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Labile and stabilised fractions of soil organic carbon in some intensively cultivated alluvial soils

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Abstract

The present investigation was undertaken in view of the limited information on the relative proportion of labile and stabilized fractions of soil organic carbon (SOC) in intensively cultivated lands, particularly under tropics. The specific objectives were i) to study the comparative recovery of SOC by different methods of labile carbon estimation under intensively cultivated lands and ii) to evaluate the impact of agricultural practices on carbon management index. For this purpose, in all, 105 surface soil samples were collected from intensively cultivated tube well and sewage irrigated agricultural lands. These samples were analysed for total as well as labile pools of SOC. Results indicated that Walkley and Black, $KMnO_4$-oxidizable and microbial biomass carbon constituted the total SOC to the extent of 10.2 to 47.4, 1.66 to 23.2 and 0.30 to 5.49%, respectively with the corresponding mean values of 26.2, 9.16 and 2.15%. Lability of SOC was considerably higher in sewage irrigated soils than tube well irrigated soils under intensive cropping. Under soybean-wheat, the higher values of carbon management index (CMI) (279 and 286) were associated with the treatments where entire amount of nitrogen was supplied through FYM. Similar results were obtained under rice-wheat, whereas in case of maize-wheat the highest value of CMI was recorded under treatment receiving NPK through chemical fertilizer along with green manure. There was also a significant improvement in CMI under integrated (chemical fertilizer + organics) and chemical fertilizer-treated plots. The values of CMI ranged from 220 to 272 under cultivated lands receiving irrigation through sewage and industrial effluents.

Key words

Carbon management index, Intensively cultivated lands, Soil organic carbon, Total and labile pools

Introduction

Soil organic matter (SOM) is the central element of soil fertility, productivity and quality (Katyal *et al*., 2001). The SOM not only affects sustainability of agricultural ecosystems, but also extremely important in maintaining overall quality of environment as soil contains a significant part of global carbon stock : 3.5% compared with up to 1.7% in atmosphere, 8.9% in fossil fuels, 1% in biota and 84.9% in oceans (Lal *et al*., 1995). Some estimates showed that increase in soil organic carbon (SOC) content by 0.01% could lead to the carbon sequestration equal to the annual increase of atmospheric carbon di-oxide carbon. Soil organic matter is a heterogeneous mixture of materials ranging from fresh plant and microbial residues to relatively inert humic compounds, with turnover rates measured in millennia. The labile fraction consists of material in transition between fresh plant residues and stabilised organic matter. On the other hand, stabilized fraction of SOM is composed of organic materials that are highly resistant to microbial decomposition (Haynes, 2005). Labile fraction of SOC is very important for maintenance of soil fertility, while enriching soil with stabilized fraction of SOC has positive impact on the environmental quality.

Assessment and monitoring of soil organic carbon either for agricultural sustainability or environmental quality have been done in most of the studies by Walkley and

Black method (Walkley and Black, 1934). In general, this method provides widely variable recovery of SOC and much lower recovery of organic carbon in carbonized materials (Blair *et al.,* 1995). Several studies attempted to identify labile pools of SOC which are more sensitive to changes in agricultural management practices and land uses than total organic carbon (Blair *et al.*, 1995; Skjemstad *et al.*, 2006). Over the years, microbial biomass carbon (MBC) has also been used as an index of lability of SOC, which mainly consists of bacteria and fungi and makes up about 1-5% of total SOC (Haynes, 2005). This fraction of SOC is highly sensitive to different management practices and soil environmental condition (Verma *et al.*, 2011). However, some studies suggested MBC as a poor index of labile carbon as this fraction of SOC is markedly affected by soil moisture content (Mazzarino *et al.*, 1991). Soil organic carbon oxidized by 333 mM $KMnO_4$ (KMOC) has been considered as a useful index of labile soil carbon and more sensitive to the changes in cultivation or agricultural management practices compared to total SOC (Blair *et al,*, 1995; Blair, 2000; Verma *et al.*, 2010). This fraction encompasses all readily oxidizable organic components including humic materials and polysaccharides, which generally accounts for 5-30% of SOC (Blair *et al*., 1995; Blair, 2000; Graham *et al*., 2002). However, very limited information is available on the extent of recovery of SOC by above-mentioned methods, particularly under tropical environment. Since the continuity of carbon supply depends on both the total pool size and lability, Blair *et al.* (1995) introduced the concept of carbon management index (CMI). The computation of CMI is based on labile carbon (C_L) and a non-labile (C_{NL}) component, the latter being calculated as the difference between total carbon and the C_L. This index compares the changes that occur in total and labile carbon as a result of agricultural practices and land uses, with an emphasis on the changes in C_L, as opposed to C_{NL} in SOM.

Application of manures and fertilizers at optimum rate increases the crop production which in turn results in greater residue inputs leading to enhanced build-up of carbon in soil (Ismail *et al.*, 1994; Rasmussen *et al*., 1998). Soil management practices have variable effects on soil microbial biomass for example, addition of fertilizer nitrogen decreased microbial biomass carbon (MBC) in pine forest, pasture and grasslands and on the contrary, other studies have shown an increase in MBC in agricultural soils (Haynes, 2005). The most dramatic changes in soil organic carbon occurs on conversion of lands under natural vegetation (e.g. forest, pasture etc.) to arable agricultural lands. In India, most of the raw sewage is a mixture of domestic, commercial and industrial activities and usually carry high load of organic matter and the long-term use of sludge or such wastewaters on agricultural land resulted into considerable build-up of organic carbon in soils (Datta *et al.,* 2000; Rattan *et al*., 2002; 2005). However, information on the relative proportion of labile and stabilized fractions of SOC under various agricultural management practices and land uses is scanty, particularly under tropics. Hence, an attempt was made to study the comparative recovery of SOC by different methods of labile carbon estimation under intensively cultivated lands and to evaluate the impact of agricultural practices on carbon management index. Indo-Gangetic plain has been contributing substantially in the food production of the country. Since, this plain is dominated by alluvial soil, it was thought proper to take up this study in intensively cultivated alluvial soil.

Materials and Methods

To accomplish the objectives of the present investigation, in all 88 composite surface soil samples (0-15 cm) were collected from the Divisional and Institute Mega Project (IARI farm, New Delhi) on integrated nutrient, tillage and water management under soybean-wheat, rice-wheat and maize-wheat cropping systems in the forth cropping cycle (Table 1, 2 and 3). To add the variability in SOC content, 13 composite surface soil samples (0-15 cm) were also collected from agricultural lands which have been receiving sewage and industrial effluents for a long period (Table 4). In addition 4 composite soil samples were also collected from respective adjacent tube well irrigated fields for reference. About 500 g of each moist soil sample were collected from the different cropping systems and land uses. One part was kept in deep freeze (for MBC analysis) and remaining part was air-dried, ground and passed through 2 mm sieve and used for subsequent analysis. Total organic carbon in soil was determined by wet oxidation method (Snyder and Trofymow, 1984). Organic carbon content in soil was determined by wet oxidation method of Walkley and Black (1934). Microbial biomass carbon of soil was determined by fumigation-extraction method (Jenkinson and Powlson, 1976). The amount of oxidizable carbon by 333 mM $KMnO_4$ in soil was determined by following the procedure of Blair *et al*. (1995). Carbon management index (CMI) was computed according to the formula given by Blair *et al.* (1995) :

$$CMI = CPI \times LI \times 100$$

$$CPI = \frac{\text{Total C of soil sample (mg g}^{-1}\text{)}}{\text{Total C of reference soil (mg g}^{-1}\text{)}}$$

$$L = \frac{\text{Carbon fraction oxidized by KMnO}_4}{\text{Carbon remaining unoxidized by KMnO}_4}$$

$$LI = \frac{\text{Lability of C in sample soil}}{\text{Lability of C in reference soil}}$$

Where, CMI = Carbon management index; CPI = Carbon pool index; LI = Lability index and L = Lability of carbon

Table 1 : Description of treatments related to sources and rates of nitrogen (N) application under soybean-wheat cropping system

Treatment	Amount of N applied to	
	Soybean	Wheat
S_1	Absolute control (without NPK)	Absolute control (without NPK)
S_2	Control (without N)	Control (without N)
S_3 (100% N)*	30 kg urea-N ha^{-1} at sowing	60 kg urea-N ha^{-1} at sowing + 60 kg urea-N ha^{-1} 35 days after sowing
S_4 (100% N)	30 kg N ha^{-1} through FYM applied 15 days before sowing	120 kg N ha^{-1} through FYM applied 15 days before sowing
S_5 (100% N)	15 kg N ha^{-1} through FYM applied 15 days before sowing +15 kg urea-N ha^{-1} at sowing	60 kg N ha^{-1} through FYM applied 15 days before sowing + 60 kg urea-N ha^{-1} applied 35 days after sowing
S_6 (150% N)	45 kg urea-N ha^{-1} at sowing	90 kg urea-N ha^{-1} at sowing + 90 kg urea-N ha^{-1} 35 days after sowing
S_7 (150% N)	45 kg N ha^{-1} through FYM applied 15 days before sowing	180 kg N ha^{-1} through FYM applied 15 days before sowing
S_8 (150% N)	22.5 kg N ha^{-1} through FYM applied 15 days before sowing + 22.5 kg urea-N ha^{-1} at sowing	90 kg N ha^{-1} through FYM applied 15 days before sowing + 90 kg urea-N ha^{-1} applied 35 days after sowing

*100% of the recommended dose of N; All the treatments have been receiving recommended dose of P and K through mineral fertilizers, except S_1, S_4 and S_7; Experimental design: Completely Randomized Block Design; Replication: 3; Total number of samples: 24

Table 2 : Treatment details of tillage, and rate and sources of N under maize-wheat cropping system

Treatments	Description
Main plot treatment (Tillage)	
Bed planting	For maize
Conventional planting	For maize
Conventional tillage	For succeeding wheat
No-tillage	For succeeding wheat
Sub-plot treatments (manures/fertilizers)	
M_1	No N
M_2 (100% N)*	120 kg urea-N ha^{-1}
M_3 (150% N)	180 kg urea-N ha^{-1}
M_4	90 kg urea-N + 30 kg N ha^{-1} applied through FYM
M_5	120 kg urea-N ha^{-1} + green manure (*Sesbania*)
M_6	120 kg urea-N ha^{-1} + crop residues (previous crop)
M_7	120 kg N/ha (50% N through FYM + 25% N through biofertilizer + 25% N through crop residue/green manure)
M_8	Blank plot under natural vegetation (Without NPK)

*100% of the recommended dose of N; All the treatments have been receiving recommended dose of P (26.2 kg ha^{-1}) and K (50 kg ha^{-1}) through mineral fertilizers, except M_7 and M_8; Experimental design : Split plot design; Replication: Two (selected for present investigation); Total number of samples: 32

Statistical analysis : Analysis of variance method (Snedecor and Cochran, 1967) was followed to elucidate the effect of agricultural management practices on carbon management index.

Results and Discussion

Ratio of relatively labile and total SOC under different land uses : Walkley-Black organic carbon (WBC) accounted for 10.2 to 47.4% of total SOC with the mean value of 26.2% taking all the samples together (Table 5). The corresponding values for the agricultural lands receiving sewage and industrial effluents ranged from 11.9 to 47.5% with the mean value of 30.6%. Whereas, WBC constituted 15.4 to 43.7% of total SOC with the mean value of 25.9% under soybean-wheat, rice-wheat and maize-wheat systems using tube well water for irrigation. Recovery of SOC by Walkley-Black method was considerably higher in soils receiving sewage-sludge and industrial effluents compared to that under different cropping systems. This may be attributed to regular addition of organic materials to soil through sewage effluents (Rattan *et al.*, 2002). Walkley-Black method that uses the heat of dilution or minimal heating that does not give complete oxidation of SOC, although most active forms of SOC are converted to CO_2 (Page *et al.,* 1982). Under

Table 3 : Treatment details of tillage, and rate and sources of N under rice-wheat cropping system

Treatments	Description
Main plot treatment (Tillage)	
Puddled (P)	For rice
Un-puddled (UP)	For rice
Conventional tillage (CT)	For succeeding wheat
No-tillage (NT)	For succeeding wheat
Sub-plot treatments (manures/fertilizers)	
R_1	No N
R_2 (100% N)*	120 kg urea-N ha^{-1}
R_3 (150% N)	180 kg urea-N ha^{-1}
R_4	90 kg urea-N + 30 kg N ha^{-1} applied through FYM
R_5	120 kg urea-N ha^{-1} + green manure (*Sesbania*)
R_6	120 kg urea-N ha^{-1} + crop residues (previous crop)
R_7	120 kg N ha^{-1} (50% N through FYM+25% N through biofertilizer+25% N through crop residue/green manure)
R_8	Blank plot under natural vegetation (Without NPK)

*100% of the recommended dose of N;Note: All the treatments have been receiving recommended dose of P (26.2 kg ha^{-1}) and K (50 kg ha^{-1}) through mineral fertilizers, except R_7 and R_8; Experimental design : Split plot design; Replication: Two (selected for present investigation); Total number of samples: 32

Table 4 : Description of soil samples collected from agricultural lands receiving sewage, sludge and industrial effluents

Location	No. of samples	Previous history
Keshopur,	2 (control)	Agricultural land irrigated withtubewell water
Western	2	Agricultural land irrigated with sewage effluents under Keshopur effluent irrigation scheme (KEIS) of
Delhi		Delhi Govt., for 5 years
	2	Sewage irrigated under (KEIS) for 10 years
	2	Sewage irrigated under (KEIS) for 20 years
Okhla,	1 (control)	Agricultural lands irrigated with tubewell water
Delhi	4	Agricultural land irrigated with sewage effluents for last 4 decades emanating from Okhla sewage treatment plant
Sonipat,	1 (control)	Agricultural land irrigated with tubewell water
Haryana	3	Agricultural land irrigated with industrial effluents for 15 years, emanating from ATLAS cycle factory

present study, recovery of organic carbon by Walkley-Black method was far below than the values (63-86%) commonly used for conversion of WBC to total SOC (Page *et al*., 1982). It was mentioned that recovery of organic carbon by Walkley-Black method was highly variable and conversion factor for individual soil varied from 1.09 (90%) to 2.27 (44%). It was also reported that Walkley-Black method gave low recovery (< 36%) of organic carbon, whereas, the methods involving external heating gave substantial high recovery of organic carbon from carbonized materials. Hence, it can be inferred that under tropical environment, poor recovery of organic carbon by Walkley-Black method (as low as 10.2%) is perhaps attributed to low organic carbon content of soil, where major share of organic carbon is present as recalcitrant carbon. Blair *et al*. (1995) reported that Walkley-Black method under-estimated the total carbon in soils, having a high proportion of recalcitrant carbon. In view of gross under-estimation of total organic carbon content in soils, generally used conversion factor of 1.3 for the conversion of Walkley and Black organic carbon to total organic carbon is not applicable to tropical soils, particularly in this region and this conversion factor has to be established for individual soil.

The proportion of $KMnO_4$ oxidizable carbon (KMOC) varied from 1.66 to 23.2% with the mean value of 9.16% of total SOC. More or less similar mean values were observed under cropping systems (9.06%). Whereas, recovery of SOC by $KMnO_4$ was considerably higher in agricultural lands receiving sewage and industrial effluents (10.9%) as compared to that under tube well-irrigated arable lands. The recovery of SOC by $KMnO_4$ is less than that of Walkley-Black method. The lower recovery of $KMnO_4$ than Walkley-Black method is expected because of the fact that chromic acid is more powerful oxidising agent at higher temperature (influenced by heat of dilution) compared to neutral $KMnO_4$. The proportions of $KMnO_4$ oxidizable carbon to total SOC as obtained under present study were well within the reported range (5-30%) in literature (Blair *et al*., 1995; Blair, 2000; Graham *et al*., 2002). Taking all the samples together,

Table 5 : Soil organic carbon pools under intensively cultivated lands

Walkley and Black organic carbon (WBC)	$KMnO_4$-oxidizable carbon(KMOC)	Microbial biomass carbon (MBC)
Soil organic carbon pools as a percentage of total soil organic carbon		
Taking all the systems together		
10.2-47.4 (26.2)*	1.66-23.2 (9.16)	0.30-5.49 (2.15)
For sewage, sludge and industrial effluent-treated soil**		
11.9-47.5 (30.6)	4.15-23.2 (10.9)	0.30-2.92 (1.68)
For soybean-wheat, maize wheat and rice wheat		
15.4-43.7 (25.9)	1.66-20.1 (9.06)	0.44-5.49 (2.25)
Soil organic carbon pools		
Taking all the systems together		
0.16-1.55 (0.47%)	0.30-6.52 (1.64 mg g^{-1})	50.2-998 (385 mg kg^{-1})
For sewage, sludge and industrial effluent-treated soil**		
0.20-1.15 (0.73%)	1.05-6.52 (2.56 mg g^{-1})	50.2-820 (418 mg kg^{-1})
For soybean-wheat, maize wheat and rice wheat		
0.29-0.59 (0.43%)	0.30-3.17 (1.53 mg g^{-1})	105-998 (384 mg kg^{-1})

*Values in parenthesis represent the mean values; **Values for control soil (tube well irrigated) were not included

Table 6 : Effect of nutrient management practices on the carbon management index under soybean-wheat, maize-wheat and rice-wheat cropping systems

Soybean – wheat cropping system									
Treatments	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	CD*
CMI	100	108	180	279	248	156	286	232	58
Maize – wheat cropping system									
Treatments	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	CD
CMI	81.3	128	121	186	208	188	140	100	41
Rice – wheat cropping system									
Treatments	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	CD
CMI	73.3	102	108	107	125	82	136	100	23

CD = Critical difference (*P = 0.05*)

microbial biomass carbon (MBC) constituted 0.30 to 5.49% of the total SOC with an average value of 2.15%. This is in conformity with the reported range of MBC, i.e. 1-5% of total SOC. On an average, share of MBC in total SOC was considerably higher in tube well-irrigated arable agricultural soils (2.25%) compared to sewage and industrial effluent-irrigated soils (1.68%). There is an opposite trend to that observed with other organic carbon pools. Relatively lower proportion of MBC in sewage sludge-irrigated soils is perhaps attributed to higher concentration of heavy metals than normal arable soils (Rattan *et al*., 2005). Chander and Brookes (1993) also reported that microbial quotient (proportion of microbial biomass carbon to total soil organic carbon) was decreased from 1.5% to 1% and 0.5% in soils receiving Zn and Cu contaminated sludge.

Effect of agricultural management practices on carbon management index : As KMOC provides useful information on the nature and turn-over rate of different organic carbon pools, carbon management index (CMI) was computed (Table 6). Results indicate that CMI was significantly affected by sources of nitrogen (N) application with reference to absolute control plot (S_1). Supplementation of whole amount of N through FYM alone or in combination (1:1) (S_4, S_5, S_7 and S_8) resulted into significantly higher values of CMI over control (S_2) as well as corresponding treatments (S_3 and S_6), where whole amount of nitrogen supplemented through urea. Application of recommended dose of N, P and K through inorganic fertilizers (S_3) also significantly improved the CMI over that of control.

Under maize-wheat, relative to blank plot under natural vegetation (M_8), supplementation of balanced amount of N, P and K either through inorganic fertilizers or integrated sources or organic sources significantly improved the CMI over control (M_1), whereas effect of tillage and its interaction with nutrient management practices were non-significant (Table 6). Improvement in the values of CMI was

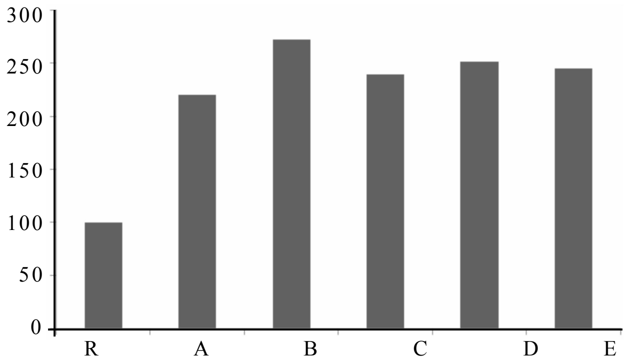

Fig. 1 : Carbon management index of agricultural lands receiving sewage and industrial effluents (R: Respective reference; A: sewage irrigated for 5 years; B: sewage irrigated for 10 years; C: sewage irrigated for 20 years; D: sewage irrigated for 40 years; E: Industrial effluent-irrigated for 15 years)

significantly higher under integrated sources of nutrient management (M_4, M_5 and M_6) compared to chemically fertilized plots (M_2 and M_3). Surprisingly CMI under 100% organics (M_7) although showed higher value than control but inferior to integrated sources. Under rice-wheat system, by and large, there was significant increase in CMI under both the categories of nutrient management treatment, *i.e.* inorganic and integrated sources over control (Table 6). The highest increase in the value of CMI was recorded under 100% organics (R_7), which was at par with 100% N + PK + GM (R_5). The substitution of 25% fertilizer N by FYM (R_4) resulted into similar value of CMI as obtained under chemical fertilizers (R_2 and R_3). However, incorporation of crop residues along with 100% N + PK (R_6) could not improve the CMI with reference to control. Effect of tillage on CMI was statistically non-significant. There was an increase in CMI as a result of addition of sewage and industrial effluents to agricultural lands with respect to land irrigated with tube well (Fig. 1). The value of CMI was increased to 220, 272 and 239 in 5, 10 and 20 year-sewage irrigated soils, respectively with reference to the adjacent tube well irrigated soils (CMI: 100). The values of CMI were recorded as 251 and 245 for waste water irrigated soils of Okhla and Sonepat, respectively.

Improvement in CMI under organic and integrated sources of N application is attributed to addition of organic carbon and other nutrients through these sources. In addition, higher crop productively even under chemically fertilized plots generally leads to higher residue input, which in turn enriched the soil with fresh organic matter. Blair *et al*. (1995) reported that inclusion of legumes to wheat cropping system restored the CMI from 22 to 37 on some soils of the Warialda. Their studies also shown that under the sugarcane, soil from Marian, which had been cropped for 90 years, the CMI was 34, whereas at Victoria Plains the CMI was 110 as a result of a shorter cropping period and a higher proportion of conservation orientated residue management. Improvement in organic carbon content of soil receiving sewage, sludge and industrial effluents was also reported earlier in several studies (Datta *et al*., 2000; Rattan *et al*., 2002; Rattan *et al*., 2005). In fact, majority of the soil quality indexing combinations indicated that the organic systems to have greater soil quality than the other management systems. Though there was no ideal value of CMI, the index provides a sensitive measure of the rate of changes in the soil carbon in the system related to the more stable reference soil (Blair *et al.,* 1995).

It can be concluded from this study that approximately, Walkley-Black, $KMnO_4$-oxidizable and microbial biomass carbon constituted 1/4, 1/10 and 1/50th respectively of the total soil organic carbon in these intensively cultivated alluvial soils. Based on the findings it appears that CMI is a sensitive and useful index for assessing and monitoring the dynamics of soil organic carbon (SOC) under different management practices and land uses.

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