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Impact of removal of rubber plantations for urbanization on CO_2 mitigating capacity by the loss of carbon sink in Kerala state, India

K.K. Ambily*, A. Ulaganathan and G.C. Sathisha[1]

Rubber Research Institute of India, Kottayam-686 009, Kerala, India
[1]ICAR-Indian Institute of Horticultural Research, Bengaluru-560 089, Karnataka, India

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Abstract

Mitigating climate change and global warming through carbon sequestration by tree ecosystems is of prime importance since they are cost-effective, environmentally friendly and ecologically sustainable. Urbanization is a part of development, and rubber plantations are usually removed for this purpose, especially in Kerala, the southern state of India. Besides latex, the economic produce, and the associated income, the rubber tree is a fairly good sink for carbon in its biomass, with an average carbon content of 42 per cent and substantial carbon stock in the soil. In the present study, an account of total carbon loss by the removal of rubber plantation for urbanization and developmental activities are given. The present popular clone (RRII 105) existing in major share (85%) of the total rubber cultivation in India accounts for carbon sink loss 57 t ha^{-1}, 57.5 t ha^{-1}, 43.2 t ha^{-1} for 23 years and 148 t ha^{-1}, 75 t ha^{-1} and 62.1 t ha^{-1} for 30 years from biomass, litterfall and sheet rubber respectively. The recent clones RRII 414, RRII 429 and RRII 417 have higher growth rates and higher biomass (44-50 per cent) carbon sink loss compared to the existing popular clone RRII 105. The carbon sink loss in the form of stored carbon in soil is 56.5, with a soil carbon content between 1.2 to 2 per cent. Due to the growth variation in diverse environments with extreme climatic conditions, the clones recorded differences in carbon stock and carbon sink loss. The central region of Kerala showed a higher loss, and a lower loss was in the drought-affected northern region than the southern region. The total carbon sink losses for 23 and 30 years were 214.2 and 341.5 t $ha^{-1,}$ respectively. This study points out that the serious carbon sink loss due to the removal of rubber plantations results in disturbing the self-sustained, carbon-friendly and economically sound perennial rubber ecosystem. Vegetation having higher C-sequestration potential and trees with higher lignin content is essential to increase carbon capture for mitigating the impact of the removal of plantations. From the present study, it is clear that the removal of rubber plantations is affecting the carbon sink loss, thereby the CO_2 mitigating capacity, and is a serious matter of concern.

Keywords: Carbon sink, CO_2 mitigation, rubber plantation, sequestration, urbanization

Introduction

Urbanization of land is aggressive nowadays for developmental activities. Most agricultural areas, including rubber plantations, and a high-land resident ecosystem, are subjected to construction activities. Tree plantations and forests act as large carbon sinks by fixing atmospheric carbon in their biomass through photosynthesis (Anjali *et al.*, 2020). Urban development and the resultant land removal are becoming major causes of loss of carbon storage (Sallustio *et al.*, 2015), exponentially increasing CO_2 in the atmosphere and causing global warming. Also, urbanization is a major process for disturbing the plantation ecosystems and associated entities like changes in climate, water bodies, and microbial activities; thereby, the complete ecosystem structure is disturbed. Rubber tree (*Hevea brasiliensis*), the major source of natural rubber, is a quick-growing tree crop in the initial phase (1-7 years), attaining a girth (50 cm) for latex harvesting and has high biomass accumulating potential (Karthikakuttyamma *et al.*, 2004).

**Corresponding Author: ambili@rubberboard.org.in*

The average biomass of the popular rubber clone, RRII 105 at 30 years, is 1.2 t tree^{-1} (Jacob, 2003a). Different clones have varying biomass accumulation potential, and some modern clones have even higher biomass (Ambily and Ulaganathan, 2015). The planting density of rubber plants is 550 plants ha^{-1} at the time of planting, and after causalities, the mature tree stand comes to around 350 trees ha^{-1}. The carbon sequestration capacity of natural rubber plantation was estimated as 142 t ha^{-1} in tree biomass and 23 t ha^{-1} in the soil (Jacob, 2003a) for the clone RRII 105. Karthikakuttyamma (1997) studied the biomass accumulation of clone RRII 105 at 20 years of age, which accounts for 192 t ha^{-1} C in the dry biomass. Jessy (2004) estimated the biomass of the clone PB 217 at 19 years, and this comes to 155 t ha^{-1} C. Annamalainathan *et al.* (2011) reported that in rubber plantation, the net ecosystem exchange (NEE) of CO_2 is 1-25 g m^{-2} day^{-1} and a 4 to 5-year-old rubber plantation sequestered 33.5 tons CO_2 ha^{-1} year^{-1} and inferred as rubber plantation as a potential sink for sequestration of atmospheric CO_2. Rajagopal and Sebastian (2011) found that using biomass gasification technology in block rubber production has reduced the emission of CO_2 when compared to diesel-fired dries, a beneficial contribution of the rubber processing sector to reduce CO_2 emission. The carbon sequestration potential of modern *Hevea* clones like the RRII 400 series was reported (Ambily *et al*., 2012). The carbon sink loss by the removal of rubber plantations has not been estimated; this is important in environmental sustainability accounting and taking policy decisions. With this background, the present study was conducted with the objectives of estimating carbon sink loss from the carbon categories, *viz*. tree biomass, annual litterfall, soil carbon and sheet rubber by the removal of rubber plantation at 23 and 30 years to estimate the carbon sink loss of clones in diverse environments and to estimate total carbon sink loss for the clone RRII 105 through the removal of plantation for urbanization in the scenario of CO_2 mitigation capacity of tree plantations.

Materials and methods

The data from published reports and the data synthesized from the parameters reported were used for accounting for the total carbon sink loss of the plantation. The data confines to different experiment locations in Kerala, the southern end state in peninsular India. For the estimation of carbon sink loss by the removal of a one-hectare rubber plantation, two planting ages were taken, *viz*. 23 years and 30 years from planting. The usual replanting period in the small holding and estate sector was around 20-25 and 30-35 years, respectively. Hence, the ages of 23 years and 30 years ages were selected. The carbon sequestration potential estimated for the modern *Hevea* clones of RRII 400 series clones and check clone RRII 105 (Ambily *et al*., 2012) in the experimental field of Rubber Research Institute of India (RRII) (09^{0}32'N; 76^{0}36'E), Kottayam was used for the 23 years calculation. For the 30-year estimates, the carbon sequestration potential estimated for clones RRII 105, RRII 203 and GT 1 (Ambily and Ulaganathan, 2015) of the experimental field at Central Experimental Station of RRII (09^{0}22' N; 76^{0}50' E) Chethacakal, Pathanamthitta district were used. These studies were conducted to estimate biomass by destructive tree felling and dividing the tree into different plant parts such as trunk, branches, leaves and roots. The average carbon content of the rubber tree was taken from the published data as 42 per cent based on the study of the carbon content of plant parts of the clone RRII 105 (Jacob, 2003a) and RRII 400 series clones (Ambily *et al.,* 2012). From this, the carbon accumulated in the tree biomass was estimated as 42 per cent of the total dry biomass of the tree and then scaled up by assuming 350 trees stand in a mature plantation to obtain the carbon sink per hectare. These data were adopted as such in this paper. The soil carbon loss was assessed from the soil organic content of rubber-growing soils. The average organic carbon content was found to be in the medium to high status in rubber plantations as per the rating for fertilizer recommendation for rubber trees (NBSS-LUP, 1999). Three different values of the per cent organic carbon content observed in rubber plantations *viz*. 1.2, 1.5 and 2.0 in 0-30 cm depth was taken and estimated the total loss of average carbon stock at 0-30 cm depth. The bulk density of rubber-growing soils was an average of 1.2 g per cm^3 (NBSS-LUP, 1999: recent soil survey, 2012 (unpublished). From this, the carbon stock in the soil in a one-hectare plantation was estimated by using the equation SOC stock (t ha^{-1}) = % OC x BD x D where OC = per cent organic carbon content, BD = bulk density g per cm^3, D= depth of the soil. This was given as the carbon sink loss through soil carbon commonly for 23 and 30 years since the carbon status is relevant rather than the age of the plantation. The annual carbon input through litterfall was estimated by litterfall data (5-6 t ha^{-1}) (Philip *et al.,* 2003). The data on litterfall was only taken from the published report and was synthesized by considering carbon content as 42 per cent. The estimate comes to 2-3 t ha^{-1} carbon, and from this, the sink loss through annual litterfall for 23 years and 30 years was calculated separately since this was a recycling process every year. The reported carbon content of the dry rubber sheet was 85.38 per cent (Jacob, 2003a). This was used to estimate the carbon locked by rubber sheet in the one-hectare plantation. The sheet rubber is produced from latex collected by tapping rubber trees, and its production was estimated per day per tapping by considering 120 tapping days annually in the S/2 d2 harvesting method. The sheet rubber production (t ha^{-1} year^{-1}) was used to obtain the carbon sink loss through rubber sheets for 23 and 30 years. The litterfall data, sheet production and soil carbon, were based on the popular clone RRII 105, widely established (85 % of the total rubber cultivation area in India). The tree biomass data for the clone RRII 105 mentioned above were also used. Hence, the total carbon sink loss per hectare by the removal of a one-hectare mature rubber plantation was estimated for the clone RRII 105, and this was extended to 23 and 30 years of age. The biomass accumulated, carbon storage and carbon sink loss of RRII 400 series and RRII 105 at 20 years of age in three diverse environments in the traditional rubber cultivated areas, *viz*. Kanyakumari, southern region (08^{0}26' N; 77^{0}36' E), Chethackal, Kottayam, central region (09^{0}22' N; 76^{0}50' E) and Padiyoor, drought-affected, northern region (11^{0}58' N;75^{0}35' E) were also estimated and compared. This estimation was based on Shorrock's allometric equation for biomass estimation validated for rubber clones (Ambily *et al*., 2012) using the girth of the trees recorded in the experiment on clone evaluation study in these three locations. Forty-two per cent of the biomass quantity was taken as the carbon sink per tree and was scaled up to plantation level by assuming 350 trees ha^{-1} in a mature rubber plantation. The carbon sink was equivalent to carbon sink loss, thereby carbon sequestration capacity and CO_2 mitigating capacity of rubber plantation.

Statistical analysis

The published data of biomass and carbon stock at 23 and 30 years were statistically analyzed by ANOVA, and standard error means, respectively. This data was adopted as such, and the carbon stock data was taken to estimate the total carbon loss from the plantation. The biomass and carbon stock data in diverse environments was analyzed by standard error means (±SE). The reported data on litterfall addition was also analyzed by ANOVA; this data was adopted as such, and the carbon sink loss from litterfall was synthesized from this base data. The soil carbon derived from the known values of soil organic carbon and bulk density was already analyzed in various experiments. The sheet rubber data was calculated from the general annual productivity standard of the Rubber Board for the clone RRII 105.

Results and discussion

The carbon content in different sink sources of rubber plantations (Jacob, 2003a) is given in Table 1. Among the carbon sink sources, per cent, carbon content was highest in sheet rubber (85.38 %) followed by seed endosperm (63.48 %). Timber and coarse root recorded a carbon sink of around 38 per cent. Other carbon sink sources like leaf lamina, petiole, small twigs (firewood), fine roots and fruit walls stored 42 to 47 per cent carbon. Among the sink sources of tree portions, the largest

Table1. Carbon content in sink sources of rubber plantation

Sink	C (%)
Leaf lamina	42.80
Petiole	47.19
Small twigs (firewood)	40.18
Timber	38.50
Fine roots	45.98
Coarse roots	38.50
Sheet rubber	85.38
Seed (endosperm)	63.48
Fruit wall	46.35

Adopted from Jacob (2003)

removal was through timber, including trunk and major branches. Small twigs are removed as firewood from the field. The leaf, petiole and below-ground root portions were allowed to decay in the field at the time of felling of the trees for replanting. But this loss is also significant when considering the carbon sink loss because releasing carbon from the leaf and root residues takes time for further deposition as soil organic carbon. Even though the seed endosperm has large carbon content, the total quantity is less than above-ground biomass, and it is usually left in the field to decay. Based on this, the carbon content of rubber trees was estimated as 42 per cent of the dry biomass for the purpose of computation of carbon stock per tree (kg tree^{-1}) and carbon sequestration capacity (t ha^{-1}) by considering 350 trees in one hectare of rubber plantation.

The biomass accumulated, carbon stock and carbon sink loss of 7 rubber clones (6 RRII 400 series clones and RRII 105) at 23 years are given in Table 2. These clones were selected from the experimental field of clone evaluation trials at the Rubber Research Institute of India (RRII), Kottayam, Kerala and are having same soil and management practices. The clones differed in biomass accumulation and, thereby, the carbon stock per tree and carbon sink loss in tons on one hectare basis. Among the clones, RRII 429, RRII 414 and RRII 417 had higher biomass than RRII 430, RRII 105 and RRII 422. Carbon stock and sink loss were also in the same pattern in these clones, as carbon storage is related to biomass accumulation. The carbon capture pattern in RRII 400 series clones from 4th year onwards is given in Figure 1 (Ambily *et al.,* 2012).

Table 2. Biomass, carbon stock and carbon sink loss of RRII 400 series clones at 23 years of age at RRII

Clone	Total dry biomass (kg tree^{-1})	C- stock per tree (kg tree^{-1})	C- sink loss by tree removal (t ha^{-1})
RRII 414	736	302	106
RRII 430	419	172	60
RRII 429	793	325	114
RRII 417	713	292	102
RRII 422	377	154	54
RRII 105	407	163	57
CD	41.35	14.47	5.06

Adopted from Ambily *et al.* (2012)

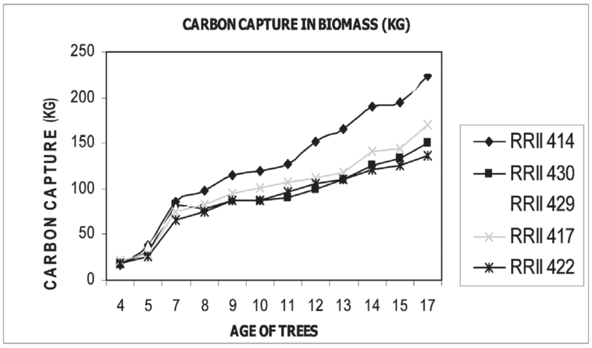

Fig. 1. Growth curve shows biomass accumulation and carbon capture in RRII 400 series clones

There was an increased carbon capture of up to seven years, uniformly in all the clones. A sharp increase in carbon capture from the 5th to 7th year and afterwards up to the 12th year was noticed irrespective of clones. However, the trend changed after the 12th year for all clones; clone-wise, changes in carbon capture were observed. This is attributed to the characteristic growth pattern in *Hevea.* Carbon sink loss observed in different clones were 114 t ha^{-1} (RRII 429), 106 t ha^{-1} (RRII 414), 102 t ha^{-1} (RRII 417), 60 t ha^{-1} (RRII 430), 57 t ha^{-1} (RRII 105) and 54 t ha^{-1} (RRII 422).

The biomass accumulated, carbon storage and carbon sink loss of RRII 400 series and RRII 105 at 20 years of age in diverse environments in the traditional rubber-cultivated areas in Kerala and Kanyakumari are given in Table 3. The locations were Regional Research Station (RRS) Padiyoor, Kannur district, the drought-affected area; Central Experiment Station (CES), Chethackal, Ranni, Pathanamthitta district, the south-central area in Kerala and *Hevea* Breeding Sub Station (HBSS), Thadikarankonam, Kanyakumari, Tamil Nadu, the South Region. The three locations had an extreme difference in agro-climatic conditions. Since the experiment fields were the clone evaluation trials of the same clones planted uniformly for participatory clone evaluation trials, similar management practices were followed even though the soil conditions varied. Because of the differences in agro-climate, total dry biomass accumulated, carbon stock and carbon sink loss showed variations in three locations. Since carbon sink is directly related to biomass accumulation, high biomass accumulating clones recorded the highest carbon sink loss. Among the

Table 3. Biomass, C- stock and C-sink loss of RRII 400 series clones (20 years) in diverse environments

Clone	Total dry biomass (kg tree^{-1}) (Above ground)			Carbon stock (kg tree^{-1})			Carbon sink loss by tree removal (t ha^{-1})		
	PD	CES	KK	PD	CES	KK	PD	CES	KK
RRII 414	346.1±29.1	627.6±47.8	427.8±29.1	145.3±7.2	263.6±20.1	179.7±12.9	50.9±2.5	92.3±7.1	62.9±4.26
RRII 430	290.8±13.6	472.7±32.5	319.6±13.6	122.1±2.1	198.5±13.6	134.3±5.7	42.7±0.7	69.5±4.8	47.1±2.1
RRII 429	290.7±109.3	695.8±26.6	598.1±109.3	122.1 ±6.6	292.3±11.2	251.2±45.9	42.8±2.3	102.87±3.9	87.9±16.1
RRII 417	327.6±37.9	615.8±40.3	448.2±37.9	137.6±9.2	258.6±41.4	188.3±15.9	48.2±3.2	90.5±5.92	65.9±5.6
RRII 422	281.7±40.5	515.3±20.3	406.7±40.5	118.3±8.9	216.4±8.5	170.8±17.1	41.4±3.2	75.8±2.98	59.8±5.95
RRII 105	285.1±20.9	465.63±24.3	412.1±20.9	119.7±6.3	195.8±10.9	173.1±8.8	41.1±2.2	57.9±3.05	58.7±4.52

*PD- Padiyoor (North); CES-Chethackal (Central); KK- Kanyakumari (South); ±mean standard error values

locations, the carbon sink loss was higher in the clones in Chethackal than in Kanyakumari and Padiyoor. When comparing the clones in Kottayam at 23 years old, the biomass accumulation in Chethackal at 20 years old was comparable, and almost the same rate of biomass accumulation was observed. The order of carbon sink loss was also similar in Chethackal and Kottayam, having an annual rainfall range of 3500-4000 mm and the mean maximum and minimum air temperature prevailing was 31-32 °C and 22-23 °C, respectively. In both these locations, the higher biomass accumulating clones, *viz*., RRII 414, RRII 429 and RRII 417 recorded the highest carbon sink loss than the comparatively lower biomass accumulating clones RRII 430, RRII 422 and RRII 105. In Padiyoor, the drought affected traditional area in the northern region of Kerala; the biomass accumulation rate was lower due to less growth due to environmental stresses like high temperature and drought.

Along with this, a prolonged dry spell of about four to five months from December to May prevails in this location every year. Even though the rainfall (3500 mm) is plentiful, moisture stress due to dry spells during this period affects the growth and yield of rubber in this area (Vijayakumar *et al.,* 2000). The mean maximum and minimum temperatures were 33 and 23 °C, respectively. Therefore, the biomass and carbon sink loss were less than the location at Chethackal and Kanyakumari. In Kanyakumari, the biomass accumulation and the resulting carbon sink loss were higher than in Padiyoor and lower than in Chethackal. The climatic condition in the Kanyakumari region is entirely different from that in the Padiyoor region. In the Kanyakumari area, the rainfall is 2000 mm annually, evenly distributed, and does not exceed more than 350 mm in any of the months. The southwest and northeast monsoons are equal, and there were no marked temperature variations. The carbon sink loss differences in these locations were attributed due to differences in growth in diverse agro-climatic conditions.

The biomass, carbon stock and carbon sink loss of RRII 105, RRII 203 and GT 1 at 30 years of age is given in Table 4. The location was at CES Chethackal, and the biomass accumulation was 1254, 1140 and 2045 kg tree^{-1} for the clone RRII 105, RRII 203 and GT 1, respectively. The corresponding carbon stock

Table 4. Biomass, C-stock and C-sink loss of RRII 203, GT 1 and RRII 105 at 30 years of age at CES Chetackal

Clone	Total dry biomass (Above-ground) (kg tree^{-1})	Carbon stock (kg tree^{-1})	Carbon sink loss by tree removal (t ha^{-1})
RRII 105	1254	527	148
RRII 203	1140	479	138
GT 1	2045	860	258
Mean	1479.7	622	188
SE	285.1	119.9	31.8

Adopted from Ambily and Ulaganathan (2015) SE- standard error values

Table 5. C- sink loss from soil at a depth of 0-30 cm of soil

Average SOC (%)	Bulk density (kg m^{-3})	Carbon sink loss from soil (t ha^{-1})
1.2	1.2	43.2
1.5	1.2	54.1
2.0	1.2	72.2
Average		56.5

Table 6. Annual C-sink loss through litter fall in the rubber plantation

Annual litterfall ($t\ ha^{-1}$)	Carbon content (%)	Annual carbon addition from litterfall ($t\ ha^{-1}$)	Total carbon sink loss from litter fall ($t\ ha^{-1}$) (23 years)	(30 years)
Range- 5-6*	42.8	2-3	46-69	60-90
Average -(5.5)	-	(2.5)	(57.5)	(75)

*Adopted from Philip *et al.* (2003); values in parenthesis are average values

Table 7. Annual C- sink loss ($t\ ha^{-1}$) through the rubber sheet

Carbon content (%) (sheet rubber)	Sheet rubber production ($t\ ha^{-1} year^{-1}$)	Carbon stock in sheet rubber ($t\ ha^{-1}\ year^{-1}$)	Total carbon stock/sink loss from sheet rubber ($t\ ha^{-1}$) (23 years)	(30 years)
85.38*	3.2	2.7	43.2	62.1

*Adopted from Jacob (2003)

per tree was 527, 479 and 860 and carbon sink loss per hectare was 148, 138 and 258 $t\ ha^{-1}$. The clones were different in their biomass accumulation due to growth variation. Even though the clones were in the same location and under similar management practices, the variation observed in the growth was the clonal character. Among the clones, the highest biomass and carbon sink loss was recorded by GT 1 followed by RRII 105 and RRII 203.

The carbon sink loss from the soil is given in Table 5. For the calculation of soil carbon sink loss, the soil organic carbon content generally observed in rubber plantations was used. The same was calculated at a depth of 0-30 cm in the present study. In general, rubber plantations have been reported to have medium to high organic carbon status (NBSS-LUP, 1999). The carbon stock calculated was 43.2, 54.1 and 72.2 $t\ ha^{-1}$ with an average value of 56.5 $t\ ha^{-1}$.

Total carbon sink loss through litterfall in rubber plantations is given in table 5. Philip *et al.* (2003) reported that the annual litterfall in rubber was 5-6 $t\ ha^{-1}$. The carbon addition through this litterfall was accounted as 2-3 $t\ ha^{-1}$ assuming the carbon content of the leaf as 42.8 per cent (Table 1). It was then accounted for 23 years and 30 years and comes to 46 to 69 and 60 to 90 $t\ ha^{-1}$. The average of this was taken for litterfall (5.5 $t\ ha^{-1}$), carbon addition through litterfall (2.5 $t\ ha^{-1}$), 23 years (57.5 $t\ ha^{-1}$) and 30 years (75 $t\ ha^{-1}$) carbon addition, respectively, and this was taken for the calculation of total carbon loss from the plantation.

Total carbon sink loss through rubber sheet, the economical production of rubber tree was given in Table 6. Annual sheet rubber production was 3.2 $t\ ha^{-1}\ year^{-1}$, and the carbon stock in rubber sheet was accounted as 2.7 $t\ ha^{-1}\ year^{-1}$ by considering the carbon content of sheet rubber as 85.38 per cent. The carbon loss calculated for 23 and 30 years was 43.2 and 62.1 $t\ ha^{-1}\ year^{-1}$, respectively.

Carbon sink loss from the removal of one-hectare rubber plantation through the carbon sink sources *viz.* tree biomass (57.0, 148 $t\ ha^{-1}$), soil carbon (56.5, 56.5 $t\ ha^{-1}$), litterfall (57.5, 75.0 $t\ ha^{-1}$) and rubber sheet (43.2, 62.1 $t\ ha^{-1}$) for 23 years and 30 years age, respectively were estimated (Table 8). Total carbon sink loss for 23 years and 30 years were 214.2, 341.5 $t\ ha^{-1}$, respectively.

Total carbon sinks/sources in rubber plantations and urban areas were compared and are given in Table 9. In rubber plantations, carbon sink/sources through tree components, plantation activities like litterfall and sheet production and a high carbon reservoir are very prominent and cannot be compared with the urban cities to be developed. It is imperative to evolve strict policy decisions for tree plantation removal. The vegetation regeneration

Table 8. Total C- sink loss by removal of rubber plantation for the clone RRII 105

Carbon sink sources	Carbon sink loss 23 years ($t\ ha^{-1}$)	Carbon sink loss 30 years ($t\ ha^{-1}$)
Tree biomass	57.0	148.0
Soil	56.5	56.5
Litterfall	57.5	75.0
Rubber sheet	43.2	62.1
Total	214.2	341.5

Table 9. Comparison of total carbon sinks/sources in rubber plantation *vs*. urbanized area

Carbon components	Carbon sink/sources	
	Rubber plantation	**Urbanized area**
Tree biomass	Huge quantity	Very little compared to tree plantation
Soil carbon	Abundant and major carbon reservoir	Completely blocked by built-in area
Litterfall	Huge and continuous supply	Incomparable with tree plantation
Rubber sheet	Only in rubber plantation	Cannot compensate in urban cities

with high carbon sequestration capacity plant species and appropriate carbon reservoir formation is very important in the case of inevitable developmental activities

Anjali *et al*. 2020 reported that urbanization is imperative in the developing world and humanity. Forming urban forests with high carbon sequestration potential is an important option to mitigate the adverse effect of removing plantations and forests. This contributes to various social and cultural benefits and economic progress. Simultaneously carbon emission savings are also possible through urban forests. Sallustio *et al*. (2015) reported that due to the loss of huge reservoirs of carbon stock in tree plantations, the urban areas are prone to higher carbon dioxide emissions and the urban soils have lesser carbon storage. Land take cause initial huge loss of carbon stock and result in a permanent decrease in the carbon sequestration potential of the land removed. It was suggested that the impact of urbanization could be mitigated by preserving urban green areas (Strohbach and Haase, 2012). Strohbach *et al*. (2012) reported that about 37.3 and 44.1 Mg C ha^{-1} could be sequestered through the maintenance of 50 year long green space project in Germany. Russell and Kumar (2019) reported that if the selection of trees has the capacity of increased carbon sequestration, like higher lignin composition, supplied with efficient management methods can achieve substantial carbon storage even in the simulated tree crop ecosystem and agricultural fields. Rubber trees also have higher lignin content, which can be selected for the selection of urban trees, and the rubber ecosystem is comparatively eco-friendly (Jacob, 2003b). The rubber ecosystem is also a good candidate for plantation forestry with the suitability of coming in Kyoto protocol (Jacob, 2005b). In the scenario of global warming and climate change, the importance of the rubber ecosystem acting as a reasonably good carbon sink in terms of its relevance as plantation forestry is evident, as reported by Jacob (2005a, b, c).

Kaul *et al.* (2010) reported that Indian forests could sequester 101 to 156 Mg C ha^{-1} in their biomass and are important CO_2 mitigation options. Also, the average carbon per hectare in soil comes to around 183 Mg C ha^{-1} in various types of forests in India. An average carbon stock at a depth of 0-1 m was reported as 20-25 Gt. Gokulapalan and Joseph (2021) reported the impact of the metro corridor on changes in sequestering carbon terrestrially. The estimated carbon loss by the building construction and city development in an area of 35.8 ha vegetation resulted in the reduction of 6877 t carbon. Ramachandra and Setturu (2020) reported the reduction in carbon sequestering capacity of Karnataka forests by changes in land utility leads to very high carbon loss.

Conclusion

The observations from the study point out carbon sink loss from the removal of rubber plantations for urbanization, one of the major development activities causing damages to the self-sustained carbon-friendly and economically sound perennial rubber ecosystem. Due to the growth variation in extreme climatic conditions, the clones recorded differences in carbon stock and carbon sink loss. The study helps to understand the huge loss of carbon and CO_2 mitigating capacity by removing rubber plantations and the importance of the steps taken as policy decisions to evolve remedial measures in the case of inevitable development activities and urbanization, especially the high-altitude tree plantation ecosystems. The study exposes the loss of a huge carbon reservoir in tree crop ecosystems and environmental issues related to CO_2 mitigating capacity. It implies that the maintenance of simulated tree ecosystems with biodiversity-rich and economically feasible green spaces must be a policy decision during urbanization. It also points out the need to develop appropriate methods for the assessment of the impact of land taken for urbanization and developments on carbon storage through well-planned strategies and policies

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