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Soil Carbon Fractions at Different Soil Depths as Influenced by Land use Practices under Cropping Systems in a Vertisol

Arpit Suryawanshi[1*], H. K. Rai[2], Aditi Chourasia[3] and G. D. Sharma[2]

[1]Department of Soil Science and Agricultural Chemistry, Rani Lakshmi Bai Central Agricultural University, Jhansi (U.P.), India.
[2]Department of Soil Science and Agricultural Chemistry, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.), India.
[3]Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, BHU, Varanasi, India.

Authors' contributions

This work was carried out in collaboration among all authors. Author AS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors HKR, AC and GDS managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The experimental field study was conducted at Borlaug Institute for South Asia (BISA) Research Farm, Lakhanwada, Jabalpur, Madhya Pradesh, India to evaluate the soil carbon fractions (very labile, labile, less labile and non-labile or recalcitrant carbon) in different land use practices with soil depths under cropping systems in Vertisols after harvest of *Kharif* and *Rabi* season crops of year 2015-16 and 2016-17. The experiment was conducted under Split plot design considering land use practices as main plot treatments [L_1: Uncultivated, L_2: rice-wheat system with conventional agriculture (CT), L_3: rice-wheat system with conservation agriculture (CA), L_4: soybean-wheat system with CT, L_5: soybean-wheat system with CA, L_6: maize-wheat system with CT and L_7: maize-wheat system with CA] and depth (0-5 cm, 5-15 cm and 15-30 cm) as sub-plot treatments replicated thrice. Very labile carbon fraction was obtained highest in L_3 (rice-wheat system with CA)

**Corresponding author: E-mail: arpitsurya226@gmail.com;*

and lowest under L_6 (maize -wheat system with CT) treatment after harvest of *Kharif* and *Rabi* season crops during 2015-16 and 2016-17and it was significantly higher at 0-5 cm soil depth than those in 5-15 cm and 15-30 cm soil depths. Similar trends were also obtained in case of labile, less labile and non-labile fraction of carbon i.e. the applied land use practices had significant effect on all the carbon fractions under study and found to be maximum under L_3 (R-W system with CA) and minimum in L_6: (M-W system with CT) treatment after harvest of both the season crops during both years of experiment. Whereas, the interaction effect of land use practices and soil depths on the carbon fractions was found statistically non-significant during both the seasons and years.

Keywords: Soil carbon fraction; conservation agriculture (CA); conventional agriculture (CT); land use practices.

1. INTRODUCTION

Soil organic carbon (SOC) plays an important role in sustaining / improving soil health and can be used as a soil quality indicator because it acts as source of energy for microbes and trigger the nutrient availability through mineralization. Presence of soil organic carbon (SOC) enhances water retention, prevent leaching of soluble nutrients, serve as source of nutrients and maintain soil fertility [1,2]. Soil organic carbon fractions in the active pool are the main source of energy and nutrients for soil microorganisms. SOC is a balance between C additions from unharvested plant residues and roots, organic amendments, erosional deposits and C losses through decomposition of organic materials and soil erosion processes [3,4]. Consequently, alteration in land use practices in terms of tillage intensity, residue management and crop rotation has great potential to mitigate the impact of atmospheric CO_2 concentrations in short-term [5,6]. Differences in SOC fractions between agricultural fields and uncultivated soils can yield information about mechanism of C-sequestration in soil [7]. Labile C-fraction in soil are more sensitive to land-use changes than the total C which may serve as early indicator of C-dynamics in soil [8]. Carbon is stored within soil mainly in inorganic and organic forms. Source of inorganic carbon in soil is either parent rock material or the dissolution and precipitation of carbonates which has relatively longer turnover time due to less activity, but redistribute rapidly under high microbial activity [9,10]. Organic form of carbon in soil is the residues of plants and animals which participate in nutrient cycling, grain yield and various other soil functioning [11,12,13]. Organic matter in soil has been categorized into diverse groups based on their turnover rates and regulatory elements [14].

The SOC has been separated into labile and recalcitrant pools where labile-C pools are used as soil quality indicators because they are more sensitive to management practices than TOC [15]. The recalcitrant pool is very slowly altered by microbial activities [16] and contributes significantly to SOC retention and hence has been identified as a potential indicator of increased carbon retention under a set of management practices [17]. C-sequestration in soil is the process of increasing carbon storage (stable and unstable C) which could be potentially affected by tillage practice (mechanisms of disrupting soil aggregates and pore size distribution), crop residue management (retention / incorporation / removal) and cropping systems [18].

Conventional agriculture (CT) is a system which synthetic chemical fertilizers, pesticides, herbicides and other continual inputs, genetically modified organisms, concentrated animal feeding operations, heavy irrigation, intensive tillage, or concentrated monoculture production. Thus conventional agriculture is typically highly resource-demanding and energy-intensive, but also highly productive. While, conservation agriculture (CA) is a technology which includes minimum disturbance of soil, leaving and managing the crop residues on soil surface and spatial and temporal crop sequencing / crop rotation to derive maximum benefits and minimize adverse environmental impacts. It has emerged as protective means of crop production which improves soil quality [19] including higher storage of carbon in soil [20]. CA has been reported to improve input-output relationship, conserve natural resources, lowering soil erosion, arrest water losses, sequester atmospheric carbon in soil and reduce energy needs in agricultural sector [21,2].

2. MATERIALS AND METHODS

The study was carried out during over the seasons and two years of 2015-16 and 2016-17 after harvest of *Kharif and Rabi* season crops at Borlaug Institute for South Asia (BISA) Research Farm, Lakhanwada, Jabalpur, Madhya Pradesh, India. The farm is situated under semi-humid Mahakaushal region of Madhya Pradesh. Geographically BISA farm is situated at $23^0$33'N latitude, $80^0$04'E longitudes and at an altitude of 407.0 metre above mean sea level. Soil of the experimental site belongs to swell-shrink type with dark greyish brown colour. Soils of the BISA Research Farm have been classified as fine, smectitic, hyperthermic family of *Typic Haplusterts* (Vertisols) and known as medium black soil. Study was initiated with seven main plots of land use practices [L_1: Uncultivated, L_2: rice-wheat system with conventional agriculture (CT), L_3: rice-wheat system with conservation agriculture (CA), L_4: soybean-wheat system with CT, L_5: soybean-wheat system with CA, L_6: maize -wheat system with CT and L_7: maize-wheat system with CA) and three sub plots of soil depths (0-5 cm, 5-15 cm and 15-30 cm) with three replications in split plot design. Soil samples were collected as per the treatments with the help of posthole auger to determine the soil carbon fractions in standard procedure. Soil sample was air dried in shade and ground by wooden pastle and mortar, thereafter sieved through 2.0 mm sieve and stored in the cloth bag. The soil sample thus obtained was subjected to analysis to assess the soil carbon fractions. However, soil carbon fraction was determined by Chan *et al.,* 2001 using the following protocol:

- Very labile: Organic C oxidisable under 12 N (6 mol l^{-1}) H_2SO_4.
- Labile: Difference in oxidisable organic C extracted between 18 N (9 mol l^{-1}) and 12 N (6 mol l^{-1}) H_2SO_4.
- Less labile: Difference in oxidisable organic C extracted between 24 N (12 mol l^{-1}) and 18 N H_2SO_4 (9 mol l^{-1}) H_2SO_4.
- Non-labile: Residual organic C after reaction with 24 N H_2SO_4 when compared with the total organic carbon (TOC- 24 N H_2SO_4) determined by the Leco combustion method and corresponds to the recalcitrant fraction of organic C.

The data on different parameters as obtained from chemical analysis were analyzed for test of significance using standard statistical procedure given by Gomez and Gomez, [22].

3. RESULTS

3.1 Very Labile Carbon

Data related to effect of land use practices and soil depths on very labile carbon fraction after harvest of *Kharif* and *Rabi* season crops during 2015-16 (Table 1) and 2016-17 are presented in Table 2. The highest values of very labile carbon fraction (3.70, 3.74, 3.81 and 3.87 g kg^{-1}), respectively were found in L_3 (rice-wheat system with CA) followed by L_5 (soybean-wheat system with CA), L_4 (soybean-wheat system with CT) and L_2 (rice-wheat system with CT) treatments, while, lowest (3.10, 3.04, 3.04 and 3.04 g kg^{-1}) respective values were obtained under L_6 (maize -wheat system with CT) treatment. It was also noted that very labile carbon fraction in CA practice was higher than those in CT under all the cropping systems but the difference for same cropping system was statistically non-significant.

The data further revealed that very labile carbon fraction in soil after harvest of *Kharif and Rabi* season crops during 2015-16 and 2016-17 at 0-5 cm depth was significantly higher (3.87, 3.75, 3.82 and 3.82 g kg^{-1}, respectively) than those in 5-15 cm (3.49, 3.43, 3.44 and 3.45 g kg^{-1}) and 15-30 cm (2.74, 2.79, 2.83 and 2.88 g kg^{-1}) soil depths. The results indicated that very labile carbon fraction decreased significantly with the soil depth across the land use practices. However, the interaction effect of land use practices and soil depths on very labile carbon fraction was found statistically non-significant.

3.2 Labile Carbon

Data on labile fraction of carbon in soil after harvest of *Kharif and Rabi* season crops during 2015-16 and 2016-17 as effect of land use practices and soil depths are given in Table 1 and Table 2. Data clearly indicated that highest content of labile carbon fraction (2.00, 2.02, 2.06 and 2.09 g kg^{-1}, respectively) after harvest of *Kharif and Rabi* season crops during 2015-16 and 2016-17 was determined in L_3 (rice-wheat system with CA) followed by L_5 (soybean-wheat system with CA), L_4 (soybean-wheat system with CT) and L_2 (rice-wheat system with CT), while it was lowest (1.67, 1.64, 1.64 and 1.64 g kg^{-1}, respectively) in L_6 (maize-wheat system with CT) treatments over the seasons.

Table 1. Effect of land use practices and soil depth on soil carbon fractions in the year 2015-2016

Main Plot	Very labile carbon (g kg^{-1})		Labile Carbon (g kg^{-1})		Less Labile Carbon (g kg^{-1})		Non-labile carbon (g kg^{-1})	
(Land use practices)	**After *kharif* season**	**After *rabi* season**	**After *kharif* season**	**After *rabi* season**	**After *kharif* season**	**After *rabi* season**	**After *kharif* season**	**After *rabi* season**
L_1:Uncultivated	3.11	3.12	1.68	1.68	2.06	2.07	1.98	1.99
L_2:R-W system-CT	3.46	3.34	1.87	1.81	2.34	2.26	2.22	2.15
L_3:R-W system-CA	3.7	3.74	2	2.02	2.46	2.5	2.37	2.4
L_4:S-W system-CT	3.51	3.36	1.89	1.81	2.33	2.24	2.24	2.15
L_5:S-W system-CA	3.56	3.46	1.92	1.87	2.35	2.31	2.27	2.21
L_6:M-W system-CT	3.1	3.04	1.67	1.64	2.04	2.02	1.97	1.94
L_7:M-W system-CA	3.15	3.18	1.7	1.71	2.06	2.11	2	2.03
SEm±	**0.127**	**0.115**	**0.076**	**0.062**	**0.086**	**0.077**	**0.087**	**0.074**
CD(*p=0.05*)	**0.39**	**0.355**	**0.233**	**0.192**	**0.265**	**0.238**	**0.269**	**0.227**
Sub-Plot (Soil depth)								
D_1: 0-5 cm	3.87	3.75	2.05	1.96	1.94	1.88	2.27	2.2
D_2: 5-15 cm	3.49	3.43	1.85	1.82	2.14	2.08	2.17	2.12
D_3: 15-30 cm	2.74	2.79	1.58	1.61	2.64	2.68	2.02	2.05
SEm ±	**0.087**	**0.064**	**0.053**	**0.034**	**0.064**	**0.042**	**0.063**	**0.04**
CD(*p=0.05*)	**0.254**	**0.185**	**0.154**	**0.099**	**0.185**	**0.122**	**0.181**	**0.116**
Main x Sub treatment	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 2. Effect of land use practices and soil depth on soil carbon fractions in the year 2016-2017

Main Plot	Very labile carbon (g kg^{-1})		Labile Carbon (g kg^{-1})		Less Labile Carbon (g kg^{-1})		Non-labile carbon (g kg^{-1})	
(Land use practices)	**After *kharif* season**	**After *rabi* season**	**After *kharif* season**	**After *rabi* season**	**After *kharif* season**	**After *rabi* season**	**After *kharif* season**	**After *rabi* season**
L_1:Uncultivated	3.2	3.21	1.72	1.73	2.11	2.12	2.04	2.05
L_2:R-W system-CT	3.34	3.27	1.81	1.77	2.26	2.21	2.15	2.1
L_3:R-W system-CA	3.81	3.87	2.06	2.09	2.55	2.59	2.44	2.48
L_4:S-W system-CT	3.36	3.33	1.82	1.8	2.24	2.23	2.15	2.13
L_5:S-W system-CA	3.54	3.61	1.91	1.95	2.37	2.41	2.27	2.31
L_6:M-W system-CT	3.04	3.04	1.64	1.64	2.02	2.03	1.94	1.95
L_7:M-W system-CA	3.27	3.34	1.76	1.8	2.17	2.22	2.09	2.14
SEm±	**0.091**	**0.069**	**0.049**	**0.038**	**0.063**	**0.05**	**0.059**	**0.045**
CD(*p=0.05*)	**0.281**	**0.212**	**0.152**	**0.116**	**0.194**	**0.153**	**0.181**	**0.139**
Sub-Plot (Soil depth)								
D_1: 0-5 cm	3.82	3.82	2	1.99	1.92	1.92	2.24	2.24
D_2: 5-15 cm	3.44	3.45	1.82	1.83	2.09	2.1	2.13	2.14
D_3: 15-30 cm	2.83	2.88	1.63	1.66	2.73	2.77	2.09	2.12
SEm ±	**0.052**	**0.05**	**0.028**	**0.027**	**0.034**	**0.034**	**0.033**	**0.032**
CD(*p=0.05*)	**0.15**	**0.145**	**0.08**	**0.078**	**0.099**	**0.099**	**0.095**	**0.093**
Main x Sub treatment	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Under different land use practices a significant difference in labile carbon content in soil at 0-5, 5-15 and 15-30 cm were obtained. It had been also noted that labile carbon fraction in soil, after harvest of *Kharif and Rabi* season crops during 2015-16 and 2016-17, at 0-5, 5-15 and 15-30 cm depth was varied from 1.96 to 2.05, 1.82-1.85 and 1.58-1.66 g kg^{-1}, respectively over the land use practices. Whereas, the interaction effect of land use practices and soil depths on labile carbon fraction was statistically non-significant.

3.3 Less Labile Carbon

The effects of land use practices and soil depth on less labile carbon fraction in the soil after harvest of *Kharif* and *Rabi* season crops during 2015-16 and 2016-17 was found statistically significant (Table 1 and Table 2). The results also showed that of this study less labile carbon fraction was maximum (2.46, 2.50, 2.55 and 2.59 g kg^{-1}) under L_3 (R-W system with CA) and lowest (2.04, 2.02, 2.02 and 2.03 g kg^{-1}) in L_6: (M-W system with CT) treatments after harvest of *Kharif* and *Rabi* four season crop during 2015-16 and 2016-17, respectively. It was also found that less labile carbon content in soil after harvest of *Kharif* and *Rabi* season crops during 2015-16 and 2016-17 under L_3 (R-W system with CA) was significantly higher than those obtained under L_1 (uncultivated), L_6 (M-W with CT) and L_7 (M-W with CA) treatments and statistically at par with L_2 (R-W system with CT), L_4 (S-W system with CT) and L_5 (S-W system with CA) treatments.

The results also showed that distribution of less labile carbon fraction with soil depths varied from 1.88 to 1.92, 2.08 to 2.14, 2.64 to 2.77 g kg^{-1}, respectively for 0-5, 5-15, 15-30 cm over the treatments of different land use practices. Further it was found that less labile carbon fraction in soil increased significantly with depth (0-30 cm) with maximum value in 15-30 cm and minimum in 0-5 cm soil depths. Whereas, the interaction effect of land use practices and soil depths on less labile carbon fraction was found statistically non-significant.

Data pertaining to effect of land use practices and soil depths on less labile carbon fraction in soil after harvest of *Kharif* and *Rabi* season crops during 2015-16 and 2016-17. It is evident from the results that highest value of non-labile carbon fraction at different depths was in L_3 (R-W system with CA) treatment. It was also noted that under the respective cropping system over soil depth the values of less labile carbon fraction was more under conservation agriculture as compared to conventional agriculture system.

3.4 Non-labile or Recalcitrant Carbon

Data on distribution of non-labile carbon fraction as affected by land use practices (cropping system under CA or CT) and depths of soils after harvest of *Kharif* and *Rabi* season crops during 2015-16 and 2016-17 are presented in Table 1 and Table 2 Data revealed that concentration of non-labile carbon fraction was significantly affected by land use practices and soil depth and highest (2.37, 2.40, 2.44 and 2.48 g kg^{-1}) value was found in L_3 (R-W system with CA) followed by L_5 (S-W system with CA) treatments, while it was lowest (1.97, 1.94, 1.94 and 1.95 g kg^{-1}) in L_6 (M-W system with CT) followed by L_2 (R-W system with CT) treatments, respectively after harvest of *Kharif* and *Rabi* season crops during 2015-16 and 2016-17.

Further it was found that over different land use practices the non-labile carbon fraction in soil at 15-30 cm depth was significantly lower than those at 0-5 and 5-15 cm depth but the difference in non-labile carbon fraction at 0-5 cm and 5-15 cm depth was statistically non-significant. Over the season's non-labile carbon fraction in soil varied from 2.20 to 2.27 g kg^{-1}, 1.13 to 1.17 g kg^{-1} and 2.02 to 2.12 g kg^{-1}, respectively at 0-5, 5-15 and 15-30 cm soil depth. Overall it was noticed that non-labile carbon fraction was more under CA as compared to CT practice.

4. DISCUSSION

4.1 Soil Carbon Fractions

Soil carbon fractions comprised of different C-pools of which some easily mineralized but some are recalcitrant. Improvement of SOM also adds to the carbon fractions that can be easily oxidized by strong oxidizing agent in presence of acids. Results revealed that contents of very labile, labile, less labile and non-labile carbon fractions in soil after harvest of *Kharif* and *Rabi* season crops during 2015-16 and 2016-17 were significantly influenced by different land use practices and soil depth. It was also found that irrespective of cropping systems higher content of different fractions of carbon were in CA as compared to CT.

Among cropping systems higher contents of very labile, labile, less labile and non-labile carbon fractions in soil were obtained in R-W system with CA followed by S-W system with CA. Higher carbon fractions in conservation agriculture system was might be because of more SOC due to which moderate the micro-environment and oxidation of soil carbon. Among the cropping systems higher contents of different fractions of carbon in rice-wheat system may be attributed to availability of more and easily decomposable biomass. Chan et al. [23] and Majumder et al. [24] also reported that the SOC fractions are comprised of active (very labile and labile) and passive (less and non-labile) pools which are significantly affected by land use practice and active pool of SOC is more important for soil health.

Lal [25], Bationo et al. [26] and Ghosh et al. [27] also found that SOC fractions were change with extent of crop residue, tillage, land use practices and soil depth and affect the food and energy source for soil had strong relationship with microbial biomass carbon and mineralizable carbon. Similarly, Weil et al. [16], Dou et al. (2008) and Bhattacharyya et al. [28] also reported that CA might have contributed to a greater C concentration in very labile and labile pool as compared to CT, while less labile and non-labile fractions of SOC are very slowly altered by microbial activities but contributes significantly to build-up of SOC.

5. CONCLUSION

Very labile, labile and less labile carbon fractions were improved under rice-wheat system with conservation agriculture practice and content were more in surface (0-5 and 5-15 cm) soil over CT and sub-surface (15-30 cm) soil. Distribution of soil carbon fractions (very labile, labile, less labile and non-labile or recalcitrant carbon) were significantly affected by land use practices and soil depth with maximum values in R-W system with CA and minimum in M-W system with CT. It was also noted that soil carbon fractions in CA practice was higher than those in CT over cropping systems. Soil carbon fractions decreased significantly with increasing soil depth across the land use practices but less labile carbon fraction in soil increased significantly with depth but interaction effect of land use practices and soil depth on soil carbon fractions was non-significant.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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