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Carbon stocks in soils of Gondia district, Maharashtra under different land use systems

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ABSTRACT

We explored and compared the quantities and pattern of soil carbon (C) stock in soils under forest, paddy and forest to paddy converted land use systems in Gondia district, Maharashtra. Forest soils were considered as "Control" and used as reference (base level) for the comparative study on C-stock and C-sequestration potentials. The major production related constraints of the soils developed in mixed basaltic were acidity and inherent nutrient stock. Recently converted forest land to paddy (i.e. land under paddy for >10 years) has resulted in highest loss in soil organic carbon (SOC) followed by soils growing paddy for more than 100 years. The area being agro-ecologically homogenous have similar soil matrix, the differences in estimated SOC stocks are presumably due to variation in land use & the management practices. The study showed increase in SOC with the duration of paddy cultivation upto 50 years and subsequently it stabilises. Increase in SOC stocl after 50 years of paddy cultivation was rather insignificant. Any endeavour to further sequester carbon beyond this limit will call for improved management strategies. The study demonstrates that the scope of sequestering organic carbon in the soils that are recently brought under plough for paddy and lost their SOC would need foremost care for prioritization for carbon sequestration.

Key words : *Carbon stock, land use systems, forest, paddy, Carbon sequestration*

Introduction

Human civilization is currently being threatened by two serious problems namely, i) food insecurity and ii) climate change. Interestingly, both of them are linked to carbon cycling of the earth. Soils are the largest carbon reservoir of the terrestrial carbon cycle. Soils store two or three times more carbon than that exists in the atmosphere as CO_2 (Davidson *et al.*, 2000) and 2.5 to 3 times as much as that stored in plants (Post and Mann, 1990 and Houghton, 1990). Carbon storage in soils is the balance between the input of dead plant material (leaf and root litter) and losses from decomposition and mineralization processes (heterotrophic respiration).

World mineral soils have major carbon reserves to a tune of 1150-2200 Pg C (Post *et al.*, 1982; Eswaran *et al.*, 1993; Batjes, 1996), 1580 Pg C (Schlesinger, 1985; Andrews *et al.*, 2000 and Houghton, 2005) in 1m soil profile. World soils contain an important pool of active carbon (C) that plays a major role in the global carbon cycle (Lal, 1995; Melillo *et al.*, 2002 and Prentice, 2001) and therefore, the part it plays in the mitigation of atmospheric levels of greenhouse gases (GHGs), with special reference to CO_2. Soil organic carbon is thus an extremely valuable natural resource. Irrespective of the climate debate, the SOC stock must be restored, enhanced and improved. Low soil organic matter (SOM) in tropical soils, particularly those under the influence of arid, semi-arid, and sub humid climates, is a major factor contributing to their poor productivity (Syers *et al.*, 1996 and Katyal *et al.*, 2001). Therefore, proper management of SOM assumes importance in sustaining soil productivity in tropical soils and ensuring food security (Scherr, 1999). Maintaining or improving organic C levels in tropical soils is, however, more difficult because of rapid oxidation of organic matter under prevailing high temperatures (Lal, 1997; Lal *et al.*, 2003). Restoration of soil quality through soil organic carbon (SOC) management is a major concern for tropical soils. To sustain their quality and productivity, knowledge of SOC in terms of its amount and quality needs to be improved.

There is a rapid change in SOC within the first 5-25 years, with losses ranging from 25 to 75 % in the uppermost soil horizon with a change from forest to agriculture (Lal *et al.*, 1995).The conversion of native ecosystems, such as forests, prairies, and wetlands, leads almost invariably to losses in vegetation and soil C stocks. Carbon (C) storage in forest ecosystems involves numerous components including biomass C and soil C. The total ecosystem C stock is large and in dynamic equilibrium with its environment. Because of the large areas involved at regional/global scale, forest soils play an important role in the global C cycle (Detwiler and Hall, 1988; Bouwman and Leemans, 1995; Richter *et al.*, 1995; Sedjo, 1992; Jabaggy and Jackson, 2000). Land use change causes perturbation of the ecosystem and can influence the C stocks and fluxes. In particular, conversion of forest to agricultural ecosystems affects several soil properties but especially soil organic carbon (SOC) concentration and stock.

Methodology

Present study was carried out in Gondia District which is situated in the western Indian state of Maharashtra and located between latitudes 20°39' and 21°38' North and longitudes 79°27' to 80°42' East. It is newly formed district and carved out by the division of Bhandara district in May 1999. The adjoining districts to Gondia are on northern side Balaghat district, Madhya Pradesh and on eastern side Rajnandgaon district of Chattisgarh state. To the south and west are Chandrapur district and Bhandara district of Maharashtra. It is located in the north-eastern part of the state and is bordered by the states of Chhattisgarh and Madhya Pradesh.

Three transects one each in Goregaon, Amgaon and Salekasa tehsils of Gondia district (representing major paddy growing soils of different ages in Gondia) were selected and studied. In each transect 3 to 4 soil profiles were selected. Paddy, the only major crop, extensively cultivated under rainfed and irrigated conditions ranging from over 10 years (after forest clearing) to centuries were selected along with a profile representing forest soil (least affected by the anthropogenic activities) was selected as control or base line in each of three transects. Survey of India topo-sheet (1:50,000) and satellite image (LISS-3) were used in identifying the sites.

The samples were air-dried, ground in a wooden pestle and mortar and passed through a 2 mm sieve for subsequent analysis. The pH, electrical conductivity, organic carbon, bulk density and mechanical analysis were determined by standard method (Jackson, 1973) and are reported in table1 as weighted mean.

The soil carbon stocks were estimated by mass,

Table 1. Physical properties of soils (weighted average)

Pedon No. (Site)	Depth (cm)	Clay (%)	Bulk Density (Mg m^{-3})	AWC (%)
Transect-I (Goregaon)				
Pedon 1 (Assalpani)	110	50.6	1.67	11.2
Pedon 2 (Bagarban)	113	58.3	1.74	11.6
Pedon 3 (Assalpani)	120	31.8	1.70	10.4
Pedon 4 (Bagarban)	118	44.2	1.78	9.8
Transect-II (Aamgaon)				
Pedon 5 (Waghdongari)	115	42.7	1.53	11.6
Pedon 6 (Waghdongari)	125	48.0	1.88	14.2
Pedon 7 (Pauldauna)	127	22.1	1.68	11.7
Pedon 8 (Pauldauna)	105	49.6	1.86	11.5
Transect-III (Salekasa)				
Pedon 9 (Salekasa)	116	55.0	1.42	11.4
Pedon 10 (Nimba)	117	40.8	1.43	12.6
Pedon 11 (Nimba naka)	80	29.3	1.47	13.1

volume and density relationship (Batjes, 1996) and reported in table 2. The SOC pool ($Mgha^{-1}$ for a specific depth) was calculated by multiplying the SOC concentration (gkg^{-1}) with bulk density (Mgm^{-3}) and depth (m).

$$C\ Stock_{Depth} = TC\ (i) * BD\ (i) * TH\ (i) * 10^{-3}\ MgKg^{-1} * 10^{4}\ m^{2}\ ha^{-1}$$

Where,C Stock (Depth) = Cumulative Soil Carbon Stock ($Mgha^{-1}$)

TC(i) = Total soil C concentration in the *i*th layer (g C kg^{-1})

BD (i) = Bulk density of the *i*th layer (Mgm^{-3})

TH (i) = thickness of *i*th layer (m)

Results and Discussion

The soils, mostly developed in basaltic alluvium are, in general, deep, medium to fine textured, well to moderately well drained, slightly to moderately acidic with low to medium cation exchange capacity and low to medium organic carbon content. The soils were classified as Vertic Haplustalfs, Vertic Endoaquepts, and Vertic Haplustepts. Bulk density of the surface soils, in general, ranged from 1.18 to 1.73 Mg m^{-3} and that of sub soils were observed to range from 1.19 to 1.95 Mg m^{-3}.The bulk density of forest soils was less than those of cultivated soils.

Table 2. Chemical properties of soils (weighted average)

Pedon No. (Site)	Depth	pH	EC	OC	$CaCO_3$	Exchangeable cations [cmol(p^+)kg^{-1}]				CEC
				(%)		Ca	Mg	Na	K	
			Transect-I (Goregaon)							
Pedon 1 (Assalpani)	110	6.47	0.04	0.54	0.71	15.8	8.5	0.26	0.16	30.6
Pedon 2 (Bagarban)	113	6.49	0.04	0.25	0.70	17.3	10.9	0.29	0.59	46.1
Pedon 3 (Assalpani)	120	6.32	0.03	0.37	0.29	13.5	6.8	0.27	0.27	24.7
Pedon 4 (Bagarban)	118	6.65	0.04	0.28	0.56	13.3	4.4	0.43	0.19	25.6
			Transect-II (Aamgaon)							
Pedon 5 (Waghdongari)	115	6.31	0.07	0.56	0.32	12.1	4.9	0.22	0.23	25.9
Pedon 6 (Waghdongari)	125	7.52	0.08	0.21	1.14	19.2	4.6	0.31	0.29	28.0
Pedon 7 (Pauldauna)	127	5.82	0.06	0.31	0.07	8.3	4.3	0.34	0.16	18.6
Pedon 8 (Pauldauna)	105	5.85	0.04	0.32	0.22	12.1	7.7	0.50	0.32	37.9
			Transect-III (Salekasa)							
Pedon 9 (Salekasa)	116	5.91	0.06	1.19	0.04	17.6	8.2	0.35	0.33	32.6
Pedon 10 (Nimba)	117	6.55	0.12	0.23	0.19	7.3	4.1	0.45	0.35	22.5
Pedon 11 (Nimba naka)	80	5.91	0.11	0.40	0.05	7.2	1.7	0.33	0.24	14.9

Table 3. Soil carbon stock (tons/ha) for 30 cm depths

Profile No	Land use	SOC	SIC	TC
	Transect-I (Goregaon)			
P1	Open forest	15.86	0.81	16.67
P2	More than 10 years paddy cultivation (Rainfed)	8.60	0.67	9.27
P3	More than 50 years Paddy cultivation (Rainfed)	11.63	0.68	12.31
P4	More than 100 years paddy cultivation (Rainfed)	11.57	0.0	11.57
	Transect-II (Aamgaon)			
P5	Open forest	12.99	0.48	13.48
P6	More than 10 years Paddy cultivation (Rainfed)	6.29	1.93	8.22
P7	More than 50 yrs paddy (Irrigated)	12.59	0.0	12.59
P8	More than 100 years paddy cultivation (Rainfed)	12.51	0.0	12.51
	Transect-III (Salekasa)			
P9	Dense forest	50.19	0.0	50.19
P10	More than 10 years Paddy cultivation (Rainfed)	9.29	0.18	9.46
P11	More than 100 years paddy cultivation (Irrigated)	13.34	0.0	13.34

The results revealed that conversion of forestland to paddy cultivation significantly increased soil bulk densities. The bulk density of all paddy growing soils, recently brought under cultivation, exhibited slight increase down the profile to a depth of 60 cm followed by gradual declination.

The surface soils were acidic with pH ranging from 4.94 to 6.26. Wide variation was observed in organic matter concentration. Forest soils were richer in organic carbon concentration (0.77 to 2.51 %) than the paddy growing soils (0.32 to 0.68 %). Irrespective of land use, the soils were found to be inadequate in nutrient stock.

Forest soils, being the least disturbed by anthropogenic activities like agriculture, were selected as control for the present study. In each of the three transects chosen, a forest soil (contiguous to the cropland) was identified as control. Pedons-1, 5 and 9 were selected as control or baseline for transect-I, II and III respectively. The soils of dense forest (Control) were found to hold the highest SOC stock of 50.19 tons/ha followed by those of open forests (ranging from 12.99 to 15.86 tons/ha). The SOC stocks in the recently converted forest to paddy ranged from 6.29 to 9.29 tons/ha. The SOC stocks of 50 and 100 years old paddy growing soils varied narrowly and ranged from 11.57 to 13.34 tons/ha. The estimates of SOC stocks clearly indicate that recent (more than 10 years) conversion of forestland into agriculture (namely paddy) resulted in huge loss of SOC (Ranging from 45.8 to 81.5 %of control soil) in the surface soil to a depth of 30 cm. The SIC pools were very low and showed considerable variation both spatially and vertically. Low SIC stock is attributed to the acidic nature of the soils. A positive impact of the duration of paddy cultivation on SOC stock was noticed where there was a gain of SOC stock (ranging from 34.5 to 100.1% to a depth of 30 cm) in soils under paddy for more than 50 years as compared to that under the same crop for over 10 years. The SOC stocks showed narrow variations among the soils under paddy for more than 50 years and those of 100 years indicating that minimum duration of 50 years is required for stabilizing SOC under the present pedo-climatic settings. Irrigated paddy was found to sequester more SOC as compared to rainfed paddy. The SOC stock estimates revealed that most soils are much below their potential level because of huge carbon loss. Therefore, the scope of sequestering organic carbon in these soils is immense. The potential to sequester organic carbon in the soils under open forest was estimated to the tune of 34.3 to 37.2 tons/ha by way of good management practices. Recently converted forestland into agriculture resulted in huge loss of SOC stock, ranging from 6.29 to 40.9 tons/ha in the surface soil to a depth of 30 cm. These are most affected soils where SOC can be sequestered well to the extent ranging from 6.7 to 40.9 tons/ha following modern methods of cultivation instead of traditional ones. Although the soils under paddy cultivation over 50 years showed a state of SOC stabilization (SOC pools ranged between 11.57 and 13.34 tons/ha), good management /intervention strategies can improve

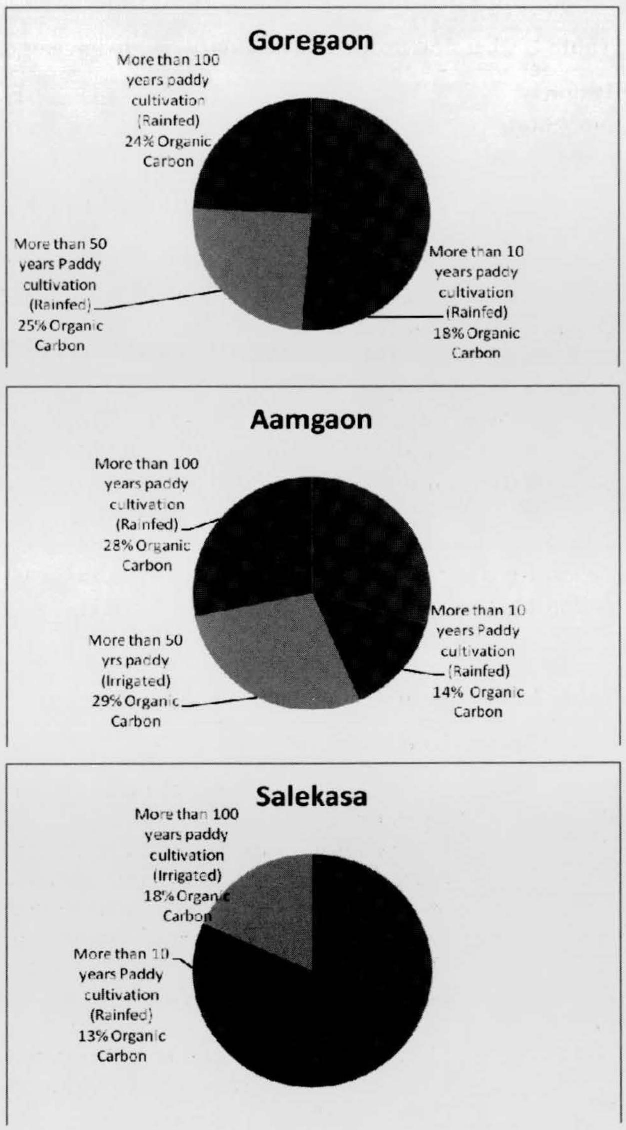

Fig. Organic carbon stock in different land use systems in Goregaon, Aamgaon and Salekasa tehsil of Gondia.

organic carbon health of these soils by sequestering SOC to the extent of 36.8 to 37.6 tons/ha.

The results conclusively indicate that the soils those are recently brought under plough (paddy) lost their SOC the most. Therefore, these soils need to be prioritized for carbon sequestration followed by the soils under paddy for over 50 years. Balanced fertilization in combination with FYM could be the possible best option for sequestering SOC in these soils.

The soils under the open forest also exhibited considerable loss of SOC due to soil erosion and lack of soil conservation measures. These soils need immediate and adequate attention to control soil erosion and enhance SOC through sequestration. Nevertheless, the soils under dense forest too deserve due care to elevate its existing SOC stocks by way of proper management and maintaining the bio-diversity.

Conversion from natural to agricultural ecosystems changes soil organic carbon (SOC) pools, the magnitude of changes depends on land use, management, and ecological factors, such as, temperature, precipitation, soil types and native vegetation. Quantification of changes in the SOC pool as a result of agricultural land use provides a reference point regarding sequestration potential of SOC through improved management. Setting the baseline is important for SOC stock estimation and comparing the C sequestration potential of various land use systems.

Conclusion

It may be concluded that conversion from natural to agricultural ecosystem brings in a considerable loss in SOC stock. Moreover, since most soils in the present investigation are much below their potential level in SOC stock (because of huge carbon loss), the scope of sequestering organic carbon in these soils is immense. Further, the stabilization of SOC stock in soils that remained under paddy cultivation for a period of more than 50 years under the existing conditions point at the maximum sequestration potential of these soils. Any endeavour to further sequester carbon beyond this limit will call for improved management strategies.

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