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Research Article

Dynamics of Soil and Tree Carbon Storage in Different Agroforestry/ Tree based Land Use Systems

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ABSTRACT

Carbon sequestration in soil as well as tree based agroecosystem is important to offset the increasing level of atmospheric CO_2. Tree based system, either forest or timber or fruit tree based system provides not only alternative avenues for additional C storage but also better than annual crop based agroecosystem with respect to C sequestration. Intercrops grown under different ecosystem *viz*., agro, horti and forestry, pasture and silviculture may play critical role in sequestering C; such sequestration depends on types and age of tree, species richness, canopy and root architecture, adoption of management practices etc. Land use system, different soil types and management system also influences C sequestration rate and amount. Above and below ground biomass prediction in tree, foliage and distribution of C in different plant parts contributes to the prediction of total C stocks. Allometric equations were also developed to predict biomass and C stocks. Different land use system like high density mango and guava orchards may sequester higher amount of C in soil as compared to normal plantations.

Key words: Land use system, C sequestration, biomass and stock estimation, intercropping

Introduction

Scientific information on carbon stocks under different ecosystem and its ecosystem services for maintaining livelihoods of farmers, forest dwellers, tribal community etc are essentially required for planning the mitigation strategy of elevated atmospheric CO_2. Trees because of its foliage, root biomass and long duration may sequester more C than other annual crop system. Plantation crops do sequester more carbon under diverse soil ecosystem. Soil organic carbon (SOC) in its different fractions is important for its long-term stability in soil. Researchers across the globe have estimated changes in SOC content under different land use system, soil and crop management adopted, age and various density plantations etc. Batjes (2004) observed the changes in SOC under different land use system and also estimated stocks in soil in Kenya. In a study, Lettens *et al.* (2005) documented the changes in SOC over decades in Belgium. Sahu *et al*. (2015) estimated the C stocks in Forest in Odisha**.** Similarly, Upadhaya *et al.* (2015) found differential C and biomass under different management regimes in Garo hills of north-eastern India. It is important to have information on above and below ground biomass for calculation of tree C stocks precisely. However, such estimation varies from species to species, canopy management adopted, leaf biomass, branches and log breadth etc. Mani and Parthasarathy (2007) estimated tropical dry evergreen forest sites of peninsular India and Negi *et al*. (2003) calculated C allocation in different plant parts. For estimation of such stock diameter at breast height (DBH) parameter was taken into consideration. However, wood density is another

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important factor to be included for precise estimation of total above ground biomass in trees (Basuki *et al*., 2009).

Soil act as a sink in carbon management system as it is a potential sink for converting the atmospheric C into its own dynamic system in different ecosystem. Soil organic carbon (SOC) may be present in different fractions in soil, its longevity depends on the type, quality and amount of C inputs. Soil physical parameters play an important role in soil carbon storage capacity across soil ecosystem. In this regard, biological part also contributes significantly towards the C storage capacity in soil. Leifeld and Kögel-Knabner (2005) reported that C in the size of sand as well as finer fractions is the early indicator of SOC content in soil. Stable C content acts as a function of clay, clay + silt along with micro aggregates for power house of soil. Haile *et al.* (2008) recorded C storage in different size fraction of soil. Presence of high silt + clay content in soil improved SOC densities in paddy soils while coastal saline soils and alluvial soils were poor in SOC content due to presence of high sand percentage (Chuai *et al*., 2012). The physical fraction of SOC floatable in water was higher in silt fraction as compared to sand, with C varying between 3.39-15.59 g kg^{-1} soil, 8.52-78.83% silt and 5.15-21.95% clay (Matus *et al.*, 2011) across different ecosystem. Grüneberg *et al*. (2013) found that 37% of SOC was stored in light fraction in a study in differently managed German beach forest. Adak *et al*. (2015) recorded positive relation of SOC with clay content while negative relationship with clay + silt content. The labile form of SOC is significantly influenced by the enzymatic activities as observed by Kalambukattu *et al*. (2013). Bernardi *et al*. (2007) reported that conversion of forest to fruit cultivation decreased SOC stocks by 12 to 24% and N stock by 4 to 21% in soils under mango, guava, cashew and banana. Further, cultivation of fruit crops *viz*., mango, bullock's heart, sapota and Guava improved SOC stratification index in Arenosol. Thus, dynamics of SOC content acts as dependent factor while soil characteristics as independent factor.

Land use system and carbon sequestration in tree based agro-ecosystem

The prime importance of land use system for sequestering carbon in soil varied with the types of land use system adopted, ages of plantation, type of soil, soil management, climatic condition existed etc. In a study conducted across India, it was estimated that upper 30 cm soil layer had 9 Pico gram C (Bhattacharya *et al*., 2000). Different land use system involving forest tree, pasture, multipurpose trees, fruit trees and crops lands either monocropping or with their integration use to sequester different amount of organic carbon. It was revealed that shifts from native forest to croplands or plantation reduced total soil carbon in soil whereas crop lands to pasture/forest/plantation improved the efficiency in soil as well as tree C storage (Fig. 1) (Guo and Gifford, 2002). Kasel and Bennett (2007) inferred reduced soil carbon content by 30% after 37 years due to conversion of native, broadleaf forest to pine plantation. Sequestration of soil organic carbon and nitrogen was significant throughout the 0-60 cm soil depths over a period of 12 years of soil management (Franzluebbers and Stuedemann, 2009). Monreal *et al*. (2005) recorded 53.5-327.7 Mg ha^{-1} total C content (above and below-ground) in hillside agricultural (10-60 yr) and 88.3-236.2 Mg ha^{-1} in adjacent forestry (10-40 yr). The vertical distribution (0-105 cm) showed a range of 119.4-140.4 Mg ha^{-1} forest and 262.4-315.8 Mg ha^{-1} in agricultural/cultivated soils. In an study, the C stock in different plant parts of mango (15 yrs) and Litchi (7 yrs) trees was estimated; the quantity being in stem 22.47 and 6.33 Mg ha^{-1}, in branch 0.17 and 0.13 Mg ha^{-1}, in

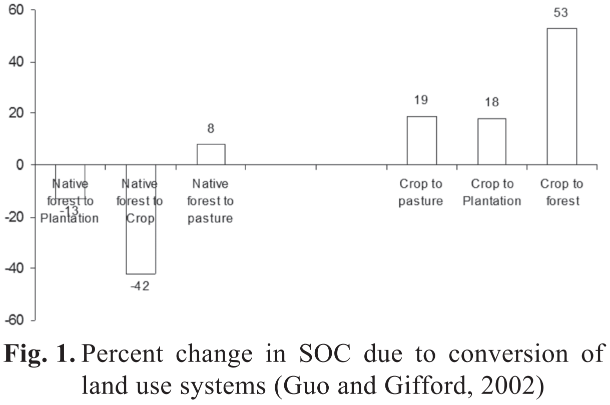

Fig. 1. Percent change in SOC due to conversion of land use systems (Guo and Gifford, 2002)

Table 1. Carbon stock (Mg ha^{-1}) of different components in tree-based ecosystem (Kanime *et al.*, 2013)

Name of tree	Above ground	Below ground	Total
Litchi	6.52	1.9	7.42
Mango	22.7	4.32	27.02
Populas	3.57	0.94	4.51
Eucalyptus	9.55	0.97	10.52
Dalbergia	35.77	7.62	43.39
Prunus	6.99	1.06	8.05

leaf 0.07 and 0.06 Mg ha^{-1} respectively (Kanime *et al.*, 2013) (Table 1).

Guava ecosystem under subtropical climatic condition of Lucknow region had sequestered 5.08 Mg ha^{-1} after 15 years of plantation (Table 2). The depth wise distribution of SOC storage was estimated at 6.65, 5.0 and 3.53 Mg ha^{-1} in 0-10, 10-20 and 20-30 cm respectively. The average bulk density, particle density, porosity and water holding capacity stands at 1.31 g cm^{-3}, 2.51 g cm^{-3}, 23.27 and 47.89% respectively. Stevens and van Wesemael (2008) recorded changes in SOC content over the periods due to change in land use history. Soil organic carbon (0-30 cm depth) decreased from 10.6 to 9.6 kg C m^{-2} with a mean rate of change -0.023 kg C m^{-2} year^{-1} over last 50 years with 0.79 g cm^{-3} mean bulk density, 22.7% sand, 60.5% silt and 16.8% clay. Soil types also contribute to differential C sequestration potential under any agroecosystem. It decides the rate at which C is sequestered in soil either in presence of bulk roots of trees or pasture. Jiménez *et al.* (2007) recorded significant differences in soil physical properties in 0-50 cm soil depth with an interval of 10 cm (bulk density, aggregate stability and mean weight diameter) across different tree ecosystem with 0.67 to 1.06 Mg m^{-3} BD in tree species as compared to 0.94-1.07 Mg m^{-3} in control/undisturbed system. Similarly, wide variations in SOC content was observed in Cambisol (14.8-29.9 g kg^{-1}) at 0-20 cm soil depths, Inceptisol (81.6-137.4 g kg^{-1}) at 0-30 cm depths and in Andosol (82.2-112.6 g kg^{-1}) at 0-30 cm soil depths under different tree species of different ages in Costa Rica. Soil management system also influences soil properties particularly soil physical properties and associated soil organic carbon content. Silva *et al.* (2011) inferred differential organic C and soil properties in agroforestry systems, silvipasture and natural vegetation in a Luvisol under semi-arid region of Brazil. A range of 22.8-35.2 g kg^{-1} total organic carbon, 1.47-1.60 Mg m^{-3} BD, 2.49-2.52 Mg m^{-3} PD, with 39.2-42.5% total porosity in sandy loam soils (sand 635-746; silt 132-192 and clay 122-173 g kg^{-1}). Improvement in different forms of soil organic carbon (dissolved organic carbon, microbial biomass carbon and light fraction carbon) in soil by six multipurpose trees over a period of 18 years was revealed by Laik *et al.* (2009). Of course there was non-significant change in bulk density across these systems. In contrast, Hazra (1994) recorded enhancement in soil BD under silvi-pastoral system involving tree species with grasses and legumes. Under existing crop cultivation, a range of 19.82 ± 2.5 to 30.29 ± 1.7 and 17.60 ± 0.8 to 27.75 ± 3.0 t ha^{-1} SOC at 0-15 and 15-30 cm soil depths were estimated in farmlands of Nubra valley under cold desert regions of Ladakh, India (Acharya *et al.*, 2012). The corresponding values for grasslands were estimated at 8.15 ± 1.3 to 35.30 ± 3.5 t ha^{-1} and 7.05 ± 1.2 to 32.85 ± 3.1 t ha^{-1} at respective

Table 2. Estimated Soil organic carbon, storage and other soil properties in guava (Allahabad Safeda) orchard of 15 years age at CISH Rehmankhera Farm, Lucknow, UP, India

Depth of soil (cm)	BD (g cm^{-3})	PD (g cm^{-3})	WHC (%)	Porosity (%)	SOC (%)	SOC stock (Mg ha^{-1})
0-10	1.27	2.53	23.84	49.68	0.52	6.65
10-20	1.33	2.50	22.98	46.73	0.38	5.00
20-30	1.32	2.51	22.98	47.27	0.27	3.53
mean	1.31	2.51	23.27	47.89	0.39	5.08

depths. Based on stock estimation in different density of Dashehari mango plantation under subtropical condition, Adak *et al*. (2016b) inferred significant variations in SOC (%) and its storage across different densities and soil depths. Higher percentage (62.5%) of stock in the range of 5.1 to 10 Mg ha^{-1} was estimated. SOC storage in soil under high density system was significantly higher than the normal density plantations showing its potential to sequester more carbon. Kanime *et al.* (2013) estimated mean annual increase in tree biomass as 2.71 and 4.06 Mg ha^{-1} yr^{-1} in Litchi and Mango tree of 7 and 15 years old respectively grown in soils having 1.03-1.12% organic carbon, 1.33 g cm^{-3} BD and neutral pH (7.4). The soil C stock of 36.3 and 40.7 Mg ha^{-1} at 0-30 cm soil depth was also determined. The foliage part *viz*., above ground biomass production was calculated as 14.35 and 50.6 Mg ha^{-1} in stem, 0.28 and 0.37 Mg ha^{-1} in branch, 0.14 and 0.15 Mg ha^{-1} in leaf in litchi and mango respectively.

C sequestration potential under intercropping in tree based ecosystem

Tree based agroecosystem is a potential area for sequestering good amount of carbon in soil. Fruit tree based watershed, intercrops in mango orchards, agroforestry based ravines/eroded soils, agroforestry based degraded and/or problematic soils, wastelands having enormous scope for carbon sinks are the key features for mitigating the higher atmospheric carbon level. Various types of trees are having different capacity for carbon sequestration based on its species, age, types of soils in which tree plantations were supported and its management undergone. The carbon stock in a homegardens of small-scale farmers in Indonesia was estimated by Roshetko *et al*. (2002) and it was recorded as 107.0 Mg C ha^{-1} from gardens having fruit and timber tree species. Kraenzel *et al.* (2003) estimated 120.2 Mg C ha^{-1} in 20-year old teak plantations. Based on a study at 0-40 cm soil depth, Kirby and Potvin (2007) reported decreasing order of tendency in carbon from upper surface (0-10 cm) to lower one (30-40 cm) (Fig. 2). Further, carbon stock of 45.1, 45.0 and 40.9 Mg ha^{-1} was observed in

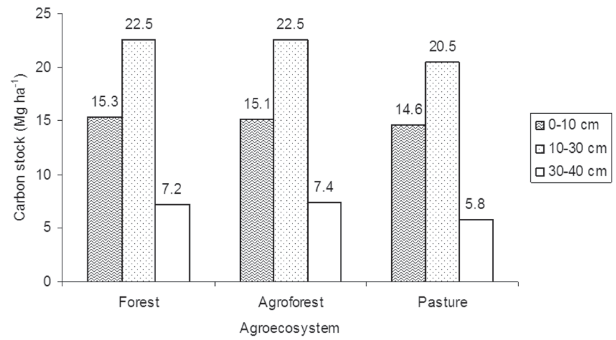

Fig. 2. Carbon stock at different soil depths and agroecosystems (Kirby and Potvin, 2007)

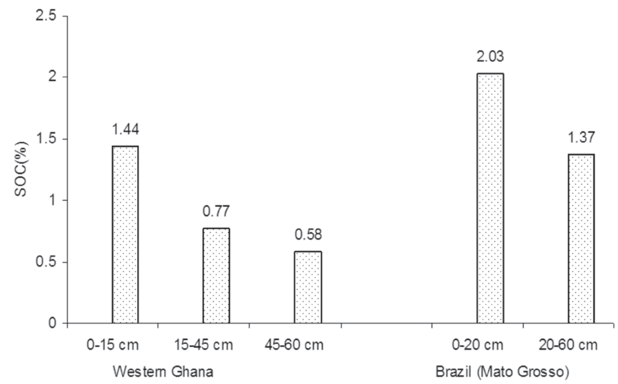

Fig. 3. Mean soil organic carbon (%) in different sites (0-60 cm depth) (Wauters *et al*., 2008)

managed forest, agro-forests and pasture ecosystem respectively. Wauters *et al*. (2008) concluded that clay content of soil and climatic components affects the soil organic carbon content at 0-60 cm soil depth in rubber plantations of Western Ghana (WG) and Brazil (Mato Grosso) being higher content in Brazil as compared to WG (Fig. 3). The estimated C stored in 14 yrs old rubber plants was 76 t C ha^{-1} (WG) and 42 t C ha^{-1} (MG) respectively, such difference may be due to variations in tree height and circumference growth patterns. Research was conducted at experimental research farm of ICAR-CISH, Lucknow, indicated that intercrops (*viz*., fodder, asparagus, mango turmeric and black turmeric etc.) grown in mango orchards can sequester an appreciable amounts of organic carbon. The SOC storage decreased from surface (0-10 cm layer) to deeper depths (20-30 cm). A range of 7.41 to 8.07 Mg ha^{-1} at the upper soil surface layer across different intercrops was recorded while at the bottom level, the values

Table 3. SOC storage (Mg ha^{-1}) in intercrops grown in mango orchards of subtropical Lucknow condition, India

Intercrops	Soil depths			
	0-10 cm	10-20 cm	20-30 cm	Average
Fodder	8.07	5.36	4.62	6.02
Asparagus	7.79	6.68	5.16	6.54
Mango turmeric	8.01	6.27	4.51	6.26
Black turmeric	7.41	5.29	4.48	5.73

were 4.48-5.16 Mg ha^{-1}. Average of root zone SOC storage thus estimated to be 5.73, 6.02, 6.26 and 6.54 Mg ha^{-1} in black turmeric, fodder, mango turmeric and asparagus respectively (Table 3).

Allometric equations for estimating above and below ground biomass

Dry biomass production is an indicator of C storage in different plant parts. Thus estimation of below as well as above ground dry biomass is essentially required in order to have an idea about the C storage in trees. Allometric equations were developed in different tree species for estimating above and below ground biomass. Thus biomass production acts as a precursor for C stock estimation. Non constructive methodology was also used to estimate the biomass C production. Ganeshamurthy *et al.* (2016) estimated C sequestration in grafted mango tree using non-destructive methods by developing allometric equations. The root biomass stands at 5.11 to 122.45 kg in the age group of 3 to 45 years of mango tree. The root: shoot ratio stands at 0.29 in grafted mango under Bengaluru condition. Based on a study in six different locations in Malawi (Karonga, Bolero, Salima, Mwanza, Bwanje and Makanjila), Beedy *et al.* (2016) inferred that biomass C stock increased with increasing diameter at breast height (DBH) and bole as well as brunches contributed majority of the above ground C stock in *Faidherbia albida* tree. Apart from DBH, Basuki *et al.*, (2009) included wood density in the allometric equations to predict above ground carbon stock, a range of 0.32 to 0.86 g cm^{-3} wood density at a range of 6.3-200 cm DBH was observed across different tree species. Using allometric equations, Ebuy *et al.* (2011) estimated total dry biomass in 12 trees. The distribution of biomass in different parts of plants was as 536.5- 2329.4 kg in stem, 24.7-329.1 kg in bark, 8.2-514.0 in branch, 1.9-185.4 kg in thin branch, leaf 1.8-120.5 and total dry biomass stands at 705.6-2832.8 kg. The above, below ground and total tree biomass (Fig. 4) was estimated in different tree based ecosystem in India under Central Himalayan *Tarai* region (Kanime *et al.,* 2013). The mean annual increase in tree biomass was calculated as 2.71, 4.06, 1.23, 2.34, 9.48 and 3.64 Mg ha^{-1} in Litchi, Mango, Populous, Eucalyptus, Dalbergia and Prunus trees respectively. Kaushal *et al.* (2016) recorded 18.91 and 109.30 Mg ha^{-1} total aboveground biomass in 6 and 20 years old plantation of bamboo and inferred 8.39 and 49.08 Mg ha^{-1} carbon stocks mitigated by these plantations.

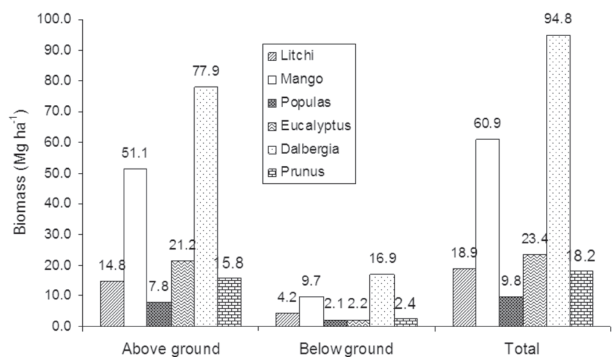

Fig. 4. Above, below ground and total biomass production (Mg ha^{-1}) in different tree based system

Limitations of allometric equations

There are several limitations in application of allometric equations in estimating above and below ground C biomass and stock. All these equations are preferably used for estimation of C stock in different parts of forest and timber trees. However, little information is available for fruit trees particularly for grafted one's; due to complicating branching behavior of trees and measuring DBH (diameter at breast height) just above the graft union. With respect to DBH, tree structure is mainly different in seedlings than grafted one's. Specific equations are needed for specific types of trees, as same equations may not be applicable to various types of fruit trees due to different canopy structure and biomass per unit area of canopy. It varies with density, species, age, canopy structure, biomass partitioning and branching behavior etc. Constants (scaling factors) are to be determined precisely and separately for the each species. Root volume either by destructive or non-destructive way is to be included appropriately in each case subjected to types of soil and its management. Moreover, amount of leaf litter is to be estimated periodically to have accurate determination of total leaf biomass as it varies within and between species and also as a function of time.

Summary

Carbon sequestration and its quantification depends on the types of soil, tree species, their age, canopy distribution, wood density, root volume and land use system adopted. Different fruit tree sequester different quantity as compared to each forest tree or timber tree. Above and below ground tree biomass @ 14.77 and 4.24 Mg ha^{-1} in Litchi plants (7 yrs old) and 51.12 and 9.73 Mg ha^{-1} in mango plants (15 yrs old) respectively was estimated. Carbon stocks in higher density plantations were revealed as compared to normal density of mango plantations. Intercropping and different land use systems also differ in C storage depending on intercrops grown. Sequestration also varied among soil types and its management.

Future prospects

Under the modern era of global warming, research focus on soil C sequestration has gained special attention worldwide to mitigate elevated atmospheric CO_2 and maintain a balance between technological intervention and development. The thrust area has gained momentum in assessing the differential capabilities of different agro-ecosystem to sequester atmospheric C in soil under diverse land use system, soil types, soil management to provide precise information to planners, policy makers and stakeholders for future planning and developing effective mitigation strategies. The role of different density plantation system in this regard may contribute much more towards C storage both in soil and tree. In this regard, researchers across the globe have estimated SOC under different density fruit tree as well as forest trees. Agroforestry acts as a precursor for enhancing the C storage in soil; intercropping in orchards or forest ecosystem also attributed to SOC storage preferably in its labile form. Even under long-term orchard management system, fractionation of C in its different from are also important to estimate the longevity of stored C.

Researchers also expressed their views on chemical composition and constituents as influenced by sites, soil, climate, tree wood density, foliage etc. The canopy and root architecture plays pivotal role in sequestering C. Allometric equations were developed in order to predict below and above ground dry biomass and C stored in the system. Age, types, mixed farming, diameter at breast height, wood density and its specific gravity was taken into consideration in estimating the tree component of C. For fruit crops, rhizospheric dynamics *viz*, root volume, active root zone, its decomposition rate etc. are to be considered for precise measurement of C components. Future study should include the accurate information on saturation point of C in soil across different land use land cover change, density plantation with agro-forestry, agro-silviculture, pasture etc. The allelopathic effects under multistory system and agroforestry system should also be given a priority in deciding the types of crops and its impact on the soil biosystem. Future thrust area might also be on canopy architecture, rate of biomass development, stem/girth circumference, distribution of C at different stage and age in different parts of tree. Canopy volume along with rate of evapo-transpiration should be determined effectively so that associated soil physical, biological and chemical parameters also be estimated regarding organic carbon. The cost of afforestation and assumption in C storage should also benefit farming community by way of providing C credit to save livelihood. Adding tree components in watershed community to reduce soil and water erosion is an approach to mitigate C loss. The role of wood density (WD) in estimation of C stock is essential it varied across different sections of tree (lower, middle and upper portion) as well as species and genera. Therefore, WD should also be given emphasis in fruit crops for precise estimation C storage in plants.

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