Carbon Sequestration Potential of Indian Forestry Land Use Systems - A Review

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Abstract: Growing demand of land for crop production, commercial cattle rearing, fuel wood, charcoal, construction timber, urbanization and industrialization have resulted in loss of forests in the past. Forests being recognized as an important component of Carbon (C) cycle have gained importance owing to its potential to sequester C. As a result large-scale forest conservation and land developmental programmes have come up at regional, national and world level besides afforestation and reforestation activities are eligible in CDM and REDD plus. This requires development of baseline scenario and estimation of C stocks with periodic monitoring of carbon stock changes to address climate change. This paper aims at presenting an overview of estimates on C sequestration potential of varied forestry land use systems in India for country level and site-specific assessments.

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1. Introduction

The United Nations Conference of Parties (COP) held in Kyoto in 1997 adopted the Kyoto Protocol as the first step towards addressing climate change. The protocol shares the convention's objective principles and institutions, but significantly strengthens the Convention by committing Annex I parties to individual, legally binding targets to limit or reduce their GHG emissions. Among the three Kyoto mechanisms of Joint Implementation (JI), Clean Development Mechanism (CDM) and Emissions Trading (ET), only CDM is relevant to developing countries such as India. Developing countries could view CDM as an opportunity not only to attract investment capital and Environmentally Sustainable Technologies (ETSs) but also to implement innovative technical, institutional and financial interventions to promote energy efficiency, renewable energy and forestry activities that contribute to sustainable development. Projects specially designed and implemented in developing countries under CDM, leading to Carbon (C) emission reduction or sequestration will receive payments from institutions and agencies in (Annex I countries with commitment to reduce GHG emissions) countries for every tone of C emission avoided or sequestered. (Sathaye *et al.*, 2006). About 80% of the world's potential for increasing C storage in forests (estimated at 60-87 Pg C between now and 2050) lies in developing countries (Brown, 1995). History shows that deforestation continues until a nation's forests are nearly eliminated. Today, however, the Kyoto Protocol offers the opportunity to reverse past trends of deforestation before most forests are gone (Houghton, 2002).

C pools are components of the ecosystem that can either accumulate or release C and have classically been split into five main categories: living above-ground biomass (AGB), living below-ground biomass (BGB), dead organic matter (DOM) in wood, DOM in litter and soil organic matter (SOM). The classification of C pools is not strict and it is not the number of categories that is important but their completeness; pools must not be double-counted and significant pools should not be excluded (UNDP, 2009). The terrestrial ecosystem is a major biological scrubber of atmospheric Carbon dioxide that can be significantly increased by careful management. Absorbing Carbon dioxide from atmosphere and moving into the physiological system and biomass of the plants, and finally into the soil is the only practical way of removing large volumes of the major green house gas (CO_2) from the atmosphere into the biological system. (Ramachandran *et al*. 2007). C sequestration in forests occurs in living above ground biomass and living biomass of soil (roots and microbes) and recalcitrant organic and inorganic C in surface soil. Globally forests contain 54 percent of the total worldwide C pool (2200 Gt) of the terrestrial ecosystems (FAO, 2001). The forestry sector is one of the important sources of CO_2 emissions that accounts for 1.6 ± 0.8 Gtons of C annually. This constitutes 20 % of the global CO_2 emissions (Ravindranath and Murthy, 2003).

1.1 C sequestration potential in varied land resources

Forestry is broadly included under "Land use, Land use change and Forestry" (LULUCF) sector in climate convention. Forestry sector in the developing country provides large and relatively low cost mitigation opportunities (Brown *et al*., 1996; Sathaye and Ravindranath, 1998) to address climate change. Agricultural lands are believed to be a major potential sink and could absorb large quantities of C if trees are reintroduced to these systems and judiciously managed together with crops and /or animals. Thus, the importance of agroforestry as a land use system is receiving wider recognition not only in terms of agricultural sustainability but also in issues related to C sequestration or climate change (Verma *et al*., 2008). Assessment of C sequestration potential of native tree and shrub species and possible response of ligneous species towards elevated C level is yet at nascent stage. Time series database along human-use gradient on vegetation characteristics, soil, water and socio-economic pressures on the forests are needed to develop dynamic vegetation models (Melkania, 2009). The total C content of forests has been estimated at 638 Gt for 2005, which is more that the amount of carbon in the entire atmosphere. (FAO, 2007; Rawat, 2010)

1. Biomass Carbon

Biomass is defined as the total quantity of live and inert or dead organic matter, above and below the ground, expressed in t of dry matter per unit area, such as hectare. Biomass carbon = above ground biomass carbon+ below ground biomass carbon + dead organic matter. Above ground biomass is the most important visible and dominant carbon pool in forests and plantations, although not in grasslands and croplands (Ravindranath and Ostwald, 2008).

1.1. Country level estimates

Flint and Richards (1995) in one of their pioneering works on historic land use and carbon estimates for south and south east Asia reported that C content of live vegetation dropped progressively thorough out the century. The forest woodland contained more C than all other categories combined, but the proportion of total C in this class progressively declined throughout the century from 73 % in 1880 to 63 % in 1980 (Table: 1).

Table 1. Estimated C content of vegetation in each land-use category, from 1880 to 1980 for the study region.

	Estimated carbon content of vegetation (mt)			
Land use category	**1880**	**1920**	**1950**	**1980**
Net cultivated area	252.9	286.2	320.2	365.4
---Temporary crops	227.0	253.5	280.9	319.7
---Permanent crops	25.9	32.7	39.3	45.7
Settled build up area	4.6	6.0	8.3	14.0
Forest woodlands	4435.4	3654.8	3021.4	2209.6
Interrupted woods	835.5	729.9	657.5	546.2
Grass-shrub complexes	221.1	258.3	253.5	232.3
Barren-sparsely vegetated	8.7	8.1	7.0	5.9
Wetlands	354.4	257.6	182.7	112.8
Surface water	0.6	0.6	0.6	0.6
Total all categories	6113.1	5201.6	4451.1	3486.8

Source: Richards, 1995

Kishwan *et al*. (2009) conducted a study using primary and secondary data (Forest cover and expansion factors) from Forest Survey of India (FSI) and estimated that from 1995 to 2005, C in biomass of our forests have increased from 2692.474 to 2865.739 m t registering an annual increment of 173.265 m t of C during a decade (Table 2).

Table 2. Component-wise Carbon in India's Forests in 1995 and 2005 (m t)

Carbon	**1995**	**2005**	**Incremental Change**
In Biomass	2692.474	2865.739	173.265
In Soil	3552.304	3755.811	203.507
Total	6244.778	6621.55	376.772

Source: Kishwan *et al.*, 2009

According to study by Sathaye and Ravindranath (reported in Climate Change, 2001) 36.9 million ha degraded forestland with carbon mitigation potential of 74.75 tC/ha is available for regeneration in India with C abatement cost in the forestry sector in India can be the basis of attracting Global Environment Facility (GEF) funded projects (Lal, 2003). Using information from reports (FSI, 1999), about the area under plantation available till 1997, the annual litter fall C flux was computed for ten important forest species planted by various state forest departments across the country. Results reveal that litter production was highest in old (60 year) Sal plantation (11.27 t/ha/yr) while in case of other stands which are comparatively younger, the values varied between 1.30-4.94 t/ha/yr. Accordingly the litter fall C flux was highest in Sal and less in other species. Assuming the Sal stand to be an exception and hence excluded, the C flux rates in the other nine species ranges between 0.58 M t C/yr in case of *P. roxburghii*, which has high values of litter fall, closely followed by C flux from *Eucalyptus* spp. a genus with a wide range of distribution (Raizada *et al*., 2003).

Bhadwal and Singh (2002) has made a comparative estimate of land use and carbon sequestration (LUCS) potential of different forestry options for India in which three scenarios were generated viz. (LUCS-I, LUCS-II and LUCS-III) for a time period of 50 years starting from the year 2000 with different land use options following the demands and present land use pattern prevailing in the country. The scenario puts maximum amount of land into the forestry sector and is an economically feasible scenario. The scenario LUCS-II is a 'business as usual' scenario, as it is projected according to the current five-year plan. The scenario LUCS-III puts maximum amount of land in the plantations category and is a potential scenario. The amount of carbon sequestered in LUCS-III is estimated to be 6.937 billion t (Table: 3), which the highest among those sequestered in all the three scenarios.

Table 3. Change in Land use categories and associated carbon uptake during the time period 2000-50

Land category (mha)	2000	2050		
		LUCS-1	LUCS-II	LUCS-III
Closed forest	36.72	92.63	93.88	91.64
Degraded forest	84.9	0.1	0.83	1.1
Open forest	26.13	6.2	6.4	6.2
Permanent agriculture	141.73	130.18	129.88	130.18
Forest fallow	7.21	1.19	1.12	1.19
Net Carbon uptake	5.27	11.92	10.5	12.21

Source: Bhadwal *et al.*, 2002

1.2. Site-specific estimates

Taking into consideration the issues related to sustainable development criteria and suitability of land categories with respect to CDM activities, farm forestry would be an eligible activity. In the developing country context C sequestration through farm forestry is perhaps a highly desirable and cost effective way in 'high population scarce land availability' scenario. Based on the data gathered by TERI, Singh (2003) assumed the figure of 1500 trees per hectare, the total area of farm forests works out to 8200 ha (estimated available trees - 12.3 million divided by 1500) and assuming a modest woody biomass productivity of 4 t ha^{-1} yr^{-1}, the total woody biomass production worked out to 32800 t per year and the stored C as 16400 t per year. Afforestation and reforestation through resource management in the degraded CARs lands offer large sequestration potential due to its larger extent in the northwestern region of India.

A period of five years for carbon sequestration that has been assumed includes both above ground and below ground biomass and soil organic carbon. Total land available for the different forestry options is 77315.4 ha. Keeping low target, this area could sequester an amount of (1532358.8 Mg C in vegetation) with a sequestration rate of 3.9 Mg C ha-1 yr-1. Soil is estimated to hold 25.8% of the total Carbon as compared to 74.2 % sequestered by vegetation. In terms of biomass, the sequestration rate works out to be 6.13 Mg C ha-1 yr-1 (Singh *et al.*, 2003).

Rawat & Rawat (2003) reported that the potential yield of natural forests in India as (6m3/ha/yr) and emphasized that plantation crops like Eucalyptus are fast growing species can contribute and enhance the carbon sequestration potential of Indian forests. In a study (Pande, 2003) to assess sequestration potential of natural forests of Madhya Pradesh, the total carbon pool in standing crop was reported to be 363.01 m t for open forest. The scrubland contributed 2.74 m t of carbon in the pool. The contribution of litter was 9.425 m t. As far as bole biomass is concerned, dense and open forests contributed 247.40 m t and 56.58 m t, respectively, in the total bole C in standing crop (304.013 m t). The storage of total soil carbon is higher for dense forest (149.85 m t) as compared to open forest (16.860 m t). Rawat and Rawat (2003) in a study on climate change mitigation suggested various strategies for enhancement of C sequestration which include conservation and management strategy for dense forests, enhanced regeneration for open and degraded forests, farm forestry for marginal farmlands and boundaries of crop lands and plantations for forested and non forested wetlands for industrial and domestic purposes.

Ramachandran *et al.* (2007) in a study on estimation of C stock in Tamil Nadu using geospatial technology reported that the very dense semi-evergreen forests occupies 1984 ha which is 50% of the total semi-evergreen forest. About 25 and 21 % of the semi-evergreen forests are under dense and open respectively. Only 4 % is under degraded semi-evergreen. The deciduous forests comprise 46% of the total forested area. The very dense deciduous forest cover occupies 1772 ha, which is 14% of the total deciduous forest type. The dense and open deciduous density classes occupy 35 and 51% of the area respectively (Table: 4).

Table 4. Growing Stock, Biomass and Soil Carbon in Kolli Hills

Forest Type	Volume (m3/ha	Timber Biomass (tons/ha)	Branch and Foliage (tons/ha)	Stumps and Root (tons/ha)	Biomass (tons/ha)	Area of each forest (ha)	Total Biomass (M tons)	TOC A/G (Tg)	SOC stock (Tg)
Evergreen Forest	428.229	196.988	47.277	63.036	307.302	3962.23	1.22	0.6	1.01
Deciduous Forest	316.06	161.316	38.716	51.621	251.653	12684.74	3.19	1.57	1.63
Secondary decid.	216.673	154.983	37.196	49.595	241.773	2960.28	0.72	0.35	0.35
Southern Thorn	73.025	42.282	10.148	13.53	65.96	6676.15	0.44	0.22	0.47
Euphorbia scrub	52.72	36.859	8.846	11.795	57.5	304.4	0.02	0.01	0.03
Total	1086.707	592.428	142.183	189.577	924.188	26587.8	5.59	2.75	3.49

Lower value is the standard deviation of respective layers. Source: Ramachandran *et al.*, 2007

Gera *et al* (2006) carried out a study on C sequestration potential of agroforestry in Rupnagar district of Punjab and found that the total carbon that can be sequestered over the period of analyses varies between 59361 t for Eucalyptus bund plantation to 330510 t for Poplar block plantation. The block plantation also gave maximum sequestration potential of 115 t/ha that was higher by 79.69% and 105.34 % with respect to Poplar bund plantation and Eucalyptus bund planting respectively.

Tiwari (1995) using GIS technique found that C fixation and assimilation in Rajaji National Park Uttar Pradesh (Now Uttarakhand) is 92760×10^9 g out of which 7541.4×10^9 g is stored in above ground components and 1734.6×10^9 g as below ground components. According to Ravindranath *et al.* (1997) the standing biomass (both above and below ground) in India was estimated to be 8.375 m t for the year 1986, for which the C storage was reported to be 4178 m t. The total C stored in forests of India including soil was estimated to be 9578 m t. Later on a spatial analysis of phytomass C in Indian forests for the period (1988-94) was carried out at district level by (Chhabra, *et al*., 2002). The data was computed by combining remote sensing based forest area inventories on 1: 250,000 scale, field inventories of growing stock volume by FSI and crown density based biomass expansion factor. Of the total 386 districts examined, only 17 districts had more than 75 % forest cover. Estimated district level forest phytomass C densities ranged from 4 Mg C ha^{-1} to 206.8 Mg C ha^{-1}. At the national level forest phytomass was estimated to be 3871.2 to 3874.3 TgC. Kaur (2007) using satellite data and ground sampling tools estimated terrestrial biomass and organic carbon of different forest types in Govind Wildlife sanctuary and National Park (Uttarkashi, Uttarakhand) and found highest carbon (338.20 t/ha) in coniferous mixed forest and lowest (30.59 t/ha) in Pine mixed forest (Table 5).

Yadava (2010) carried out an experiment to investigate C sequestration in different agroforestry systems in Tarai region of Central Himalaya and found that C sequestration ranged from 4.66 to 18.53 t C ha^{-1}. Maximum value was recorded in systems S_1 (*Populus deltoides* 'G-48' + wheat) as 18.53 t C ha^{-1}, which was followed, by systems S_4 (*P. deltoides* + Lemon grass). Minimum C sequestration was recorded in System S_3 (P. deltoids + wheat boundary plantation). One of the studies carried out by (Chauhan and Gera, 2010) on the sequestration potential of medicinal tree species reports appreciable levels of carbon sequestration for the period of thirty years (2008-2038). After analysis of parameters for all species in a spreadsheet model PRO-COMAP, the best results were shown by *Terminali arjuna* (Arjun) with 137 t C and lowest storage potential shown by *Emblica officinalis* (Amla) with 48 t C with NPV positive for all the species.

Table 5. Terrestrial Biomass and carbon in different forest types

Vegetation Type	Biomass (t/ha)	Carbon (t/ha)	Soil Organic Carbon (%)
Pine forest	246.12	116.91	2.33
Pine mixed forest	64.41	30.59	1.36
Abies-Betula forest	NR	NR	NR
Coniferous mixed forest	712.2	338.2	3.56
Ban mixed forest	551.62	262.02	2.4
Betula-Simru forest	NR	NR	NR
Deodar forest	608.52	289.05	2.01
Moru mixed forest	124.2	59	2.4
Juglans mixed forest	603.09	286.47	4.67
Kharsu mixed forest	610.26	289.87	3.24
Total	3520.42	1672.11	21.97

Source: Kaur, 2007

Borah and Chandra (2010) in a study to estimate C sequestration potential of selected bamboo species of Northeast India reported highest total above ground carbon in *Bamboosa balcooa* (234.17 t ha^{-1}) followed by *Bamboosa tulda* (86.99 t ha^{-1}) and *Bambusa nutans* (63.25 t ha^{-1}). Sexana, *et al*. (2003) in another study estimated Forest Cover, Growing Stock and Biomass for the year 1984 state-wise for the whole country reported a total of

1083.81 (m t) of carbon for the year 1994 with Maharashtra topping the list with 198.43 (m t) of carbon.

2. Soil Organic Pool

The carbon held in the upper profile is often the most chemically decomposable and directly exposed to natural and anthropogenic disturbances (IPCC, 2003). The global forest ecosystem has been reported to account for approximately 90% of annual carbon flux between atmosphere and soil carbon (IPCC, 1996). Hence it soil as a component becomes tremendously important in assessing total carbon pool and its sequestration potential.

2.1. Country Level Estimates

A study was carried out by Jha *et al*. (2003) to estimate soil organic carbon store in different forests of India as per 1994 stands and reported highest organic pool in Sal (*Shorea robusta*) as 899.86 m t with sequestration potential of 119.38 ha^{-1}. Conifers showed maximum sequestration potential of carbon with Spruce (*Picea smithiana*) having the highest value of 386.00 t ha^{-1}. The study indicates the maximum contribution of broad leaved forests in SOC pool among major forest types in India (Table: 6).

Table 6. Soil Organic Carbon Store under major forest groups in India

Type	Forest (million ha)	SOC Pool (m t)	% of total
Conifers	41840	849.1	8.65
Broad Leaved	170603	2456.08	25.02
Mangroves	0.4598	39.23	0.4
Alpine Pasture	0.0067	1.74	0.018
Miscellaneous	40.7316	6469.81	65.912

Source: Jha *et al*., 2003

A significant study was conducted at country level, by Kishwan *et al.* (2009) to estimate stratified carbon in forests of India covering 571 soil samples in forests across the country. IPCC guidelines were followed and the study reported that an incremental change of 203.507 m t took place from 1995 to 2005. However highest positive net increment was shown by tropical moist deciduous forests 65626 m t and the least shown by tropical wet evergreen forest with a net negative increment of -4543.66 m t for the period (Table 7).

Table 7. Soil Organic Carbon Pool Estimates (0 - 30 cm) in India's Forests (m t) Area in 000 ha

Forest Type (Group)	Area 1995	Area 2005	SOC	SOC 2005
Himalayan dry temperate forest	31	32	1122.144	1158.343
Himalayan moist temperate forest	2230	2447	159616.937	175149.168
Littoral and swamp forest	383	481	27216.904	34181.021
Montane wet temperate forest	2583	2593	298233.293	299387.893
Sub alpine and alpine forest	2021	2067	149698.375	153105.661
Sub tropical broad leaved hill forest	260	303	22518.833	26243.102
Sub tropical dry evergreen forest	1223	1248	79836.78	81468.766
Sub tropical pine forest	4556	4743	229031.601	238432.151
Tropical dry deciduous forest	18233	19156	623475.447	655037.332
Tropical dry evergreen forest	134	165	7021.363	8645.709
Tropical moist deciduous forest	23091	24284	1270222.177	1335848.398
Tropical semi evergreen forest	2573	2946	140549.907	160925
Tropical thorn forest	1604	1827	32681.741	37225.399
Tropical wet evergreen forest	5040	5414	511078.124	549003.366
Total	63962	67706	3552303.628	3755811.31

Source: Kishwan *et al.*, 2009

2.2. Site Specific Estimates

Negi and Gupta (2010) conducted a study to assess soil organic carbon store under different land use systems in Giri Catchment of Himachal Pradesh and found that maximum SOC pool (93.47 t ha^{-1}) was in the soils where under Spruce and Fir with Kail and Quercus at higher altitude followed by soils under deodar forests (82.14 t ha^{-1}). SOC pool under hir and miscellaneous forests were more or less equal i.e. 57.33 t ha^{-1} and 57.66 respectively. Soils under Sal have the least SOC pool 47.29 t ha^{-1} (Table 8).

The SOC content of Kolli hills soils ranged from 0.1 to 9.7%, 0.1 to 5.38 % and 0.1 to 4.92 % in surface, middle and bottom soil layers respectively. The mean SOC contents of surface, middle and bottom layers were 1.40 (CI: 1.18, 1.63), 0.86 (CI: 0.73, 0.99) and 0.66 (CI: 0.55, 0.78) percent respectively (Ramachandran *et al*., 2007) (Table 9).

Table 8. Soil Organic Carbon pool (t ha^{-1}) under different land uses in Giri Catchments

	Forests	Soil Organic Carbon (t ha^{-1})
i)	Sal	47.29
ii)	Deodar	82.14
iii)	Chir	57.33
iv)	Kail+Silver Fir and Spruce; Kail+Quercus	93.47
v)	Miscellaneous	57.66
	Weighted Average SOC Pool under Forest	61.68

Source: Negi and Gupta, 2010

Table 9. Soil Organic Carbon % of different forest types in Kolli hills

		Soil organic carbon content (%)		
Forest Type	Area (ha)	Surface (0-30 cm)	Middle (30-60 cm)	Bottom (60-90 cm)
Very sense evergreen	1984.23	3.7	2.21	1.82
Dense evergreen	978.42	3.43	1.62	1.39
Medium evergreen	851.74	1.83	1.13	0.76
Degraded evergreen	147.84	2.4	1.1	0.91
Total evergreen	3962.23	2.9	1.58	1.27
Very dense deciduous	1772.34	1.72	1.31	0.98
Dense deciducous	4471.51	1.45	0.89	0.66
Medium deciduous	6440.89	1.14	0.66	0.42
Total deciduous	12684.74	0.92	0.93	0.67
Secondary deciduous	2960.28	0.78	0.6	0.39
Southern thorn	6676.15	0.68	0.55	0.44
Euphorbia scrub	304.4	1.4	0.4	0.37
Total Kolli hills	26587.8	1.4	0.86	0.66

Source: Ramachandran *et al., 2007*

In a study to assess sequestration potential of natural forests of Madhya Pradesh, the total C pool in the soils was reported to be 167.831 m t including scrublands. It is about 37.81 % of the total C in the biomass and 27 % of the total forest C pool. The total C pool including biomass, standing crop plus litter stock and soil was 623.305 m t (Pande, 2003). A study was conducted by Gupta and Sharma (2010) to assessed soil organic carbon under different land use systems in Champawat district of Uttarakhand and reported an average of 85.476 t ha^{-1} SOC pool for Champawat forests, the maximum being found under *Cedrus deodara* (106.19 t ha^{-1}), followed by miscellaneous (93.87 t ha^{-1}), *Quercus leucotrpchophora* (86.38 t ha^{-1}), *Pinus roxburghii* (66.42 t ha^{-1}) and *Shorea robusta* (44.00 t ha^{-1}) and soils supporting *Pinus wallichian*a had minimum (30.52 t ha^{-1}). (Verma, 2008) studied soil organic carbon and sequestration potential of Agroforestry Systems in Himachal Pradesh and found average carbon stocks (t ha^{-1}) in the decreasing order as Silvipasture (31.71), Natural grassland (19.2), Agri-horti-silviculture (18.81), Horti-pastoral (17.16), Agri-silviculture (13.37) and Agri-horticulture (12.28).

3. Conclusion

The pressure on India's forests continues to be very high, with more than 200 million people being dependent on forests for livelihood. The rapid growth of the Indian economy puts additional demands on forests for infrastructure and industrial development. There is an ever increasing demand for diverting forest lands for construction activities like dams, roads, power stations, townships etc. The variation in biomass and soil organic carbon content in different forestry systems observed can be linked to different reasons which may include, species, temperature, soil type, biotic pressure, management practices. Even the same species may have varying different carbon sequestration potential at a different location with a different set of physical features.

This call for rigorous carbon monitoring agencies at national level and individual studies at both national and sub-national level for periodic carbon assessment using approved refined methodology. In this context, scientific monitoring of the country's forests and tree cover is an important natural priority (FSI, 2009). C inventory leads to estimations of t of CO_2 emissions avoided by halting deforestation and fossil fuel substitution or, alternatively, estimation of t of C sequestered in biomass and soil as a result of enhancement of sinks through afforestation, reforestation and grassland reclamation activities. (Ravindranath, 2008).

Efforts are to be made for expansion of carbon pool on a sustainable growth model by planting the under-stocked forests and optimum utilization of over-stocked forests with due consideration to the needs of people. (Srivastava, 2007) suggested some measures for the expansion of carbon sequestration in existing forest as under-planting, increased length of rotation period, shifting to fast growing tree species, modifying thinning practices and implementing measures aimed at increasing the C pool in the organic matter of forest soils.

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