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Carbon Sequestration and Carbon Credits in Fruit Crops: Turning Orchards into Climate Solutions

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INTRODUCTION

Climate change is becoming an increasingly important challenge for Indian agriculture. Farming systems must become more resilient to climate change, while also reducing emissions and, where technically and economically feasible, removing carbon dioxide (CO_2) from the atmosphere. One promising pathway is carbon sequestration through perennial crops, orchards, agroforestry and improved soil management. Fruit orchards are particularly interesting because they are perennial that remain in the field for many years and continuously accumulate biomass. Carbon sequestration is the process of capturing carbon dioxide (CO_2) from the atmosphere and storing the carbon in plants, soils or other long-term carbon pools. In fruit orchards, atmospheric CO_2 is absorbed through photosynthesis and converted into plant biomass. Carbon is subsequently stored in trunks, branches, leaves, roots, fruits, fallen leaves and litter soil organic matter Among these, tree biomass and soil organic carbon are the two most important carbon pools in an orchard. The amount of carbon stored depends on fruit species, tree age, planting density, climate, soil type, irrigation, nutrient management and orchard practices. Therefore, carbon-storage values should be determined for specific crops and locations rather than applying a single value to all orchards.

Why Fruit Crops Are Important Carbon Sinks

Perennial fruit crops have an advantage over annual crops because they remain established for several years. Important fruit crops such as mango, apple, citrus, walnut, apricot, peach, plum, guava and other perennial species can therefore contribute to long-term biological carbon storage. Orchards also provide several benefits simultaneously:Fruit production + Farmer income + Biomass accumulation + Soil improvement + Carbon storage.

Recent research supports the carbon-storage potential of orchard systems. A 2026 study of apple, peach, plum and apricot orchards in the mid-hills of Himachal Pradesh reported ecosystem carbon stocks ranging from approximately 32.16 to 63.94 Mg C/ha across the systems studied. The study also showed that fertilizer use, pesticides, fuel consumption and residue burning can contribute to orchard emissions (Kapur *et al.,* 2026). This demonstrates why both carbon storage and carbon emissions must be considered when evaluating an orchard's climate benefit.

Carbon Storage in Different Fruit Crops

The carbon-sequestration capacity of fruit crops varies considerably. Published studies have reported substantial carbon storage in crops such as mango, apple, walnut and hazelnut, but the values differ according to location, tree age and management.

Table1: Examples reported in previous studies include

Crop	Biomass (kg/tree)	Country/Region	Carbon sequestration	Reference
Mango *(Mangifera indica)*	733.025	India	73.59 t/ha	Ganeshamurthy *et al.* (2019a)
	269.07	Konkan, India	26.91 t/ha	Ganeshamurthy *et al.* (2019b)
Hazelnut *(Corylus avellana)*	-	Italy	58.8 Mg CO/ ha/year	Granata *et al.* (2020)
Apple *(Malus domestica)*	224.08	China	6,871.8 g C/m^2/ year	Wu *et al.* (2012)
Apple *(Malus domestica)*	-	India	0.01-35.00 MT/ ha	Attar *et al.* (2016)
Apricot *(Prunus armeniaca)*	-	India	0.04-61.22 MT/ ha	Attar *et al.* (2016)
Walnut *(Juglans regia)*	-	India	0.35-62.50 MT/ ha	Attar et al. (2016)
Nagpur mandarin (*Citrus reticulata*)	5.94	India	1.65 t C/ha	Mehta *et al.* (2016)

*Values are examples from individual studies and should not be treated as universal values for the crop.

The important question is not simply how much carbon a fruit tree stores, but how much carbon is stored by the entire orchard system over time**.** Increasing soil organic carbon can improve soil structure, water-holding capacity, nutrient cycling and biological activity. These improvements can also make orchards more resilient to drought and heavy rainfall. Practices such as mulching, cover cropping, maintaining ground vegetation, recycling organic residues and reducing unnecessary soil disturbance can help build soil organic matter under appropriate conditions.

Factors Affecting Carbon Sequestration in Fruit Orchards

Several factors influence how much carbon a fruit orchard can capture and store.

1. Fruit species: Different fruit trees have different growth rates, canopy sizes, wood densities and root systems. Consequently, mango, apple, citrus, walnut and other crops can have very different carbon-storage capacities.
2. Tree age:Young trees have relatively low biomass but may accumulate carbon

rapidly as they grow. Mature trees contain larger carbon stocks, although the annual rate of additional accumulation changes with age.

3. Planting density: Tree spacing affects canopy development, biomass production and orchard productivity. High-density systems may accumulate substantial biomass, but they can also require greater inputs.
4. Water availability:Adequate water supports photosynthesis and tree growth. Efficient irrigation can improve productivity while reducing unnecessary water and energy use.
5. Nutrient management: Adequate nutrients are necessary for healthy tree growth. However, excessive nitrogen fertilizer can increase nitrous oxide emissions. Therefore, **balanced and efficient fertilizer use** is essential.
6. Soil management: Mulching, cover crops, organic amendments and reduced soil disturbance can increase organic matter and improve soil health.
7. Climate: Temperature, rainfall and solar radiation strongly influence photosynthesis, tree growth and carbon accumulation.

Orchard Practices for Increasing Carbon Storage

Fruit growers can incorporate carbon-friendly practices into normal orchard management. Important practices include:

- Mulching around fruit trees
- Maintaining suitable cover crops and follow intercropping
- Recycling pruning residues
- Reducing excessive soil disturbance and prevent soil erosion
- Applying compost or suitable organic amendments
- Efficient irrigation, including drip systems where appropriate
- Balanced fertilizer application
- Improving nutrient-use efficiency
- Maintaining healthy tree canopies
- Selecting locally adapted fruit varieties and rootstocks
- Maintaining soil organic matter

Additional economic opportunities for farmers

Carbon credits can potentially provide an additional income stream for fruit growers, but the income is not guaranteed. India's agricultural carbon market is nevertheless developing. In January 2024, the Government introduced a Framework for the Voluntary Carbon Market in Agriculture Sector to encourage sustainable agricultural practices and facilitate participation of farmers in carbon markets. A significant development reported in September 2026 was the release of agricultural soil-carbon payments to more than 2,500 farmers in Punjab and Haryana, demonstrating that agricultural carbon projects are beginning to translate verified climate benefits into payments to participating farmers (Ministry of Agriculture & Farmers Welfare, 2026). This particular programme focused on soil-carbon and emission-reduction practices rather than fruit orchards, but it demonstrates the emerging potential of agricultural carbon markets in India.

CONCLUSION

Fruit orchards have significant potential to contribute to climate-change mitigation because perennial fruit trees store carbon in their wood, roots and soil while simultaneously producing food and generating income.The emerging carbon market creates another possible opportunity for farmers. However, carbon credits should be viewed as a potential additional source of income rather than

guaranteed revenue. Credible credits require scientific measurement, transparent accounting, independent verification and clear benefit-sharing arrangements. Thus, the orchard of the future can be more than a source of food. With appropriate management and credible measurement, it can also become a living carbon sink that contributes to climate mitigation while supporting farmer livelihoods.

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