Carbon sequestration in plantation crops

[1]Subramaniyan, P., [2]L. Jeeve Jothi, [3]N. Shoba, [4]S. Murugesan

[1]Student, [2]Professor and Head, [3]Professor and Head, [4]Assistant Professor
Department of Spices and Plantation crops,
Horticultural College and Research Institute, TNAU, Periyakulam, Theni, Tamil Nadu, India

***Abstract*--One of the principal global concerns at the onset of the 21st century is the alarming increase in atmospheric carbon dioxide (CO_2) concentrations. Several options of carbon sequestration being considered are geologic, oceanic, chemical transformations and terrestrial. Among these the transfer of atmospheric CO_2 into biotic and pedologic carbon pools is called terrestrial carbon sequestration. It is a natural process with ancillary benefits besides cost-effectiveness. Plants fix atmospheric CO_2 through photosynthesis and convert them as bio mass by storing them in various organs. Plantation crops are perennials that are grown in large scale and are mostly found in mixed species cropping systems. Such cropping systems offer a large amount of bio mass production per unit area than mono cropping system. Hence, they act as carbon pools and help in reducing the effect of global warming. Cocoa is an excellent crop in sequestering atmospheric carbon (35 t/ha by 15 year old plantation) and storing in various plant parts as well as in soil aggregates. Carbon capture and storage decreases with increase in plant density. The sequestration potential of tea varies between clones and seedlings as well as age. It increases with age. Seedlings have potential of capturing more carbon than clones. The carbon content of the foliage and roots of seedlings was higher than of clonal plants. The amount of carbon that rubber plantations sequester ranges from 135 to 153 t /ha out of which 39 – 69% is contributed by soil organic carbon pool. The bulk density of soil in top 15 cm was low when compared to 15-30 cm depth of soil and the Bulk density decreased with age. The total carbon sequestrated was higher in the top 0-15 cm soil layer and lower in 15-30 cm. Estimates of C in upper 40 cm of soil in mature plantations of coffee showed soil stock of 97.27and 95.78 Mg/C/ ha in shaded and open grown coffee systems. Plantation crops are perennials with large biomass production, and act as 'natural Sponges' for absorbing CO_2 from atmosphere. Mostly grown in mixed cropping system, these crops form an excellent species in sequestering atmospheric carbon besides providing nutritional security and restoring soil fertility. With global carbon trading becoming reality, emitters unable to meet their own targets could pay of through carbon sequestration in plantations.**

Index Terms- **Carbon sequestration, terrestrial sequestration, plantation crops- agro ecosystems.**

I. Introduction

Carbon sequestration is natural removal of carbon from atmosphere by soil and plants. It has also been described as any of the several processes for removal of excess carbon dioxide (CO2) from atmosphere in an effort to mitigate global warming. Carbon sequestration can be termed as capture and long-term storage of carbon dioxide before it is emitted into atmosphere. Globally, soils are estimated to contain approximately 2,700 gigatons of soil organic carbon, more than amount in vegetation (575 Gt in bio mass and Photosynthesis 60 Gt/ year) and atmosphere (780 Gt) reported by Lal and Rattan, (2008). Modification of agricultural practices is a recognized method of carbon sequestration in soil can act as an effective carbon sink offsetting as much as 20% of CO_2 emissions annually.

a. Reducing emissions

Increasing yields and efficiency generally reduces emissions as well, since more food results from the same or less effort. Techniques include more accurate use of fertilizers, less soil disturbance, better irrigation and crop strains bred for locally beneficial traits and increased yields. Replacing more energy intensive farming operations can also reduce emissions. Reduced or no-till farming requires less machine use and burns correspondingly less fuel per acre. However, no-till usually increases use of weed-control chemicals and residue now left on the soil surface is more likely to release its CO_2 to atmosphere as it decays, reducing the net carbon reduction. In practice, most farming operations that incorporate post-harvest crop residues, wastes and byproducts back into soil provide a carbon storage benefit. This is particularly case for practices such as field burning of stubble - rather than releasing almost all of the stored CO_2 to the atmosphere, tillage incorporates the biomass back into soil where it can be absorbed and a portion of it stored permanently *(www.esrl.noaa.gov/gmd/ccgg/trends/).*

b. Enhancing carbon removal

All crops absorb CO_2 during growth and release it after harvest. The goal of agricultural carbon removal is to use the crop and its relation to carbon cycle to permanently sequester carbon within soil. This is done by selecting farming methods that return biomass to soil and enhanced conditions in which is carbon within the plants will be reduced to its elemental nature and stored in a stable state. Methods for accomplishing this include: 1). Use cover crops such as grasses and weeds as temporary cover between planting seasons. 2). Concentrate livestock in small paddocks for days at a time so they graze lightly but evenly. This encourages roots to grow deeper into the soil. 3). Cover bare paddocks with hay or dead vegetation. This protects soil from the sun and allows the soil to hold more water and be more attractive to carbon-capturing microbes. 4). Restore degraded land, which slows carbon release while returning the land to agriculture or other use. Agricultural sequestration practices may have positive effects on soil, air and water quality, be beneficial to wildlife, and expand food production. On degraded croplands, an increase of

1 t of soil carbon pool may increase crop yield by 20 to 40 kg/ha of wheat, 10 to 20 kg/ ha for maize, and 0.5 to 1 kg/ha for cowpeas (William, 1999). The effects of soil sequestration can be reversed. If the soil is disrupted or tillage practices are abandoned, the soil becomes a net source of greenhouse gases. Typically after 15 to 30 years of sequestration, soil becomes saturated and ceases to absorb carbon. This implies that there is a global limit to the amount of carbon that soil can hold. Many factors affect the costs of carbon sequestration including soil quality, transaction costs and various externalities such as leakage and unforeseen environmental damage. Because reduction of atmospheric CO_2 is a long-term concern, farmers can be reluctant to adopt more expensive agricultural techniques when there is not a clear crop, soil, or economic benefit. Governments such as Australia and New Zealand are considering allowing farmers to sell carbon credits once they document that they have sufficiently increased soil carbon content.

c. Global concern is in air

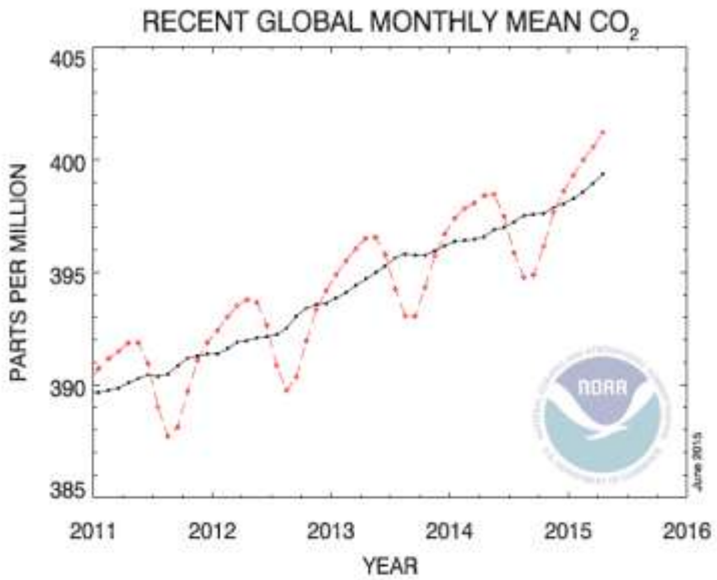
The concentration of CO_2 has increased from a pre industrial level of 280 ppm to 390 ppm as of date. Similarly methane concentration in the atmosphere is around 1745 ppb while nitrous oxide accounts for 314 ppb (Conway *et al*., 1994 and Ballantyne *et al*., 2012).

Table 1. Green house gases in the atmosphere (www.esrl.noaa.gov/gmd/ccgg/trends/)

Gas	Pre-industrial level	Current level (2015)	Increase since 1750	Contribution to global warming
Carbon dioxide	280 ppm	400 ppm	108 ppm	36 – 72%
Methane	700 ppb	1745 ppb	1045 ppb	9 – 26 %
Nitrous oxide	270 ppb	314 ppb	44 ppb	4 – 9 %
CFC	0	533 ppt	533 ppt	3 – 7 %

(Intergovernmental Panel on Climate Change, 2016)

Fig. 1. Global-warming potential (GWP)



Global warming potential is calculated based on CO_2. Global-warming potential (GWP) is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of gas in question to amount of heat trapped by a similar mass of CO_2. GWP is expressed as a factor of carbon dioxide (whose GWP is standardized to 1).

II. Carbon Cycle

Carbon cycle is biogeochemical cycle by which carbon is exchanged among the biosphere, pedosphere, geosphere, hydrosphere and atmosphere of earth. It is one of the most important cycles of earth is allows for carbon to be recycled, reused throughout the biosphere and all of its organisms.

1. Terrestrial Carbon Sequestration

The process of increasing net fixation of atmospheric CO_2 by terrestrial vegetation, retaining carbon in plant materials and enhancing the transformation of carbon to soil organic matter. The emission of CO_2 from soils caused by heterotrophic oxidation of SOC has to be reduced and increasing the capacity of deserts and degraded lands to sequester carbon.

III. Carbon sequestration and plantation crops

Plantation crops are perennial crops and acts as "Natural Sponges" for absorbing CO_2 from atmosphere. The crops are grown as mixed species cropping systems and the density of vegetation is high per unit area when compared to other annual crops. In this plants are produce a large amount of biomass besides producing economic produces of commerce. They retain soil fertility, physical and chemical properties through decomposition of large volume of litter fall, pruning wastes etc. The sequestration capacity of plantation crops depends on cropping system, species richness, population/unit area, inter cultivation practices like tillage, irrigation etc. Besides providing nutritional and food security, plantation crops helps in sequestering carbon from atmosphere and store them as bio mass for long period. The percentage of Carbon in plant tissues of plantation crops is in the range of 39-50 %. The carbon will also be sequestered in soil as soil organic carbon in different soil fractions. The macro aggregates of soil are capable of storing large amounts of C because of larger surface area. Cocoa has capability of capturing and sequestering carbon in large volume than any other plantation crops. Since, the amount of foliage produced is large, quantity of biomass added to soil through litter fall and pruning is in the tune of around 1 t/ ha.

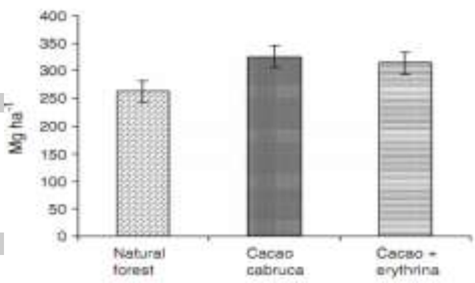
1. Carbon stock in smallholder chocolate forest in southern Cameroon and potential role in climate change mitigation

Carbon stock was evaluated in above ground, litter, root and soil in 60 cocoa plantations within a benchmark covering (i) the sub-region of Yaoundé, (ii) the sub-region of Mbalmayo and (iii) the sub-region of Ebolowa. Market access, population density and resource use intensity all decreased from first to third sub-region (Thenkabail, 1999) On average, chocolate forest of southern Cameroon store 243 Mg/ ha of carbon. Plants associated with cocoa, cocoa trees, litter and roots store respectively 170, 13, 4, and 18 Mg of carbon/ ha. These constituted respectively 71, 4, 2 and 8% of the total carbon stock of the plantation. The soil under cocoa agroforest store 37 Mg/ ha.. High value timber trees, edible [i.e. exotic plants, Non Wood Forst Products (NWFP), Musa spp and oil palm] and medicinal plants carbon stock account respectively for 30, 15 and 7% of total amount of carbon stored by plants associated with cocoa. Exotic plants stored 13.3 Mg carbon/ha around Yaoundé as against 3.4 and 1.1 respectively around Ebolowa and Mbalmayo areas. The carbon stored by edible NWFP around Yaoundé represented 40% of the amount stored by similar plants in Ebolowa and Mbalmayo (Sonwa *et al.*, 2009).

2. Carbon storage in soil size fractions under two cacao agro forestry systems in Bahia, Brazil.

The study was carried out to characterized SOC (Soil Organic Carbon) storage in relation to three soil fraction-size classes, >250 µm - macroaggregate, 250–53 µm - microaggregate , <53 µm - silt and clay size fractions. It was estimated with in humid tropical climate. Three land use systems were studied *viz.*, a) Cacao cabruca system of 30 years old with 550 cocoa plants/ha and 70 shade trees/ ha, b) Cacao + Erythrina – 30 years old with 1111 plants/ha and 30 shade trees /ha and c) Natural forest. The soils were sampled for organic carbon content at 0–10, 10–30, 30–60, and 60–100 cm depth.

Fig. 2. SOC storage in the 0–100-cm soil layer



In Emanuela *et al.*, (2010) conducted cocoa cabruca system which comprises of growing cocoa under that shade of tall growing timber trees of natural forest showed the highest SOC when compared to other systems. The systems with cocoa as a component showed higher SOC than natural forest. Since, the litter fall from cocoa trees added to total carbon pool. The cocoa cabruca system stored more carbon in top 30 cm of soil layer. While, cocoa erythrina system in 30-60 cm soil and natural forests in 60-100 cm of soil. The macro aggregates of soil stored the major amount of carbon pool in soil. This is due to the larger surface area available in macro aggregates to hold carbon. Which is confirmed using sonication process.

3. Carbon sequestration in sub-tropical soils under rubber plantations in north-east India

Impact of rubber plantations on C fractions, stocks and sequestration in reforested degraded sub-tropical forest lands in Tripura, India was studied. Sample plots are identified from 5, 10, 15, 20, 25 and 30 years old rubber plantations with a control (initial). The standing biomass and annual C flow as litter-fall were calculated. The soil samples were analyzed which were sampled at 0 - 15 and 15 - 30 cm depths for Non-oxidizable C (C_{NOX}), Oxidizable organic C (C_{OX}), Total C_T , Bulk density, C concentration and stocks.

The results showed that the bio mass accumulation in standing trees was increasing up to 20 years of age and no significant difference in bio mass accumulation was observed in later stages of growth. Similar trend was noticed in bio mass carbon content. Litter fall was found increasing up to 10-12 years after planting and the rate was maintained after that period. The bulk density at 0-15 cm of soil layer was found decreasing as the decomposition of litter fall will reduce BD of soil. The BD of lower 15-30 cm of soil was higher than the 0-15 cm layer, as the compactness of soil in lower layers is high when compared to upper layers where there will be inter cultivation practices disturbing soil layers. The carbon sequestration potential of 30 years old rubber plantation is found to be 83 t/ C/ ha which is stored in plant biomass reported by Mandal and Islam, 2004.

4. Simulation of the impacts of three management regimes on carbon sinks in rubber and oil palm plantation ecosystems of South- Western Cameroon

The impacts of managed, extended and complete rotation on carbon sequestration in rubber and oil palm plantations were simulated using CO2FIX V.2 model, using degraded farmland carbon stocks as a baseline. Results was showed that the extended rotation in higher C-sequestration in rubber (264 Mg C/ha) and complete rotation (88 Mg C/ha) for oil palm plantation. There was better soil carbon recovery in rubber under the extended rotation and better recovery in palms under a complete rotation. With respect to soil carbon fractions, fine litter had highest value in rubber (19 Mg C/ha) and coarse litter in palms (63 Mg C/ha) all under complete rotation. Humus was most permanently increasing soil carbon component, with the best sinks at 9 and 12 Mg C/ha in rubber and palm under extended reported by Andrew *et al.*, (2012).

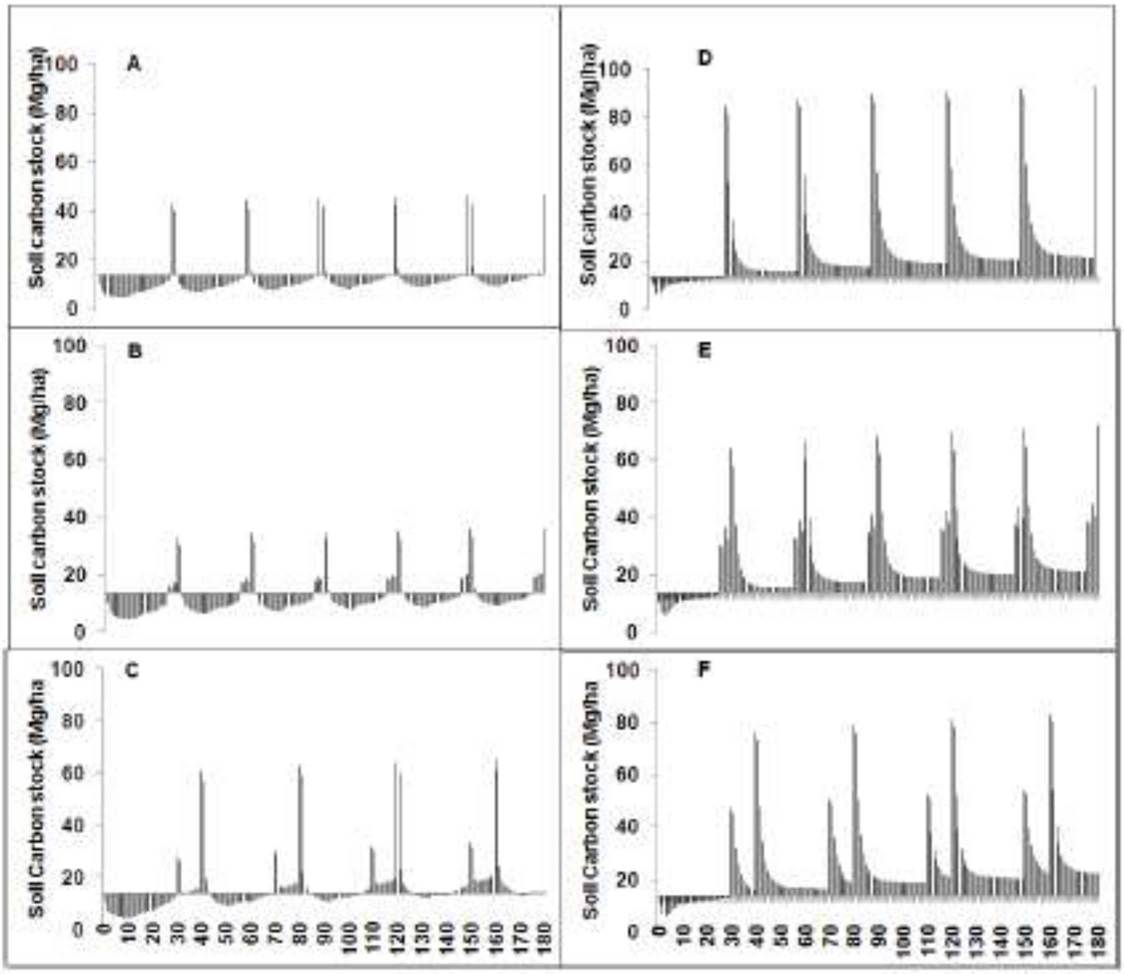


Fig.3. impact of different management options on soil carbon recovery in rubber(A-C) and oil palm (E-F) plantation system. A and D complete rotation, B and E managed rotation and C and F extended rotation. Bars represent net stock.

5. Above- and belowground biomass, nutrient and carbon stocks contrasting an open-grown and a shaded coffee plantation.

The objectives of the study was to quantify total vegetation biomass and biomass distribution in a mature coffee plantation with and without shade of *Albizia adianthifolia* in Southwestern Togo, were determine nutrient and carbon storage in biomass in the two coffee agro ecosystems .The results showed that the biomass carbon was highest in shade grown coffee systems. Since, the shade trees have contributed to additional carbon bio mass. In both systems, the major contribution of C was from stems. Total plant C stock in shaded coffee system was recorded as 82 Mg/ha, of which 67 Mg (82%) was found in aboveground fractions. In open system, it was recorded as 23 Mg/ha of which 63 % was found in aboveground fractions. In case of aboveground C stock, the shaded coffee system was dominated by Albizia trees (82 %). While in open system, it was dominated by Coffee stem (53 %) (Dossa *et al.*, 2008).

6. Carbon sequestration in tea plantation

The tea plant is a strong carbon sink and it too uses atmospheric CO_2 as a source of CHO biosynthesis. Therefore, C sequestration was estimated four tea variety TV1(Ass.), TV18(cam.), TV25(Cam.) and TV20(Ass.) considering the metabolic activity of tea leaves, bush canopy are divided in to two layer 1). Top 10 cm canopy is biologically more active and consume more quantity of CO_2 for CHO manufacturing. 2). The bottom layer below the top 10 cm is biologically lees active and less CO_2. This study was reported by Barman *et al.*, (2012).

Table 2. Carbon sequestration/ha/yr

Clones	Carbon sequestration by top layer (kg/ha/yr)	Carbon sequestration by bottom layer(kg/ha/yr)	Total carbon sequestration (kg/ha/yr)
TV1(Ass.Ch.)	41400	219	41619
TV18(Cam)	47250	143	47323
TV25(Cam)	47250	302	47551
TV25(Ass.)	3550	159	35709
Mean	**34863**	**206**	**43051**

7. Carbon and nutrient stocks of tea plantations differing in age, genotype and plant population density

The study was carried out to determine temporal dynamics in standing biomass and dry matter partitioning in tea bushes varying in genotype, age and population density, to determine the C and nitrogen, phosphorus, potassium (NPK) stocks of tea plantations and to assess the consequences of C and NPK stocks for tea crop productivity and stability. Each tea bush was partitioned into 'two leaves and a bud', maintenance foliage, twigs, stem, thick woody roots and thin feeder roots.

Table 3. Dry mass of plant parts (kg DM /bush)

Plant part(s)	Clonal			Seedling		
	14-year[a]	29-year	Mean[b]	43-year	76-year	Mean
Foliage	0.6 a	0.6 a	0.6 A	0.7 a	0.9 a	0.8 B
Frame	7.2 a	9.7 b	8.5 A	11.4 a	16.0 b	13.7 B
Roots	1.2 a	1.2 a	1.2 A	1.5 a	2.9 b	2.2 B
Total	9.0 a	11.5 b	10.3 A	13.6 a	19.8 b	16.7 B

[a] Values connected horizontally by the same lower-case letter are not significantly different at $P<0.05$.

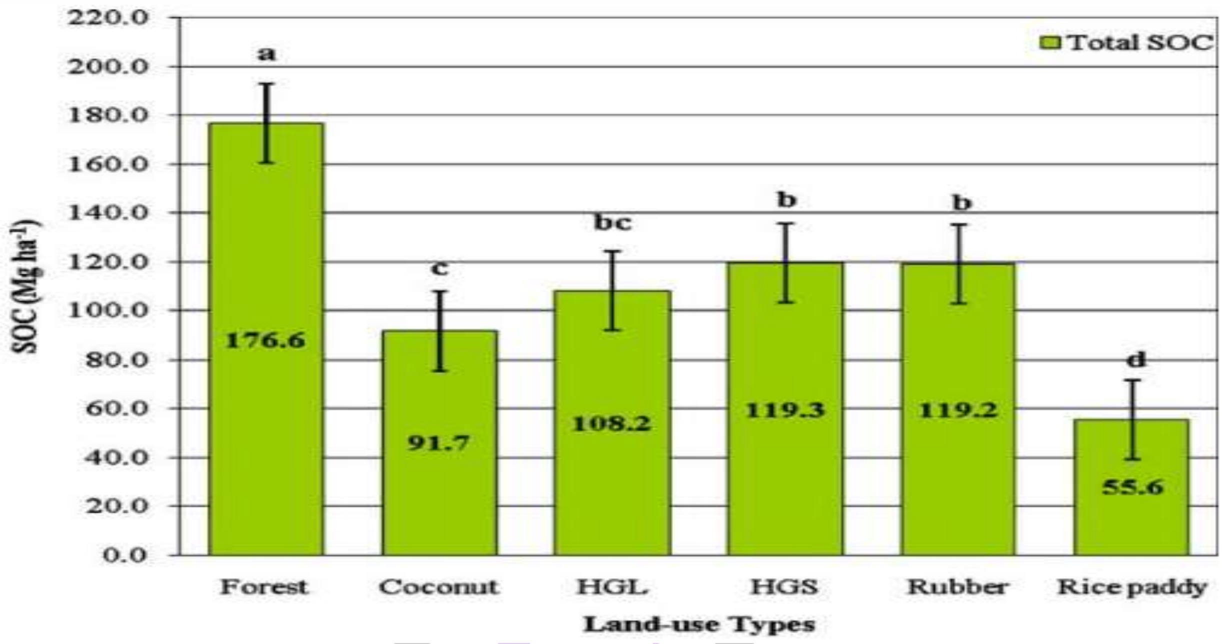
[b] Means connected horizontally by the same upper-case letter are not significantly different at $P<0.05$.

Kamau *et al.*, (2008) was reported in ageing of tea plantations increased stocks of carbon and major nutrients per bush and per unit area. There was a significant difference between the carbon sequestration potential of seedlings and clones. The seedlings captured more carbon than the seedlings. Within clones, when the age increased, total potential for capturing carbon increased. The geographical influence may also contribute to difference in sequestration potential. Total amount of C stored in Biomass 83.3 Tg, Litter layer – 8.0 Tg, Soil – 225.0 Tg was reported by Shiyu Li *et al.*, (2011).

8. Carbon storage in relation to soil size-fractions under tropical tree-based land-use systems

In this system home gardens, Natural Forest – Decidious, Coconut Plantation – 30 years old, Rice fields and Rubber plantation (500 trees/ha – 12 years old).Soil Sampling was done up to 1 m and 3 size classes based on soil fractions >250 µm, 250–53 µm, <53 µm were separated and analyzed (Saha *et al.*, 2010).

Fig. 4. **Total soil organic carbon (SOC) content in the whole soil up to 1 m depth**



The total soil organic carbon content was highest in forest soils (176.6 Mg/ha) followed by large homestead gardens of Kerala and rubber plantations. The lowest soil organic carbon was recorded in rice paddy fields (55.6 Mg/ha). Soil organic stock decreased with increase in soil depth. The forest soil recorded highest soil carbon stock irrespective of depths involved. The lowest stock was found to be in the rice fields in all depths. Root proliferation activity was found highest in forest soils which may be reason for high SOC. Species richness and density also contribute to total carbon stock in soils (Saha *et al.*, 2010).

IV. Summary

The Carbon sequestration in plantation crops depends on, 1) Land use and cropping system, 2) Age of the plantation, 3) Management intensity, 4) Spacing and 5) Species richness.

V. Conclusion

Plantation crops are perennial crops which act as Natural sponges in capturing the CO_2 from atmosphere and storing in more stable form, i.e., bio mass. These crops are generally raised in high density multi species cropping system and thus increasing the potential for sequestering carbon. Besides providing nutritional security, they also provides in ameliorating the ill effects of enhanced greenhouse effect due to increased green house gases. The 'United Nations Framework Convention on Climate Change' flexibility mechanism is to assist developed countries in pursuing least-cost options to meet their target commitments through the generation of certified credits from projects undertaken in developing countries. While details of implementation are yet to be settled, it may involve the establishment of plantations. With global emission trading becoming a reality, emitters unable to meet their own targets could pay off through carbon sequestration in plantations.

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