parts of the city around industrial area, Janta Nagar and along Ludhiana-Ambala G. T. Road. Local pollution plumes exist around Budha Nallah which flows in a lowlying area and is one of the palaeochannels of River Sutlej as revealed by LANDSAT and IRS data. Ludhiana city is located in an upland area. As already mentioned, ground water flow direction is from south-east to north-west, i.e. towards the Budha Nallah. The main cause of groundwater pollution in Ludhiana is attributed to the disposal of industrial effluents on land without treatment in the city industrial area which get infiltrated down into the aquifer system and not the Budha Nallah. The Budha Nallah, however, receives sewage, industrial effluents from 20 points and pollutes the river Sutlej further downstream. Local pollution plumes, however, around Budha Nallah do occur.

It is suggested that remedial measures to control pollution of groundwater such as treatment of industrial effluents before disposal, setting up of special courts for summary trials and setting up of treatment plant for sewage need to be taken up on priority besides generating environment awareness amongst industrialists and the general public. In the critical polluted areas demarcated, installation of shallow tubewells/hand pumps should be banned. The area also requires regular monitoring of the quality of groundwater.

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Potential of wastelands for sequestering carbon by reforestation

Raj K. Gupta and D. L. N. Rao

Central Soil Salinity Research Institute, Karnal 132 001, India

Indian soils are largely carbon-depleted but can be brought back to their native carbon-carrying capacity by reforestation. The current stock of organic carbon in Indian soils (24.3 Pg) can be increased to 34.9 Pg, the difference representing the potential for sequestering additional carbon in soils. Reforestation of 35 m ha of wastelands with suitable tree and grass species can sequester 0.84 and 1.06 Pg of carbon in vegetation and soil respectively. Restoration, maintenance and enlarging the carbon stocks of Indian soils are an urgent developmental priority.

THE increasing levels of CO_2 in the atmosphere leading to global warming, rise of sea level etc are a potentially serious threat to agriculture and environment[1]. The impact of global warming on soils is immediate because soils interface between geosphere and environment. Soil temperature affects the decomposition of soil organic matter[2,3], nutrient uptake and plant growth. Increasing soil temperature combined with aridity causes extensive loss of organic carbon from soils[2]. However, with reforestation and other suitable measures for ecological rehabilitation, it is possible to increase carbon levels of tropical soils[4–6]. Increasing CO_2 levels in the environment may also increase plant growth in some instances[7,8]. Soils and vegetation therefore represent potential sinks for this additional carbon[9] and reforestation had been suggested as a possible means of mitigating global warming[10,11]. However, quantitative studies are few and it is important to know what kinds of soils store substantial carbon below ground and devise suitable soil, water and crop management strategies to increase this capacity.

Each soil has a carbon-carrying capacity i.e., an equilibrium carbon content depending on the nature of vegetation, precipitation and temperature[2]; when the equilibrium is disturbed as for example by forest clearing, intensive cultivation etc., soil carbon rapidly declines. In the arid and semi-arid zone tropical soils, as for example in India, nearly 50% of the carbon is lost[2]. Jenny and Raychaudhuri's classical study on Indian soils[12], showed depletion to be as high as 60–70% in many soils. Many of the arid zone soils are affected by high salinity and alkalinity and become barren[13]. Wastelands in India are estimated at over 100 million ha[14] (of which 70% are badly degraded) and are extremely carbon-depleted; organic carbon can be as low as 0.2%. Soils with the greatest potential for C accumulation are those that are severely C-depleted but still retain the requisites (eg., nutrients, biology and structure) for primary production or can be suitably managed to increase productivity in the short term. Several experiments in India[4,5,15] show that extremely carbon-depleted sites like salt-affected soils have a relatively high potential for accumulating carbon in vegetation and soil if suitable tree and grass species are grown along with proper soil conservation measures to conserve rain water[16]. After restoration of the lost carbon it is possible to enlarge the stocks as demonstrated in studies in partially reclaimed soils[6] which rapidly accumulate C if planted by suitable multipurpose tree species.

The present carbon stocks of Indian soils, covering 328.5 m ha were calculated using organic carbon data of soil profiles of 32 benchmark[17] and 16 other sites characterized later[18] which are the representative sites for all 12 soil classes in 22 agro-ecological regions of India. Soil depth averaged 38 cm (range 20 to 61 cm) for the surface and sub-surface layers and total profile depth averaged 137 cm (range 44 to 186 cm) with a bulk density averaging 1.55–1.60 Mg m^{-3}. Carbon content (Mg ha^{-1}) of surface, sub-surface soil and the rest of the profile was calculated (in cm) as a product of the depth of the horizon, bulk density and % organic C content and summed up to arrive at the total C content. Data of all profiles in each sub-group was averaged and multiplied with area of that sub-group in million ha to arrive at current stocks (Pg). The current total stocks are estimated at 24.3 Pg of carbon (Table 1).

Table 1. Current and potential stocks of organic carbon in Indian soils, 1 Pg = 10^{15} g

Soils	Area (m ha.)	% of total area	Carbon content (kg/m^2)	Carbon stocks (Pg)	% of total carbon	Carbon carrying capacity (Pg)
Red loamy	50.5	15.3		4.20	17.3	6.01
Eastern ghats (T. N uplands) and Deccan plateau			9.5	2.15		3.08
Eastern plateau (Chhotanagpur plateau)			6.6	1.85		2.67
Andaman & Nicobar Islands and Lakshadweep			24.8	0.20		0.26
Red and Lateritic soils	20.8	6.3		1.99	8.2	3.22
North Eastern hills			8.1	0.87		1.49
Western ghats & W. coastal plain			11.1	1.12		1.73
Red and yellow soils						
Eastern plateau (Chattisgarh region)	13.3	4.0	4.6	0.60	2.5	0.85
Shallow & medium (inclusion deep) black soils	33.0	10.0	8.2	2.71	11.1	3.57
Deccan plateau						
Medium and deep black soils	26.6	8.1		2.45	10.0	3.30
Central highlands (Malwa region & Kathiawar peninsula)			7.4	1.36		1.94
Central highlands (Malwa and Bundelkhand)			8.5	1.09		1.36
Mixed red and black soils	39.2	11.9		4.75	19.5	6.51
Deccan plateau			9.8	0.46		0.69
Deccan plateau and Eastern ghats			13.0	2.71		3.59
Deccan plateau central highlands (Bundelkhand)			11.5	1.58		2.23
Coastal alluvium derived soils	8.1	2.5	5.3	0.43	1.8	0.70
Eastern coastal plains						
Alluvium derived soils	66.1	20.1		3.77	15.5	5.65
Northern plains and C. highlands			3.7	1.21		1.81
Northern plain			5.3	0.65		0.95
Eastern plain			6.7	0.62		0.88
Assam & Bengal plains			11.0	1.29		2.01
Desert (& saline) soils	29.6	9.0	2.8	0.84	3.4	1.30
Western plains & Kutch peninsula						
Brown & red hill soils	8.0	2.4	12.9	1.04	4.3	1.68
Eastern Himalayas						
Shallow & skeletal soils	15.6	4.7	1.2	0.19	0.8	0.28
Western Himalayas						
Brown forests & podzolic soils	17.7	5.4	7.7	1.36	5.6	1.87
Western Himalayas						
Total	328.5			24.33		34.93

The potential stocks were estimated by assuming that currently depletion is 50% in surface and sub-surface and 10% in the rest of the profile[2,12]. Thus potential stocks were calculated to be 34.9 Pg (Table 1) and the difference of 10.6 Pg was taken to represent the potential for sequestering additional carbon in soil.

Sequestration of carbon implies not only increasing the amount of carbon entering the soil but also a decrease in the amount leaving either through decomposition or erosion[19]. For example, land levelling, reclamation of alkali soils by gypsum application, irrigation, cropping, planting of tolerant multi-purpose tree species, fertilization, drainage of saline soils etc. can lead to rapid restoration of vegetation cover and increase of soil carbon as shown in many studies in India[4,5,15]. Growth of tolerant grasses like *Leptochloa* along with tree species like *Acacia*, *Prosopis* in silvi-pastoral systems in degraded sites in 4 to 7 year rotations have yielded biomass of 20 Mg ha^{-1} yr^{-1} for tree and 4 Mg ha^{-1} for the grass, along with dramatic increases in soil carbon even in 4 years[15]. Growth of high nitrogen-fixing tree species like *Sesbania* rapidly increased soil carbon even of moderate sites in field studies[6].

For calculating carbon sequestration in vegetation we have assumed that reforestation is attempted in 35 m ha (half the badly degraded sites) @ 5 m ha yr^{-1} for 7 years so that at the end of the period one afforestation cycle with MPTS is completed. Assuming 80% sapling survival and 60% productivity of research farms the biomass productivity of tree + grass reduces to a conservative figure of 12 Mg ha^{-1} y^{-1} or about 6 Mg C ha^{-1} y^{-1}, i.e. sequestration of 0.03 Pg C in 5 m ha in first year rising to 0.21 Pg in seventh year. When all the target area is afforested by the seventh year the total C sequestered in vegetation works out to 0.84 Pg. Assuming that soils achieve their potential carbon-carrying capacity in 7 years, C sequestration in soils in 35 m ha would be 1.06 Pg. Modifying factors such as the likely increases in biomass production due to CO_2 fertilizing effect[7] on the positive side, increased CO_2 emissions from soils due to global warming[3,20] on the negative side have been ignored. The total C thus sequestered, 1.9 Pg in 7 years would offset a great proportion of CO_2 emissions from India which work out to 2.27 Pg (CO_2–C) in 7 years according to a 1989–90 estimate[21].

However, even such a massive afforestation programme may not significantly reduce the CO_2 concentration of the atmosphere or slow down warming because of the global nature of the problem. Some researches have even demonstrated no significant sequestration of carbon in vegetation[20] and soils[22], and our results may be due to the extremely carbon-depleted sites in tropics in general and degraded soils in particular. But it must be recognized that once the forests are cut and reverted to agriculture, CO_2 emissions will follow because of rapid microbiological decomposition of organic matter. Burning of woody biomass will also lead to additional C emissions and therefore the benefits are likely to be temporary. Even so reforestation and restoring carbon to carbon-depleted soils should be an urgent priority in tropics for the additional reason of reducing soil erosion, maintaining soil fertility, ecological rehabilitation etc. After restoration, it is equally important not only to maintain it but also enlarge the soil-carbon pool by suitable management strategies[19]. Such measures may be the most feasible options at present for slowing global warming[23] even though future salvation will lie in cutting down fossil fuel consumption and greater dependence on renewable natural resources.

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