CARBON MANAGEMENT IN FOREST FLOOR – AN AGENDA OF 21ST CENTURY IN INDIAN FORESTRY SCENARIO

A. RAMACHANDRAN*, S. JAYAKUMAR**, A.R. MOHAMED HAROON*** AND A. BHASKARAN***

Introduction

Carbon is the fundamental building block of all life. All biological substances are based upon compounds in which carbon is the central component, combined with other elements. The concept of carbon sequestration emerged in the 1980s due to the consequences of steadily increasing level of carbondi-oxide in the atmosphere since at least 1958. This global scenario has generated interest in strategies to reduce emissions of carbondioxide to the atmosphere or to offset emissions by storing additional carbon in forests (IPCC, 1990).

The biodiversity of India is a miracle with a wide spectrum of habitat from tropical rain forests to alpine vegetation and from temperate forests to coastal wetlands. The forests of the country are mainly distributed in the Himalayas, the Western and Eastern Ghats, the Vindhya ranges and Estuarine forest. India is one of the 12 mega biodiversity centres in the world and it has 2 hotspots – the Western Ghats and Eastern Himalayas. There are at least 15,000 known and described species of flowering plants in India. Recent estimates of Forest Survey of India (FSI, 2003) show 7,57,009 km^2 area is under forest cover, which constitutes 23.03 per cent geographical area of the country. This reflects an increase of 1,16,190 km^2 area under forest cover in comparison to that of 1987. But it is still far less than the recommended 33 per cent of forest cover. Such a rich diversified ecological complex had been seriously degraded due to anthropogenic problem and different need based forest management practices of the past.

Degradation of forests is very common in Indian scenario since 1901 to to-date. The reasons are removal of large scale timber species for railway sleepers, ship building, charcoal, for all kinds of transports, cumri cultivation in the forest woodlands, reforestation of softwoods and miscellaneous species, cattle grazing and human induced fire. The aforementioned problem of degradation led to loss of carbon stock in the standing biomass as well as in soil carbon pool. Such kind of huge loss of carbon pool both in standing biomass and soil had a breakdown in carbon cycle leading to climatic imbalance.

In response to the growing concern and the mounting evidence of global climate change, the United Nations

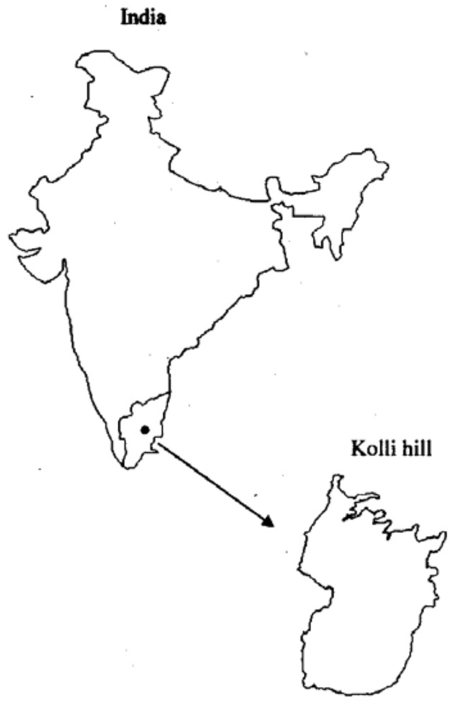
* Tamil Nadu Forest Department, Chennai (Tamil Nadu).
** Department of Eco-Biotechnology, School of Environmental Sciences, Bharathidasan University, Tiruchirappalli (Tamil Nadu).
*** Department of Soil Science, Anbil Dharmalingam Agricultural College and Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli (Tamil Nadu).

Framework Convention on Climatic Change (UNFCCC) was adopted at the United Nations Conference on Environment and Development at Rio in 1992. The objective of the convention was "to stabilize atmospheric green house gas concentration at the level that would prevent dangerous anthropogenic interference with the climate system". The most significant protocol to date has been the Kyoto Protocol (KP) tabled at the December 1997 meeting of the 3rd Conference of parties in Kyoto, Japan. The KP identified three possible "flexibility mechanisms" for countries to meet emission reduction target: Joint implementation, a Clean Development Mechanism (CDM), and emission trading. CDM would facilitate for carbon sequestration and storage investments in reforestation, afforestation and in reducing deforestation to qualify as emission reductions credits by the investing countries. In order to cope with the current situation on carbon sequestration in tropical forests, the present study aims at estimating the total carbon stock and its sequestration potential in the degraded tropical forest.

Study area

Kolli hill, one among the hills of Eastern Ghats, situated in the Namakkal District of Tamil Nadu, at the Eastern side above the river Cauvery is the study area. Geographically it is situated between 11° 10' 00" - 11° 30' 00" N lat. and 78° 15' 00" - 78° 30' 00" E long., covering an area of about 503 km^2 (Fig. 1). It is a hilly terrain and the altitude ranges from 200 to 1415 m amsl. It is a structural hill and the composite slopes are completely occupied by reserved forests of deciduous and thorn types and the upper plateau is

Fig. 1



Map of study area

occupied by broad leaved hill forests (semi-evergreen) and agricultural lands.

Material and Methods

In the present study IRS 1D LISS III digital satellite data of 28th February 2002 of path: 101 and row: 65 and 66, Survey of India (SoI) toposheets, 58 I/7, I/8, HP – Workstation, Leica GS 20 PDM Global Positioning System, Erdas Imagine 8.6, ArcGIS 9.1 and MstatC statistical software were used.

Forest Cover Mapping : Expert classification technique is followed to prepare the forest cover density map of the study area. Normalized Difference Vegetation Index (NDVI) is prepared and recoded into 4 classes based on the density viz., very density (>70%), density (40 - 70%), open (10-40%) and degraded (<10%) (39). Digital elevation model (DEM) is prepared using the 20 m contours. Based on the field knowledge and secondary data of altitudinal distribution of forest types in the Eastern Ghats, the DEM as recoded into 3 classes viz. <450 m, 450 - 1,000 m and >1,000 m. Knowledge classifier module was used to classify the forest using the above recoded DEM and NDVI. Final field check was carried out in the field with classified map, FCC, toposheets, compass and GPS. Corrections were made in the classified map and final forest type and cover density map of February 2002 was prepared.

Estimation of Biomass carbon : Plot sampling technique is followed to estimate the stand density in different forest types. Twenty five 20 x 20 m quadrates in each forest type are laid and the variables such as girth at breast height (gbh), height were recorded. Using Smalian's formula (Chaturvedi and Khanna, 1982) timber volume of about 1,000 trees was worked out and bivariate regression equations derived using calculated volume (y) on gbh (x1) and height (x2) for different girth classes as under :

$y = i + j \times x1 + k \times x2$

where :

y = volume

i = intercept

j = regression value for variable x1

x1 = GBH

k = regression value for variable x2

x2 = height

For GBH 30 – 50 cm ($r^2 = 0.79$)

Equation = - 0.191 + 0.004936 × GBH + 0.01222 × length

For GBH 51 – 100 cm ($r^2 = 0.83$)

Equation = -0.609 + 0.008246 × GBH + 0.0409 × length

For GBH 101 – 150 cm ($r^2 = 0.80$)

Equation = - 2.328 + 0.01902 × GBH + 0.103 × length

For GBH 151 – 200 cm ($r^2 = 0.83$)

Equation = - 4.771 + 0.02683 × GBH + 0.211 × length

For GBH > 201 cm ($r^2 = 0.96$)

Equation = - 13.194 + 0.05515 × GBH + 0.368 × length

Growing stock of each species recorded in different forest types in the one hectare area is estimated based on the regression equation. Biomass of stem (timber volume) of each tree species is calculated by multiplying the volume with the wood density of each species published by Forest Research Institute, Dehra Dun. For certain non-timber species wood density is calculated based on the universal mean wood density of 0.2 t/m^3 (Moore *et al.*, 1981). From the timber biomass, the biomass of crown as well as the stump and root is calculated using biomass expansion factors. Finally the total biomass of each species present in the 1 ha area in different forest types is summed up and the total biomass of each forest type is estimated. The carbon estimation from the biomass is calculated based on the methodology described by Koach (1989) and adopted the minimum value of 49.1 as the conversion factor.

Estimation of soil organic carbon (SOC) : Systematic random sampling technique is adopted to estimate the SOC, using georeferenced satellite data. The total area in the satellite data is divided into 2 km^2

grids and random value of longitude and latitude were noted for each grid for soil sampling. With the help of GPS the pre-determined sampling points (longitude and latitude) were located and soil samples collected at 145 locations. Removing the top organic litter, soil samples were collected in surface (0 to 30 cm), middle (30 to 60 cm) and bottom (60 to 90 cm) layers (McKenzie *et al*., 2000). Soil samples were collected from each layer separately, dried, processed using wooden mallet and sieved through 2 mm sieve. The per cent coarse fraction (>2.0 mm size) was worked out for each layer. Undisturbed soil clods were collected from each layer and preserved for the determination of bulk density. Bulk density was determined by Clad method and the determined bulk density was corrected for per cent coarse fractions. The corrected bulk density (Mg m^{-3}) was used for the estimation of SOC density (Mg ha^{-1}) and SOC stock. The stored soil samples were sub-sampled and ground to fine powder using an agate pestle and mortar and sieved through 0.5 mm sieve. The soil organic carbon content in the sieved soil samples was estimated by following Walkley and Black's wet oxidation method (Walkley and Black, 1934) as described by Page *et al*. (1982).

The data was statistically analyzed for the computation of standard deviation, frequency distribution and analysis of variance (ANOVA) for each forest type using Microsoft® Excel® worksheet. The Least significant difference (LSD) was worked out using MstatC software (Russell and Scott 1996) to compare the SOC mean values of different forest types at different depths. Soil organic carbon density was calculated for each layer in each profile as follows (Akala and Lal, 2001) :

SOC density (mg ha^{-1}) =

$$\frac{\text{SOC (\%)}}{100} \text{ x corrected } \rho_b \text{ (Mg m}^{-3}\text{) x layer depth (m) x } 10^4 \text{ (m}^3 \text{ ha}^{-1}\text{)}.........6$$

where ρ_b = bulk density

Corrected bulk density (Mg m^{-3}) =
Bulk density (Mg m^{-3}) x [100 – per cent coarse fraction)]/100 7

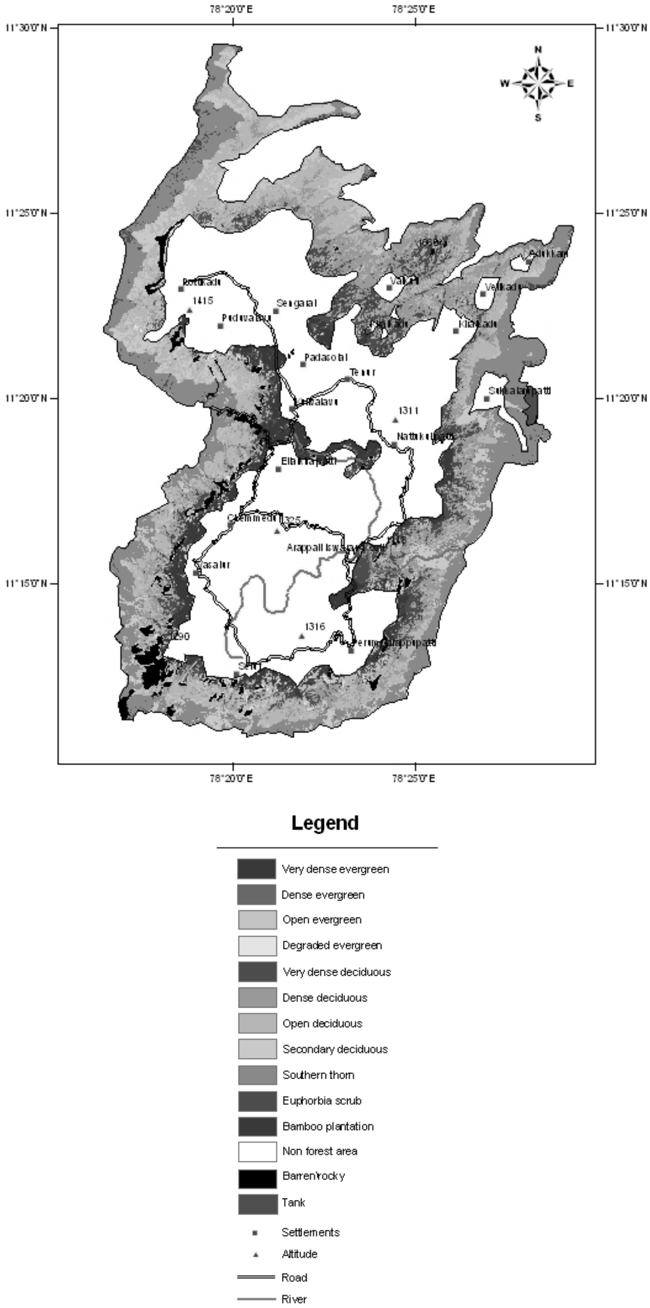
The data on SOC content (%) and SOC density (Mg ha^{-1}) of surface, middle and bottom were mapped using the ArcGIS software.

Total SOC storage =
SOC density (Mg ha^{-1}) x Forest area (ha) 8

Results and Discussion

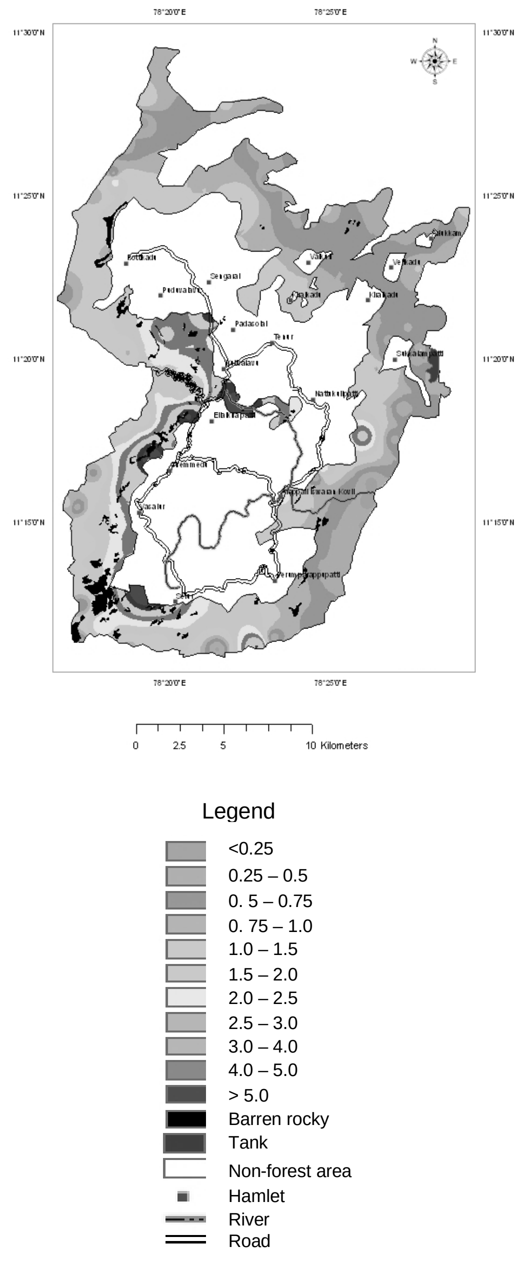
In Kolli hill the reserve forests (RF) occupy about 27,103 ha and there are five forest types, namely Tropical broad leaved hill forest (8A/C1) (semi-evergreen), Southern dry mixed deciduous forest-5A/C3, Secondary deciduous forest (5/2S1), Southern thorn forest (6A/C1) and Euphorbia scrub forest. The total area under the semi-evergreen forest type is about 3,962 ha that comprises 15% of the total forest area (Fig. 2 and Table 2). This forest type has been classified further into 4 sub classes based on the crown density, viz., very dense (>70%), dense (40-70%), open (10-40%) and degraded (<10%). The very dense semi-evergreen forest occupies 1,984 ha which is 50% of the total semi-evergreen forest. About 25 % and 21% of the semi-evergreen forest are under dense and open respectively. Only 4% is under degraded semi-evergreen. The deciduous forest comprises 46% of the total forested area. The very dense deciduous forest cover

Fig. 2



Forest type and cover density map of Kolli hill 2002

Fig. 3



Soil organic carbon distribution in the surface layer (0 – 30 cm) in Kolli hill

Fig. 4

Area below potential SOC content in Kolli hill

Table 1

Growing stock, biomass and biomass carbon in Kolli hill

Forest types	Volume (m^3/ha)	Timber Biomass (MT/ha)	Branch and Foliage (MT/ha)	Stumps and Root (MT/ha)	Biomass (MT/ha)	Area of each forest (ha)	Total Bio-mass (mill. MT)	TOC/ A/G (Tg)
Evergreen	428.229	196.988	47.277	63.036	307.302	3962.23	1.22	0.60
Deciduous	316.060	161.316	38.716	51.621	251.653	12684.74	3.19	1.57
Sec. deciduous	216.673	154.983	37.196	49.595	241.773	2960.28	0.72	0.35
Southern thorn	73.025	42.282	10.148	13.530	65.960	6676.15	0.44	0.22
Euphorbia scrub	52.72	36.859	8.846	11.795	57.500	304.40	0.02	0.01
	1086.707	592.428	142.183	189.577	924.188	26587.80	5.58	2.74

occupies 1772 ha, which is 14% of the total deciduous forest type. The dense and open deciduous density classes occupy 35 and 51% respectively (Table 2).

The secondary deciduous forest is a secondary type derived from the deciduous forest by persistent exploitation of the commercially valued species by the way of removal of timber and fuelwood under prescribed forest management system. It occupies an area of about 2,960 ha, which is 11% of the total forest area. Southern thorn forest is the largest category and it occupies 6,676 ha, which is 24% of the total forest area. The *Euphorbia* scrub forest occupies only 304 ha which is about 1% of the total forest area. Apart from these forest types tank and rock outcrop area are also present. The tank is situated in the eastern side of the hill and the rock outcrop occupies an area of about 515 ha, which is distributed invariably in all reserved forest. The total degradation of forest in terms of canopy density (degraded semi-evergreen, secondary deciduous, Southern thorn and *Euphorbia* scrub forests) is 10,088.67 ha.

Estimation of biomass carbon (above and below ground) : The total above and below ground biomass carbon stock in Kolli hill in different forest types comes to 2.74 Tg of carbon of which, the semi-evergreen forest contributes 22%, the deciduous forest contributes to the maximum of 57% and the other forest types contribute the rest. The vegetation biomass carbon density is 0.60 Tg ha^{1} in semi-evergreen forests, 1.57 Tg ha^{1} in deciduous forests, 0.35 Tg ha^{1} in secondary deciduous forests, 0.22 Tg ha^{1} in thorn forests and 0.01 Tg ha^{1} in *Euphorbia* forests are recorded (Table 1). This estimate has similarity with the average carbon density of the tropical forests. The average biomass carbon density recorded in tropical forests was from 63.33 to 156 t ha^{1} (Bolin *et al.,* 1986) and 70 t ha^{1} adopted from German Budestag (1990). The secondary deciduous forests, southern thorn and *Euphorbia* forests are derivatives of

Table 2

Soil organic carbon content (%) of different forest types of Kolli hill

Forest type	Area (ha)	SOC content (%)			Confidence Interval (%) (p=0.05)					
		Surface (0 to 30 cm)	Middle (30 to 60 cm)	Bottom (60 to 90 cm)	Surface (0 to 30 cm)		Middle (30 to 60 cm)		Bottom (60 to 90 cm)	
					From	To	From	To	From	To
1	2	3	4	5	6	7	8	9	10	11
Very Dense Semi-Evergreen	1984.23	3.70 (2.73)	2.21 (1.64)	1.82 (1.68)	1.92	5.48	1.14	3.28	0.73	2.92
Dense Semi-Evergreen	978.42	3.43 (2.91)	1.62 (1.49)	1.39 (1.45)	1.28	5.59	0.51	2.72	0.32	2.46
Medium Semi-Evergreen	851.74	1.83 (0.76)	1.13 (0.36)	0.76 (0.45)	1.30	2.35	0.88	1.38	0.44	1.07
Degraded Semi-Evergreen	147.84	2.40 (1.04)	1.10 (0.50)	0.91 (0.33)	1.49	3.31	0.66	1.53	0.62	1.20
Total Evergreen	3962.23	2.90 (2.21)	1.58 (1.24)	1.27 (1.23)	2.09	3.70	1.13	2.03	0.82	1.72
Very Dense Deciduous	1772.34	1.72 (0.52)	1.31 (0.48)	0.98 (0.50)	1.40	2.04	1.02	1.61	0.67	1.29
Dense Deciduous	4471.51	1.45 (0.73)	0.89 (0.41)	0.66 (0.32)	1.14	1.77	0.71	1.06	0.53	0.80

Contd...

1	2	3	4	5	6	7	8	9	10	11
Medium Deciduous	6440.89	1.14 (0.85)	0.66 (0.57)	0.42 (0.48)	0.64	1.65	0.33	1.00	0.13	0.70
Total Deciduous	12684.74	1.44 (0.74)	0.93 (0.52)	0.67 (0.45)	1.21	1.66	0.77	1.09	0.54	0.81
Secondary Deciduous	2960.28	0.92 (0.49)	0.60 (0.36)	0.39 (0.29)	0.71	1.14	0.44	0.76	0.26	0.52
Southern Thorn	6676.15	0.78 (0.54)	0.55 (0.43)	0.44 (0.34)	0.62	0.94	0.42	0.67	0.34	0.54
Euphorbia Scrub	304.40	0.68 (0.67)	0.40 (0.38)	0.37 (0.24)	0.28	1.07	0.17	0.62	0.23	0.51
Total Kolli Hills	26587.80	1.40 (1.38)	0.86 (0.78)	0.66 (0.71)	1.18	1.63	0.73	0.99	0.55	0.78

Values within parentheses are standard deviation of respective layers original deciduous forests. Had it been intact as deciduous forest, these three forest types would have been produced about 2.50 M tonnes of vegetation biomass instead of the present value of 1.18 M tonnes, assuming the biomass value of deciduous forest (Table 1). Thus there is a potential for these forest types to produce 1.32 M tonnes of vegetation biomass additionally. These additional 1.32 M tonnes of vegetation biomass would have sequestered 0.64 Tg of carbon from the atmosphere.

Estimation of soil organic carbon : The soil organic carbon (SOC) content of Kolli hill soils range from 0.1 per cent to 9.7 per cent, 0.1 to 5.38 per cent and 0.1 to 4.92 per cent in surface (Fig. 3), middle and bottom soil layers, respectively. The mean SOC contents of surface, middle and bottom layers are 1.40 (CI: 1.18, 1.63), 0.86 (CI: 0.73, 0.99) and 0.66 (CI: 0.55, 0.78) per cent respectively (Table 2). The mean SOC content between different forest types and between the three layers differ significantly as revealed from the ANOVA studies. In general, the distribution of SOC followed the order of surface > middle > bottom layer.

Soil organic carbon density : The data on SOC density of different forest types of Kolli hill is presented in Table 3. The highest mean SOC density is found in semi-evergreen forest 184 Mg ha^{-1} (CI: 139.19, 228.82). Among the other forests, the mean SOC densities are, 114.49 Mg ha^{-1} (CI:97.20, 131.78), 84.37 Mg ha^{-1} (CI: 63.82, 104.91), 76.85 Mg ha^{-1} (CI:61.85, 91.85), and 63.19 Mg ha^{-1} (CI:33.17, 93.22) in deciduous, secondary deciduous, southern thorn and *Euphorbia* scrub, respectively. The mean SOC density in the total Kolli hill is 96.05 Mg ha^{-1} (CI: 83.37, 108.73).

Total SOC stock in Kolli hill : The total SOC stock of Kolli hill is 3.48 Tg (Table 4). The SOC stock distribution in different forest types are as follows: semi-evergreen forest which occupies 14.9% of geographical area had a SOC stock of 1.01 Tg. The deciduous forest with an area occupying 47.7% to total RF had a SOC stock of 1.63 Tg. The SOC stock of other forest types are, secondary deciduous (0.35 Tg), southern thorn forest (0.46 Tg), and *Euphorbia* forest (0.03 Tg).

Net carbon stock in Kolli hill : The total biomass carbon of Kolli hill is 2.74 Tg and total SOC is 3.48 Tg. The ratio between SOC and biomass carbon is 1.18. Post *et. al.,* (1990) reported that the ratio between SOC and biomass carbon is 2.5 to 3 times in terrestrial ecosystem. However, the tropical forest the carbon in soil is roughly equivalent or lesser than the above ground biomass due to degradation (Budestag, 1990). In the case of Kolli hill, the carbon content in the soil is little higher than the above ground biomass carbon due to heavy exploitation of timber and sandal wood. Higher content of SOC than the above ground biomass carbon indicates that the sequestered SOC was result of its original vegetation what had, had in the past before exploitation.

Potential SOC content : The areas where the surface SOC content and surface to middle SOC ratios were below their respective lower confidence intervals were classified as areas below the potential SOC contents (degraded lands) using GIS software and the results are furnished in (Fig. 4 and Table 5). The lower confidence interval ($\alpha = 0.05$) of SOC and SOC ratio signifies that the probability of occurrence of surface SOC and/or the surface to middle layer SOC is 95 per cent. Hence it is

Table 3

Soil organic carbon density (t/ha) of different forest types Kolli hill

Forest type	Area (ha)	Soil Organic Carbon density (t/ha) (0 to 90 cm)		Confidence Interval (t/ha) (α=0.05)	
		Mean	SD	From	To
Very Dense Semi-Evergreen	1984.23	274.06	175.57	159.35	388.76
Dense Semi-Evergreen	978.42	233.65	193.92	89.99	377.31
Medium Semi-Evergreen	851.74	143.02	54.85	105.01	181.03
Degraded Semi-Evergreen	147.84	193.49	80.62	122.83	264.15
Total Evergreen	3962.23	184.00	123.13	139.19	228.82
Very Dense Deciduous	1772.34	146.14	45.45	117.98	174.31
Dense Deciduous	4471.51	111.41	45.50	91.95	130.87
Medium Deciduous	6440.89	91.60	76.18	46.59	136.62
Total Deciduous	12684.74	114.49	57.17	97.20	131.78
Secondary Deciduous	2960.28	84.37	45.69	63.82	104.91
Southern Thorn	6676.15	76.85	50.77	61.85	91.85
Euphorbia Scrub	304.40	63.19	50.81	33.17	93.22
Total Kolli Hills	26587.80	96.05	77.91	83.37	108.73

Table 4

Soil organic carbon storage and potential in different forest cover density in Kolli hill

Forest types	Area (ha)	SOC stock (Tg)		
		Actual	Potential	Difference
Total Evergreen	3962.23	1.01	1.05	0.05
Total Deciduous	12684.74	1.63	1.73	0.10
Secondary Deciduous	2960.28	0.35	0.38	0.03
Southern Thorn	6676.15	0.47	0.50	0.03
Euphorbia Scrub	304.40	0.03	0.04	0.00
Total Kolli hill	26587.80	3.48	3.69	0.21

Table 5

Soil organic carbon ratio between surface (0 to 30 cm) to middle (30 to 60 cm) layer and surface (0 to 30 cm) to bottom (60 to 90 cm) layer of different forest types of Kolli hill

Forest types	Area (ha)	Soil Organic Carbon ratio (ha)				Confidence Interval (ratio) (α =0.05)			
		Surface/middle		Surface/bottom		Surface/middle		Surface/bottom	
		Mean	SD	Mean	SD	From	To	From	To
Very Dense Semi-Evergreen	1984.23	1.97	1.20	3.65	4.01	1.18	2.75	1.03	6.27
Dense Semi-Evergreen	978.42	2.44	1.33	3.61	2.28	1.46	1.92	3.43	5.30
Medium Semi-Evergreen	851.74	1.60	0.36	3.13	2.27	1.35	1.56	1.85	4.71
Degraded Semi-Evergreen	147.84	3.03	2.31	3.25	2.59	0.43	1.89	0.46	2.13
Total Evergreen	3962.23	2.04	0.98	3.32	2.68	1.68	2.34	2.40	4.29
Very Dense Deciduous	1772.34	1.36	0.32	2.24	1.79	1.16	1.13	1.56	3.35
Dense Deciduous	4471.51	1.70	0.61	2.30	0.82	1.44	1.95	1.96	2.65
Medium Deciduous	6440.89	2.19	1.34	4.26	2.84	1.40	2.98	2.59	5.94
Total Deciduous	12684.74	1.75	0.85	2.80	1.94	1.49	2.00	2.22	3.39
Secondary Deciduous	2960.28	1.80	0.93	3.28	2.18	1.38	2.22	2.30	4.26
Southern Thorn	6676.15	1.72	0.99	2.50	2.73	1.42	2.01	1.70	3.31
Euphorbia Scrub	304.40	2.06	2.03	2.13	2.10	0.86	3.26	0.89	3.37
Total Kolli Hills	26587.80	1.83	1.05	2.83	2.40	1.66	2.00	2.44	3.22

assumed that it is possible to maintain either the surface to middle layer SOC ratio at 1.66 or the surface SOC content at 1.18 per cent with a probability of 95 per cent. In the absence of any historical inventory on SOC, the combination of the above said two criteria *viz*., surface to middle SOC ratio >1.66 and surface SOC >1.18 per cent is considered as threshold parameter to identify the degradation.

On an average, about 9,285.08 ha (34.2%) of the total Kolli hill soil is found to have surface SOC below the potential SOC contents. Of the 9,285.08 ha the deciduous forest occupies major area of 4,255.34 ha (46%), which is followed by southern thorn forest 3,325.30 ha (36%), secondary deciduous 1,082.68 ha (12%), the semi-evergreen and *Euphorbia* scrub occupy the remaining 6% of the area. Within different forest types, the highest proportion of area below potential surface SOC content (49.8%) was in southern thorn forest, which is followed by the *Euphorbia* scrub (43.0%). In the secondary deciduous, deciduous and semi-evergreen forests occupy 36.6, 33.5 and 12.4% respectively. If the gap between the actual surface SOC and potential SOC content is bridged, a total of 0.21 Tg of SOC can be sequestered in the surface layer of different forests of Kolli hill over and above the existing stock of 3.48 Tg. The improved SOC status will enhance the forest soil health and will pave way to improve the forest cover to its original glory. This will not only help to restore the original biodiversity, but also improve the climatic conditions in and around the Kolli hill.

When the forest area is degraded because of anthropogenic disturbances, surface soil gets exposed. The mineralization rate of SOC in the surface layer will be higher than the middle layer due to exposure to solar radiation and hence higher microbial decomposition rate. Hence, the impact of forest clearance will lower the surface layer SOC in a shorter time period than the middle layer SOC. In a moderate forest cover, where surface layer is least disturbed due to erosion or forest clearance, the surface to middle SOC ratio is maintained above 1.66 (lower confidence interval). Any accelerated degradation in the surface SOC will result in reduced surface to middle SOC ratio as the middle SOC is not affected. But relying only on the surface SOC to assess the degradation is difficult due to complete or partial removal of surface layer by erosion. At this juncture it is inferred that degradation has to be assessed based on the ratio of surface and middle layer for future management of forest. However, there must be a minimum level of 1.2% of soil SOC has to be maintained for the minimum support of the soil to the initial root proliferation tree species.

Minimum threshold of SOC for future management of forest

In the present study it has been inferred after repeated ground verification that in the same climatic and edaphic condition, wherever there is forest degradation, surface SOC and the surface to middle SOC ratio were lesser than the minimum threshold. Because SOM or humus generally accounts for 50 to 90 per cent of the cation adsorbing power of mineral surface soils. Humus colloids hold nutrient cations (potassium, calcium, magnesium, etc.) in exchangeable form, wherein they can be absorbed by plants and not readily leached out of the profile by percolating waters. In addition, nitrogen, phosphorus, sulfur, and micronutrients are stored as constituents of soil organic matter, from which they are slowly released by mineralization. Humic acids attack soil minerals and accelerate their decomposition, thereby releasing essential nutrients as exchangeable cations (Brady and Weil, 2002). In addition to that, SOM also acts as a binding agent and imparts structural stability. SOM also supplies energy and nutrients to consortia of soil microbes. In any stabilized soil eco-system, both addition of organic carbon and mineralization/humification are in equilibrium. Any disturbance to any one of these processes will affect the SOC content. Thus SOC act as a premier tool than that of all other soil properties in assessing the changes in both soil health and degradation. An extent of 9,285.08 ha of forest area, which is potentially degraded based upon the surface SOC content and surface to middle layer SOC ratio, has to be tackled with appropriate afforestation techniques and soil conservation measures. Therefore the prime target should be to upgrade the soil and aerial biomass of this locality.

Strategy for enhancement of soil and vegetation cover

Soil carbon can be conserved by physically modifying land configuration or by creating vegetative barriers to control the movement of soil. Those areas, which are susceptible for soil erosion, to be treated with contour bunding preferably with dry packed stones. Raising *Agave sissalana, Agave weightii, Commiphora berriyi, Commiphora caudate, Gliricidia sepium,* the promising species in this locality are preferable to check the soil erosion across the contour and gullies. Small dry stone gully plugging structures without much disturbance to soil may also contribute substantial soil conservation. Check dams of appropriate sizes are required to arrest the soil and water erosion and to recharge the ground water potential.

In the aforesaid low SOC area, the moisture retention is very poor due to low SOM and/or removal of top soil. The degraded soil layer does not permit the precious rain water to percolate down and make available for tree growth. Mineralization is also poor due to lack of SOM, eventually does not support tree growth. In such situation, soil ameliorants are highly warranted to create conducive soil climate to support tree growth. Increasing plant biomass is the only option to increase carbon in soils. Since degraded soil can not support higher plant biomass, they must be rehabilitated to sustain higher productivity of biomass through modern techniques.

Rehabilitation of degraded area with SOC below the minimum threshold

The major area that comes under the category falls in three forest types namely, secondary deciduous, southern thorn, and *Euphorbia* scrub forests. The floristic composition of these localities are *Acacia chundra, Albizia amara, Acacia leucophloea, Azadirachta indica, Acacia latronum, Commiphora berryi, Euphorbia antiquorum, Erythroxylon monogynum, Euphorbia nivulia, Dodonea viscosa, Dichrostachys cinerea,* etc. This area consists of very skeletal soil with exposed mineral layer, after years of soil erosion due to heavy exploitation of timber and grazing. Human induced fire for grazing purpose also caused considerable damage to this forest area and exposed the surface soil to direct sunlight. Hence, most of the areas are invaded with thorny shrubs and trees followed by heavy grasses and *Lantana camara* bushes. The surface soil carbon content is less than 1.18 per cent and supports only poor growth of tree species and more of shrubs and herbs. The exposed mineral layer and pebbles have no much of nutrient contents besides the less SOC content. It is highly warranted to emphasis that these areas have to be improved with soil amendments and nutrients. While planting tree species, a minimum of 60 cm deep pits must be dug and fertile imported soil (three fourth of pit volume) must be filled in addition to composted organic manure (one fourth of pit volume). Addition of organic manure is essential, apart from its physical and biological benefits, to release sufficient mineral nutrients needed for root growth and proliferation in the initial growth of the trees. This addition of organic manure might provide the microbial inoculum to subsoil area, which is poor in biological activity. In addition to mineralization of nutrients, these micro biota increase auxin content that invigorate the root proliferation when deep pits are prepared for planting. Well proliferated root system can withstand drought situation by foraging nutrients and water from a larger soil volume. Adequate supplement of major nutrients *viz.,* N and P may also be needed to boost up the initial root growth and proliferation. Yadav *et al.* (1975) recommended the application of 700 g single super phosphate and 400 g of ammonium sulphate in two equal splits. Only by achieving enhanced soil fertility status, one can bring back these areas with tree cover. Apart from this amelioration, aforesaid soil conservation measures are also required to up keep the area without any further erosion. While reforestation is being considered as mechanism, to reduce C emission, planting N- fixing legume species are more preferable, because, microbes manufacture enzymes to decompose organic substrates and enzymes require N. Microbes supplied with more N might produce more enzymes that speed up decomposition of organic litter (Aber and Melillo, 1991). It is important to recognize that, from a soil C sequestration standpoint, tree species differ in their effects. N- fixers sequester 0.05 to 0.12 kg $m^{-2}y^{-1}$ more C in their soils than non-N-fixers. Pure and mixed species of forests that include N-fixers appear to be an option for soil C sequestration in Tropical countries (Johnson, 1992; Cole *et al.,* 1995; Kaye *et al., 2000*). Several studies have shown good results of enrichment planting of native species in different areas (Butterifeld, 1997; Montagnini *et al.,* 1997; Parrota *et al.,* 1997; Ricker *et al.,* 1999; D'Oliviera, 2000). Thereby it has been proven that native species do have the potential to perform as well as or better than widely used, exotic species. Locally promising quick grown and drought enduring species such as *Albizia amara, Albizia lebbek, Albizia odoratissima, Chukrasia tabularis, Dalbergia latifolia, Garuga pinnata, Gmelina arborea, Melia azadirachta, Pterocarpus marsupium, Terminalia chebula, Terminalia tomentosum, Terminalia paniculata, Trema orientalis*, *Zizyphus oenoplia* can be planted in deciduous forest area. *Acacia chinensis, Acacia leucophloea, Acacia planiferan, Acacia chundra, Albizia amara, Albizia lebbek, Albizia odoratissima, Azadirachta indica, Hardwickia binata, Tamarindus indica, Tecomella undulata, Wrightia ticntoria, Zizyphus mauritiana* are good choice for planting in secondary deciduous, Southern thorn and *Euphorbia* forests.

Conclusions

Forest land under degradation has to be assessed based on SOC status – a fine tool to assess the land degradation rather than assessing the degradation by canopy density of forests as in the case of Forest Survey of India. In order to conserve existing biodiversity, the SOC must be improved and maintained at the identified minimum threshold levels (1.18 % of surface SOC or a surface to middle layer SOC ratio of 1.66). Mapping of SOC distribution on a GIS platform revealed its spatial distribution, based on which the site specific reforestation techniques for the management of degraded forest lands could be evolved, which helps in future monitoring. Areas with below minimum SOC threshold levels are to be treated with appropriate soil amendments including importing of fertile soil, addition of organic manure and supplementing major nutrients to enhance the soil health and biodiversity. Site specific choice of species is the most essential criteria preferably drought hardy C4 plants, legumes and nitrogen fixing tree species, which are capable of sequestering more CO_2 from the atmosphere in such degraded condition. Carbon management is indispensable in future forestry management in the context of mitigating climatic changes. Hence, carbon inventories and databank are prerequisite for future sustainable management of forests in India.

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SUMMARY

In response to growing concern on global climatic change, carbon management in forests is inevitable in order to offset the carbon emission in the atmosphere. Forests act as a sink for the CO_2 to mitigate the global climatic change. In developing countries like India, due to various need based forest management practices, cultivations, forest fire, etc, there has been a continuous loss of original biodiversity and soil. These degradations led to a loss of sequestered carbon of standing biomass and in the soil as well. The total area under forest cover in Kolli hills is about 27,103 ha. The total biomass carbon estimated is about 2.74 Tg. The total SOC estimated in the forest area is about 3.18 Tg. The ratio between the biomass carbon and SOC is much less than the tropical forests of the world. This indicates that there has been a heavy degradation of forest especially of forest soil. Hence, restoration of soil organic carbon (SOC) lost over the period of time due to anthropogenic interferences has to be built up and maintained with minimum threshold to support the tree growth. A pioneer attempt is made to identify the minimum threshold of surface SOC to the level of 1.2% to be maintained in the forest floor. This paper analyzes the intricacies of biomass carbon and SOC in a degraded condition. Detailed strategies for sustainable management of these degraded forests are discussed.

वन तल पर कार्बन प्रबन्धन : भारतीय वानिकी परिदृश्य में 21वीं सदी की कार्यसूची

ए० रामचन्द्रन, एस० जयकुमार, ए०आर० मोहम्मद हारून व ए० भास्करन्

सारांश

वैश्विक जलवायु परिवर्तन के प्रति बढ़ती हुई चिन्ता को देखते हुए वनों में कार्बन का प्रबन्ध करना अनिवार्य हो गया है जिससे वातावरण में आने वाली कार्बन को कम किया जा सके। वैश्विक जलवायु परिवर्तन को घटाने

के लिए वन कार्बन डायोक्साइड को डालने के निमज्जक कुण्ड का काम देते हैं। भारत जैसे विकासमान देशो में आवश्यकता आधारित वन प्रबन्धन विधियों, खेती, वनों में लगती आग इत्यादि के कारण उनकी मूल जैवविविधता और मृदा में निरन्तर क्षति होती रही है। इन व्याह्रासों ने वन में खड़े हुए जैवपुंज और मृदा में भी हुए कार्बन संचयन को हानि पहुंचाई। कोल्लि पहाड़ियों में वन लगा हुआ कुल भूमिक्षेत्र लगभग 27103 हेक्टेयर अनुमानित किया गया है। इसका कुल जैवपुंज कार्बन लगभग 2.74 ज्ह अनुमानित है। वन क्षेत्र का कुल मृदा जैव कार्बन लगभग 3.18 Tg अनुमानित है। जैवपुंज कार्बन और मृदा जैव कार्बन का अनुपात विश्व के उष्ण वनों की तुलना में काफी ज्यादा कम है। इससे संकेत मिलता है कि यहां के वनों विशेषतः वन मृदा में भारी व्याह्रास हुआ है। इसलिए पिछले समयों में मानवजनित हस्तक्षेत्र के कारण मृदा जैव कार्बन में हुए व्याह्रास को पुनर्स्थापित करके उतनी न्यूनतम सीमातक ऊपर उठाया जाना जरूरी है जिसपर वृक्ष वृद्धि कराई जा सके। यहां एक नया प्रयास किया गया है जिसमें मृदा जैव स्तर की भूतल पर न्यूनतम सीमा 1.2% ज्ञात की गई है जो वहां रहनी ही चाहिए। इस अभिपत्र में व्याह्रास दशाओं में जैवपुंज कार्बन और मृदा जैव कार्बन की बारीकियों का विश्लेषण किया गया है। इन व्याह्रासित वनों का दीर्घकाल तक टिकाऊ प्रबन्ध कैसे किया जाए इसकी समरनीतियों का विवेचन भी किया गया है।

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