (0–15 cm, 15–30 cm and 30–45 cm). A total of 45 samples were collected in each orchard, with 9 samples representing per depth. Soil samples were sieved using a 0.2 mm sieve and further SOC was estimated using the Walkley and Black method (9). Soil bulk density was determined using a core sampler. SOC (Mg ha^{-1}) was calculated by using the standard method (10).

$$\text{Soil organic carbon stock (Mg ha}^{-1}\text{)} = \text{Soil organic carbon (\%)} \times \text{Depth (cm)} \times \text{Bulk density (g cm}^{-3}\text{)} \quad \text{(Eqn.5)}$$

Statistical analysis

The raw data was fed into an Excel database and imported into SPSS IBM software version 16. Descriptive statistics were used to calculate the mean height, DBH and basal girth of trees and shrubs. Significant differences within the quadrat were examined using one Analysis of Variace (ANOVA) followed by Duncan's Multiple Range Test (DMRT). Pearson correlation was performed among biomass, carbon stock and different growth parameters.

Results

The introduction of fruit-based systems is one of the alternative methods to sequester carbon and mitigate climate change. The growth and performance of each orchard vary due to its structure, composition, function and other economic attributes. The area, density and spacing details have been described in Table 2. The mean height (m) of *A. marmelos* and *C. myxa* was almost on par, recording 5 m. Similarly, *C. myxa* recorded the average diameter (cm) of 20.64 ± 4.74, followed by *F. carica* (13.01 ± 2.67) and *A. marmelos* (11.61 ± 3.25) (Table 2).

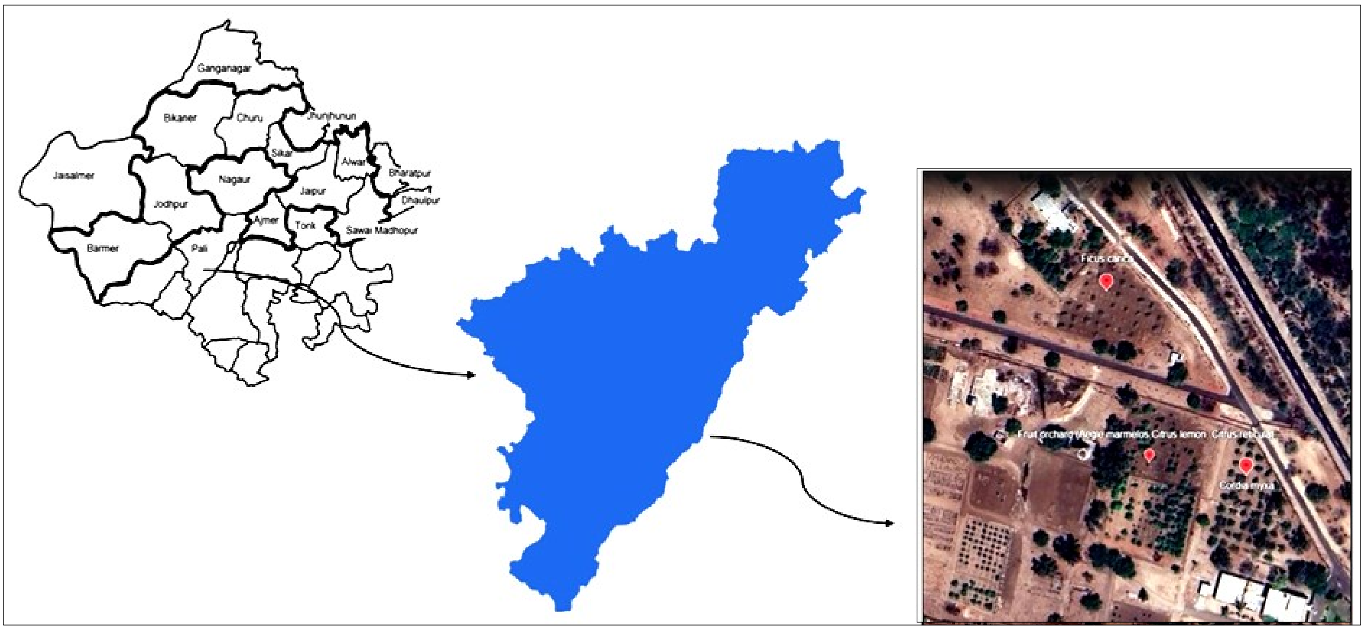

Fig. 1. A map representing an aerial view of different orchards in a semi-arid region.

Table 2. Morphological parameters of different fruit trees in the semi-arid region

Common name	Scientific name	Area (m^2)	Density (ha^{-1})	Spacing (m)	Height (m)				Diameter (cm)			
					Mean	Min	Max	SD	Mean	Min	Max	SD
Anjeer	*Ficus carica*	2352	277.78	6 × 6	4.01	2.50	4.70	0.46	13.01	2.67	18.47	2.67
Gunda	*Cordia myxa*	4104	277.78		5.24	3.20	6.80	0.86	20.64	9.55	29.62	4.74
Lemon	*Citrus limon*	897	833.33	4 × 3	3.88	2.00	6.00	0.97		-		
Rough Lemon	*Citrus jambhiri*	1035	833.33		4.10	2.00	6.50	1.45		-		
Bael	*Aegle marmelos*	828	833.33		5.43	3.00	8.90	1.43	11.61	4.78	19.75	3.25

Biomass and carbon stock

ANOVA showed significant differences among fruit trees for biomass and carbon stock ($p < 0.001$). The highest above-ground biomass (Kg $tree^{-1}$) was recorded in *C. myxa* (46.47 ± 22.51), followed by *A. marmelos* (42.93 ± 15.24) and *F. carica* (18.58 ± 4.45). The total carbon stock (Kg $tree^{-1}$) varied from 29.28 ± 14.18 (*C. myxa*) to 6.37 ± 2.78 (*C. limon*). *A. marmelos* (22.53 ± 7.76) exhibited the significantly highest carbon stock per hectare, followed by *C. jambhiri* (8.78 ± 5.81) and *C. myxa* (8.11 ± 3.81). The highest carbon sequestration rate was observed for *A. marmelos* (3.66 Kg $tree^{-1}$ yr^{-1}), whereas the lowest was recorded for *C. limon* (0.79 Kg $tree^{-1}$ yr^{-1}). The carbon dioxide mitigation potential (Mg CO_2e ha^{-1}) followed the order of *A. marmelos* (82.69) > *C. jambhiri* (32.22) > *C. myxa* (29.76) > *C. limon* (19.49) > *F. carica* (11.89) (Table 3). The Pearson correlation coefficient indicates that tree height is positively correlated with above-ground biomass and carbon stock (0.98), whereas negatively correlated with diameter (-0.41) (Fig. 2).

Soil organic carbon in a fruit orchard

Among the five fruit orchards, SOC was highest in *C. myxa* (8.45 Mg ha^{-1}), followed by *C. limon* (7.86 Mg ha^{-1}). In the surface layer (0–15cm), the SOC in *C. myxa*, *A. marmelos* and *C. jambhiri* ranged from 7.27 to 6.68 Mg ha^{-1}. The same trend was observed for soil depth (15–30 cm). However, at the deeper layer (30–45 cm), the lowest SOC was recorded in *C. limon* (4.31 Mg ha^{-1}), followed by *C. jambhiri* and *A. marmelos* (4.91 Mg ha^{-1}) (Fig. 3).

Discussion

Perennial fruit trees are natural sponges that absorb carbon dioxide from the atmosphere and play an important role in carbon sequestration (11). In the current study, *C. myxa* and *A. marmelos* have recorded the highest biomass and carbon stock. The enhanced biomass is ascribed to the factors including inherent growth characteristics, nature of tree trunk, canopy structure, number of branches, density of trees and other management factors (training/ pruning) (12). Moreover, both the indigenous trees possess straight or tortuous bole formation, leading to the highest biomass. The current results corroborate with the findings of highest carbon stock (44 t ha^{-1}) reported in *A. marmelos*–based silvipasture system (13). Similarly, carbon accumulation in different fruit trees like Mango based Agrihorti (26.01 t ha^{-1}) and Guava orchard (2.11 t C ha^{-1} yr^{-1}) were also reported (13). Despite recording the highest above-ground biomass and total carbon per tree (29.28 ± 14.18), the total carbon stock per hectare was low (8.11 ± 3.81) in *C. myxa,* as the density of trees (277 nos ha^{-1}) was less in comparison to *A. marmelos* (833 nos ha^{-1}). The carbon stock was negatively correlated with the density and diversity of trees (14, 15). The current study has also registered the highest carbon sequestration rate for *C. myxa* and *A. marmelos* (Table 3). A similar type of carbon sequestration rate in a semi-arid region was noticed in Mango (1.77 t C ha^{-1} yr^{-1}) and guava orchard (2.11 t C ha^{-1} yr^{-1}), respectively (16).

Tree height is a key characteristic of orchard trees, having major economic consequences, as larger trees may produce more fruit (16). Similarly, trees with larger crowns increase light interception and photosynthesis of a tree and thereby lead to higher fruit yield and carbon sequestration (17). Generally, tree height and diameter have been reported by plenty of researchers as the best predictors for determining biomass and carbon sequestration (18, 19). In contrast, diameter is negatively correlated with the carbon stock as the *C. myxa, A. marmelos* and *F. carica* have bolous trunks; however, the other two species from the citrus family are shrubby in nature; therefore, basal girth, length of main trunk and the number of branches were considered for carbon stock calculation in the present study.

Soil is the primary terrestrial carbon sink, where carbon remains stored for a long time or it can be returned to the atmosphere through respiration via soil microbes. The current study recorded the highest SOC in *C. myxa* and this is attributed to the fact that litter fall, including leaves, fruits and small twigs, adds a substantial amount of organic matter to the soil, which naturally decomposes over time. The soil organic carbon in the upper soil is 20.9 % higher than *F. carica*-based fruit orchard (Fig. 3). A similar type of increase in SOC in surface layers was also noticed (20, 21). It was also noticed that the SOC decreases gradually with increasing depth (15–45 cm) as most of the litter or root exudates add carbon to the surface layer. The results are consistent with previous findings that also reported higher SOC in upper soil layers (22, 23).

Table 3. Biomass and carbon stock of different fruit trees in the semi-arid region of Rajasthan

Common name	Scientific name	AGB (kg $tree^{-1}$)	Average carbon stock (kg $tree^{-1}$)		Total carbon (kg $tree^{-1}$)	Carbon sequestration rate (kg $tree^{-1}$ yr^{-1})	Carbon stock (Mg ha^{-1})	Mg CO_2e ha^{-1}
			AGB-C	BGB-C				
Anjeer	*Ficus carica*	18.58 ± 4.45[a]	9.29 ± 2.22[a]	2.41 ± 0.57[a]	11.71 ± 2.80[a]	1.46	3.24 ± 0.75[a]	11.89
Gunda	*Cordia myxa*	46.47 ± 22.51[b]	23.23 ± 11.25[b]	6.04 ± 2.92[b]	29.28 ± 14.18[b]	3.66	8.11 ± 3.81[b]	29.76
Lemon	*Citrus limon*	10.12 ± 4.42[a]	5.06 ± 2.21[a]	1.31 ± 0.57[a]	6.37 ± 2.78[a]	0.79	5.31 ± 2.25[a]	19.49
Rough Lemon	*Citrus jambhiri*	16.72 ± 11.41[a]	8.36 ± 5.70[a]	2.17 ± 1.48[a]	10.53 ± 7.19[a]	1.31	8.78 ± 5.81[b]	32.22
Bael	*Aegle marmelos*	42.93 ± 15.24[b]	21.46 ± 7.62[b]	5.58 ± 1.98[b]	27.04 ± 9.60[b]	3.38	22.53 ± 7.76[c]	82.69

Data presented as Mean ± SD (p<0.001). According to DMRT values with different superscripts vary significantly; AGB-C (Above ground biomass-carbon), BGB-C (Below ground biomass -carbon).

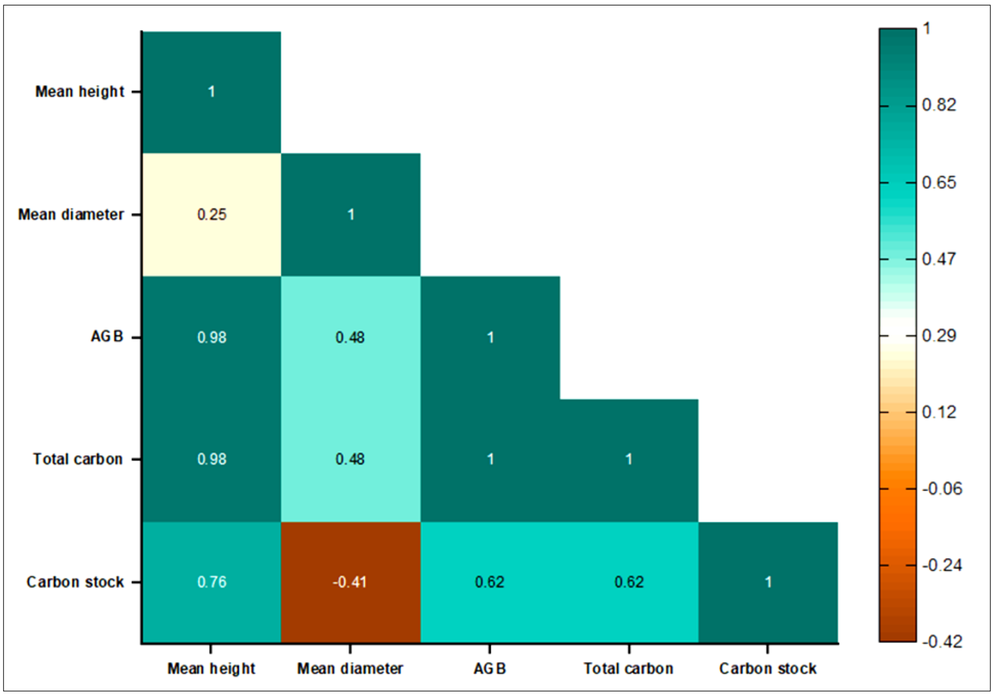

Fig. 2. Correlation matrix between morphological parameters and carbon stock.

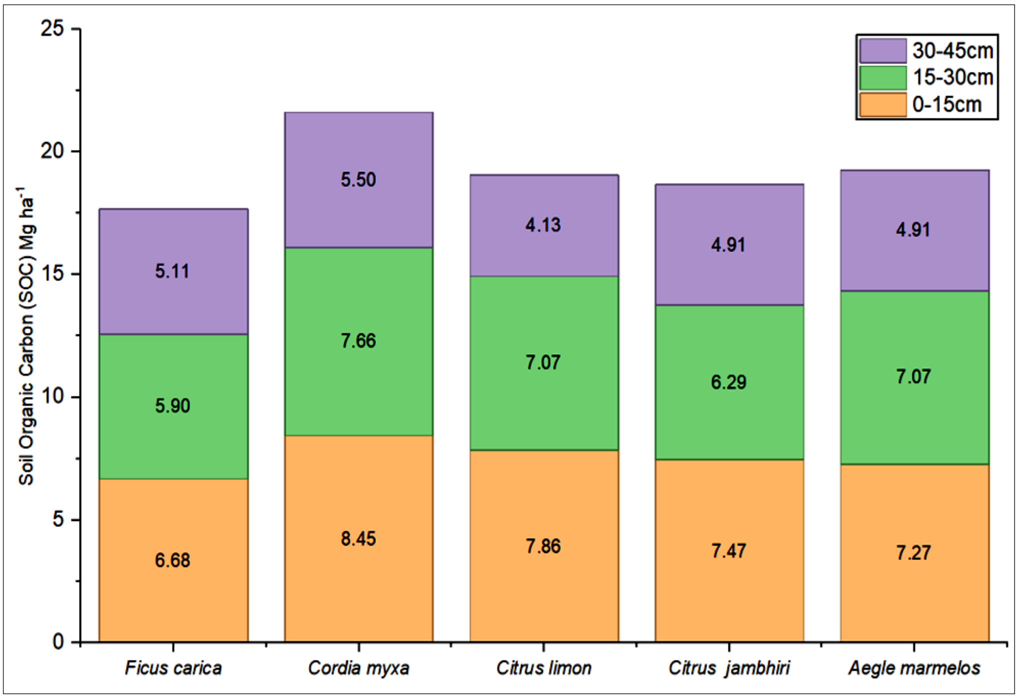

Fig. 3. Soil organic carbon stock from different orchards of the semi-arid region.

Conclusion

Overall, *Cordia myxa* and *Aegle marmelos* are indigenous fruit trees that can serve as a potential carbon sink in arid and semi-arid regions of Rajasthan. Farmers in this region should be encouraged to cultivate more fruit trees in different land-use systems like orchards, horti-agri and horti-pastoral systems to obtain economic benefits and at the same time mitigate and reduce climate change effects in the long term.

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Authors' contributions

KA was responsible for data collection, analysis and writing of the manuscript. KKC handled soil sample collection and analysis of soil organic carbon. AKS contributed to providing resources and validation. MBN was involved in the review and editing of the manuscript. RSM performed data analysis, while SRM participated in reviewing and editing the manuscript. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

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

Ethical issues: None

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