Carbon Sequestration Potential of Perennial Horticultural Crops in Indian Tropics

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A. N. Ganeshamurthy, D. Kalaivanan, and S. Rajendiran

Abstract

Large numbers of horticultural crops are grown in India due to its wide variety of soil and climatic conditions. However, perennial horticultural crops have edge over annuals as they generally need low inputs such as water, energy, etc., and have high productivity values. India has large tracts of waste and marginal lands (96 million hectares of cultivable wasteland). These lands can be brought under perennial horticultural crops for successful and profitable commercial horticulture. Moreover, putting these marginal lands to perennial horticultural crops can enhance carbon sequestration and improve organic carbon content and health of the soils. This also rejuvenates degraded soils, improves the land productivity, enriches the diversity, and protects the environment. Horticultural crops have a great scope for sequestering more carbon in terrestrial ecosystem than agricultural or agroforestry systems. Studies reported that the carbon dioxide sequestration was significantly greater under the perennial crops as compared to annual crops. The carbon sequestration potential of different horticultural cropping systems ranked in the order of mango > cashew > rose > vegetable > medicinal and aromatic plants, and addition of more residues in perennial systems to soil records less emission of CO_2 than annual crops. As a consequence, perennial horticulture-based systems provide economic gain through carbon credits. Enhancement of carbon sequestration in perennial systems can be attained by improving soil health and through better carbon management strategies. These include planting high-biomass-producing crops, recycling crop residue, application of manures, switching from annual to perennial crops, adopting crop rotation in place of monoculture, and promotion of agroforestry systems. This chapter mainly describes the role of perennial horticultural systems in enhancing soil carbon, soil organic matter dynamics, carbon fractions, and its assessment in

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P. K. Ghosh et al. (eds.), *Carbon Management in Tropical and Sub-Tropical Terrestrial Systems*, https://doi.org/10.1007/978-981-13-9628-1_20

horticultural systems, carbon sequestration potential of perennial horticultural crops, and also the management options available for improving C sequestration under such system.

Keywords
Carbon sequestration · Horticultural crops · Indian tropics · Management options

20.1 Introduction

Horticulture is undergoing a boom in the country in recent years because of higher production of horticultural crops that are surpassing food grain yields and also due to increase in the consumption of fruits and vegetables due to changes in food habits. The current horticultural production is more than 300 million metric tonnes (MMTs) against food grain production of 275 MMTs. The per capita consumption of fruits and vegetables has also increased over a period because of the incremental production. Further area under perennial horticultural crops is 12.1 mha; (6.10 mha fruits, 3.22 mha plantation crops, 2.63 mha spices, and 0.14 mha nuts) with annual production of 214 mt. Though these crops occupy hardly 7% area, they contribute over 18% to the gross agricultural output in the country. Due to high remuneration/outcome from horticultural crops than the food grain crops, the attention of growers is changing now towards perennial horticultural crops. India is endowed with wide variety of soil and climatic conditions that can be suitable for growing varieties of horticultural and agricultural crops. However, horticultural crops particularly perennial crops have edge over field crops in the sense they generally need low inputs such as water, energy, etc. and have high productivity values as well.

India has large tracts of waste and marginal lands (96 mha of cultivable wasteland).The need for great utilization of available wastelands against the background of dwindling water and energy resources has focused attention to dry land, to arid and semiarid tracts, and to horticultural crops which have lesser demands for water and other inputs besides being three–four times more remunerative than field crops. Therefore, these lands can be brought under perennial horticultural crops for successful and profitable commercial horticulture. This can also help in attaining nutrition security and bringing positive change in the outlook of the growers through more profitable land use. Moreover, putting these marginal lands to perennial horticultural crops can improve organic carbon content and health of the soils. Earlier studies reported that the carbon dioxide sequestration was significantly greater under the perennial crops as compared to annual crops. It was also observed that perennial horticulture crops increase the soil organic carbon (SOC) and carbon dioxide storage than annual crops and reduce the carbon emissions to the atmosphere which helps to mitigate the global warming. Therefore, growing of perennial horticulture crops is one of the strategies to improve soil conditions which would help to sequester more organic carbon and carbon dioxide in soil as compared to annual crops.

20.2 Role of Tropical Horticultural Crops in Enhancing Soil Carbon

The quantity and quality of C inputs to soil under different tropical horticultural land-use systems may vary due to the differences in growth pattern, phenology, leaf size, number of new flushes, and decomposition rates of litters among the fruit trees. For instances, waxy surface of litchi leaves can result in long decomposition time than mango, guava, and jamun leaves. Under guava land use, there is bark fall as well as fruiting that takes place twice. During rainy season, guava fruits are normally not marketed due to insect attack. These fruits also contribute a good amount of C in soil after decomposition. Studies conducted on soil organic carbon (SOC) pool up to 30 cm soil depth under different forest and horticultural land uses in Uttarakhand state of India indicated the highest amount under forest lands followed by grasslands and orchards (mango, guava, and litchi). It was also recorded that soils under apple orchard showed maximum SOC pool at 30 cm depth followed by mango, litchi, and guava.

Depth-wise changes in the content of organic carbon under perennial tropical horticultural land-use systems, such as guava, jamun, litchi, and mango on reclaimed sodic soils, have been reported (Datta et al. 2015). The quantity of dichromate oxidizable organic carbon (OOC) varied with land uses. The highest mean OOC was recorded in soil (surface) under guava (25.9 Mg C ha^{-1}) followed by jamun (25.1 Mg C ha^{-1}) = litchi (25.0 Mg C ha^{-1}) > mango (16.5 Mg C ha^{-1}), while the total organic carbon (TOC) stock in soil was guava (28.8 Mg C ha^{-1}) > jamun (27.3 Mg C ha^{-1}) > litchi (25.7 Mg C ha^{-1}) > mango (19.2 Mg C ha^{-1}). In all the land uses, carbon content in passive pool was recorded an increase with soil depth due to its more physical, chemical, and biochemical stabilization in lower depths. Among these systems, soils under guava plantation recorded the highest SOC storage (61.0 Mg C ha^{-1}) as well as maximum passive pool C (25.3 Mg C ha^{-1}) up to 60 cm soil depth. Within a land-use system, there was a significant reduction in soil organic carbon stock along depth. A sharp decrease in the content of this pool of SOC was observed in soils between 0–20 and 20–40 cm layer under all land-use systems. The highest decrease in magnitude of SOC was in jamun (74%) followed by litchi (62%) > guava (46%) > mango (44%) in 20–40 cm soil depth compared to 0–20 cm. In all the land uses, second and third soil layer contained considerable quantities of oxidizable as well as TOC, demonstrating the importance of subsoil horizons for carbon storage.

20.3 Perennial Horticultural System and Soil Organic Carbon Equilibrium

The soil systems attain a quasi-equilibrium stage after accumulation and loss of organic matter in soil over a period of time as per prevalent land-use system. Again the soil system acquires a new equilibrium level of SOC over a period of time after each change in land-use system depending on the vegetation cover and management practice. Thus SOC levels show toothlike cycles of accumulation and loss (Batjes

1996). The rate of storage will depend on a number of factors including plantation variety, and variation is caused by climate, geography, species, and stand age (Liao et al. 2010). A period of constant land-use management is required to reach a new quasi-equilibrium value (QEV) which is a characteristic representative of the new land use, vegetation cover, management practice, climate, and soil. In case of forest systems of tropics, SOC values tend to attain QEV in 500–1000 years (Jenny 1950) and in 30–50 years in agricultural systems after forest clearing (Johnson 1995). Naitam and Bhattacharyya (2004) reported that quasi-equilibrium values of 0.7 and 0.8% SOC were attained in swell–shrink soils under horticulture and forest system, respectively, over a period of 30 years and several centuries. Unlike natural ecosystems, in horticultural systems the equilibrium is disturbed by removal of trees when the fruit trees become uneconomical and followed by new planting. Therefore, under horticultural ecosystems, the steady state of soil organic carbon frequently gets disturbed and a new steady state is attained after a period of constant management.

20.4 Soil Organic Matter Dynamics in Horticultural Systems

Major factors that influence soil organic matter dynamics in any production system include (i) the quality of the substrates added, (ii) the role of the soil microorganisms, (iii) physical protection such as in aggregation, (iv) interaction with the soil matrix such as the silts and clays as well as Ca and sesquioxides, and (v) the chemical nature of the SOM itself. These factors are interactive. Long-term studies are needed to examine the influence of these factors.

20.4.1 Carbon Inputs

The quality of carbon inputs and the rates of organic matter applied in any production systems are majorly influenced by the climate factors (temperature and precipitation), vegetation type (a woody tree such as mango, litchi, or apple; soft tissue like banana or papaya), landscape (sloppy land, level land, etc.), soil type, and orchard management practices (conservation horticulture, intensive orchard management, etc.).

The amount and quality of SOM are dependent on the amount and type of plant inputs as well as their microbial turnover before stabilization. The fresh litters or fallen plant residues on the soil are steadily modified through physical fragmentation, mineralization, soil fauna, and microbial interactions and humus formation. Decomposition process and turnover rates are largely influenced by climatic factors, organic residue type and quality, chemical and physicochemical association of organic matter with the soil mineral components, and the location of the organic matter within the soil (Jastrow and Miller 1997).The mean annual mineralization is higher in humid tropics (about 4–5%) when compared to the temperate climate (only 2%). Moreover the rate of carbon mineralization is more rapid under the intensive cultivation management than the conservation tillage or zero tillage practices within the given region. The humid tropics climatic conditions are more favourable for higher biomass production; however, it is limited by nutrient supply in the soil. In carbon sequestration point of view, the changes in quality of SOM are more vital than the changes in the quantity of SOM.

Carbon allocation within a plant depends on the interaction between source organs (mainly shoots) and sink organs (roots and fruits). This is a very complex process that comes from both regulations and interactions between various plant processes involving carbon. Carbon partitioning in plants is controlled by a number of factors that include photosynthesis, the number and location of competing sinks, storage capacity, and vascular transport. The plant architecture also plays an important role in carbon partitioning and transport within the plant. Further research is needed on the root-shoot-fruit interactions, influence of many agricultural practices such as thinning, pruning, fertilization, and irrigation and their interactions. The transport of material and signals in the plant architecture with a special focus on interactions between compounds has to be studied.

20.5 Stability of Soil Carbon

Some good management practices such as promotion of native vegetation growth, cover cropping, regular addition of organic manures/composts, crop residue recycling and incorporation, inclusion of legumes/grasses as intercrop, and even mulching can improve soil organic carbon storage in perennial horticultural systems (Wang et al. 2010; Ganeshamurthy 2009). The SOC storage changes with land-use change and changes in different OC components of soils provide information in advance about this. Stability of organic carbon in soil depends on the source of plant litter, occlusion within aggregates, incorporation in organo-mineral complexes, and location within the soil profile. However, physical fractionation is widely adapted to study OC storage and turnover in soil (Six et al. 2002; Verchot et al. 2011). Physical protection of SOM is mainly dominated in the soil aggregates, which are the secondary organo-mineral complexes of soil. Thus, changes in soil aggregates may be used to characterize the impacts of management strategies on soil carbon storage (Christensen 2001), particularly carbon stored in macroaggregates which has a stronger response to land-use change (Denef et al. 2007). To some extent, the protection of macroaggregates is considered to be fundamental for sustaining high SOC storage and has been used in many ecological models (Six et al. 2002). The responses of different fractions of soil organic matter pool to management practices vary due to their composition and association with the mineral matrix (Gregorich et al. 2006). The composition of organic matter and its association with mineral matrix influence its accessibility to decomposers and the stability in the soil environment. The labile fraction is easily decomposable. Its relative amount and the degree to which it is protected determine its degradability (Wendling et al. 2010). The more stable and recalcitrant fraction of soil organic matter contains more processed degraded material, and it is associated with soil mineral to form organo-mineral complexes (Wiesenberg et al. 2010). The stable fraction is a major sink for C storage and contains little mineralizable C (Jagadamma and Lal 2010).

20.6 Soil Carbon Fractions and Carbon Sequestration in Perennial Horticultural Systems

With respect to carbon sequestration, it is most desirable to fix atmosphere carbon in those pools having long turnover time. In terms of the residence time, the soil organic pools are divided into several homogeneous compartments. Based on carbon dynamics under perennial systems, soil carbon can be grouped into four main groups (Eswaran et al. 1995):

- Labile C or active C
- Slowly oxidizable C
- Very slowly oxidizable C
- Recalcitrant or passive C

Active or Labile Pool Formation and quality of active pool in perennial systems is influenced by climate change and type of management practices adopted that result in plant residue inputs.

Slowly Oxidizable Pool This pool is mainly associated with soil macroaggregates and influenced by soil physical properties like mineralogy and aggregates and horticultural practices.

Very Slowly Oxidizable Pool This pool is mainly associated with the soil microaggregates wherein the main controlling factor is the water stability of the aggregates.

Recalcitrant or Passive Pool This pool is mainly controlled by the soil mineralogy. Horticultural practices have little effect on its formation. The residence time of different types of organic matter, their proportion in total organic matter, and residence time of these pools of soil organic carbon are presented below (Table 20.1).

20.7 Assessment of Carbon Stocks in Horticultural System

Carbon stocks in the horticultural system can be measured through destructive and non-destructive methods. But the later has more advantage over the former. Further the carbon storage in perennial tree-cropping systems is categorized into (i) carbon

Table 20.1 Estimated ranges in the amounts and turnover time of various types of organic matter stored in soils under horticultural systems (Jastrow and Miller 1997)

Type of soil organic matter	Proportion of total organic matter (%)	Turnover time (year)	Carbon pool
Microbial biomass	2–5	0.1–0.4	Labile
Litter	–	1–3	Rapid
Particulate organic matter	18–40	5–20	Moderate
Light fraction	10–30	1–15	Moderate
Inter microaggregate[a]	20–35	5–50	Moderate to slow
Intra microaggregate[b]			
Physically sequestered	20–40	50–1000	Passive
Chemically sequestered	20–40	1000–3000	Passive

[a]Within macroaggregates but external to microaggregates including particulate, light fraction, and microbial C; [b]within microaggregates including sequestered light fraction and microbially derived C

Table 20.2 Level of accuracy and ease of implementation from measuring different carbon pools in a perennial ecosystem (Hamburg 2000)

Pool	CV	Ease of implementation
Aboveground biomass	5%–10%	Simple
Belowground biomass	10%–20%	Simple, but requires high initial investment
Soil, organic layer	10%–20%	Moderate
Soil, mineral layer	Highly variable	Difficult
Necromass	40%	Difficult

in aboveground biomass, (ii) carbon in belowground biomass, (iii) carbon in dead biomass (necromass), and (iv) carbon in soil.

All the above-mentioned carbon pools are not likely to be acceptable as sources of sequestration in a carbon market, and not all pools need to be measured at the same level of precision or at the same frequency during the life of the orchards. In the initial inventory, the relevant carbon pools must be measured to establish the baseline, but in subsequent monitoring only selected pools need to be measured, depending on the type of project (Brown 2001). The level of precision to which each pool can be measured at reasonable cost was estimated by Hamburg (2000). The table below presents a summary of these estimates. The measurement of each pool is briefly explained below (Table 20.2).

20.7.1 Aboveground Living Biomass

There are standard and well-accepted methods available for measuring aboveground biomass carbon in forested areas. These methods can be used in horticultural crops. The simplest procedure consists of measuring a sample of trees and using allometric equations to estimate biomass. Allometric equations relate tree biomass (*B*) to quantities (*Vi*) that can be measured by non-destructive means. Allometric equations have the general form:

$$B = f\left(V1, V2, \ldots, Vn\right) \tag{1}$$

The independent variables (*Vi*) may include diameter at breast height (*D*), height (*H*), and wood density (ρ). Experience with generic equations has shown that *D* explains more than 95% of the variation in tree biomass (Brown 2001). Brown (1997) has published allometric equations for tropical environments and presents wood density values for a large number of species. The assumption that 50% of aboveground living biomass is considered as C is well accepted (Hamburg 2000; Brown 2001), so it is straightforward to convert measured biomass to carbon units. Allometric methods are very robust among species and genera and can predict biomass of closed canopy forest to within ±10% uncertainty. In some special cases, it may be necessary to use destructive techniques to estimate allometric equations for a project (the techniques used to undertake these measurements are explained by Brown (1997)), but in general, parameter values available in the literature can provide acceptable levels of precision. Hence the main expense would be field measurement of trees.

20.7.2 Belowground Living Biomass

Belowground living biomass is an important pool among all and consists mostly of roots. This particular pool represents up to 40% of total biomass (Cairns et al. 1997). Direct estimation of belowground living biomass through destructive techniques is very expensive (Brown 2001). This pool can be estimated with some accuracy as that of aboveground biomass but at lower precision. Constant root/shoot ratio (R/S ratio) method is found to be the very simplest one for estimating belowground biomass. Although the R/S ratio varies with site characteristics and stand age, a range of R/S ratios can be obtained from the scientific literature (Hamburg 2000). To avoid measuring roots, a conservative approach recommended by MacDicken (1997) is to estimate root biomass at no less than 10 or 15% of aboveground biomass. Hamburg (2000) recommends a default R/S ratio for re-growing forests of 0.15 in temperate ecosystems and 0.1 in tropical ecosystems. Although ratios as high as 0.4 have been measured in temperate forests, the author recommends erring on the side of caution to avoid the possibility of crediting non-existent carbon.

20.7.3 Soil Carbon

Direct measurement of soil carbon can be expensive because of the strong effect that soil characteristics have on carbon dynamics. Hamburg (2000) argued that with the help of few generalized principles, it should be possible to quantify soil carbon to a satisfactory level of precision for biological mitigation projects. Hamburg (2000) recommends that the soil carbon be estimated to at least 1 m of depth and that measurements of soil carbon and bulk density be taken from the same sample. Fortunately, for projects that are known to have non-decreasing effects on soil carbon, it may not be necessary to measure soil carbon after the baseline is established. Information on soil oxidation rates under diverse land-use systems is already available in the literature (Brown 2001). In general, reforestation projects in waste or degraded land would tend to increase soil carbon. If the cost required for measuring this carbon pool is greater than the marginal benefit of the carbon credits obtained, the project developer would be better off not to measure this pool. The Alternatives to Slash and Burn (ASB) group have argued that most of the sequestration potential in the humid tropics is aboveground rather than in the soil. In tree-based systems planted to replace degraded pastures, they found that the time-averaged carbon stock increased by 50 t/ha in 20 years; whereas the carbon stock in soil increased by 5–15 t C/ha (Tomich et al. 1998; Palm et al. 1999). Modelling can complement measurement methods available for estimation of soil carbon (Brown 2001). Modelling techniques can be mainly worthwhile to forecast slow changes in soil carbon pools. An example of this technique developed based on soil carbon sequestration by agroforestry is presented by Wise and Cacho (2002).

20.7.4 Carbon in Dead Biomass (Necromass)

Carbon contained in dead trees, branches, leaves, and other vegetation is considered as necromass pool. It is not needed to include annual leaf litter inputs as part of the necromass pool, since this input is well adjusted by decomposition losses within the soil and the net effect is added in the measurement of the soil pool (Hamburg 2000). The volume of necromass carbon pool fluctuates substantially with the type of forest and disturbance history, and assessing this constituent precisely can be very time consuming and subject to high uncertainty. Brown (2001) states that both lying and standing dead wood is an imperative carbon pool in forests and should be measured. Methods for this constituent have been tested and require no more effort than measuring living biomass.

20.8 Soil Carbon Sequestration of Perennial Horticulture Crops

Soil carbon sequestration is not just a process of carbon tapping and storing in soil but a multipurpose strategy. It rejuvenates degraded soils, improves the land productivity, enriches the diversity, and protects the environment (Wang et al. 2010). Horticultural crops, particularly perennial crops, have a great scope for sequestering more carbon in terrestrial ecosystem than agricultural or agroforestry systems. Several researchers across the world reported that perennial horticultural system has always had an edge over annual cropping systems (Bhavya et al. 2017; Wu et al.

Table 20.3 Soil carbon storage/stocks under different horticulture land-use systems (Bhavya et al. 2017)

	4-year-old cultivation				
	Carbon stocks (Mg ha^{-1})				
Horticulture land-use system	0–15 cm	15–30 cm	30–50 cm	50–100 cm	Total (1 m depth)
Mango orchard	1374.75	1361.20	1811.24	4478.19	9025.38
Cashew orchard	1244.10	1245.02	1679.50	4075.50	8244.12
Rose block	1005.75	1003.62	1305.90	3215.22	6530.49
Vegetable block	990.00	973.35	1308.40	3110.07	6381.92
Medicinal and aromatic block	973.95	954.24	1265.00	3082.30	6275.49
SEm ±	62.22	61.45	81.56	199.45	405.45
CD at 5%	186.25	184.56	245.55	599.56	1215.66

Table 20.4 Carbon dioxide sequestration under different horticulture land-use systems (Bhavya et al. 2017)

	4-year-old cultivation			
	CO_2 sequestration (Mg ha^{-1})			
Horticulture land-use system	0–15 cm	15–30 cm	30–50 cm	50–100 cm
Mango orchard	5045.33	4995.60	6647.25	16434.95
Cashew orchard	4565.84	4569.22	6163.76	14957.08
Rose block	3691.10	3683.28	4792.65	11800.95
Vegetable block	3633.30	3572.19	4801.82	11413.95
Medicinal and aromatic block	3574.39	3502.06	4642.55	11312.04
SEm ±	228.45	227.45	300.04	733.45
CD at 5%	684.45	677.45	900.12	2194.45

2012; Shrestha and Malla, 2016; Janiola and Marin 2016; Chandran et al. 2016). For instance, the carbon sequestration potential of different cropping systems was ranked in the order of mango >cashew > rose > vegetable > medicinal and aromatic plants (Bhavya et al. 2017) and reported that addition of more residues in perennial systems to soil recorded less emission of CO_2 than annual crops. Soil carbon storage and CO_2 sequestration at different depths as influenced by different horticulture land-use systems is presented in Tables 20.3 and 20.4. Comparison among the different land uses such as perennial horticultural system and agroforestry/annual agricultural system showed that perennial horticultural system improved soil organic carbon content and stocks (Chandran et al. 2016). Carbon dioxide mitigation of agri-horticulture was found to be better than that of agriculture, horticulture, silvipasture, and forest land-use systems under all altitude levels of Himalayan region (Rajput et al. 2017). Carbon sequestration and credits of different fruit crops is given in Table 20.5. Further agri-horticulture system provides economic gains including C credits seem to be the better option. Because of their perennial nature and deep-rooting systems, orchards have the potential to increase subsoil carbon stocks below 0.3 m depth. Potential of land-use change and agroforestry (LUCF)

Table 20.5 Carbon sequestered and C credits of *Mangifera indica* (mango) and *Uapaca kirkiana* orchards

Species	Type	Age (years)	DBH class (cm)	Mean DBH (cm)	CO_2[b] (kg ha^{-1})	Value[a] ($ ha^{-1})
Mangifera indica	Grafted	6	<10	9.2	107,500	475
Uapaca kirkiana	Un-grafted	8	<10	6.98	56,500	250
	Grafted	8	<10	5.79	36,500	175

DBH diameter at breast height; [a]calculated at $4.50 per tonne of CO_2 (Ecosystem Marketplace 2010); [b]biomass calculations are after Brown (1997), carbon content is assumed to be 50% of dry biomass

and land-use change and horticulture (LUCH) activities to offset greenhouse gas emissions have been reviewed by Bloomfield and Pearson (2000).

A field experiment was carried out in a coconut garden having red sandy loam soil at ICAR-CPCRI, Kasaragod, Kerala, during May–July 2015 to study the effect of cropping system on above- and belowground carbon sequestration in a 50-year-old plantation intercropped with 7-year-old fruit crops. Among the different cropping systems, coconut (*Cocos nucifera*) + jamun (*Syzygium cumini*) system sequestered the highest aboveground carbon (60.93 t/ha) followed by coconut + mango (*Mangifera indica*) system with 56.45 C t/ha, coconut + garcinia (*Garcinia indica*) sequestered 53.02 C t/ha, whereas, coconut alone had sequestered 51.14 C t/ha. The belowground soil carbon stock in the rhizosphere of 0–60 cm depth was the highest in coconut + mango (82.47 t/ha) system followed by coconut + jamun (79.13 t/ha) and coconut + garcinia (78.69 t/ha), and it was the lowest in coconut monocrop (47.06 C t/ha). The total carbon sequestration by coconut + jamun (140.06 t/ha) is followed by coconut + mango systems (138.91 t/ha) and coconut + garcinia (131.72 t/ha), whereas it was only 98.2 C t/ha under coconut monocrop (Bhagya et al. 2017).

20.8.1 Age of Orchard: An Important Factor of Carbon Sequestration

It is required to produce nearly 2.2 tonnes of wood for sequestering 1 tonne of carbon from the atmosphere (Chaturvedi 1994). In the tropical regions, carbon sequestration by perennial trees is much faster due to the prevalence of favourable climatic conditions. The growth rates and carbon sequestration potential of perennial horticulture and plantations diminish as trees approach maturity. Fruit orchards and plantations store carbon in young and middle age, but the accumulation rates reach zero as the trees mature. Decline in the aboveground net primary production in mature orchards and plantations are due to following reasons:

- An altered balance between photosynthetic and respiring tissues
- Reducing soil nutrient availability
- Increasing stomatal limitations leading to reduced photosynthetic rates

Changes in the belowground biomass during orchard stand development and with aging of the orchards are very poorly understood. Hence, it is very difficult to speculate how this important flux may change during development of the orchards, plantations, and gardens. The long residence time of particulate organic matter from high-latitude forest soils, however, provides indirect evidence that if flux of carbon from vegetation to the soil increases, as a result of global change, these soils have the capacity to act as a carbon sink on decadal timescale.

20.8.2 Management Options for Improving C Sequestration in Horticultural Systems

Carbon sequestration in perennial horticultural crops mainly depends on their enhanced growth and productivity. The same can be attained by improving health of soil through better carbon management strategies. Hence attention towards management options to improve C sequestration should be diverted solely towards management of the soil. A net C sequestration in soil can be achieved through either by increasing carbon input to the soil or reducing carbon losses. Management practices that cause an increase in carbon input in agroecosystems are planting high biomass-producing crops, crop residue recycling, application of manures, switching from annual to perennial crops, adopting crop rotation in place of monoculture, and promotion of agroforestry systems (Nieder and Benbi 2008).

Life-cycle assessment (LCA) model can be adopted to evaluate the impacts of different sets of orchard management practices and to inform growers about the best options for mitigating GHG emissions. The following production stages are generally considered in LCA model:

- Orchard establishment (e.g. soil preparation, planting)
- Orchard management, including pruning, irrigation, tree replacement, pest control, and fertilizer use (including its production and transport)
- Orchard removal and disposal
- Postharvest processing and handling
- Transportation along the entire life cycle

The key sources of GHGs under different growth stages can be derived through LCA, and based on the results we can focus on farm management alternatives which may offer the greatest potential for lowering GHG emissions. Earlier studies indicated that nutrient management accounted for up to 40% of GHGs emissions, while irrigation accounted for up to 20%, depending on the crop. This indicates that increasing nitrogen use efficiency and improving irrigation efficiency could significantly reduce emissions. Further, open burning of orchard waste is another source of GHGs. Hence alternative disposal methods for pruning need to be found out including removal of trees by incorporating the biomass back into the soil or converting the waste to bioenergy, etc.

The most suitable soil management options should be selected based on their effects on agronomic productivity, profitability, and environmental quality. Primarily, there can be three key soil management options for managing soil organic carbon and reducing the greenhouse gas emissions (GHG):

- Preserving the current levels of soil organic carbon (SOC)
- Reinstating depleted soil organic carbon (SOC) levels
- Expanding soil organic pools beyond their historic carrying ability keeping in mind that these upsurges may be of fixed magnitude and period.

The carbon storage/sequestration potential of degraded or marginal lands is literally very high under the set of sustainable management options. There are several land management strategies for improving C sequestration in soil (Fig. 20.1). The following lists of practices either alone or in combination are proven to be the best suitable management practices for soil carbon sequestration:

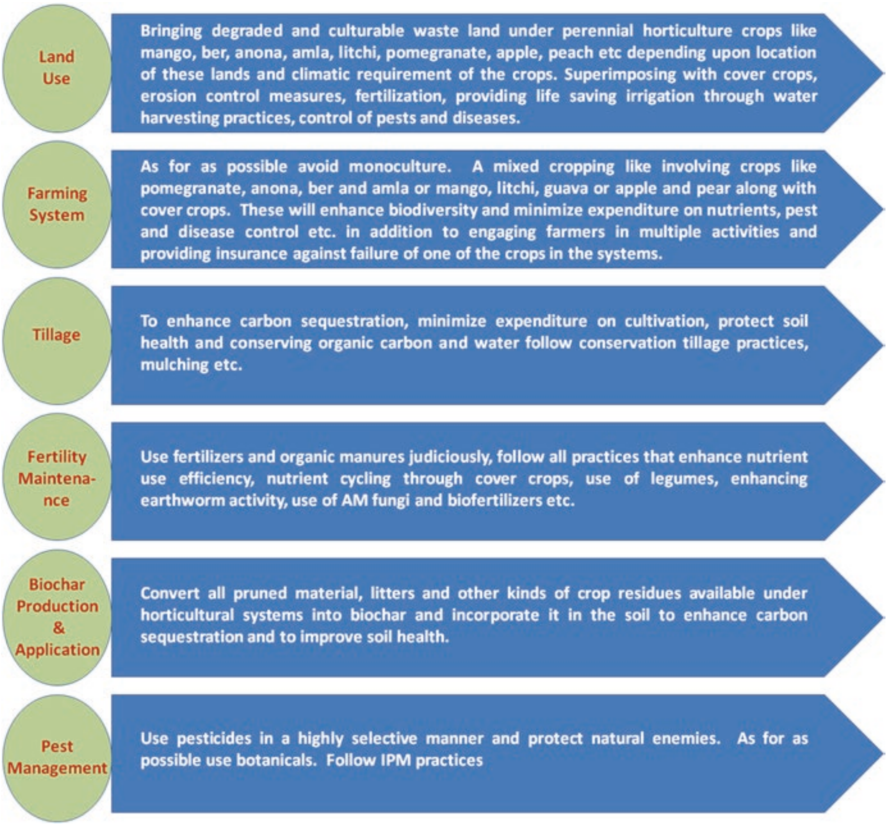

Fig. 20.1 Management options for sequestering C in soils under horticultural systems

- Residue management and tillage methods (zero tillage, conservation tillage, mulching, composting, etc.)
- Nutrient and soil fertility management (all management options to improve nutrient-use efficiency)
- Appropriate water management techniques (lifesaving irrigations, surface and subsurface drainage, rainwater harvesting, etc.)
- Control of soil erosion using suitable soil and water conservation measures (soil surface amendments, mulching, contour bunding, terracing, and trenching)
- Choices of crops, cover crops, intercrops, etc.

20.9 Conclusion

Perennial fruit crops–based system is a common land-use system in several parts of the temperate and tropical region of the globe. It has a significant role on economic, nutritional, and food security of the regions. Additionally, it offers a vital environmental service through mitigation of atmospheric CO_2. Further, the perennial plant-based system has more C stock in plant biomass than in the soil. This implies that even in the future, if temperature increases, not much change will happen to the stored C than that of annual-based cropping system where more C is stored in soil. In addition, perennial horticultural-based systems will provide economic gain through carbon credits. Therefore practicing perennial-based cropping system could be a potential option to mitigate increasing atmospheric CO_2. Further improved planting materials and standardizing the number of trees per unit area with appropriate management interventions will help in the storage of more carbon in a short period on the same land management unit.

The carbon sequestration potential and environmental services offered by perennial fruit trees are remain untapped. Therefore, the emphasis of research should be to develop efficient management systems and identify suitable species and propagation protocols to enhance carbon storage and to maximize fruit productivity. More investigations are required to quantify CO_2 sequestration potential in diverse fruit trees including native fruit tree species to indigenous communities. Location centric land-use systems need to be prioritized considering carbon sequestration potential and socio-economic needs. The major focus areas for further enhancing C sequestration of cropped systems include interactions among tillage, climate, and soil type on C sequestration; contribution of above- and belowground plant biomass to SOC; total GHG emissions from C sequestration practices, since most commonly recommended management practices like integration of legumes or fertilizer applications, which augment soil carbon, may perhaps also contribute to N_2O release from soil; role of tree pruning to increase light penetration in fruit orchards for higher photosynthesis; transformation of pruned tree biomass and other horticultural wastes into biochar and their addition into the fruit orchards or plantations soils to preserve soil carbon; quantification of C sequestration in promising horticultural systems; and benefits of conservation practices beyond C sequestration need to be elucidated. Further, much attention also to be given on the different properties of biochar made under different conditions, rates of decay of biochar in soil, effects of biochar on water usage and soil microorganisms, and behaviour of biochar under different environmental conditions.

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