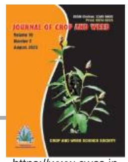
Journal of Crop and Weed, 19(2): 78-83 (2023)

ISSN- O : 2349 9400 ; P : 0974 6315



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The disparity in soil organic carbon concentrations under short-term conservation agriculture with rice-based cropping systems in a very fine textured soil of lower Indo-Gangetic plain, West Bengal

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Received : 17.03.2023 ; Revised : 18.04.2023 ; Accepted : 30.04.2023

DOI: https://doi.org/10.22271/09746315.2023.v19.i2.1706

ABSTRACT

The study aimed to evaluate the disparity in soil organic carbon (SOC) concentrations using different fertilizer doses, crop residues, tillage, and cropping systems in a very fine textured soil (silt + clay-90%) of lower Indo Gangetic Plain (IGP) of West Bengal. Surface soil (0-10 and 10-20 cm) samples were collected from the plots of short-term (three years) conservation agricultural (CA) practices with rice-based cropping systems [rice-mustard-black gram (RMuB), rice-wheat-green gram (RWG), and rice-lentil-fallow (RLF). Significant variation in SOC was found between the depths of 0-10 and 10-20 cm. The adoption of zero tillage (ZT) and reduced tillage (RT) practices increased 30.9 % and 27.9 %, of the total SOC in the 0-10 soil depths and 12.3 % and 15.5 % in the 10-20 cm soil depth as compared to the conventional tillage (CT) practice. The addition of residue or fertilizer did not impact SOC concentration, even tillage-residue interaction showed no disparity in the short-term experiments. Among the rice-based cropping system, RWG showed the highest change in SOC concentration. Residue addition, minimum soil disturbance, and crop diversification or inclusion of legumes after three years of ZT and RT systems improved SOC and hence the significance of CA in sustaining better soil health was established in the lower Indo-Gangetic Plain.

Keywords **:** Clayey soil, conservation agriculture, conservation tillage, rice-based cropping system, soil organic carbon

Soil organic carbon (SOC) has a major role in the formation and stabilisation of soil structure, the improvement of soil physical qualities, and nutrient recycling (Beare *et al*., 2014). In the cereal-growing regions of India, tillage-intensive (CT or ZT) cropping techniques have degraded soil physical properties and reduced SOC levels as well (Mandal *et al*., 2007; Choudhary *et al*., 2022). One of the crucial management strategies is conservation agriculture (CA), which encourages minimal soil disturbance, protects the soil through cover crops or surface residue, and facilitates crop rotation (Pittelkow *et al*., 2015; Naik *et al*., 2022). In contrast to conventional tillage (CT), the use of minimum tillage (MT), reduced tillage (RT), zero tillage (ZT), or no-tillage (NT) has been deemed an effective strategy for increased C sequestrations in soil; nonetheless, its effects are varied, both in terms of time and location. (Mondal *et al*., 2021).

In the IGP, rice-based cropping systems are followed, which is imperative to ensure the food security of this region (Mandal *et al*., 2007; Jat *et al*., 2019). The puddling operation for rice cultivation reportedly undermines the soil structure and creates a hard-compact layer that prevents roots from moving freely and reduces soil fertility (Bandyopadhyay *et al*., 2016; Mondal *et al*., 2019). Achieving food security is also being seriously hampered by the progressive degradation of the soil, the burning of residue, the use of organic manures being reduced or absent, and the improper use of fertilizers. The cropping systems primarily alter the distribution of SOC and the active habitat of microorganisms, resulting in changes in soil aggregates, which in turn provide conditions for the decomposition as well as the transformation of soil organic matter. Thus, it is necessary to modify the resource-intensive conventional rice-based cropping systems with effective management techniques that are compatible with soil quality, and resource conservation for the sustainability, and profitability of the system. This study aimed to evaluate the disparity in soil organic carbon (SOC) concentrations using different fertilizer doses, crop residues, tillage, and cropping systems.

MATERIALS AND METHODS

Description of the experimental site

The field experiment was conducted for eight cropping seasons during 2018-2021 at Balindi Research

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How to cite : Dey Sarkar, J., Kundu, A. and Bandyopadhyay, P. K. 2023. The disparity in soil organic carbon concentration under short-term conservation agriculture with rice-based cropping systems in a very fine textured soil of lower Indo-Gangetic plain, West Bengal. *J. Crop and Weed*, 19(2): 78-83.

Complex of BCKV, Nadia, West Bengal, India. The experimental site has an average elevation of 10 m and is located at 22°582 N and 88°322 E. The climate is hot and humid subtropical. The average annual rainfall is about 1470 mm, and the mean annual minimum and maximum temperatures range from 18 to 35ºC. The soil of the experimental site is clayey in texture with a hyperthermic temperature regime and the soil order is Inceptisol. In Table 1, the initial physicochemical characteristics were presented.

Experimental details

The experiment was carried out with three cropping systems (RMuB: rice-mustard-black gram, RWG: rice-wheat-green gram and RLF: rice-lentil-fallow) following split-split plot design in main plots, 3 tillage systems (CT: conventional tillage, ZT: zero tillage and RT: reduced tillage) in sub-plots and 3 regimes of residue and nutrient management (R1: No rice residue retention + 100% RDF fertilization, R2: 100% rice residue retention + 75% RDF fertilization, R3: 50% rice residue retention + 75% RDF fertilization) in sub-sub plots. Depending upon doses of residue and NPK fertilizers, sub-sub-plot treatments were assigned for the cultivation of *rabi* and *pre-kharif* crops. The total production of the rice straw was considered as 100%. After harvesting rice, rice straw was used as mulch as a conservation technique before sowing mustard, wheat and lentil (for RMuB, RWG and RLF cropping systems, respectively). A quantity of 100% and 50% of the rice straw were retained in the field for respective treatments. Treatment details were described in Table 2. The size of each experimental plot was 20 × 6.3 m^2.

Sampling and analysis of soil

Soil samples were drawn in 2021 (after 8 cropping seasons) after harvesting of *rabi* crops i.e. mustard for RMuB, wheat for RWG and lentil for RLF, from two distinct soil depths viz., 0-10 cm and 10-20 cm with a bucket auger from each replication of the sub-sub-plots. Six representative samples were randomly selected from each plot in a zigzag pattern and merged to create a composite sample. The samples were manually crushed, air-dried in the shade, processed, put through a 2.0 mm sieve, and then stored in airtight containers for chemical analysis. Soil pH and EC of the soil were determined with standard methodology as described by Jackson (1973). The total SOC (TSOC, g C kg^{-1} soil) was estimated from the method followed by Nelson and Sommers (1983) and oxidizable organic carbon by the method of Walkley and Black (1934). Plant available-N content in the soil samples was estimated by the alkaline permanganate method (Subbiah and Asija 1956). Plant available P content by standard methodology (Olsen *et al*. 1954). The K concentration of standards and samples was estimated by using a flame photometer following the method described by Hanway and Heidel (1952).

In a split-split plot design, the analysis of variance (ANOVA) was carried out using GenStat (Version 16.0) to ascertain the impacts of cropping systems, tillage, and residue management systems as components and interaction between them. Duncan's Multiple Range Test (DMRT) ($p<0.05$) was used to compare the treatment means.

RESULTS AND DISCUSSION

Effect of tillage on SOC distribution

After three years of CA management, the tillage practices significantly affected the SOC distribution. In the RMuB cropping system, the highest TSOC content in the surface soil (0-10 cm depth) was observed (Table 3) under ZT (24.28 g kg^{-1}), followed by RT (22.03 g kg^{-1}) and the lowest in CT (20.38 g kg^{-1}) treatment. The carbon gain in ZT and RT was observed as 19.14% and 8.09 %, respectively. In the subsurface soil of 10-20 cm depth, the trend was as follows: ZT (20.71 g kg^{-1}) e" RT (19.5 g kg^{-1}) = CT (18.05 g kg^{-1}). Both depths of soil tillage showed significant variations. In the case of the RWG cropping system, the highest total organic carbon content was observed under ZT (32.16 g kg^{-1}) followed by RT (24.42 g kg^{-1}) and the lowest in CT (22.39 g kg^{-1}) treatments in the surface soil (0-10 cm depth) with a carbon gain of 43.6% and 9.06% in ZT and RT, respectively. In the subsurface soil (10-20 cm), the same trend was observed (Table 3). However, across all the soil depths (0-20 cm), the rank was: ZT (29.29 g kg^{-1}) >RT (23 g kg^{-1}) > CT (20.53 g kg^{-1}). In the case of the Rice-Lentil-Fallow cropping system, the highest TSOC content was observed under ZT (30.79 g kg^{-1}) followed by RT (28.43 g kg^{-1}) and the lowest in CT (23.87 g kg^{-1}) treatments in the surface soil (0-10 cm depth) and in subsurface soil (10-20 cm), the trend was as follows: ZT (28.10 g kg^{-1}) = RT (26.83 g kg^{-1}) > CT (22.09 g kg^{-1}) (Table 3). Across all the soil depths (0-20 cm), SOC gain of 28.11% and 20.23% in ZT and RT, respectively, was observed. Hence, the ZT practice significantly enhanced the total C concentrations over the CT practice. Similar higher C concentration in the ZT system was also reported by Alvarez *et al*. (2011), Metay *et al.* (2007) and Nandan *et al.*, (2019). Repeated CT degrades soil aggregates (Zotarelli *et al.*, 2007) and enhances soil aeration as a result, stimulating soil microbial activity and biomass (Guo *et al.*, 2013). Therefore, SOC oxidation is accelerated (Green *et al.*, 2007) and SOC is decreased.

Table 1: Physicochemical properties of the surface soils at the inception of the experimental field

Soil properties	Unit/ description	Value
Soil type	*Inceptisol*, Alluvial soil	-
Sand	%	7.1
Silt	%	30.1
Clay	%	63.8
Textural class	Clay	-
Bulk density	Mg m^{-3}	1.42
Particle density	Mg m^{-3}	2.75
pH (1:2.5, H_2O)	-	7.39
Electrical conductivity	dS m^{-1}	0.97
Soil organic carbon	g kg^{-1}	9.1
Available nitrogen	kg ha^{-1}	222.05
Available phosphorus	kg ha^{-1}	25.04
Available potassium	kg ha^{-1}	297.58

Table 2: Treatments used in the experimental site

Cropping systems (3)	Tillage practices (3)	Nutrient and crop residue Combination (3)
1. Rice-mustard-black gram (RMuB)	i. Conventional tillage (CT)	a) 0% Residue + 100% RDF (R1)
		b) 100% Residue + 75 % RDF (R2)
		c) 50% Residue + 75 % RDF (R3)
	ii. Zero tillage (ZT)	a) 0% Residue + 100% RDF (R1)
		b) 100% Residue + 75 % RDF (R2)
		c) 50% Residue + 75 % RDF (R3)
	iii. Reduced tillage (RT)	a) 0% Residue + 100% RDF (R1)
		b) 100% Residue + 75 % RDF (R2)
		c) 50% Residue + 75 % RDF (R3)
2. Rice-wheat-green gram (RWG)	i. Conventional tillage (CT)	a) 0% Residue + 100% RDF (R1)
		b) 100% Residue + 75 % RDF (R2)
		c) 50% Residue + 75 % RDF (R3)
	ii. Zero tillage (ZT)	a) 0% Residue + 100% RDF (R1)
		b) 100% Residue + 75 % RDF (R2)
		c) 50% Residue + 75 % RDF (R3)
	iii. Reduced tillage (RT)	a) 0% Residue + 100% RDF (R1)
		b) 100% Residue + 75 % RDF (R2)
		c) 50% Residue + 75 % RDF (R3)
3. Rice-lentil-fallow (RLF)	i. Conventional tillage (CT)	a) 0% Residue + 100% RDF (R1)
		b) 100% Residue + 75 % RDF (R2)
		c) 50% Residue + 75 % RDF (R3)
	ii. Zero tillage (ZT)	a) 0% Residue + 100% RDF (R1)
		b) 100% Residue + 75 % RDF (R2)
		c) 50% Residue + 75 % RDF (R3)
	iii. Reduced tillage (RT)	a) 0% Residue + 100% RDF (R1)
		b) 100% Residue + 75 % RDF (R2)
		c) 0% Residue + 75 % RDF (R3)

Table 3: Effect of Conservation agricultural practices in bulk soil organic carbon (g kg $^{-1}$) in different cropping systems at 0-10 and 10-20 cm depth

Treatments	Cropping system								
	RMuB			RWG			RLF		
	Soil depth (cm)		Mean	Soil depth (cm)		Mean	Soil depth (cm)		Mean
	0-10	10-20		0-10	10-20		0-10	10-20	
Tillage									
CT	20.38bA	18.05bB	19.22c	22.39cA	18.67cB	20.53c	23.87cA	22.09bB	22.98c
ZT	24.28aA	20.71aB	22.5a	32.16aA	26.41aB	29.29a	30.79aA	28.10aB	29.44a
RT	22.03bA	19.5abB	20.76b	24.42bA	21.57bB	23b	28.43bA	26.83aB	27.63b
Residue									
R1	21.94aA	18.98aB	20.46a	25.75aA	22.03aB	23.89a	27.28aA	25.34aB	26.31a
R2	22.62aA	19.78aB	21.2a	26.76aA	22.18aB	24.47a	28.13aA	26.00aB	27.07a
R3	22.13aA	19.51aB	20.82a	26.47aA	22.44aB	24.45a	27.68aA	25.67aB	26.67a
ANOVA									
Tillage (T)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Residue(R)	ns	ns	ns	ns	ns	ns	ns	ns	ns
T×R	ns	ns	ns	ns	ns	ns	ns	ns	ns
Depth (D)	-	-	<0.001	-	-	<0.001	-	-	<0.001

Notes: RMuB: rice-mustard-blackgram cropping system, RWG: rice- wheat-greengram cropping system, RLF: rice-lentil-fallow cropping system * Different letters are significantly different at p< 0.05 according to Duncan's multiple range test. ** Different lowercase letters in the vertical line denotes the interaction effects between tillage and residue management and different upper-class letters in the horizontal line denote the effect of soil depth.

Among the rice-based cropping systems, RWG (cereal-cereal crop rotation) showed the highest TSOC change concerning conventional tillage followed by Rice- Lentil-Fallow and Rice-Mustard-Blackgram cropping system (Fig.1). The significant influence of crop rotation on SOC was most probably from the differences in underground biomass and contribution from leaf litters in short-term rotations (Kim *et al*., 2016). However, across all the soil depths (0-20 cm), the adoption of ZT practices increased by 17.06 %, 42.66 % and 28.11% of the total SOC concentration in comparison to conventional tillage (CT) in RMuB, RWG and RLF cropping system respectively. The adoption of reduced tillage (RT) practices increased 8.012 %, 12.03 % and 20.23 % of the total SOC in comparison to the conventional tillage (CT) in RMuB, RWG and RLF cropping system respectively concentration across all the soil depths (0-20 cm). Irrespective of the cropping system, the adoption of reduced tillage (RT) and zero tillage (ZT) practices increased by 30.9 % and 27.9 %, 12.3 % and 15.5 % of the total SOC concentration in the 0-10 and 10-20 cm depths in comparison to the conventional tillage (CT). For the Rice-Wheat-Greengram cropping system, the change in SOC in subsurface soil under the reduced tillage was higher than in surface soil (Fig.1). This might be due to the deep root system of Wheat which added more carbon under reduced tillage condition (Ghosh *et al.*, 2018).

Effect of residue on SOC distribution

The fertilizer or residue had no impact on the concentration of SOC, even tillage-residue interaction showed no disparity in the experiment (Table 3). The reasons for the differentiation of bulk SOC in our soils might be due to short-term (3 years) CA practice which did not provide the necessary time for the decomposition of the crop, heavy textural class of the experimental soil might shade the effects of residue addition.

The tillage treatments, residue treatments as well as interaction values between tillage and residues were significant with depth. The findings demonstrated that as depth increased, the total organic carbon content values declined. In our experiment, we observed that the concentration of SOC in the surface layer was increased because crop residues were left on the soil surface and the soil was not disturbed. Several studies also indicated the drastic effect of the tillage system on SOC stratification in the surface layer (Puget and Lal, 2005; Sa and Lal, 2009).

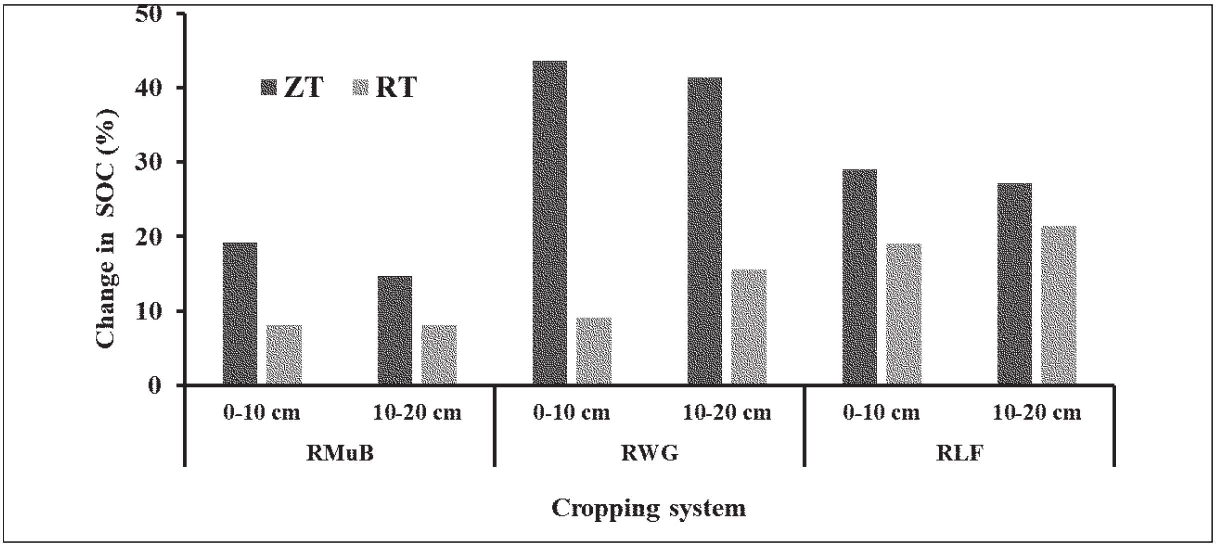

Fig. 1: Change in soil organic carbon in ZT and RT compared to CT across three cropping systems at 0-10 cm and 10-20 cm depths

CONCLUSION

From this study, it is concluded that reduced soil disturbance (ZT) improves the concentration of SOC. Due to the difference in the distribution of plant biomass, the SOC was increased in the surface layers but lowered in the subsurface layers. Among the rice-based cropping systems, rice-wheat-greengram showed the highest variation in SOC due to tillage (due to both the tillage and higher biomass). The results of this study will help adopt conservation agriculture techniques more effectively in the long run, which will lead to improve the soil health in the lower Indo-Gangetic plains.

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