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Relationship between dichromate oxidizable and total soil organic carbon and distribution of different pools of organic carbon in Vertisols of Central India

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ABSTRACT

Geo-referenced soil samples (0-15 cm) were collected from the farmers fields of Sehore (n = 120) and Vidisha (n = 156) district representing AESR 10.1 to establish the relationship between oxidizable SOC and total SOC in Vertisols of Central India and also to study the distribution of different pools of SOC as well as their relationship with crop yield. Total SOC was apportioned into different pools by using 5, 10 and 20 ml of concentrated H_2SO_4 that resulted in 3 acid-aqueous solution ratio of 0.5:1, 1:1 and 2:1. Also crop yields during the following winter season and rainy season from the geo-reference fields were recorded and were transformed to % relative yield. Oxidizable SOC (y) was related to total SOC (x) in the form of $y = 0.825x - 0.086$ ($R^2 = 0.958$, n = 276), indicating that oxidizable SOC comprised 82.5% of the total SOC. Therefore it was recommended that a correction factor of 1.21 should be used to convert oxidizable SOC values to get the estimate of total SOC. The mean crop productivity was better related to oxidizable SOC (r = 0.5275) as compared to total SOC(r = 0.4886). The threshold and optimum values of oxidizable SOC were 3.2 and 11.2 g C/kg, respectively, whereas the threshold and optimum values for total SOC were 3.87 and 14.1 g C/kg, respectively. Among the different pools, less labile C was highly correlated (r = 0.5871) with the crop productivity, the computed threshold and optimum value for less labile C were 1.53 and 5.2 g C/kg, respectively.

Key words: Optimum and threshold values, Oxidizable soil organic carbon, Soil organic carbon pools, Total soil organic carbon, Vertisol

The most widely used technique for delineation of soil organic carbon (SOC) is wet dichromate oxidation method of Walkley and Black (1934) which is used mostly by all soil testing laboratories as a standard method because of its simplicity, minimal time and equipment requirement (Nelson and Sommens 1996). In this method, variable proportion of SOC is determined depending upon soil type, depth and nature of SOC, whereas the procedure involving the total SOC analysis by dry combustion method generally determines all forms of organic C in soil. Therefore, a number of workers proposed that a correlation factor ranging from 1.19 to 1.35 be used to account for total SOC from the values for oxidizable SOC obtained by the dichromatic oxidation method (De Vos *et al.* 2007, Ghosh *et al.* 2001). Thus, the relationship between Oxidizable SOC (of Walkley and Black 1934, method) and total SOC (by dry combustion method) has implication in SOC related research, especially pertinent to SOC stocks estimation for Indian soils. There are several evidences to indicate that certain fractions of SOC are more important in maintaining soil quality and are therefore more sensitive to the impact of management practices (Duxbury and Nkambule 1994, Chan 1997). Using different concentration of H_2SO_4, Chan *et al.* (2001) differentiated total SOC into four pools, namely, Very labile C, Labile C, Less labile C and Non-labile C and showed that the amount of organic C oxidizable by a modified Walkley and Black method, which involves only half of the amount of H_2SO_4, is a more sensitive indicator of the improvement in soil quality. Hence, the present investigation was carried out to establish the relationship between oxidizable SOC and total SOC in Vertisols of Central India using large number of soil samples from farmer's field and

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to study the distribution of different pools of SOC as well as their relationship with crop yield.

MATERIALS AND METHODS

In the present study geo-referenced soil samples (0-15 cm) were collected in 2008 (before the sowing of winter crops) from the farmers fields of Sehore (n=120) and Vidisha (n=156) district of Madhya Pradesh. For selection of farmers' field in each identified district, we followed stratified multistage stratified random sampling where 'Tehsil' was considered as strata. From each tehsil, 3 - 4 villages were selected randomly (Table 1). From each selected village, six farmers' fields were selected based on high, medium and low resource use following Participatory Rural Appraisal (PRA) technique and also one pristine sample from uncultivated soils around the farmers field was collected. Thereafter, each identified site was geo-referenced using GPS tool. Prior to analysis soil samples were air dried, ground and sieved to less than 0.2 mm diameter. Basic information on physical, chemical and biological attributes of the collected soil are presented in Table 2. These soil samples were analyzed for oxidizable SOC by wet digestion method of Walkley and Black (1934) and total SOC by CHN – analyzer (Thermo Fisher Flash 2000 model). The total SOC was apportioned 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 H_2SO_4 that resulted in 3 acid-aqueous solution ratio of 0.5:1, 1:1 and 2:1. The amount of C, thus determined, allowed the apportioning of total SOC into very labile C (oxidizable SOC by 12.0 N H_2SO_4), labile C (the difference in SOC oxidizable by 18.0 N and that by 12.0 N H_2SO_4), less labile C (the difference in SOC oxidizable by 24.0 N and that by 18.0 N H_2SO_4) and non labile C (difference in SOC between total SOC as measured by CHN Analyzer and oxidizable SOC as measured by using 24.0 N H_2SO_4).

After the collection of soil samples from the fields, the identified farmers were asked to maintain earmarked plot of 10 m × 10 m size for growing wheat (*Triticum aestivum* L.) and chickpea (*Cicer arietinum* L.) in 2008-09 winter season and soybean [*Glycine max* (L.) Merr.] and rice (*Oryza sativa* L.) in 2009 rainy season with uniform package and practices. In Vidisha district all the farmers (156) had soybean-wheat rotation and the average yield of the wheat and soybean were 2 624 kg/h and 1 515 kg/ha, respectively. In Sehore district 82, 22 and 16 farmers had soybean-wheat, soybean – chickpea and rice-wheat rotation, respectively and the average yield of wheat (n = 98), chickpea (n = 22), soybean (n = 104) and rice (n =16) were 3 125 kg/ha, 885 kg/ha, 940 kg/ha and 2 510 kg/ha, respectively. At the end of each growing season yield data were collected by harvesting crop from 3 sub plots of 5 m × 3 m size from the earmarked plot. The crop yield data of winter and rainy season crops in each farmer's field was transformed to % relative yield by dividing with the maximum yield of the respective crops and thereafter we computed mean relative yield (%) of each of the farmers' field as per following expression.

$$\text{Mean relative yield (\%)} = (W_0 / W_m + R_0/R_m)/2 * 100$$

Where, W_0 and W_m are the observed yield and maximum yield of the winter crop, whereas R_0 and R_m are the observed yield and maximum yield of the rainy season crop.

Table 1 Selected tehsils and respective villages from where the soil samples were collected in Sehore district and Vidisha district

Tehsil name	Number of sample (Cultivated soil + Pristine soil)	Village name	Tehsil name	Number of sample (Cultivated soil + Pristine soil)	Village name
Sehore			Vidisha		
Sehore	24+4	Janpur Bawadiya, Bairagarh Ganesh, Niwariya, Gudbela	Basoda	24+4	Gamakar, Maholi, Sunari, Bhuarajagir
Ashtha	24+4	Samardi, Arniya Gaji, Malipura (Ashta), Gwala	Kurwai	24+4	Sikandarpur, Parasari, Saidpur, Banoh
Budni	24+4	Chachmau, Bayan, Pangurariya, Semri Khanpura	Nateran	24+4	Karmedi, Seu, Palalakpur, Mudra Pitamber
Nasrullahganj	24+4	Balagaon, Satrana, Chhapari, Bhada Khoi	Seronj	18+3	Khanpur, Lalatori, Pamakhedi
Ichhawar	24+4	Bhau Khadi, Bordi Kalan, Mogra, Dabla mata	Lateri	18+3	Muraria, Lateri, Sunkher
			Vidisha	24+4	Emalia, Naarot, Mudra Abela, Bankhedi
			Gyaraspur	24+4	Sojna, Atarikhejda, Kheriajagir, Olynza
Total	120+ 20			156+ 26	

Table 2 Basic information on Soil Physical, Chemical and Biological Attributes

Soil Properties	Sehore		Vidisha	
	Range	Mean	Range	Mean
Sand (%)	27.6-66.8	36.6	29.6-44.0	34.4
Clay (%)	16.6-51.6	41.3	31.8-49.9	41.3
Silt (%)	14.6-33.3	22.1	14.6-33.3	24.3
MWD (mm)	0.15-1.31	0.56	0.25-1.42	0.65
MWD of sand free aggregates (mm)	0.14-1.32	0.48	0.19-1.26	0.53
Plant available moisture (%)	7.2-15.1	10.7	8.1-15.9	12.3
Clod BD (Mg/m^3)	0.9-1.8	1.5	1.08-1.78	1.43
pH	6.98-8.32	7.71	6.08-8.30	7.80
EC (dS/m^2)	0.05-0.289	0.137	0.036-0.570	0.126
C:N	10.12-15.7	12.5	10.12-17.12	12.48
$KMnO_4$-N (kg/ha)	275.2-1186.8	491.9	162.5-1140.2	379.2
Avail. P (kg/ha)	6.99-60.79	18.72	6.72—55.01	15.29
Avail. K (kg/ha)	103.1-448	211.7	96.32-443.5	195.6
Avail. S (mg/kg)	3.8-23.8	11.3	4.0-32.0	12.3
Avail. Zn (mg/kg)	0.13-1.60	0.44	0.11-0.69	0.25
Total Zn (mg/kg)	340-1540	1046.9	220.0-1520.0	809.8
Avail. Cu (mg/kg)	0.63-4.91	2.04	0.60-3.62	1.23
Total Cu (mg/kg)	16-251	93.6	20.0-151	52.2
Avail. Mn (mg/kg)	2.0-37.3	10.7	1.72-30.6	6.9
Total Mn (mg/kg)	204.0-3326.0	1325.6	154-2543	1011.7
Avail. Fe (mg/kg)	0.98-25.8	9.1	2.3-25.5	7.2
Avail. B (mg/kg)	0.02-3.02	0.68	0.03-1.82	0.42
Dehydrogenase (µg TPF/g soil/hr)	16.70-83.29	47.26	15.21-78.11	36.76
Alkaline phosphatase (µg PNP/g/hr)	10.4-169.9	83.1	12.7-187.9	93.9
Total N (%)	0.03-0.094	0.057	0.019-0.107	0.042
Total P (mg/kg)	330-890	550	330-890	680
Inorganic P (mg/kg)	210-690	390	270-680	410
Organic P (mg/kg)	70-310	160	190-360	270
Non Exch. K (mg/kg)	426-1029	712.6	428-1236	684.2
MBC (µg/g)	137-943	378	85-995	253

RESULTS AND DISCUSSIONS

The relationship between oxidizable SOC in the Vertisols of Sehore and Vidisha districts showed that the amount of oxidizable SOC recovered by dichromatic oxidation were considerably lower than by dry combustion method. The regression line relating oxidizable SOC (Y, in g C/ kg soil) and total SOC (x, in g C/kg soil) showed linear relationships in the form of Y = 0.85 x – 0.30 (n = 120, R^2 = 0.965) for Sehore district and Y = 0.819 x –0.024 (n = 156, R^2 = 0.938) for Vidisha district, indicating that oxidizable SOC comprised 85% and 81.9% of the total SOC in Sehore and Vidisha district, respectively. When soil samples of both districts were combined, the relationship was in the form of Y = 0.825 – 0.086 (n = 276, R^2 = 0.958), suggesting that oxidizable SOC comprised 82.5% of the total SOC in the vertisols of central India, which in turn showed that the correction factor (inverse of the slope of linear regression line) was found to be 1.212. A standard correction factor of 1.32 was proposed by De Vos *et al.* (2007) for converting the oxidizable SOC to total SOC. In spite of more stable organic carbon in clay-humas complexes (Wattel – Kockkocke *et al.* 2001), the observed correction factor was found lower in Vertisols in the present study indicating high recovery (82.5%) of oxidizable SOC. Ghosh *et al.* (2001) suggested that correction factor ranging from 1.15 to 1.33 was required to be multiplied to the values of oxidizable SOC to get the estimates of total SOC in sandy loam Inceptisol of NW Himalayas, while Krishnan *et al.* (2009) worked out correction factor 2.40 and 1.95 for Himalaya soils and Vertisols of central India, respectively. The very high values of correction factor reported by Krishnan *et al.* (2009), particularly for Vertisols could possibly be due to lower number of sampling sites (44 samples), and represented different horizons of the soil profiles.

The distribution of different pools of SOC in cultivated and pristine Vertisols of Sehore and Vidisha districts are presented in Table 3. The total SOC was found higher in the cultivated soils of Sehore district (7.30 g C/kg soil) as compared to cultivated soils of Vidisha district (5.31 g C/kg soil) possibly because of higher productivity in Sehore district. The pristine soils of both districts had relatively higher amount of total SOC as well as oxidizable SOC. As compared to pristine soils, cultivation over the years resulted decrease in total SOC and oxidizable SOC to the tune of 32.03% and 33.77% in Sehore districts, respectively, and 46.45% and 55.52% in Vidisha district, respectively. The loss of total SOC due to cultivation over the years in Sehore district was largely took place from Very labile C (VLC) and labile C (LC) fraction and both these two fractions contributed 77.94% of the loss of total SOC. Similarly, in cultivated Vertisols of Vidisha district, both VLC and LC fraction contributed 84.28% of the loss of total SOC due to cultivation over the years. Marked changes in % distribution different fractions of SOC (as measured by the method of Chan *et al.* 2001) in cultivated soil was also observed due to cultivation practices over the years. In pristine soils of

Table 3 Distribution of different pools of SOC (g/kg) in soils of Sehore and Vidisha districts

District			SOC Pools (g/kg)				
			VLC	LC	LLC	NLC	Total SOC
Sehore	Cultivated (n = 120)	Range	0.63-4.91	0.38-2.82	0.75-6.97	0.69-2.78	3.09-14.88
		Mean	2.04	1.20	2.70	1.38	7.32
		% CV	32.78	34.06	41.28	30.92	29.74
		% of TOC	27.94	16.43	36.98	18.90	
	Pristine	Range	1.95-69.54	1.09-3.52	1.3-4.73	0.54-3.41	1.56-16.79
		Mean	3.77	2.159	3.04	1.80	10.77
		% CV	33.38	33.37	35.68	37.58	33.78
		% of TOC	33.43	21.41	30.15	17.85	
Vidisha	Cultivated (n = 156)	Range	0.51-4.49	0.28-3.40	0.47-6.67	0.36-2.36	2.14-16.04
		Mean	1.35	0.83	2.14	0.96	5.28
		% CV	40.40	45.78	38.12	35.67	36.5
		% of TOC	25.42	15.63	40.30	18.07	
	Pristine	Range	1.81-6.66	0.95-4.50	0.47-4.64	1.01-3.42	4.99-18.01
		Mean	3.95	2.09	1.74	2.08	9.86
		% CV	34	36	52	33	33
		% of TOC	40.14	21.23	17.68	21.13	

Table 4 Correlation coefficients of various soil carbon pools and mean relative yield

Parameters	Mean relative yield		
	Sehore (n = 120)	Vidisha (n = 156)	Vidisha+Sehore (n = 276)
Very labile C (VLC)	0.5185	0.6140	0.3893
Labile C (LC)	0.4273	0.5904	0.3748
Less labile C (LLC)	0.6299	0.7023	0.5871
Non labile C (NLC)	0.1656	0.5527	0.2007
Active C pool#	0.5008	0.6150	0.3920
Passive C pool^	0.6020	0.7133	0.5295
Total SOC	0.6048	0.6799	0.4886
Oxidizable SOC	0.6512	0.6915	0.5275

#Active pool = Very labile C + Labile C, ^Passive pool = Less labile C + Non-labile C

Sehore, the VLC, LC, less labile C (LLC) and non-labile C (NLC) contributed 33.43%, 21.41%, 30.15% and 17.85% of the total SOC and this distribution pattern changed to 27.94%, 16.43%, 36.98% and 18.90%, respectively in cultivated soils. Similar trend was also observed in cultivated soils of Vidisha district. In a long term field experiment under rice based cropping on an Inceptisol, Mandal *et al.* (2008) observed that the mean distribution of different pools of SOC, namely VLC, LC, LLC and NLC where 33.6%, 17.6%, 11.5% and 37.3% of the total SOC, respectively. One the most important point that is to be noted here is that % distribution of C in LLC fraction markedly increased from 30.15% to 36.98% in cultivated soils of Sehore and 17.68% to 40.30% in cultivated soils of Vidisha district. As LLC and NLC together contribute the passive pool, it is very important to note that in these cultivated Vertisols, the passive pools were higher, ranging from 55.88% to 58.37% of the total SOC. Thus, our results are higher than the range assigned (30-40%) to the "passive pool" of SOC used in the century model (Parton *et al.* 1992).

The relationship between different pools of SOC and the mean relative yields of the crops, as measured by simple correlative coefficient, is presented in Table 4. In both the districts, mean relative yield was highly correlated with the LLC fraction of SOC, suggesting that LLC fraction influenced the crop yield in a way more than other fraction of SOC. Comparing the effect of oxidizable SOC and total SOC, the crop yields were better related to oxidizable SOC in both

Table 5 Threshold and optimum levels of different soil carbon pools computed on the basis of regression lines relating mean relative yield and different pools of C

Carbon pools	Regression line	R^2	Threshold value (g/kg)	Optimum value (g/kg)
Very labile C	Y = 7.504x + 44.27	0.151	0.764	4.761
Labile C	Y = 11.48x + 45.28	0.140	0.411	3.024
Less labile C	Y = 8.194x + 37.39	0.644	1.539	5.200
Non labile C	Y = 5.883x + 49.86	0.040	0.024	5.123
Total SOC	Y = 2.917x + 38.70	0.538	3.874	14.158
Oxidizable SOC	Y = 3.743x + 38.00	0.578	3.206	11.221

Sehore (r = 0.651**) and Vidisha (r = 0.691**) districts. As LLC fraction of SOC is in part of passive pools - C in both Sehore (r = 0.602**) and Vidisha (r = 0.713**) districts.

Thereafter, regression lines relating mean relative yield (%) and different pools of SOC were worked out on the basis of the results from both the districts (Table 5). It was observed that the coefficient of determination (R^2) were more than 0.5 in the regression lines relating mean relative yield with less labile C, oxidizable SOC and total SOC, while for other pools of C, the R^2 values were not acceptable (less than 0.5) for making any conclusion. The less labile C, oxidizable SOC and total SOC were related to mean relative yield in the form of Y = 8.194x + 37.39 (R^2 = 0.644), Y = 2.917x + 38.70 (R^2 = 0538) and Y = 3.743x + 38.00 (R^2 = 0.578), respectively. Putting 'Y' = 80%, we calculated the value of 'x' from those equations which indicated the optimum value of each of this measurement of SOC at which mean relative yield is likely to be 80% of the maximum mean relative yield. The calculated optimum values for less labile C, oxidizable SOC and total SOC for the Vertisols of central India were 5.123 g C/kg soil, 11.221 g C/kg soil and 14.158 g C/kg soil, respectively. Similarly putting 'Y' = 50%, we calculate the value of 'x' from those regression lines to obtain the threshold values of each of the measurements of SOC at which yield is likely to be around 50% of the maximum mean relative yield. The computed threshold values for less labile C, oxidizable SOC and total SOC were 1.539 g C/kg soil 3.206 g C/kg soil and 3.874 g C/kg soil in the Vertisols of central India. Here we assumed that threshold and optimum value of each SOC pools is level at which mean relative yield of the crop are likely to be around 50 and 80% of the maximum yield.

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