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Chapter 10

Carbon Sequestration in Plantation Crops

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1. Introduction

Carbon (C) sequestration in the agriculture sector refers to the capacity of agriculture lands to remove carbon dioxide from the atmosphere. Carbon dioxide is absorbed by trees, plants and crops through photosynthesis and stored as carbon in biomass in tree trunks, branches, foliage and roots and soils (EPA, 2008b). Forests and stable grasslands are referred to as carbon sinks because they can store large amounts of carbon in their vegetation and root systems for long periods of time. Compared to normal tropical agricultural crops, tree crop plantations have a significantly larger sequestration potential and are able to sequester C for longer periods (typically for more than 30 years) with smaller annual fluctuations. Many annual crops such as maize can fix more C than forestry systems in comparable time, but their biomass usually decomposes rapidly, and the rate and return of assimilated C to the atmosphere are very fast (Liguori *et al.*, 2009). Soils are the largest terrestrial sink for carbon on the planet. The ability of agriculture lands to store or sequester carbon depends on several factors, including climate, soil type, type of crop or vegetation cover and management practices.

Most of the plantation crops are trees and have long life span and hence store large amount of carbon in their vegetation. This knowledge is important as tree crop plantations could be a more feasible mitigation solution in many parts of developing countries compared to pure afforestation and reforestation projects, since tree crop plantations also provide work, income and food, especially when established in smallholder systems where local people have control over production. As such, plantations may also be an important element in increasing adaptive capacity in the sense of adapting to climate change and other pressures that are being faced by local communities in developing countries. Use of tree crop plantation to sequester C and and increase sustainable development would link climate change mitigation and adaptation, and an enhancement of this link has been called for by several authors (Ayers and Huq 2009; Halsnæs and Verhagen 2007; Klein *et al.*, 2007; Klein *et al.*, 2005; Tol 2005; Verchot *et al.*, 2007) Information on C sequestration in tree-crop plantation monoculture systems is limited. Some studies have been conducted, mainly in India on coconut (Naresh Kumar 2009; Kasturi Bai 2009), arecanut (Balasimha 2009, Balasimha and Naresh Kumar, 2013), rubber (James 2009), tea (Mohan and Rajkumar 2009), coffee (Devakumar 2009) and oil palm (Suresh and Kochbabu 2009) and from Southeast and East Asia, on the C content of oil palm (*e.g.* Chase and Henson 2010; Foong-Kheong *et al.*, 2010; Germer and Sauerborn 2008) and rubber plantations (*e.g.* Cheng *et al.*, 2007; Song and Zhang 2010). With regard to Africa, only a very few studies have been conducted on tree-crop plantation monoculture systems, for example, Wauters *et al.* (2008) on rubber and Duguma *et al.* (2001) on cocoa in an agroforestry system. Farming system, which integrates diverse crops – perennials, semi-perennials and annuals – animals, fishery and forestry enhances the productivity per unit area, time and inputs.

2. Carbon Sequestration of Plantation Crops

The plantation crops play a pivotal role in the Indian economy. The statistics on major plantation crops are given in Table 10.1.

Table 10.1: Area, Production and Productivity of Plantation Crops in India

Sl.No.	Crop	Area('000 ha)	Production ('000 tonnes)	Productivity (kg/ha)
1.	Arecanut[1]	445	729	1,164.0
2.	Cashew[2]	1027.0	725.0	706.0
3.	Cocoa[3]	78.0	16	475.0
4.	Coconuts[4]	2141.0	21665.0 (number)	10119.(number/ha)
5.	Coffee[5]	343.0	348.0	1014
6.	Tea[6]	567.0	1200	190.3
7.	Rubber[7]	758	919.0	1351.0
8	Oil Palm[8]	95.0	102.0	30-35(t/ha ffb)

**Source*: 1 DASD; 2,3 DCCD; 4 CDB; 5 FAO; 6 Tea Board; 7 CMIE; 8 Oil palm World Annual 2009

2.1. Arecanut and Cocoa

The areca-cocoa mixed crop not only gives a sustainable production, but also serves as a good system for biomass production and carbon accumulation. Arecanut is grown either as mono-plantation or intercropped with other plantations like cocoa, banana, etc, whereas, cocoa is grown only as intercrop of either coconut or arecanut. Presently, cocoa is grown in an area of 78000 hectares with about 16,000 tonnes production. There is an ambitious programme to bring more areas under cocoa with a projected production potential of about 30,000 tonnes during next five years. On the other hand arecanut is being consumed at local and national level. However, the income levels of farmers are highly fluctuating owing to market dynamics. These suggest the importance of stable income from arecanut-cocoa plantation systems. The net primary productivity in the areca-cocoa system and areca high density crop systems in terms of biomass production, carbon stocks and carbon sequestration indicate a very good potential of carbon sequestration.

Table 10.2: Average Annual Biomass and Carbon Stock in Plantation Crops

Crop	*Biomass (t/ha/yr)*	*Carbon Stock (t/ha/yr)*
Arecanut+Cocoa	6.92	2.88
Coconut	34.00	13.6
Cashew	4.27	1.71
Coffee	11.69	5.85
Oil palm	21.00	7.35
Rubber	–	7.62
Tea	20.12	8.05

Table 10.3: Total Estimated CO_2 Sequestration by Different Plantation Crops in India (Source; Naresh Kumar, 2015)

Crop	*Total Area under the Crops in India (million ha)*	*Total Estimated CO_2 Sequestration potential in India (% of total potential from plantations)*
Arecanut	0.445	8.5
Cocoa	0.078	2.2
Coconut	2.14	44.1
Cashew	1.02	17.9
Oil Palm	0.095	0.4
Coffee	0.343	6.0
Rubber	0.758	13.8
Tea	0.67	7.2
Total	5.446	100.01

Areca - cocoa system had a standing biomass of 23.15, 54.09 and 87.10 t ha^{-1} in 5^{th}, 8^{th} and 15^{th} years of growth, respectively at CPCRI Regional Station Vittal (75° E longitude, 12°N latitude, 90m altitude) in lateritic soil with 5.4 pH (Table 10.1). Cocoa plants were spaced at 2.7 x 5.4m with in areca plantation spaced at 2.7 x 2.7m. A simple parametric regression model was developed for estimation of arecanut and cocoa standing biomass. Data on pod and bean yield (in case of cocoa) and nut yield (in case of arecanut) were collected from the experimental plot. All data collected as mentioned above were summed to get total above ground biomass production. Harvest index was calculated as ratio of bean dry weight (in case of cocoa) and dehusked nut dry weight (in case of arecanut) to annual total dry matter increment.

Carbon in different plant part samples like tissues of stem, leaf, twigs, pods, husk, nuts and beans was estimated by combustion method (Balasimha 2009, Balasimha and Naresh Kumar 2010, Balasimha and Naresh Kumar 2013).

Annual increments in biomass or net primary productivity ranged from 1.38-2.66t ha^{-1} in cocoa and 3.34-7.11 t ha^{-1} in areca (Balasimha and Naresh Kumar 2013). (Table 10.2). The study has thus revealed that the biomass and primary productivity is considerable with areca-cocoa mixed crop and comparable to any agroforestry systems involving cocoa. These methods on above ground biomass and carbon estimations provide useful basic information on these aspects and can be used as models in future. Other areca based models have also been worked out. The model involving multispecies cropping systems studied at Vittal also contribute considerably to carbon stocks and CO_2 sequestrations (Tables 10.3).

Similar studies on slightly different models at North East of India at Kahikuchi showed considerable carbon sequestrations (Tables 10.4 and 10.5).

Table 10.4: Standing Biomass and Carbon of Areca and Cocoa System

Years	Cocoa		Areca		Total	
	Biomass t/ha	Carbon t/ha	Biomass t/ha	Carbon t/ha	Biomass t/ha	Carbon t/ha
3	3.02	1.21	2.93	1.23	6.01	2.44
5	11.01	4.4	15.56	6.56	23.15	10.96
8	17.19	6.88	36.90	15.5	54.09	23.38
15	26.82	10.73	60.28	25.32	87.1	36.05

Table 10.5: Annual Net Primary Productivity, Carbon Stock Increments and CO_2 Sequestration in Areca-Cocoa System

Parameter	Annual Increment (t ha^{-1}) in Areca			Annual Increment (t ha^{-1}) in Cocoa		
	3-5 years	6-8 years	9-15 years	3-5 years	6-8 years	9-15 years
Biomass	4.21	7.11	3.34	2.66	2.06	1.38
Carbon stock	1.78	2.98	1.40	1.06	0.83	0.55
Net CO_2 sequestration*	6.53	10.94	5.14	3.89	3.05	2.02

* 1 CO_2 $t.ha^{-1}$ = C ($t.ha^{-1}$) x 3.67

2.2. Coconut

Carbon sequestration potential of coconut was found to be quite high compared to most of the tree crops. Naresh Kumar (2007; 2008a and b, ; 2009; 2015) analyzed whole plant (above ground) carbon stocks and sequestrations and worked-out carbon sequestration for coconut plantations under different agro-climatic zones. Apart from these, variations due to cultivar, agro-climatic zone and management were also analyzed. The results indicate that annual C sequestration in coconut above ground biomass varied from 15 to 35 tCO_2/ha/year depending on cultivar, agro-climatic zone, soil type and management. Annually sequestered carbon stocked in to stem in the range of 0. 3 to 2.3 tCO_2/ha/year. Standing carbon stocks in 16 year old coconut cultivars in different agro-climatic zones varied from 15 to 60 tCO_2/ha/year. Annual carbon sequestration by coconut plantation is higher in red sandy loam soils and lowest in littoral sandy soils (Naresh Kumar, 2007 and 2008a and b, 2009; 2015).

Table 10.6: Annual Biomass, Carbon Stock and CO_2 Sequestration in Areca high Density System at Vittal

Parameter	Biomass (t/ha/year)	Carbon Stock (t/ha/year)	Net CO_2 Sequestration* (t/ha/year)
Areca (1300)*	4.86	1.994	7.134
Pepper (1300)	1.027	0.410	1.507
Banana (210)	2.683	1.073	3.938
Cocoa (210)	0.683	0.273	1.003
Clove (180)	0.195	0.078	0.286
Total	9.448	3.779	13.869

*Figures in parentheses indicate number of plants/ha.

Table 10.7: Annual Biomass, Carbon Stock and CO_2 Sequestration in Areca High Density System at Kahikuchi-Model I

Parameter	Biomass (t/ha/year)	Carbon Stock (t/ha/year)	Net CO_2 Sequestration* (t/ha/year)
Areca (1372)*	6.28	2.51	9.21
Pepper (1372)	0.93	0.372	1.37
Clove (228)	0.58	0.232	0.851
Citrus (438)	0.71	0.284	1.042
Total	8.5	3.39	12.47

* Figures in parentheses indicate number of plants/ha.

Table 10.8: Annual Biomass, Carbon Stock and CO_2 Sequestration in Areca High Sensity System at Kahikuchi-Model II

Parameter	Biomass (t/ha/year)	Carbon Stock (t/ha/year)	Net CO_2 Sequestration* (t/ha/year)
Areca (1372)*	6.13	2.45	8.99
Pepper (1372)	0.90	0.36	1.32
Nutmeg (228)	0.78	0.312	1.15
Citrus(438)	0.69	0.376	1.02
Total	8.5	3.49	12.48

* Figures in parentheses indicate number of plants/ha

Productivity per unit area of land can be increased by adopting high density multi species cropping system (HDMSCS). The principle of multistoried cropping is to use the basic production inputs such as light, water and nutrients to the maximum extent with minimum soil deterioration. This is attained by growing suitable crops having different canopy patterns and root systems. Crops with deep and shallow penetrating root systems will utilize soil nutrients and moisture available in the zones of their penetration. High and low canopied crops will have minimum mutual competition for solar energy. Hence maximum utilization of solar radiation can be realized by appropriate combination of crop. Multi-storied cropping thus is an effective method for increasing agricultural production per unit area. A variety of crops are grown in the interspaces of coconut ranging from short season annuals to perennial tree species. Biomass production of various crops in a cropping system gives a rough indication of their compatibility. The beneficial changes in rhizosphere of the main crop and intercrops not only improve the soil micronutrients, but also result in increasing yields considerably and also help in carbon sequestration. Utilization of land, airspace and inputs with maximum sustainable returns are the advantages of HDMSCS. The observations clearly revealed that the system not only gave an additional income from the increased coconut yield (Bavappa, *et al.*,

Table 10.9: Biomass and Carbon Stock of Coconut Monocrop and Component Crops

Crop.	*Biomass t/ha (Dry wt. basis)*	*Carbon (t/ha)*
Coconut (175)		
Root	18	7.20
Leaf	10.5	4.20
Stem	16.9	6.76
Bunches, nuts and other bio-materials	23.6	9.44
Total biomass	69 t/ha	27.60
Tapioca (930)		
Shoot	7.34	2.93
Tuber	1.07	0.42
Total	8.41	1.675
E. Foot Yam (930)		
Shoot	0.38	0.152
Yam	1.45	0.580
Total	18.3	0.732
Banana (300)		
Pseudostem (Including leaf)	0.71	0.284
Fruit/bunch	0.81	0.324
Total	1.52	0.608
Pineapple (6500)	14.31	5.73

Value in bracket indicates population.

1986) as well as from the yield of inter crops, but also the system will function as a strong candidate for cabon sinks for the overall benefit of the farmer. Estimation of carbon stock in an 18 year old coconut plantation with tapioca, elephant foot yam, banana and pineapple as intercrops revealed that the total biomass (including the economic produce) was about 86.3 t/ha Taking an average of 13.14 t CO_2/ha/yea, it is estimated that coconut mono-plantations can sequester about 27.6 million tonnes of CO_2/year in India (Naresh Kumar, 2015), which is equivalent to 0.013 per cent of India's total GHG emission during 2010 (India emitted 2,136.8 million tonnes of CO_2 eq in 2010, BUR, 2015).

2.3. Rubber

A mature rubber plantation can sequester as much as 35 to 45 ton CO_2/ha/yr (Annamalainathan *et al.*, 2011). Fast growing tree species like natural rubber are efficient in sequestering atmospheric CO_2. Carbon sequestration starts in natural rubber plantation from the first year of planting onwards and the end of 21 years, the plantation fixed a total of 164.18 t carbon per ha, equivalent to 601.99 t CO_2 per ha making the annual rate of CO_2 sequestration 28.7 t CO_2/ha/year (Jacob 2009).

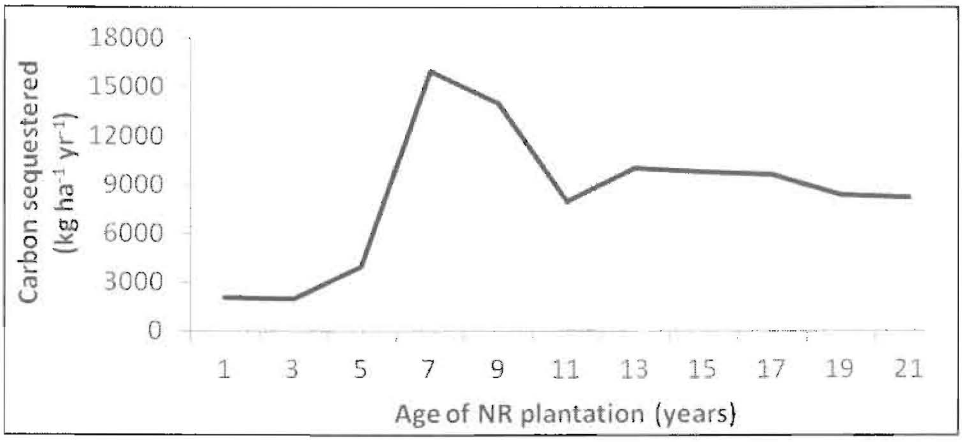

Figure 10.1: C-sequestration of Natural Rubber at different Age Groups.

Total C Sequestered = 164.18 T C/ha (in 21 Years)

Annualized Mean = 164.8/21 =7.818 T C/ha

That is equal to 28.7 T CO_{2e}/ha/year

The rate of CO_2 sequestration by natural rubber holdings varied from 28.8 to 40.1 t CO_2/ha/year in the different countries, possibly due to the differences in the agro-climatic conditions prevailing in these countries. Nevertheless, natural rubber plantations fixed much more carbon than the mature natural forests (Dixon *et al.*, science, 1994, 263, 184-190). It has been reported that the mature Amazonian forests fix just 3X t C/ha/year. Taking a modest mean rate of 30 t CO_2/ha/year, the world's over 10.4 million hectare of rubber plantations fix as much as 312 million t CO_2 every year.

2.4. Tea

It has been reported that tea plants are highly heterogenic in nature due to their free natural hybridization. They also exhibit variation in their metabolic activities, principally the photosynthetic carbon dioxide (CO_2) assimilation. Values presented on the basis of Pn rate varied from carbon dioxide sequestrated by biomass. However, estimated per cent net carbon dioxide sequestrated by tea sector (CO_2 sequestrated – less emission) was > 87 per cent (Mohan Kumar and Rajkumar 2009).Though the tea plants exhibited variations in their metabolic activities, on an average, they could produce 12.5 t biomass/ha/year. In addition, shade trees contribute a biomass of 7.6 t/ha/yr. Computing the overall biomass produced per unit area, it accounts 20.12 t/ha/yr. It may be noted that the inter crops like pepper/citrus species cultivated are not included in this computation. As per the biomass produced per unit area, the carbon stock was derived which accounts for 8.05 t C/ha/yr or 29.54 t of CO_2 equivalents. As per the land cover in Indian tea sector, 15.36 million t CO_2/ha/yr sequestrated which is a significant CDM sink besides providing livelihood to over a million people in the country directly and preserving the ecological balance. Total world's tea production is 3.2 million kg with a mean yield of 1145 kg/ha from an area of 27,94,759 ha. C absorption @ 18.9 t/ha or 69.36 t/ha as CO_2 (African conditions) is equivalent to CO_2 sequestration of 194.2 million t CO_2 or 54.96 as C worldwide.

2.5. Coffee

Coffee based agroforestry system is one of the most potential land use systems in India. Unlike the most other countries, both the species of coffee cultivation in India is done under the shade of tree. This is the practice followed from the time of inception of coffee cultivation in India. From the results it was found that, highest carbon accumulation in the above ground biomass of shade trees was found in native tree species (141.81, 131 t/ha) compared to silver oak (78.47, 102 t/ha) trees under evergreen and moist deciduous vegetation, respectively. The carbon content of litter biomass under these situations were 1.71, 0.98 and 1.02, 0.92 t/ha, respectively. The soil organic carbon content was 273, 260 and 282, 286 t/ha, respectively. The total carbon sequestration found in coffee plantation ranged from a minimum of 304.27 t/ha to 366.41 t/ha which is quite high compared to even evergreen vegetation of natural forest (Devakumar 2009).

The field study on partitioning of biomass and harvest index (HI) in twelve to fourteen years old arabica cultivars by collar pruning plants at the base level indicated that the most of the synthesized photosynthates translocated towards the development of the main stem to an extent of 32 per cent followed by branches/primaries (28 per cent), fruit biomass (Sink) (22 per cent) and leaf biomass (18 per cent) in arabica cultivar. Similarly the mean of 3 years observations on harvest index and leaf area index was 0.22 and 2.29 respectively. Also, the root shoot ratio in 20 to 40 years old uprooted field established arabica cultivars was presumed 30.09 to 39.28 per cent (Mean of 34.69 per cent).

Based on the above results, the biomass production is extrapolated as follows:

National productivity: 839.6 kg/ha

Total fruit biomass productivity: 1679.2 kg/ha/yr (22 per cent translocation of photosynthates)

Total biomass of coffee: 7.633 tons/ha/yr (Total translocated photosynthates)

Total biomass including root: 11.69 tons/ha/yr

Total biomass of coffee in India: 40,08,756 tons/yr

2.6. Cashew

The amount of carbon sequestered by cashew plantations under normal density planting (156 trees/ha) and high density planting (625 trees/ha) is presented. Carbon in the above ground biomass as well as root biomass of cashew trees is included in this analysis. The amount of carbon sequestered in cashew was estimated by a carbon content of 40 per cent of biomass. Based on research undertaken at Directorate of Cashew Research, Puttur (Karnataka), it was found that, cashew genotype (VTH-174) trees of 7 years old sequestered about 2.2 fold higher carbon under high density planting system as compared to normal density planting system. Carbon storage by cashew has been estimated as 32.25 and 59.22 t CO_2/ha at 5th and 7th years of growth, respectively under high density planting. The extent of C sequestered will depend on the amounts of C in standing biomass, age of the crop, tree density, variety etc.

2.7. Oil Palm

Oil palm is an introduced crop under Indian conditions and is being grown to an extent of 0.08 million ha. The potential areas identified for the cultivation of oil palm in different states of India is approximately 1.04 million ha. The standing above ground biomass in the different oil palm hybrids (mature plantations) grown under Indian conditions ranged from 55.08 to 91.58 t ha^{-1}. The amount of carbon sequestered by the hybrids ranged between 17.98 and 35.44 t C.ha^{-1}. It has been reported that mature oil palm hybrids accumulated about 20-22 t_{dm}.ha^{-1}.yr^{-1} under Indian conditions, which can sequester 7.35 tC.ha^{-1}.yr^{-1}, which roughly comes to 26.98 tCO_2.ha^{-1}.yr^{-1}. In real terms, if we take the current area of oil palm in India in to consideration, the estimated carbon storage by the oil palm would be approximately 2.158 million t CO_2.yr^{-1} from 0.095 m ha. The estimated storage of carbon by oil palm under Indian conditions could be to the tune of 28.05 million t CO_2.yr^{-1} from the potential 1.04 m ha identified. However the above estimates may vary depending upon the age of plantations, source of planting material, soil type, management condition, agro climatic region, (Suresh and Kochu Babu, 2009).

Table 10.10: Carbon Sequestration Potential of Oil Palm at different Age Groups

Age (years)	*Biomass (t ha^{-1})*	*Carbon Sequestered (t C ha^{-1})*
1-3	14.5	2.527
4-8	40.3	17.113
9-13	70.8	16.455
14-18	93.4	21.327
19-24	113.2	21.104
>25	102.5	20.753

3. Conclusions

Tree crop plantations can be a potential path for coupling climate change mitigation and economic development by providing C sequestration and supplying wood and non-wood products to meet domestic and international market requirements. At the same time they provide work, income and food. The magnitude of mitigation depends on natural, social barriers, economic factors and time frame. While most of the Clean Development Mechanism (CDM) projects are awarded to industries who can justify the reduction of CO_2 emission and get Certified Emission Reduction unit or CER and get it traded, those who have farms, small plantations, fruit orchards, plantations and field crops do not get any support. This is a question of emitters getting the advantage, while the absorbers of CO_2 are left off. Therefore, the mitigate it is essential to highlight at appropriate forum about need for monetary compensation to the farmers.

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