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Chapter 12

Role of Plantation Crops in Climate Change Mitigation: Special Reference to Natural Rubber

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Climate is changing in the plantation crop tracts of India. The progress of climate warming profoundly impacts on the growth and yield of plantation crops and spices. Perennial plantation crops sequester significant quantities of atmospheric CO_2 into plant biomass and soil organic carbon and therefore, involved in mitigation of greenhouse gas (GHG) emission. Though rubber like plantation crops themselves prone to changing climate they can be effectively used in tree planting programmes to ameliorate, at least partially, the CO_2 emissions. Measurement of Net ecosystem exchange (NEE) of CO_2 by eddy covariance method and estimation of carbon sequestration by biomass inventory method indicated that rubber plantation is a potential sink for atmospheric CO_2. The estimated CO_2 sequestration in different plantation crops indicated that plantations in India can play an important role in offsetting considerable level of emissions to atmosphere. Climate change in the plantation tracts of India, carbon sequestration potential of various plantation crops and payment for ecosystem services etc. are discussed in this review article.

Keywords: *Carbon sequestration, Ecosystem service, Net ecosystem exchange, Plantation crops.*

duction

ion of greenhouse gases (GHG) to the atmosphere is mainly responsible ng climate. The major GHG includes carbon dioxide, methane, nitrous other oxides of nitrogen. While anthropogenic emission of all GHGs has asing over the years, atmospheric CO_2 concentration has registered the rease in terms of the absolute amount and thus contributed the maximum warming and climate change. Fossil fuel combustion and cement re which dramatically increased with industrialization were responsible an 75 per cent of the increase in atmospheric CO_2 concentration. A high umulation of GHGs in atmosphere would result in unfavourable weather such as a rise in temperature, floods and drought. This would adversely production, especially in countries with fragile economy.

e change is perhaps the single most important factor that will adversely th and productivity of crops in the years to come (Cynthia *et al.*, 2001). perature, changes in the quantum and distribution of rainfall leading to ell, decrease in soil moisture content etc. are some factors that may have npact on crops (Ainsworth and Ort, 2010). Spices and plantation crops ed in Western Ghats and their foot hills along the Malabar coast, packets hats and parts of sub-Himalayan regions in North Eastern India. Climate ese regions have undergone remarkable changes starting from plantation nitiated in these regions (Satheesh and Jacob, 2011). Unlike other annual spices and plantation crops are perennial in nature, once planted will changes happening to the climate for several years or decades ahead. e deficit with concomitant occurrence of high light and temperature drought in the field and it may be the most important environmental ould occur in the plantation tracts of India as a result of climate change.

change mitigation is defined as various actions taken to reduce the changing climate thereby protecting the global ecosystems from Most often climate change mitigation scenarios involve reductions in ations of greenhouse gases, either by reducing emission from sources or their sinks (Molina *et al.*, 2009). Trees are considered to be major terrestrial Forests play a vital role in regulating the greenhouse gases, particularly tmospheric CO_2, hence afforestation has been identified as one of the available to mitigate the effects of climate change (Houghton, 2005). er (*Hevea brasiliensis*) is a multipurpose tree which provides economically ns of both latex and timber production) and socially acceptable system. er like plantation crops themselves prone to changing climate they can used in tree planting programmes to ameliorate, at least partially, the s. Although the availability of carbon in rubber trees has been assessed *al.*, 2005), the potential capacity of sequestering atmospheric CO_2 in r trees has not been quantified. Managed forests and plantation crops carbon both in biomass and soil. In this review article, climate change he Indian plantation sector and possible mitigation potentials of ops are discussed with a special emphasize on the role of rubber

2. Climate Change in the Plantation Tracts of Indi

Plantation crops, mainly coconut, rubber, tea, coffee, oil palm, are and cocoa, are grown in ecologically sensitive areas such as coastal be and areas with high rainfall and high humidity. Among these tea, cof were introduced into India by the erstwhile colonial rulers. Plantati like cocoa, oil palm and vanilla etc. were newly introduced into India. T crops are mostly rainfed crops vulnerable to the adverse effects of c Many of the spices and plantation crops are generally cultivated regions where the average rainfall ranges from 1000-4000 mm year^{-1}. Th requirements also vary for different plantation crops. For instance tea temperature with a high annual rainfall but rubber needs a well distr rainfall with temperature ranging from 20-35°C. The general ind temperature, (both T_{max} and T_{min}) has changed in the plantations belt Prolonged drought associated with lengthy periods of high temperat monsoon and summer season affecting growth and productivity of al and plantation crops.

India is one of the countries that are more vulnerable to climate c plantation crops are not remain immune to the adverse effects of globa associated climate change. Temperature has been warming and ra changing in unprecedented easy in the plantations and spices belts (Shammiraj *et al.*, 2011; Satheesh and Jacob, 2011). These changes profound impact on crop growth, flowering behaviour, productivity o spread of pest and diseases *etc*. In most of the spices and plantation be monsoon (SWM) contributes close to 70 per cent of the annual rainfall (*et al.*, 2009). There was a significant reduction of 233 mm in SWM and 94 mm NEM during the last 135 years in traditional plantation crop India. The annual rainfall had a positive trend over central India and trend over some parts of eastern India for the period 1901-1960 (Part Dhar, 1974). There was an increasing trend in mean annual SWM rainfa Haryana, West Rajasthan and West MP and a significant decrea Jharkhand, Chattisgarh and Kerala during the period 1901-1982. There increasing trend in extreme rain events over central India during mons same time a significant decreasing trend in the frequency of moderate the same period (Goswamy *et al.*, 2006). Mean annual temperature w increasing in all India basis during the period 1901-1982 (Hingane *et a* and Kumar (1997) reported that a significant warming trend of 0.57°C in India. The magnitude of warming was higher in the post monsoo seasons. There was an increase of 0.92 °C in the mean Tmax over the la that a rise of 1.1°C in mean winter temperature and 0.94°C in mean p temperature were reported by Arora *et al.* (2005).

Number of rainy days and cool nights per year showed a declin that of hot days per year increased (Satheesh and Jacob, 2011). They h the direct impact of climate warming on rubber productivity. A m regression analysis (MLR) model indicated for 1°C rise in T_{max} and T_{min} average yield depression would be around 7 per cent in traditional ru ever, it is likely that new regions and countries could become suitable for on in future. For example, region where low temperature is presently a or for cultivating NR such as NE India could become more suitable for on in a warmer world.

al, SWM rainfall with a decreasing trend and pre and post monsoon an increasing trend have been reported in most of the spices and op cultivating areas of India (Satheesh and Jacob, 2011). Thus, there the normal rainfall pattern all over the plantation areas in recent past. of uncertain weather pattern will be more pronounced during the nt and early growth of spices and rubber like plantation crops. monsoon season is the ideal planting season of rubber in India. In uncertainty in rainfall and other weather factors is making the scheduling rm operations like planting difficult even in traditional rubber growing urrence of unexpected dry spells and bright sunny days with warm even during the monsoon season increases casualty. Temperature is the main factors affecting the performance of perennial crops. A rise in affected black pepper, cocoa and cardamom in the absence of sufficient (Rao and Alexander, 2007). Every crop species has its own growing for its optimum growth and reproduction. If the temperature is increasing e required growth degree-days will attain earlier and as a result flowering will happen unseasonal and abnormal. This can affect both productivity f the produce.

n Sequestration by Plantation and Agricultural ns

c principle of carbon sequestration potential of any cropping system groforestry systems is the difference between carbon gained by sis and carbon lost or released through respiration and decomposition nents of the ecosystem. This overall gain or loss of carbon is usually by net ecosystem productivity. Mostly carbon enters the ecosystem via sis in the leaves and accumulation is obvious when it occurs in d biomass. But around half of the assimilated carbon is eventually below ground via root growth, release of organic substances and litter herefore, soils contain the major stock of C in the ecosystem. The tree in agroforestry systems can be significant sinks of atmospheric C heir fast growth and long storage of biomass in their plant body (Nair, cluding trees in agricultural production systems as agroforestry or ops that can eventually be increased the amount of carbon stored in d to agriculture (Kürsten, 2000). Recapturing atmospheric CO_2 can be changing carbon-poor ecosystems into carbon-rich ecosystems, for regeneration of grasslands into secondary tropical forests has been a way to recapture C through accumulation and long-term storage of nt biomass and soil organic matter (Houghton et al., 1993).

an store around 20 to 50 times more carbon per hectare than agricultural and Meganck, 1994). Carbon is sequestered and stored in aboveground

biomass, roots, litter and soil in forest ecosystem. Most of this carbo forests are removed and replaced by other land-uses. Table 12.1 prese storage potential of various ecosystems and illustrates the significa tropical forests have on the global carbon cycle.

Table 12.1: Mean Carbon Storage of Various Ecosystems

Ecosystem	*Ecosystem Carbon Storage (t C*
Tropical forest	220
Temperate forest	150
Boreal forest	90
Grassland/savann	15
Agriculture	5

Source: Cairns and Meganck, 1994.

Generally during summer, the CO_2 concentration in the atmos reflecting the high rate of global sequestration through photosynthesis 1996). The low temperature during winter inhibits photosynthesis bo and in the oceans and this result in the atmospheric CO_2 concentratio winter. Thus, accumulation of CO_2 in the atmosphere is a dynamic f balance between the amount of CO_2 emitted by the world and the total a sequestered by the planet (through photosynthesis) during a given pe

Atmospheric CO_2 concentration = CO_2 Emission – CO_2 Sequestrat

From the above equation, it is evident that growing more tree atmospheric CO_2 concentration. Globally, the rate of deforestation is than that of reforestation. The rate of forest destruction in the Amazo which has come down markedly in recent years is still as large as abo km² per year (Carrington, 2010). Recent studies estimated a net emiss from the Mato Grosso region of Brazilian Amazon, ranging from 2.8 to equivalents (CO_2-e) from 2006 to 2009 (Galford et al., 2010). It was between 1996 and 2005, the Brazilian Amazon rainforest was defores km² per year and converted to pastures and farmland releasing 0.7 to year^{-1} to the atmosphere (Daniel et al., 2009). Avoided deforestation is th of afforestation, even as new and massive efforts at planting more tree parallel strategy in order to reduce build-up of CO_2 in the atmosphere.

Niggli et al.,(2009) estimated the global average sequestration poten croplands to be 0.9 to 2.4 Gt CO_2 year^{-1}, which is equivalent to an average potential of about 200 to 300 kg C per hectare per year for all cropland carbon sequestration potential of pastures with improved managem was calculated as 0.22 t C ha^{-1}year^{-1} (Watson et al., 2000). Studies o species with medicinal and economic importance have been reported offering opportunities for CO_2 mitigation by sequestering accumulat atmosphere in its vegetation. Studies on medicinally important tree spec Arjun, Bael, Bahera, Harar, Jamun, Neem and Reetha had shown t sequestration potential in the range of 3.05 to 11.01 tons of CO_2 ra and Suresh, 2010). Recent study by Hooda *et al.*,(2005) on sequestration ree species planted on farm lands, *viz.*, Poplar, *Eucalyptus* and Teak have arbon sequestration potential in the range of 1.42 to 2.85 tons of C ha 10.46 t CO_2 ha^{-1} yr^{-1}). The same study has also reported the sequestration Orchard species like Mango, Litchi and Citrus to be in the range of 0.20 to $ha^{-1}year^{-1}$. In another study carried out on the farm lands of Punjab has t Poplar and *Eucalyptus* species have the capacity to sequester 1.42 to $ha^{-1}year^{-1}$ (Gera *et al.*, 2006). Kraenzel *et al.*,(2003) measured above and d biomass and tissue carbon content of 20 year old teak (*Tectona grandis*) plantations in Panama and estimated the carbon storage potential. They a regression model relating the diameter at the breast height (DBH) and ed carbon in teak. From this model they calculated the plantation level on storage as 120 t C ha^{-1}.

the perennial plantation crops have profound role in mitigating climate ugh their C-sequestration potentials. Tea, coffee, coconut, rubber and rdamom sequester considerable amount of atmospheric CO_2 into biomass l in emission reduction. There was no much interest shown among the ion researching with respect to plantation crops whereas forest system tensively studied with a strong belief that forest may have influence over bon cycle. At present very few studies have been carried out in plantation on effect (Steffan-Dewenter *et al.*, 2007; Li *et al.*, 2011). The carbon stored ground biomass of oil palm plantations ranges from 48 t C ha^{-1} to 80 t C *al.*, 2008). Steffan-Dewenter *et al.*,(2007) have indicated that conversion l in to cocoa plantation reduced the total carbon stock in a tropical rain nd they have estimated a range of 40 to 90 t C ha^{-1} in a mature stand of 12.2). Annual increment in biomass or net primary productivity ranged t ha^{-1} in cocoa and 3.34 - 7.0 t ha^{-1} in areca plantations was reported by nd Nareshkumar, (2013). They have worked out the CO_2 sequestration 2.0 -3.9 and 5.0 – 10.9 t CO_2 $ha^{-1}year^{-1}$ in cocoa and arecanut, respectively. rennial plantation cash crop, intensively managed and covers ly 3 million hectares in the world's cultivable land (FAO, 2007). In a study with entire tea plantation and forest C storage in China indicated orage of 316.2 Tg for which 26.3 per cent C was stored in plant biomass 2.5 per cent in litter (8.0 Tg C) and 71 per cent in soil organic carbon (225 Tg C). The average ecosystem C density of tea plantation 193 t C ha- an that of forests (187 t C ha^{-1}) and grass lands (133 t C ha^{-1}) (Li *et al.*, nber of studies have investigated the carbon-stock of coffee bushes in ems. Specifically, Suárez Pascua (2002) reported coffee carbon-stocks 1 to 2.8 t C ha^{-1} y^{-1}. It has been reported that a carbon stock of 3.93 t C ha- plants grown in association with other shade giving trees and 3.77 t C coffee component in a study conducted in Guatemala (Marquez, 1997).

Table 12.2: Above Ground Carbon Storage of Mature Stand of various Pla

Plantations	*Carbon Storage (t C ha^{-1})*
Tea	30 - 50
Coffee	56 - 80
Cocoa	40 - 90
Coconut (15 years old)	50-100
Oil palm	48 - 80
Rubber	76 - 120

Source: Gibbs *et al.*, 2008; Steffan-Dewenter*et al.*, 2007; Suárez Pascua, 2002; Amb *et al.*, 2011; ISPC, 2009

The carbon sequestration potential of various plantation crops analyzed by scientists working in respective Research Institutes a projected that plantation crops are potential sinks for atmospheric CO The estimated CO_2 sequestration in different plantation crops in plantations in India can play an important role in offsetting conside build up from emissions (Table 12.3). Total estimated CO_2 sequestered crops in India is around 148 million t CO_2 $year^{-1}$. This may account fo considerable level of CO_2 in the atmosphere and provides a significa service. However, the magnitude of mitigation depends on age of th natural and social barrier and time frames.

Table 12.3: Estimated Carbon Dioxide Sequestration by Plantation Crops i

Crop	*Mean CO_2 Sequestered ($t\ ha^{-1}\ y^{-1}$)*	*Total Area in India (million ha)*	*Estimate Sequestere (million*
Arecanut	7.54	0.38	2.9
Cocoa	3.0	0.034	0.1
Coconut	50	1.9	95.0
Cashew	6.3	0.9	5.6
Oil palm	26	0.08	2.0
Coffee	21.5	0.34	7.3
Rubber	28.7	0.68	19.3
Tea	29	0.56	16.0
Total	**173.3**		**148.**

Source: ISPC, 2009

4. Planting Trees and Climate Mitigation

A few reports are available from which it is understood that planti not sufficient to mitigate the entire emission globally. At the current sequestration by terrestrial vegetation, which is roughly 3303 million t

study shows that we need an additional land area equivalent to more
nets to sequester fully the present global CO_2 emission and thus offset
e of build-up of CO_2 in the atmosphere. Even if we take the sequestration
th the land and ocean together, the analysis showed that we still need
ther planet to fix all the CO_2 that the world is presently emitting into the
The study clearly demonstrates that build-up of CO_2 in the atmosphere
d more by the amount of global CO_2 emission rather than the CO_2
by the planet. While planting trees is good for the environment, and
promoted for the various ecosystem services that they offer, including
stration, it should be borne in mind that trees are not adequate to
huge amount of CO_2 that the world emits today. Therefore, it has been
t other than growing more trees, deliberate reduction in emission of
atmosphere is also definitely required to reduce and stabilize the
of CO_2 in the atmosphere.

nual agricultural crops also sequester large amounts of CO_2 from the
lmost the entire amount of carbon stored in them is returned to the
t the end of the crop cycle when the crop is consumed by man or animal
residues are used as cattle feed or they are incorporated into soil or
s not so in forestry or plantation agriculture with perennial tree species.
plantation like natural rubber (*Hevea brasiliensis*) has an economic life
) years and therefore, the carbon sequestered in rubber plantation will
ong.

n Sequestration Potential of Natural Rubber
ns

rubber plantations help to mitigate the atmospheric CO_2 concentration
nt ways. First, it supplies natural rubber which can be used in place of
bers that are produced from petroleum stocks; therefore NR avoids huge
O_2. Secondly, natural rubber plantations have the capacity to sequester
antities of CO_2 from the atmosphere. Several studies have been reported
rubber can sequester significant amount of carbon dioxide from the
Published data shows that natural rubber plantation can sequester 139
$_2$ ha^{-1} over a life cycle of 27 to 29 years. The existing stands of rubber
the world have the capacity to absorb 90 million plus tons of carbon
ear. Thus, a rubber plantation is nearly as effective as a virgin forest in
rbon dioxide and giving out life sustaining oxygen (Sivakumaran and
mbily *et al.*,(2012) have reported that different clones of rubber plants
ent biomass and carbon sequestration potential. They have compared
f modern clones belong to RRII 400 series with the biomass of RRII 105
; the clones RRII 429 (114 t C ha^{-1}), RRII 414 (106 t C ha^{-1}) and RRII 417
showed a highest C sequestration potential. Other clones like RRII 430,
RRII 105 showed a low carbon sequestration potentials of 60, 54 and 57
ctively. Chantuma *et al.*,(2005) had studied the wood production potential
M 600 in the non-traditional rubber cultivation area of North Eastern
Nong Khai province a 15-year old plantation recorded wood volume
n Chachoengsao province, a plantation aged 19 had a moderate level

wood volume 188 m^{3}ha^{-1}. However, in a traditional rubber cultivation are
and Surat Thani in Southern Thailand, where plantations were 25 years ol
was 78 per cent and 83 per cent and wood volume recorded as 256 and
respectively (Chantuma *et al.*, 2005).

Soil carbon sequestration is a complex process, affected by many fact
vegetation type, climate, soil microbes, management, and land-use practic
stock turn over in the soil over a period of time indicates the carbon se
potential of particular soil. Results from a few studies showed that rubber
decreased soil organic carbon (Jiao and Yang, 1999; Schroth *et al.*, 2002; A
2005). In contrast, a few studies have demonstrated that rubber planta
potentially enhance soil carbon sequestration (Wang and Li, 2003;Yang

Three approaches currently exist for measuring or estimating the
woody plantation crops. The first is based on the use of volume estimates
directly estimates biomass using existing biomass regression equations ar
and most complex method, involves the collection of primary dat
measurements in order to develop site-specific regression equation
inventory method is the most easily available and commonly used meth
the CO_2 sequestration potential of a perennial plantation crop like nat
which gives an estimate of the total amount of carbon stored in the various
over a period of time (Jacob and Mathew, 2004; Jacob, 2005). In this art
conducted at Rubber Research Institute of India is included as a case stu
the carbon sequestration potential of rubber plantation. Various atmo
parameters, carbon assimilation and storage into the biomass o
sequestration potential of rubber plantation are discussed in the followi

The experimental site was situated at the Central Experimental Stat
Rubber Research Institute of India (RRII) at Chethackal, Pathanamth
Kerala. The location is 9° 26′N and 76° 48′E. The study was carried out in a
(five-six year old) rubber plantation, with different *Hevea* clones namely,
260 and RRII 430 spread over more than five hectare area with almost unif
The average height of the trees was 10 m and girth was 35 cm at 150 cm a
union of the plant when the studies began in March 2009.

6. Accounting of Tree Biomass

The dry weight of above ground rubber tree biomass was calculat
Shorrock's regression model:

$W = 0.002604\ G^{\wedge 2.7826}$ (Shorrocks *et al.*, 1965)

where, G is trunk girth (cm) at the height of 150 cm from bud unio

Generally the root biomass is 15-20 per cent of shoot biomass i
natural rubber trees. The amount of carbon stored in the trees was es
biomass calculated using the above formula.

7. Eddy Covariance Technique for Atmospheric Flu

A state-of- the- art method known as eddy covariance (EC) techni
for measuring CO_2 and water flux in a 5-7 year old natural rubb

y for a period of two years at Rubber Research Institute of India, Kottayam, derstand the ecosystem and canopy level CO_2 and water exchange and estration potential of rubber plantation (Annamalainathan *et al.*, 2011). ipments were commissioned on a flux tower of 18 m height and the fixed on the tower at 4 m above the canopy. Eddy covariance method is ted micro-meteorological method in which the fluxes of CO_2 and water three-dimensional wind velocities are measured on real time basis 2003). The EC system comprises of a three dimensional sonic anemometer mpbell, USA) which is used together with an open path infra-red gas -7500, Li Cor, USA). Additionally the system is equipped with a net NR-Lite, USA) and temperature and relative humidity (RH) sensors (HMP Finland). Carbon dioxide (Fc) and water vapour fluxes (ET) of the rubber were continuously measured by eddy covariance technique (Massman 2).

CO_2 exchange obtained from the EC system is the difference between etic assimilation by the canopy and the total respiratory CO_2 efflux from roots and soil (Lalrammawia and Paliwal, 2010). The diurnal pattern of m exchange of CO_2 (NEE) clearly indicates two phases namely, the net ppening during day time and net release of CO_2 from the system into the during the night time. By default day time CO_2 fixation (net esis) is shown as negative flux and night time respiration is shown as ux which includes respiration from all living components and on, collectively termed ecosystem respiration (Reco). The difference amount of net fixation during the day and the CO_2 lost as Reco during the net fixation of CO_2 by the ecosystem for a given day. As sunlight creases, the net flux gradually becomes negative (indicating net esis or CO_2 sequestration into the ecosystem) and generally remains il sunset. In the evening as light intensity declines Reco becomes greater ation (Figure 12.1).

the study period, the daily NEE by the rubber ecosystem has ranged from y^{-1}. Most of the days recorded CO_2 influx in to the plantation; however, a corded net carbon efflux from the plantation to atmosphere. On those d 1 - 7g CO_2 $m^{-2}day^{-1}$ was released to atmosphere and during these days in and relatively less sunshine hours. The net efflux values in certain d the possible high rate of total soil respiration (Rs) both by autotrophic erotrophic (Rh) components of the soil in addition to the net CO_2 release piration. The soil respiration rate generally depends on the soil moisture, organic composition, density of microbial population and rate of on of organic contents (Stephen and Theodore, 1979). On an annual NEE was 11g CO_2 $m^{-2}day^{-1}$ which is equivalent to 33.5 tons of CO_2 ha^{-1} net CO_2 assimilation (Aeco) and net respiratory CO_2 efflux (Reco) ted for the entire year (Table 12.4). While the mean Reco was 2.5g CO_2 e net assimilation rate (Aeco) recorded was 13.5g CO_2 $m^{-2}day^{-1}$ (Figure h there was considerable rate of ecosystem respiration at night, the CO_2 during daytime was much higher in rubber plantation. In a study with

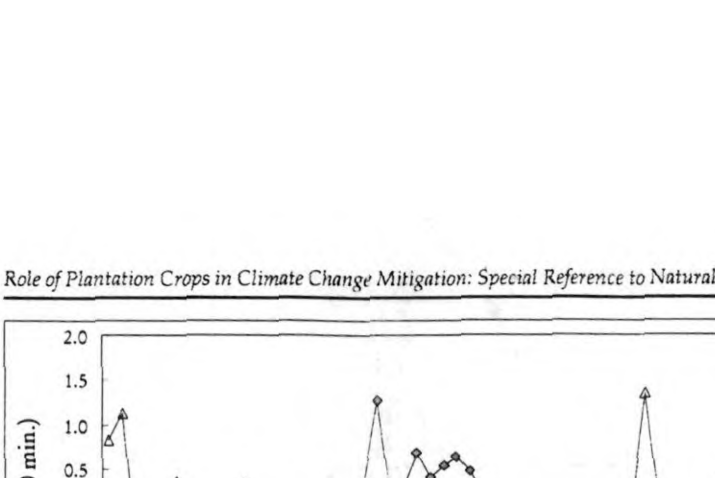
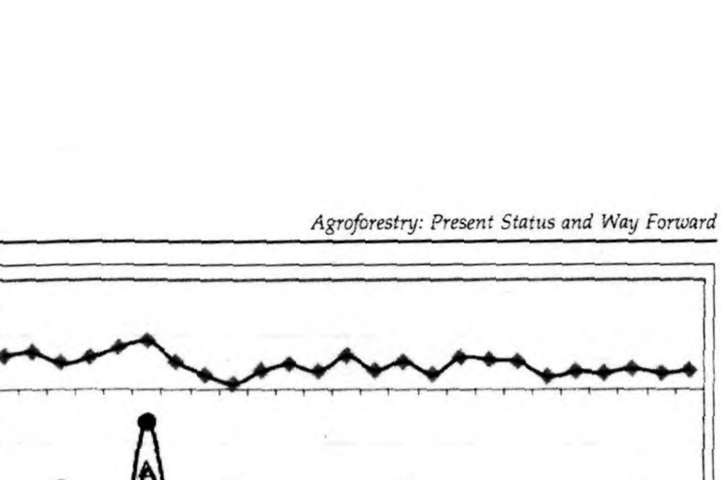


Figure 12.1: A Typical Diurnal CO_2 and Evapotranspiration of Water (ET) Immature Rubber Plantation.

mature rubber plantation in Thailand, Thaler *et al.* (2008) have su ecosystem level EC measurement of CO_2 and water fluxes could be used exchange of rubber plantation according to prevailing climat environmental parameters.

Table 12.4: Daily Net Carbon Dioxide (g m^{-2} day^{-1}) Assimilation in a Five- Immature Rubber Plantation in a Traditional Rubber Growing Belt

Monthly Mean	*Carbon Dioxide Flux (Net carbon exchang NEE (g m^{-2} day^{-1})*
April	12.6±0.9
May	14.6±1.0
June	9.6±0.6
July	12± 1.2
August	11±1.5
September	13± 1.1
October	15± 0.8
November	12.0± 0.9
December	10.2± 1.2
January	11.8± 1
February	9.4 ± 0.9
March	11.3±1.2



Mean Monthly Net Ecosystem Exchange in Immature Rubber Plantation for The mean ecosystem respiration (Reco), ecosystem CO_2 assimilation (Aeco) ystem exchange (NEE) on per day basis.

ith lengthy sunshine hours recorded high rate of net ecosystem exchange. mer months sunlight was plenty but soil moisture deficit and high VPD restrict canopy photosynthesis and hence NEE. The NEE was gher during pre-monsoon period with fully recharged soil moisture after owers. During continuous cloudy and incessant rainy days either NEE v or the net ecosystem respiration rate was higher than net assimilation.

ount of carbon sequestered by the rubber plantation was estimated during iod by estimating the annual shoot biomass increment during this period ock's method. From the shoot biomass estimation, the amount of CO_2 n was calculated as 20 t CO_2 $ha^{-1}y^{-1}$ which does not include root biomass, ion, litter decomposition and sequestration by weeds and cover crops. k in rubber plantations was worked out by many workers by biomass ethods (Jacob and Mathew, 2004, Wauters *et al.*, 2008). Total carbon by rubber plantations under Kerala (South India) conditions for a 21 was estimated to be 67 t C $acre^{-1}$ and it was reported that the sequestration ubber plantation is much higher than most other terrestrial ecosystems Iathew, 2004). A 14 year old rubber stand has a carbon stock of 76 t C ha⁻ ground biomass whereas the contribution of the soil organic carbon ounted to 135 t C ha^{-1} (Wauters *et al.*, 2008). In a report from Sri Lanka it hat on average, mature rubber is capable of sequestering 81 MT of CO_2 annually and, within the 24 years of mature phase, 1,296 MT of CO_2 questered in a hectare of rubber (Munasinghe *et al.*, 2011). Our studies

showed that natural rubber plants are good sink for atmospheric CO_2. values are good indicator of net carbon movement in rubber ecosystem

8. Payment for Ecosystem Services

The Kyoto Protocol triggered a strong increase in investment in p carbon sinks, although the legal and policy instruments and gu management are still debated (FAO, 2001). A number of countries prepared themselves for the additional funding for the establishment of forests. In an initiative claimed to be the first of its kind, in 1997 Costa Ric tradable securities of carbon sinks that could be used to offset emis utilize independent certification insurance. According to a FAO report gas mitigation funding covered about 4 million hectares of forest worldwide (FAO, 2001). The recognition of afforestation and reforestatio eligible land use under the CDM of the Kyoto Protocol is expected to le increase in forest plantation establishment in developing countrie development Mechanism of the protocol allows developing countries t in planting tree crops for carbon trading.

The potential of fixing atmospheric CO_2 in rubber trees is over 45 addition to that rubber trees add 84 MT ha^{-1} of CO_2 to the soil through th fall and litter (Munasinghe *et al.*, 2011). Further cover crops and interc huge amounts of organic matter to the soil and enhance soil properties. the afforestation and/reforestation projects targeting direct sale of ca based CDM projects could be built up. Biogas generated from rubber fac could be used as a replacement for fossil fuel and emission reduction. rubber cultivation project has so far been marketed under CDM or car But new forestry projects have been registered in CDM. Even rubber pl satisfying all the criteria given by UNFCCC for a forest ecosystem, the serv by world NR plantations go unappreciated in negotiations on m mechanisms to address climate change in a post Kyoto regime, ir UNFCCC's Doha climate summit during December 2012. The reasons ignored acknowledgement in the negotiations are due to the CDM rul Kyoto Protocol (KP). These rules are more difficult to consider the carbon s credits from afforestation/reforestation (A/R) sector than credits from e As on 22nd December, 2012, out of 6202 registered CDM projects A/R p only 41. That itself means the authorities are not giving much importanc projects and there are no serious buyers for the credits from this sector.

The only way forward to this issue is to set up a domestic car mechanism for rubber or any other plantation sector independent of CDM a market for these credits nationally. Payment for ecosystem (environmen (PES), in which a voluntary agreement that offering financial supports ar to an environmental service (ES) provider. It is a transparent system for th provision of environmental services through conditional payments t service providers (Tacconi, 2012). To assess the state of the world's ecosy 2005 designed a Millennium Ecosystem Assessment (MEA) report in whic and identified twenty four ecosystem services. However there is a

mong theses 24 services which are climate change mitigation, watershed
l biodiversity conservation. These three services are now getting more
oney and interest worldwide. The ecosystem services are representing a
tal economic value of the world by contributing to human welfare directly
tly. It was reported from a study that an average of US$ 33 trillion year^{-}
trillion year^{-1}) were estimated as the economic value of 17 ecosystem
16 biomes. This is equal to almost double of the global gross national
NP) of US$ 18 trillion/year (Costanza *et al.*, 1997). The advantage of PES
s that it considers standing forests and allows the community to enter into
nt with formal institution like Government.

usion

like perennial plantation crops sequester vast amount of atmospheric
biomass. Cultivation of rubber trees on non-forested land could directly
sink by sequestering carbon in biomass and indirectly as organic carbon
vever, it is understood that planting trees alone cannot sequester all the
into the atmosphere though it is a good option to curb emission at some
er Kyoto protocol, forestry or plantation sector activities can be used to
ffset credits that could further help in reduction of fossil fuel use (Suruchi
002). However, no plantation crop cultivation has so far been registered
ect. The alternate funding sources like voluntary environmental protection
d government institutions may be explored for the ecosystems services
the perennial plantation crops.

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rements in rubber plantations. *Natural Rubber Res.* 24 (1): 28-37.

, K.K., Meenkumari, T., Jessy, M.D., Ulaganathan, A. and Nair, N.U. 2012.
sequestration potential of RRII 400 series clones of *Hevea brasiliensis.*
Sci. 25(2): 233-240.

orth, E.A. and Ort, D.R. 2010. How do we improve crop production in a
ng world? *Plant Physiol.* 154: 526-530.

Q.R., Comerford, N.B., Ogram, A.V., Al-Agely, A., Santos, L.P. and Santos.
5. Soil carbon and physical property changes in Brazilian coastal tableland
vith land use following tableland soils with land use following
tation. *Agroforest. Sys.* 63: 193-198.

M., Goel, N.K. and Singh, P. 2005. Evaluation of temperature trends over
Hydro. Sci. J. 50: 81-93.

nha, D. and Nareshkumar, S. 2013. Net primary productivity, carbon
ration and carbon stocks in areca-cocoa mixed crop system. *J Plant. Crops.*
-13.

chi, D.D. 2003. Assessing ecosystem carbon balance. Problems and
cts of the eddy covariance technique. *Glob. Change Bio.* 9: 476-492.

8. Cairns, M. and Meganck, R. 1994. Carbon sequestration, biologi
and sustainable development: Integrated forest management. *Env*
18(1): 13-22.

9. Carrington, D. 2010. Amazon deforestation in dramatic decline, of
show. Guardian Newspapers Ltd, United Kingdom, 23 July 2010.

10. Chantuma, A., Maenmeun, S., Chantuma, P. and Paechana, P. 2005
rubber wood production and quality- Case productivity in the Nort
woods properties. Paper presented in "Rubber: Wood, Cropping a
work shop. May 25.-27. 2005. Kasetsart University, Bangkok. pp7.

11. Costanza, R., Ralph, d'Arge., Rudolf, de G., Stephen, F., Monica,
Karin, L., Shahid, N., Robert, V. O' Neill, Jose, P., Robert, G.R., Paul, S
van den Belt. 1997. The value of world's ecosystem services and na
Nature, 387: 253-260.

12. Cynthia, R., Iglesias, A., Yang, X.B., Epstein, P.R. and Chivian, E. 2
change and extreme weather events: Implications for food prod
and pests. *Glob. Change and Human Health* 2(2): 90-104.

13. Daniel, N., Britaldo, S. S., Frank, M., André, L., Paulo, M., John,
Andrea, C., Hermann, R., Stephan, S., David, G. M., Claudia, M.
Pedro, P., Sergio, R., Ane, A., Oriana, A., and Osvaldo, S. 2009
deforestation in the Brazilian Amazon. *Science*. 326: 1350-1351.

14. FAO, 2001. Plantations and greenhouse gas mitigation: a short re
D.J. (*ed.*) Moura-Costa, P., Aukland, L., In: Forest Plantations Ther
Working Paper (FAO), no. FP/12/FAO, Rome (Italy). Forest Resou
P 18.

15. FAO, 2007. State of the world's Forest, 2007. *Food and Agriculture o*
UN. Rome.

16. Galford, G.L., Melillo, J.M., Kicklighter, D.W., Cronin, T.W., Cerri, E.P
J.F. and Cerri, C.C. 2010. Greenhouse gas emissions from alternati
deforestation and agricultural management in the southern Ama
Nat. Acad. Sci. 107 (46): 19649-19654.

17. Gera, M. and Suresh, C. 2010. Opportunities for carbon sequestra
from growing trees of medicinal importance on farm lands of Ha
Fores. 136 (3): 287-300.

18. Gera, M., Giresh, M., Bisht, N.S. and Gera, N. (2006). Carbon s
potential under agroforestry in Rupnagar district of Punjab. *Indian*
543-555.

19. Gibbs, H.K., Johnston, M., Foley J.A., Holloway T., Monfreda C., Ra
Zaks D. 2008. Carbon payback times for crop-based biofuel exp
tropics: the effects of changing yield and technology; *Environ. Res.*

20. Goswami, B.N., Venugopal, V., Sengupta, D., Madhusoodanan, M.S
P.K. 2006. Increasing trends of extreme rain events over India i
environment. *Science* 314: 1442-1445.

ane, L.S., Rupa Kumar, K. and Ramana Murthy Bh V. 1985. Long-term ls of surface air temperature in India. *Internation. J Climat.*5: 521-528.

la, N., Gera, M., Vasistha, H.B., Chandran, M. and Rassaily, S.S. 2005. Phase-ort on Methodologies in Forestry Mitigation Project-case studies from ital and Udham Singh Nagar Districts of Uttaranchal. ICFRE, Dehradun.

ghton, R.A., 2005. Above ground forest biomass and the global carbon ce. *Glob. Change Bio.* 11, 945–958.

ghton, R.A., Unruh, J.D., Lefebvre, P.A. (1993). Current land cover in the s and its potential for sequestering carbon; *Glob. Biogeochem. Cycles* 7:305-

, Fourth Assessment Report (AR4), Climate Change 2007. The Physical ce Basis. Contribution of Working Group I to the Fourth Assessment Report Intergovernmental Panel on Climate Change. Cambridge University Press, bridge, United Kingdom and New York, NY, USA, 2007.

2009. Report of the panel meeting on carbon sequestration in plantation and trading under CDM. CPCRI, Kasargod, Kerala

J and Mathew, N.M. 2004. Eco-friendly NR plantations can tap vast global ng. *Rubber Asia.* March-April 2004.

J. 2005. The science, politics and economics of global climate change: cations for the carbon sink projects. *Current Sci.* 89 (3): 464-474.

R.Z. and Yang, C.D. 1999. The changes of the soil microorganism in sphere and outside in different developing stages of the Chinese fir tion. *Sci. Silvae Sinic.* 35: 53-59.

g, C.D., Chin, J.F.S. and Whorf. T.P. 1996. Increased activity of northern tion inferred from atmospheric CO_2 measurements. *Nature* 382: (6587) 146-

zel, M., Castillo, A., Moore, T. and Potvin, C. 2003. Carbon storage of st-age teak (*Tectona grandis*) plantations, Panama. *Forest Eco. Manage.* 173, 5.

akumar, K.N., Rao, S.S.L.H.V.P. and Gopakumar, C.S. 2009. Rainfall trends ntieth century over Kerala, India. *Atmos. Environ.* 43: 1940-1944.

n, E. 2000. Fuel wood production in agroforestry systems for sustainable se and CO2-mitigation. In: Forests in Focus, Proceedings Forum "Forests ergy" 17 - 21 January 1998, NNA Reports, Vol. 12, Spl. Issue 1, 1999, 141-ological Engineering 16, Supplement 1, (2000), pp 69-72.

nmawia C and Paliwal K. 2010. Seasonal changes in net ecosystem ge of CO_2 and respiration of *Cenchrus ciliaris* L. grassland ecosystem in rid tropics: an eddy covariance measurement. *Current Sci.* 98 (9): 1211-

Wu X, Xue, H., Gu, B., Cheng,H., Zeng, J., Peng, C., Ge,Y. and Chang, J. Quantifying carbon storage for tea plantations in China. *Agri. Ecosys.* t. 141: 390– 398.

36. Márquez, L. 1997. Validación de Campo de los Méodos del Institu para el Establecimiento de Parcelas Permanentes de Muestreo para Carbono en Sistemas Agroforestales. Guatemala: Universidad d Guatemala thesis.

37. Massman, W. J and Lee, X. 2002. Eddy covariance flux corre uncertainties in long term studies of carbon and energy exchange. *A meteorol.* 113: 121-144.

38. Molina, M., Zaelke, D., Sarmac, K. M., Andersen, S. O., Ramanat Kaniaruf, D. 2009. "Reducing abrupt climate change risk using th Protocol and other regulatory actions to complement cuts in CO_2 *Proc. Natl. Acad. Sci.*106 (49): 20616–20621.

39. Munasinghe, E. S., Rodrigo, V. H. L., Karunathilake, P. K. W. 20 sequestration in mature rubber (*Hevea brasiliensis* Muell. Arg.) plan genotypic comparison. *J. Rubber Res. Inst. Sri Lanka* 91: 36-48.

40. Nair P.K.R. 2001. Agroforestry. In: Our Fragile World: Chal Opportunities for Sustainable Development, Forerunner to The Enc Life Support Systems. UNESCO, Paris, France and EOLSS, UK. pp.

41. Niggli, U., Fliessbach, A., Hepperly, P. and Scialabba, N. 2009. Low gas agriculture: mitigation and adaptation potential of sustainal systems. FAO, April 2009, Rev. 2-2009.

42. Pant, G.B. and Kumar, K.R. 1997. *Climates of South Asia*, John Wiley, UK.

43. Parthasarathy, B. and Dhar, O.N. 1974. Secular variations of regic over India. *Quarterly J. Royal Meteorol Society.* 100: 245-257.

44. Rao, G.S.L.H.V.P and Alexander, D.2007. Impact of climate cha agricultural sector in tropical countries. Proceedings of the WTC Kochi, 14th Dec. 2007. Kerala Agricultural University. pp 80.

45. Satheesh, P.R. and James Jacob. 2011. Impact of climate warming rubber productivity in different agro-climatic regions of India. *Nat* 24(1): 1-9.

46. Schroth, G., D'Angelo, S.A., Teixeira, W.G., Haag, D. and Lieber Conversion of secondary forest into agroforestry and monoculture in Amazonia: Consequences for biomass, litter and soil carbon st years. *Forest Eco. Manage.* 163: 131-150.

47. Shammiraj, Satheesh, P.R. and James Jacob. 2011. Evidence for clima in some natural rubber growing regions of South India. *Nat. Rubber R* 17.

48. Shorrocks, V.M.1965. Mineral nutrition, growth and nutrie *Heveabrasiliensis*. Growth and nutrient content. *J. Rubber Res. Inst.* 32-47.

49. Sivakumaran, S. and Tee, N.K. 2010. Sustainable cultivation of rubber: A possible framework. *The Rubber Internation. Magazine*, January 2010: 34-42.

50. Steffan-Dewenter, I., Kessler, M., Barkmann, J., Bos, M.M., Buchori, D., Erasmi, S., Faust, H., Gerold, G., Glenk, K., Gradstein, S.R., Guhardja, E., Harteveld, M., Hertel, D., Höhn, P., Kappas, M., Köhler, S., Leuschner, C., Maertens, M., Marggraf, R., Migge-Kleian, S., Mogea, J., Pitopang, R., Schaefer, M., Schwarze, S., Sporn, S.G., Steingrebe, A., Tjitrosoedirdjo, S.S., Tjitrosoemito, S., Twele, A., Weber, R., Woltmann, L., Zeller, M., Tscharntke, T., 2007. Tradeoffs between income, biodiversity, and ecosystem functioning during tropical rainforest conversion and agroforestry intensification. *Proc. Natl Acad. Sci. USA* 104, 4973–4978.

51. Stephen G. P and Theodore T. K (1979). Stomatal response of populus clones to light intensity and vapor pressure deficit. *Plant Physiol.* 64: 112-114.

52. Suárez Pascua, D. 2002. Cuntificación y Valoración Económica del Servicio Ambiental Almacenamiento de Carbono en Sistemas Agroforestales de Café en la Comarca Yassica Sur, Metagalpa, Nicaragua. Turrialba, Costa Rica: CATIE thesis.

53. Suruchi B and Singh R. 2002. Carbon sequestration estimates for forestry options under different land-use scenarios in India. *Current Sci.* 83: 1380-1386.

54. Tacconi, L. 2012. Redefining payments for environmental services. *Ecological Econ*, 73 (1): 29-36.

55. Thaler P., Siripornpakdeekul P., Kasemsap P., Kunjet S., Chairungsee N., Kositsup B., Roupsard O., Gay F., Chantuma A., Thanisawanyangkura S., Sangkhasila K., Sathornkich J., Bonnefond J.M. 2008.Rubberflux. Progress inCO_2 and water budget evaluation of rubber plantations in Thailand. AsiaFlux Workshop 2008, 17-19 November 2008, Seoul, Republic of Korea.

56. Wang, H.H. and Li, D.H. 2003. Effect of man-made rubber-tea community improving ecological condition of soil. *J. Mountain Sci.* 21: 318-323.

57. Watson R.T., Noble I.R., Bolin B., Ravindranath N.H., Verardo D.J. and Dokken D.J. (eds). 2000. Land Use, Land-Use Change and Forestry. Intergovernmental Panel on Climate Change (IPCC), Special report. Cambridge Univ. Press. New York.

58. Wauters, J B., Coudert S., Grallien, E., Jonard, Mand Ponette, Q. 2008. Carbon stock in rubber plantation in Western Ghana and Mato Grosso (Brazil). *Forest Eco. manage.* 255 (7): 2347-2361.

59. Yang, J.C., J.H. Huang, J.W. Tang, Q.M. Pan and X.G. Han. 2005. Carbon sequestration in rubber tree plantations established on former arable lands in Xishuangbanna, SW China. *Acta Phytoeco. Sini.* 29: 296-303.