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Effect of land use and bio-climatic system on organic carbon pool of shrink-swell soils in Vidarbha region, Maharashtra

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Abstract : Representative shrink-swell soils from central India were investigated to identify different fractions of total soil organic carbon (TOC) that influence active and passive pools which, in turn, control lability of organic carbon in soils. Bio-climatic systems and land use (cropping pattern and management) often control these pools. TOC was hitherto considered as the most important soil quality parameter (SQP). It is now realized that instead of TOC, its fractions are more important in terms of growth of plants and trees suggesting that active pool of TOC could be a better SQP than the TOC itself. The datasets of these shrink-swell soils indicated the exact land use practices to increase active pool of TOC and thus help in sequestering more organic carbon in soils. Such datasets should act as a model understanding to maintain soil health and combat global warming.

Additional key words : *Global warming, total soil organic carbon*

Introduction

Soil carbon is important as it determines ecosystem and agro-ecosystem functions, influencing soil fertility, water-holding capacity and other soil parameters. It is also of global importance because of its role in the global carbon cycle and, therefore, the part it plays in the mitigation of atmospheric levels of greenhouse gases (GHGs) with special reference to CO_2 due to global warming (Bhattacharyya *et al.* 2008a). Different authors have attempted to estimate soil organic carbon stocks at the global level with varying results (GEFSOC 2006). Batjes (1996) updated the earlier estimates and highlighted the importance of the tropics for global soil carbon storage. Enrichment of soils with organic carbon to minimize global warming and ensure global food security has also been postulated (Lal 2004).

A prudent approach to ensure organic carbon sequestration by soils requires information on content of carbon. Organic carbon, which is intimately incorporated into soil and in equilibrium with the soil environment is referred to as 'humus'. Its chemical composition is variable and fluctuates with time, a fact which complicates its extraction and determination (Hesse 1971). Special technique are, therefore, required for its determination.

Research findings suggest that certain fractions of organic matter are more important in maintaining soil quality and thus could be an important indicator to assess the impact of management practices (Camberdella and Elliot 1992; Chan 1997). The conventional methods used to determine soil organic carbon were developed to maximize oxidation and recovery of carbon (Walkley and Black 1934; Nelson and Sommers 1982). Interestingly, TOC measurement might not be a sensitive indicator to represent SQP. Adoption of procedures that can extract relatively labile fraction of organic carbon might be a more useful approach to find out the influence of different management practices on TOC. Blair *et al.* (1995) used the amount of soil organic carbon oxidizable by potassium permanganate as a measure of TOC lability. These authors showed a decline of a more labile form of organic carbon in soils under agricultural crops, in contrast to the accumulation of more labile form under a legume pasture of lucerne.

It has been reported that TOC follows different processes for its stabilization within the soil environment. To understand these processes, TOC has been separated into labile (or actively cycling) and stable (resistant or recalcitrant) pool in view of their different residence time. The labile carbon pool of TOC has been reported to have rapid turnover rates which effect very fast oxidation of these pools as carbon dioxide from soils to atmosphere. The labile pool of carbon has been the main source of nutrition which influences the quality and productivity of soil (Chan *et al.* 2001; Majumdar *et al.* 2008, Mandal *et al.* 2008). The resistant pool of organic carbon is slowly altered by microbial activities (Weil *et al.* 2003). Due to its stable nature, this resistant pool may not be considered as a good SQP, although it will contribute towards overall stock of TOC (Mandal *et al.* 2008).

A number of studies have been conducted to find out the relative share of active (labile form of TOC) and passive (stable or resistant form of TOC) pools. Most of these studies are restricted to the temperate part of the globe (Weil *et al.* 2003). Recent efforts to fractionate TOC in Indian soils following the standard methods (Walkley and Black 1934; Chan *et al.* 2001) have been limited to soils of the Indo-Gangetic Plains (IGP) and that too their surface horizons only (Majumdar *et al.* 2008). Using microbiological methods, different pools of TOC in soils have been tried (Manna *et al.* 2005) which is also limited to soils of the IGP. No efforts were so far made to sub-fractionate organic carbon in shrink-swell soils to show their importance in soils. It is in view of this we attempt to find out exact TOC pool to represent SQP in these soils. These soils are exposed to relatively high atmospheric temperature causing depletion of organic carbon (Bhattacharyya *et al.* 2008a). Besides estimating different pools of TOC, the present effort aims at finding the influence of land use and bioclimatic system on these pools. In the event of increased temperature due to global warming, these selected soils from central part of India might thus represent actual scenario depicting natural process of change in TOC pool in a relatively high temperature regime. The study will establish which pool of TOC should be representative of SQP.

Materials and Methods

Study area

The study area falls in the Vidarbha region (18°45′ and 21°45′N latitudes and 76°0′ and 81°0′E longitudes) situated in the eastern part of Maharashtra state, India. This region consists of eleven districts and occupies a total geographical area of about 97 lakh hectares accounting for 31.6% area of the state. The annual rainfall varies from 687 to 1551 mm distributed over 60 to 70 days. The mean annual air temperature varies from 25 to 29°C. High temperatures of 45°C or more are witnessed during April, May and June while low temperature of 8 to 10°C is recorded in the months of December and January. Keeping in view the dominant soils in the study area (Challa *et al.* 1999), eleven benchmark spots were selected for the present study (Fig. 1). These sites represent four distinct bio-climatic regions *viz* sub-humid moist (SHm), sub-humid dry (SHd), semi-arid moist (SAm) and semi-arid dry (SAd) under three land use systems *viz* agriculture, horticulture and degraded forest (Table 1) (Shrikant 2008).

Oxidizable soil organic carbon and its pool

The oxidizable total soil organic carbon (TOC) was determined by wet oxidation (Walkley and Black 1934). This was approximated into different pools by the modified Walkley and Black method as described by Chan *et al.*(2001) using 5, 10 and 20 ml of concentrated (36 *N*) H_2SO_4 that resulted in three acid-aqueous solution ratios of 0.5:1, 1:1 and 2:1 (corresponding to 12, 18 and 24*N* of H_2SO_4, respectively). The amount of C thus determined all-owed the sub-fractionation of TOC into the following

Table 1. Lability index of TOC *vis-a-vis* climate and soil management practices

District	Soil Series	Soil classification [k]	MAR, mm	MAT ^0C	Fertilizer dose (kg/ha) N	P	K	FYM t/ha	LI (cm) 0-50	50-100	100-150	Land Use (crops)
					Sub-Humid Moist (>1100mm) [l]							
Gadchiroli	Kurul [a]	Ustic Endoaquerts	1551	28	23	16	-	6	0,966	0,844	0.786	Paddy-Mung/Gram
Bhandara	Dighori [b]	Chromic Haplusterts	1388	26	103	18	10	4	0.826	0.344	0.801	Paddy-Chickpea
Gondia	Rajegaon[b]	Vertic Haplustalfs	1363	27	69	48	-	6	0.771	0.721	0.917	Paddy-Mustard
Chandrapur	Haldi[c]	Vertic Haplustalfs	1312	28	-	-	--	--	0.812	0.676	0.451	Degraded Forest
Nagpur	Linga[d]	Typic Haplusterts	1242	25	-	-	--	--	1.172	1.373	1.081	Citrus
Wardha	Brahmni[e]	Typic Haplusterts	1134	28		48	--	20	0.535	0.656	0.355	Banana
Yavatmal	Pahur[f]	Sodic Haplusterts	1133	28	40	20	20	2	1.236	1.233	0.951	Cotton + Pigeonpea-Sorghum / Gram (2 years)
					Sub-humid Dry (1100-1000mm)							
Amravati	Asra[g]	Typic Haplusterts	976	27	120	120	--	30	0.919	0.910	1.029	Soybean - Pigeonpea
Washim	Hisai[h]	Chromic Haplusterts	926	29	46	46	25	30	0.841	0.699	0.931	Cotton/Jowar/ Soybean-wheat/gram
					Semi-arid moist (1000-850mm)							
Buldhana	Dhanora[i]	Vertic Haplustepts	901	27	45	45	25	3	0.746	1.346	1.485	Cotton - Sorghum
					Semi-arid dry (850-550mm)							
Akola	Paral[j]	Sodic Haplusterts	687	26	60	40	---	--	0.626	0.624	0.631	Cotton+Pigeonpea - Sorghum

[a] one bag urea, 18:18:10 and a trolley FYM/acre
[b] one bag SSP (single super phosphate), a bag of urea, and a trolley FYM/acre
[c] The site is sloping and under degraded forest. The upper part of this site was dominated by red soil with thick vegetation of different forest species. This particular site represents black soils and is without any forest species management (Bhattacharyya *et al*. 2008b)
[d] This site was old experimental area for citrus cultivation. Natural vegetation consisting of thick population of native grasses increased TOC
[e] High level management 3 bags of SSP, 2 Bags of DAP (1 bag ~ 50kg) and 4 to 5 trolly FYM/acre
[f] Conventional farming with cotton and pigeonpea intercropping, fertlizer and FYM are also applied (Venugopalan *et al*., 2004)
[g] 15--20 cartloads FYM,120 N,120 P_2O_5: cotton +green gram+pigeon pea (Venugopalan *et al*., 2004)
[h] DAP 25 kg/acre, SSP 50 kg/acre, 18:18:10 mix fertilizer and 5-6 trolly FYM
[i] 18:18:10 and15:15:10 mix fertilizer, 2-3 tonnes cowdung (Shrikant 2008)
[j] 40-60 kg N/ha and 30-40 kg P_2O_5/ha with no amendment
[k] Soil Survey Staff (2003)
[l] SHm – sub-humid (moist) (mean annual rainfall >1100 mm); SHd – sub-humid (dry) (mean annual rainfall 1100-1000 mm); SAm – Semi-arid (moist) (mean annual rainfall 1000-850 mm); SAd – Semi-arid (dry) (mean annual rainfall 850-550 mm) (Bhattacharyya *et al*. 2008b)

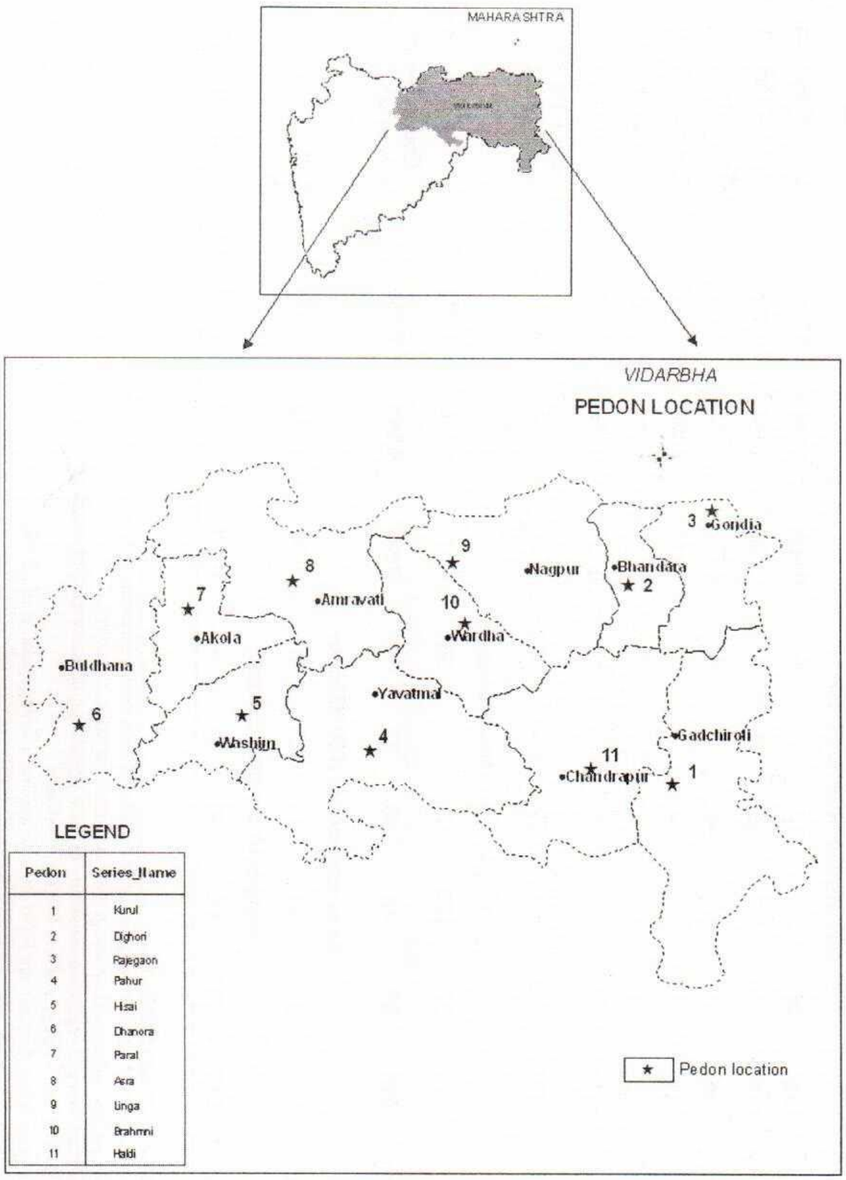

Fig. 1. Pedon location in the study area

four different pools according to their decreasing order of oxidizability.

Pool I (C_{VL} very labile soil carbon) : Organic C oxidizable by 12*N* H_2SO_4

Pool II (C_L labile soil carbon) : The difference in C oxidizable by 18 *N* and that by 12 *N* H_2SO_4

Pool III (C_{LL} less labile soil carbon) : The difference in C_{tot} oxidizable by 24 *N* and that by 18 *N* H_2SO_4

Pool IV (C_{NL} non labile soil carbon) : The difference between TOC and oxidizable C by 24 *N* H_2SO_4

The pool I and II together represent the active pool [active pool = Σ (pool I + Pool II)] while pool III and pool IV together constitute the passive pool [Passive pool = Σ (pool III + Pool IV)] of TOC in soils (Chan *et al.* 2001).

Lability index of TOC

A lability index (LI) for TOC was computed by first expressing the amount of each of the three labile pools namely C_{LL}, C_L and C_{VL} as a fraction of total organic carbon and then multiplying the fraction with their respective weightages of 3, 2 and 1 given on the basis of ease of their oxidation and finally adding and averaging them (Majumdar *et al.* 2008; Mandal *et al.* 2008). Accordingly LI is calculated using the following equation :

$$\text{Lability Index} = \frac{C_{VL}}{C_{tot}} \times 3 + \frac{C_L}{C_{tot}} \times 2 + \frac{C_{LL}}{C_{tot}} \times 1 \ldots\ldots (a)$$

The values thus obtained are compared for assessing the relative performance of different treatments in maintaining labile soil organic C at different depths.

According to equation (a) if the entire amount of TOC is very labile (C_{VL}) then LI should be 3.0 for a soil containing one per cent of native TOC. On the contrary, for the same soil, assuming 100% TOC in non-labile form (C_{NL}), LI value should be zero. Equation (a) also suggests that different degrees of weightage assigned in three different forms of carbon (C_{VL}, C_L and C_{LL}) produce different values of LI. These values were assigned on the basis of relative ease of the oxidation of C_{VL}, C_L and C_{LL}. Ease of oxidation indirectly controls the ease of availability of respective fractions of TOC for plant. From this point of view, C_{VL} and C_L are considered as the active pool of TOC.

Results and Discussion

Effect of bio-climate and land use on TOC and its fractionation

Total organic carbon (TOC) content, in general, decreased with depth with some exception in all the four bio-climatic systems (Table 2). In SHm bioclimate, very labile form of carbon (C_{VL}) was not found in Kurul, Dighori, Rajegaon, Haldi and Brahmni soils and in sub-surface horizons of Linga soils. Pahur soils contained C_{VL} which shows a decreasing trend with depth. Labile, less labile and non-labile forms of carbon (C_L, C_{LL} and C_{VL}) also decreased with depth with some exception. Similar trend of distribution of these four subfractions of TOC was observed in soils of other bioclimatic systems (Table 2). Hisai and Dhanora soils did not contain C_{VL}.

Citrus-growing Linga soils contained C_{VL}. Soils under agricultural land use systems showed C_{VL} when legume was part of the cropping pattern. A decline in more labile form of TOC in soils under agriculture was earlier reported; although it was found to be accumulated in legume growing areas (Blair *et al.* 1995).

Distribution of active and passive pool of TOC

Table 2 shows the distribution of various pools of TOC in horizon-wise soil samples. Passive pool always remained dominant over the active pool in these soils. Active and passive pools ranged between 6 to 42 per cent and 52 to 93 per cent of TOC, respectively in the seven soils (SHm) (Table 2). Active and passive pools in Hisai and Asra soils (SHd) ranged between 21 to 44 per cent and 58 to 79 per cent, respectively. For soils of SAm and SAd, these values were 7-65 per cent and 35-93 per cent, respectively (Table 2). Active pool of carbon gradually decreased in drier tracts (SAm and SAd) with a corresponding increase in those of passive pool carbon as compared to wetter areas (SHm and SHd) (Fig. 2).

Effect of land use on different pools of TOC

Average (weighted mean) of active and passive pools of TOC for 0-50 cm depth is shown in table 3. Nearly 12 to 44 per cent of TOC was found to be in active pool for all the soils under agriculture. In paddy soils, active pool of carbon was maximum in Rajegaon soils (44 per cent) (Table 3). In cotton growing soils, active pool of carbon gradually decreased with decrease in rainfall. In horticultural land use, the soils under citrus stored more active pool of carbon in surface soils than those under banana (Table 3). In general, agricultural system stored 12-44, horticulture 22-37 and forest 31 per cent C in active pool. In agricultural landuse, paddy system stored more C in active pool than cotton (Pahur soils).

Lability index for TOC in different bioclimatic systems

Sub-fractions of C (C_{VL}, C_L and C_{LL}) were assigned different weightages to estimate lability index (LI). High LI usually corresponds to high C_{VL} and / or C_L indicating a larger active pool of carbon in soil.

Table 2. Sub-fractionation of organic carbon from soils under different bio-climatic regions

Depth of soil (cm)	C_{VL} %	C_{L} %	C_{LL} %	C_{NL} %	TOC %	Active Pool (%)	Passive Pool (%)
Sub-Humid Moist (> 1100 mm)							
Kurul (Gadchiroli : MAR 1551 mm) (agriculture: paddy)							
0-12	0.00(0)	0.62 (35)	0.23 (13)	0.90 (51)	1.75	0.620 (35)	1.130 (65)
12-28	0.00(0)	0.21(36)	0.02 (3)	0.31 (57)	0.54	0.214 ((40)	0.327 (60)
28-50	0.00(0)	0.119 (40)	0.02 (7)	0.18 (58)	0:32	0.113 (360	0.205 (64)
50-76	0.00(0)	0.04 (18)	0.03 (12)	0.15 (70)	0.21	0.039 (18)	0.175 (82)
76-101	0.00(0)	0.01 (6)	0.00 (2)	0.15 (82)	0.16	0.010 (60	0.151 (94)
101-126	0.00(0)	0.02 (14)	0.00 (2)	0.13 (84)	0.16	0.023 (14)	0.138 (86)
126-150	0.00(0)	0.03 (40)	0.01 (14)	0.03 (40)	0.06	0.029 (46)	0.035 (54)
Dighori (Bhandara : MAR 1388 mm) (agriculture: paddy)							
0--13	0.00(0)	0.42 (38)	0.08 (7)	0.59 (55)	1.08	0.416 (38)	0.664 (62)
13--27	0.00(0)	0.13 (32)	0.05 (12)	0.22 (56)	0.40	0.126 (32)	0.270 (68)
27--53	0.00(0)	0.09 (31)	0.01 (3)	0.20 (66)	0.30	0.091 (31)	0.205 (69)
53--76	0.00(0)	0.05 (21)	0.03 (12)	0.16 (67)	0.24	0.051 (21)	0.192 (79)
76--105	0.00(0)	0.09 (33)	0.06 (23)	0.11 (44)	0.26	0.086 (33)	0.174 (67)
105--160	0.00(0)	0.11 (41)	0.03 (11)	0.13 (49)	0.27	0.111 (41)	0.162 (59)
Rajegaon (Gondia : MAR 1363 mm) (agriculture: paddy)							
0--10	0.00(0)	0.38 (41)	0.10 (11)	0.45 (48)	0.93	0.384 (41)	0.551 (59)
10--25	0.00(0)	0.13 (44)	0.04 (12)	0.13 (43)	0.29	0.128 (44)	0.161 (56)
25--55	0.00(0)	0.10 (48)	0.01 (3)	0.10 (49)	0.20	0.098 (48)	0.105 (52)
55--74	0.00(0)	0.03 (30)	0.02 (17)	0.05 (54)	0.10	0.029 (30)	0.069 (70)
74--107	0.00(0)	0.05 (34)	0.02 (16)	0.07 (50)	0.14	0.050 (34)	0.095 (66)
107--150+	0.00(0)	0.04 (36)	0.01 (11)	0.06 (53)	0.11	0.040 (36)	0.072 (64)
Haldi (Chandrapur : MAR 1312 mm) (degraded forest)							
0-14	0.00(0)	0.08(30)[a]	0.06(21)	0.13(48)	0.26	0.079(30)[a]	0.181(70)
14-46	0.00(0)	0.17(31)	0.11(20)	0.26(49)	0.54	0.166(31)	0.371(69)
46-82	0.00(0)	0.06(30)	0.02(10)	0.12(60)	0.20	0.059(30)	0.139(70)
82-114	0.00(0)	0.05(26)	0.02(13)	0.11(61)	0.18	0.047(26)	0.135(74)
114-135	0.00(0)	0.03(15)	0.01(7)	0.14(78)	0.18	0.027(15)	0.149(85)
Linga (Nagpur : MAR 1242 mm) (horticulture – citrus)							
0--16	0.31(32)	0.07(7)	0.05(5)	0.56(56)	0.99	0.386(39)	0.604(61)
16--44	0.22(35)	0.01(1)	0.13(20)	0.28(44)	0.63	0.225(36)	0.402(64)
44--69	0.00(0)	0.16(34)	0.04(8)	0.29(59)	0.49	0.165(34)	0.327(66)
69--102	0.00(0)	0.17(34)	0.04(8)	0.29(58)	0.50	0.170(34)	0.334(66)
102--128	0.00(0)	0.16(36)	0.01(2)	0.27(62)	0.44	0.158(36)	0.278(64)
128--150+	0.12(30)	0.01(3)	0.02(5)	0.25(62)	0.40	0.132(33)	0.269(67)

Depth of soil (cm)	C_{VL} %	C_L %	C_{LL} %	C_{NL} %	TOC %	Active Pool (%)	Passive Pool (%)
Brahmni (Wardha : MAR 1134 mm) (horticulture – banana)							
0--13	0.00(0)	0.33(35)	0.15(16)	0.45(49)	0.93	0.326(35)	0.603(65)
13--32	0.00(0)	0.18(30)	0.02(3)	0.39(67)	0.58	0.177(30)	0.408(70)
32--59	0.00(0)	0.08(23)	0.01(2)	0.25(75)	0.33	0.077(23)	0.255(77)
59--81	0.00(0)	0.11(34)	0.02(8)	0.18(58)	0.31	0.108(34)	0.206(66)
81--115	0.00(0)	0.06(24)	0.03(13)	0.17(63)	0.26	0.063(24)	0.199(76)
115--145	0.00(0)	0.01(7)	0.01(4)	0.14(89)	0.16	0.010(7)	0.147(93)
Pahur (Yavatmal : MAR 1133 mm) (agriculture – cotton/pigeonpea)							
0--19	0.28(30)	0.07(8)	0.11(12)	0.45(49)	0.91	0.349(38)	0.561(62)
19--40	0.26(40)	0.01(1)	0.04(5)	0.35(53)	0.66	0.270(41)	0.386(59)
40--78	0.24(38)	0.01(2)	0.04(6)	0.34(54)	0.63	0.253(40)	0.372(60)
78--122	0.15(32)	0.05(11)	0.02(4)	0.25(54)	0.47	0.200(42)	0.273(58)
122--150	0.09(14)	0.13(19)	0.02(3)	0.45(64)	0.69	0.225(32)	0.469(68)
Sub-humid Dry(1100-1000mm)							
Hisai (Washim : MAR 926 mm) (agriculture – cotton)							
0--10	0.00(0)	0.11(34)	0.01(4)	0.21(62)	0.33	0.114(34)	0.220(66)
10--31	0.00(0)	0.11(42)	0.03(11)	0.12(48)	0.26	0.110(42)	0.153(58)
31--53	0.00(0)	0.06(37)	0.01(5)	0.10(58)	0.16	0.060(37)	0.104(63)
53--81	0.00(0)	0.03(21)	0.01(5)	0.11(74)	0.15	0.032(21)	0.116(79)
81--114	0.00(0)	0.09(44)	0.01(4)	0.11(52)	0.21	0.093(44)	0.120(56)
114--150	0.00(0)	0.09(43)	0.02(8)	0.10(49)	0.20	0.086(43)	0.115(57)
Asra (Amravati : MAR 976 mm) (agriculture – soybean)							
0--14	0.17(22)	0.07(9)	0.08(10)	0.46(59)	0.77	0.239(31)	0.534(69)
14--35	0.11(17)	0.07(11)	0.10(15)	0.37(56)	0.66	0.187(28)	0.477(72)
35--69	0.11(19)	0.02(4)	0.14(25)	0.30(52)	0.57	0.133(23)	0.436(77)
69--107	0.09(12)	0.18(24)	0.05(7)	0.41(57)	0.73	0.263(36)	0.463(64)
107--150	0.15(24)	0.07(11)	0.06(10)	0.35(55)	0.63	0.225(36)	0.409(64)
Semi-arid moist (1000-850mm)							
Dhanora (Buldhana : MAR 901 mm) (agriculture – cotton)							
0--9	0.00(0)	0.14(28)	0.10(20)	0.26(52)	0.50	0.139(28)	0.364(72)
9--28	0.00(0)	0.08(22)	0.09(24)	0.20(53)	0.38	0.085(22)	0.295(78)
28--45	0.00(0)	0.08(24)	0.09(28)	0.16(48)	0.33	0.082(24)	0.252(76)
45--61	0.00(0)	0.06(55)	0.00(3)	0.05(42)	0.12	0.064(55)	0.053(45)
61--91	0.00(0)	0.03(65)	0.01(19)	0.01(16)	0.05	0.034(65)	0.018(35)
Semi-arid dry (850-550mm)							
Paral (Akola : MAR 687 mm) (agriculture – cotton/pigeonpea)							
0--9	0.10(14)	0.01(2)	0.19(27)	0.40(57)	0.70	0.115(16)	0.589(84)
9--35	0.06(1)	0.02(4)	0.16(30)	0.30(56)	0.54	0.077(14)	0.465(86)
35--69	0.02(3)	0.02(4)	0.19(35)	0.31(57)	0.54	0.039(7)	0.500(93)
69--105	0.05(8)	0.06(10)	0.14(23)	0.36(59)	0.61	0.111(18)	0.500(82)
105--132	0.04(6)	0.05(7)	0.15(23)	0.41(63)	0.66	0.091(14)	0.569(86)
132--150	0.02(3)	0.13(20)	0.13(21)	0.34(55)	0.62	0.144(23)	0.476(77)

[a] *Parentheses show percent of TOC*

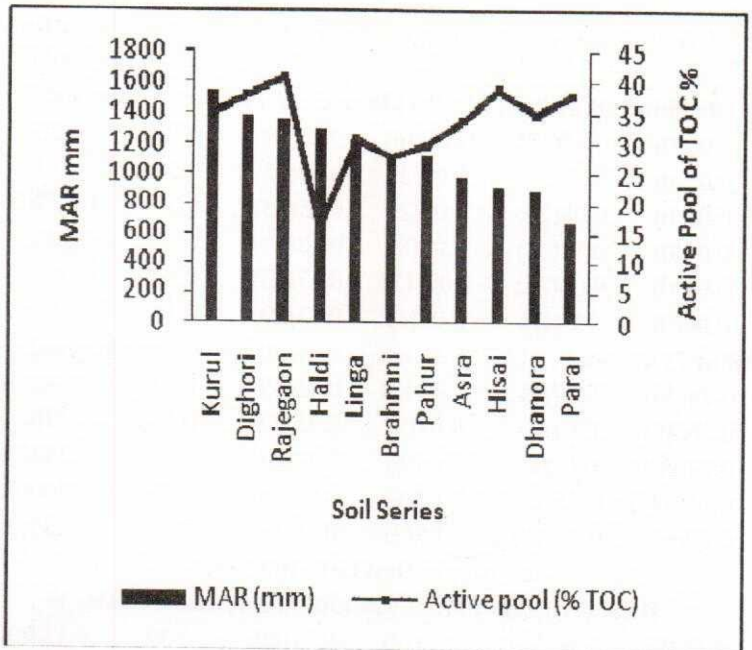

Fig. 2. Distribution of active pool of TOC (0-50 cm soil depth) as influenced by rainfall

Table 3. Active and passive pools of soil organic carbon in different land use systems

Sl No	District	Soil Series	MAR (mm)	Active pool[a]	Passive pool[a]	MAT ^{0}C
			Agriculture (Paddy)			
1	Gadchiroli	Kurul	1551	36	64	27
2	Bhandara	Dighori	1388	35	65	26
3	Gondia	Rajegaon	1363	44	56	28
			Agriculture (Cotton)			
4	Yavatmal	Pahur	1133	40	60	28
5	Washim	Hisai	926	38	62	29
6	Buldhana	Dhanora	901	25	75	27
7	Akola	Paral	687	12	88	26
			Agriculture (Soybean)			
8	Amravati	Asra	976	28	72	27
			Horticulture			
9	Nagpur	Linga	1242	37	63	25
10	Wardha	Brahmni	1134	22	78	28
			Forestry			
11	Chandrapur	Haldi	1312	31	69	28

[a] *values are for 0-50 cm of soil depth and expressed as percent of total soil organic carbon.*

Linga and Pahur soils registered very high LI as compared to other soils in the same bioclimatic region (Table 4). This is because Linga and Pahur soils, representing SHm bio-climate contain 31-35 per cent C_{VL} which has appreciable contribution towards LI. C_{VL} was not found in other five soils (Kurul, Dighori, Rajegaon, Haldi, and Brahmni) of this bioclimate. Similar observations were made when LI values are compared with soils under SHd and SAm bioclimatic systems. Relative proportion of C_{VL} and C_L, the two important components of LI decide its value in Paral and Brahmni and the three paddy-growing soils. (Table 4).

Table 4. Lability indices for soil organic carbon in different bioclimatic systems and land use (for Ap horizon only)

District	Soil Series	C_{VL}	C_L	C_{LL}	C_{NL}	TOC	LI
			Sub-Humid moist(>1100 mm)				
Gadchiroli	Kurul	0.000	0.62 (35)	0.23 (13)	0.90 (51)	1.75	1.22
Bhandara	Dighori	0.000	0.42 (38)	0.08 (7)	0.59 (55)	1.08	0.852
Gondia	Rajegaon	0.000	0.38 ((41)	0.10 (11)	0.45 (48)	0.93	1.301
Chandrapur	Haldi	0.000	0.08 (30)	0.06 (21)	0.13 (48)	0.26	0.846
Nagpur	Linga	0.31 (32) [a]	0.07 (7)	0.05 (5)	0.56 (56)	0.99	1.131
Wardha	Brahmni	0.000	0.33 (35)	0.15 (16)	0.45 (49)	0.93	0.871
Yavatmal	Pahur	0.28 (30)	0.07 (8)	0.11 (12)	0.45 (49)	0.91	1.198
			Sub-Humid dry (1100-1000 mm)				
Amravati	Asra	0.17 (22)	0.07 (9)	0.08 (10)	0.46 (59)	0.77	0.949
Washim	Hisai	0.000	0.11 (340	0.01 (40	0.21 (62)	0.33	0.670
			Semi-arid moist (1000-850mm)				
Buldhana	Dhanora	0.000	0.14 (28)	0.10 (20)	0.26 (52)	0.50	1.080
			Semi-arid dry (850-550mm)				
Akola	Paral	0.10 (14)	0.01 (2)	0.19 (27)	0.40 (57)	0.70	0.729

[a] *Parentheses show percent of TOC.*

Lability index for TOC in different land use systems

Lability indices were high in soils under agriculture (paddy, cotton, soybean) and horticulture (citrus) in various depth intervals (0-50, 50-100, 100-150 cm) (Table 1). Cotton cultivation produced different values of lability indices ranging from 0.626 to 1.236 in first 150 cm depth of soils. Pahur soils (cotton) showed higher LI than Brahmni (banana), Dhanora (cotton) and Paral (cotton) in the surface layer (0-50 cm). Soybean-growing soils (Asra) showed marginal increase of LI with depth whereas reverse trend was observed in soils (Haldi) under forest. Among paddy-growing soils, LI increased down the depth in Rajegaon and Dighori. The distribution of LI values was irregular in soils under horticulture (Linga, Brahmni) (Table 1).

The findings on relatively high TOC values in the paddy soils of Vidarbha (0.93-1.175 per cent, Table 2) are in accordance with earlier observations (Jenny and Raychaudhuri 1960, Sahrawat *et al.* 2005, Bhattacharyya *et al.* 2000, 2008b. It has been reported that organic matter preferentially accumulates in soils that remain submerged for prolonged period. Accumulation of organic matter and C sequestration have also been reported to be significant in double-cropped lowland paddy (paddy-paddy) even during relatively short-term experiments. The mechanism involved in preferential accumulation of organic matter under paddy (wetlands) was ascribed mainly to anaerobiosis and the associated chemical and bio-chemical changes that take place in submerged soils (Sahrawat *et al.* 2005). This is true for the soils in IGP (Indo-Gangetic Plains) as well as BSRs (Black Soil Regions). Interestingly, this process of anaerobiosis to stock more TOC does not appear helpful to very labile form of C (C_{VL}) in paddy soils under BSR. This is in sharp contrast to those in IGP soils (Majumdar *et al.* 2008; Mandal *et al.* 2008).

Shrink-swell soils are known for low (<0.5 per cent) organic carbon (Bhattacharyya et al. 2001). The TOC of the shrink-swell soils under study ranged from 0.05 to 1.75%. Soils under horticulture contain more TOC than those under agriculture limited to cotton and soybean (Naitam and Bhattacharyya 2003). However, paddy soils contain very high TOC in the surface soils (Table 2). Legume intercropping increased TOC content (Naitam and Bhattacharyya 2003; Bhattacharyya *et al.* 2007; Wani *et al.* 2003).

LI has a decreasing trend with decrease in rainfall (Table 1). Legume intercropping not only increases TOC but also LI in Pahur and Asra soils. Very high doses of farm yard manure (FYM) (@ 20-30 tonnes/ha for Asra, Bramhni and Hisai soils) also influenced LI. Grass as natural vegetation increased in Linga soils under horticulture (Table 1).

C_{VL}, considered to be the most important form of organic carbon for plants, was not detected in seven soils (Kurul, Dighori, Rajegaon, Haldi, Brahmni, Hisai and Dhanora). Various proportions of C_{VL} found in the remaining four soils (Linga, Pahur, Asra and Paral) showed a decreasing trend with depth. This trend followed the combined influence of temperature (MAT) and rainfall (MAR) in different bio-climatic systems. The influence of climate (temperature and rainfall) was overshadowed by management interventions as evidenced by effects of grass vegetation and legume intercropping in the four soils where C_{VL} was not detected. For cotton growing soils, 12 to 40 percent TOC is contributed towards active pool (Table 3) whereas for Hisai and Dhanora soils, active pool constitutes only C_L (Table 2).

Soils of cooler climate in UK (Chan *et al.* 2001) and humid climate of the Indo-Gangetic Plains of India (Majumdar *et al.* 2008; Mandal *et al.* 2008) contain all the four sub-fractions of TOC. We did not get contribution of all the forms of soil carbon in the shrink-swell soils of the study area. It seems that C_{VL} is susceptible to higher atmospheric temperature (summer temperature as high as 45°C during April, May and June in Vidarbha, Maharashtra) and is lost readily from these soils in SAT, if not supplemented by external organic amendments. Since plant uptake is directly related to active pool, which is again governed by C_{VL}, TOC stocks of soils may not be a realistic estimate of availability of the nutrients through organic carbon for plant growth.

TOC has been considered as an important and robust soil quality parameter (SQP). Interestingly, only a portion of TOC is available to plant. In view of this, subfraction (s) of TOC, namely, C_{VL} and C_L should be considered as more logical SQP. Since contents of C_{VL} and C_L vary with climate and land use (including cropping pattern and management), SQP in terms of these sub-fractions may be used with caution. Very labile form of C (C_{VL}) ranged from 14 to 32% in the surface (9-19 cm depth) of shrink-swell soils of the study area. High atmospheric temperature in central India, in contrast to the humid part of IGP, does not allow very labile form (C_{VL}) of organic carbon to persist in soils. Adoption of legumes as intercropping and natural vegetation in the horticultural field and external applications of organic amendments shall sequester organic carbon in very labile form (C_{VL}) and shall thus mitigate the effect of high atmospheric temperature.

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