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Effect of Long-Term Conservation Agriculture on Soil Organic Carbon and Dehydrogenase Activity under Maize-Based Cropping Systems

Amresh Chaudhary, Mahesh C. Meena*, Chiter M. Parihar and Abir Dey

ICAR-Indian Agricultural Research Institute (ICAR-IARI), New Delhi, 110012, India

*Corresponding author

ABSTRACT

Keywords

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A long-term field experiment on conservation agriculture (CA) is continuing since 2008 at the research farm of the ICAR-Indian Institute of Maize Research (IIMR), New Delhi to evaluate the impact of twelve combinations of tillage practices (03) and irrigated intensive maize-based systems (04) on Walkley and Black C (WBC) and dehydrogenase activity of a sandy loam soil in north-western Indo-Gangetic plains of India. The CA-based tillage practices consist of zero-till (ZT), permanently raised beds (PB) and conventional tillage (CT) in main-plots and four intensive irrigated maize-based crop rotations (MWMb: maize-wheat-mungbean, MCS: maize-chickpea-*Sesbania*, MMuMb: maize-mustard-mungbean, MMS: maize-maize-*Sesbania*) in sub-plots. Results revealed that across the soil depths, WBC content of different tillage practices and diversified cropping systems varied from 0.55 to 0.40%. The CA-based practices resulted in higher WBC over CT, and the value decreased with soil depth. The DHA registered 49.2 and 50.1% higher in 0-5 and 5-15 cm soil depth under PB over CT, respectively which showed improvement in soil health and SOC due to crop diversification. Thus, our long-term study suggests that PB and ZT with diversified maize-based systems *i.e.* MCS and MWMb can be advocated for restoration and improvement in soil health of light textured soils of north-western India.

Introduction

Soil organic carbon (SOC) is the epicenter of soil physical, chemical and biological health (Chen *et al.*, 2017; He *et al.*, 2015). Indiscriminate use of fertilizers in post green revolution era (for the past four decades) discouraged application of organic matter in soil which ultimately reduced SOC to a very low level (< 0.5%) (Velayutham *et al.*, 2000). Tillage is manipulation of soil for providing better condition for plant growth but also increases the rate of SOC mineralization resulting in SOC loss. In India, about 500 Mt of crop residue (CR) is generated through agricultural production system annually, and

more than one-fifth of those are disposed of by burning to clear fields after harvest (Aulakh *et al.*, 2012). Crop-residue burning is a major cause of environmental pollution especially in the north western part of Indo-gangetic plains (NW-IGP) (Punia *et al.*, 2008) resulting in environmental pollution, generation of greenhouse gases and loss of soil nutrients. Therefore, proper management of crop residues is crucial for sustainable agriculture (Meena *et al.*, 2017). Conservation agriculture is a crop management based practices on no-tillage, residue retention and crop diversification and has potential to increase

the soil organic matter content through efficient management of crop residue.

Maize-based diversified cropping system has been found as a better alternative to rice-wheat cropping system due to its low irrigation water requirement, higher productivity and better adaptability to harsh environment due to its C₄ nature and increasing demand for maize in livestock and processing industries (Parihar *et al.*, 2016). Diversified maize-based rotation promoted accumulation of SOC in Inceptisols (Nath *et al.*, 2017). No-till maize-based crop rotation reported a reduction in greenhouse gas emission in the form of nitrous oxide along with improvement in soil carbon status (Lehman *et al.*, 2017). Conservation agriculture improves soil biological properties, microscopic bio-diversity and enzyme activities (Dai *et al.*, 2017). However, detection of change in SOC content in different soil layers due to alteration of tillage practices from conventional to conservation (no-tillage) is difficult over a short period of time. Information regarding long-term effects of different tillage practices and maize-based cropping systems on Walkley-Black carbon (WBC) and its impact on biological activities in the IGP is scarce. Therefore, there is need for extensive study of long-term effect of CA on SOC and soil health. In the current study we hypothesized that residue retention on soil surface during different cropping seasons under similar type of agronomic management practices would result in difference in SOC content and dehydrogenase activity. The aim of this study was to evaluate the best cropping system in terms of SOC status, and dehydrogenase activity (DHA) activity as affected by tillage and residue retention.

Materials and Methods

Experimental site and treatment details

A long-term field experiment on conservation

agriculture (CA) with different cropping systems has been initiated in the year 2008 at the research farm of the ICAR-Indian Institute of Maize Research (IIMR), New Delhi, and is continued till date. The site is situated at 28°4' N latitude, 77°12' E longitude and 228.6 meters above mean sea level. The experimental soil was taxonomically characterized as Typic Haplustept, neutral and non-saline in nature. Important soil properties are given in Table 1. Delhi represents semi-arid sub-tropical environment with cold winter and hot summer. The mean annual precipitation is about 650 mm, which is mostly through by N-W monsoon contributing 80% of total rainfall in this reason. The mean daily evapotranspiration was 10.9 mm in the month of June and minimum (1.5 mm) in January. The annual pan evaporation was approx. 850 mm. The maximum value of mean relative humidity approaches during the south-west monsoon period and the minimum in the hot summer months.

The experiment was laid-out in split-plot design with three tillage practices of which two are CA-based practices like permanent bed (PB) and zero tillage (ZT) with 30% crop residues retained on the soil surface in each year, and a conventional tillage (CT) in main-plots and four sub-plots consisting of cropping systems *i.e.* maize-wheat-mungbean (MWMb), maize-chickpea-*Sesbania* (MCS), maize-mustard-mungbean (MMuMb) and maize-maize-*Sesbania* (MMS), with three replications (Table 2).

Soil sample collection and analysis

Depth-wise soil samples (0-5, 5-15 and 15-30 cm) were collected after harvesting of *kharif* crop in October 2015. Samples were air dried, ground with wooden pestle and mortar and passed through 0.2 mm sieve to determine the SOC content as procedure outlined by Walkley and Black (1934) and reported as

WBC. Samples were also collected after harvesting of crops in each season *i.e.* *kharif*, *rabi* and summer seasons from two soil depths *i.e.* 0-5, 5-15 cm. Immediately, the fresh samples were used for determination of dehydrogenase activity according to Casida *et al.* (1984). The 2, 3, 5-triphenyltetrazolium chloride was added to field moist soil along with glucose solution. After 24 hours incubation at 37°C, formed triphenylformazon was extracted with methanol and measured spectrophotometrically at 485 nm.

Statistical analysis

The data recorded for different parameters were analyzed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez 1984) for split-plot design using SAS 9.1 software (SAS Institute, Cary, NC). The least significant difference (LSD) test was used to decipher the effect of treatments at 5% level of significance ($P=0.05$).

Results and Discussion

Walkley-Black C

Walkley-Black C (WBC) content under long-term tillage practices was highest under ZT with average value 0.46% across the soil depths (Table 3). The WBC content under PB was statistically similar to ZT at different soil depths, whereas CT contained lowest WBC. The WBC content under PB and CT averaged across the soil depth was 0.44% and 0.39%, respectively. Compared with CT, WBC content of 0-5 cm soil layer was higher under PB and ZT by 21.3 and 19.7%, respectively. In 5-15 cm depth, PB and ZT had similar and significantly higher WBC (0.47%) compare to CT (0.40%). Differences between tillage practices were not significant at 15-30 cm depth. The WBC content was reported in different cropping systems, which followed the trend as MCS>MWMb>MMS>MMuMb across the soil depths. The interaction

between tillage and cropping systems were significant for 0-5 cm and 15-30 cm depth, and shown the advantage of adoption of CA treatments (PB and ZT) equally in MCS and MWMb systems (Fig. 1).

Dehydrogenase activity

Dehydrogenase activity (DHA) was found significantly higher in PB and ZT over CT in all soil depth across the seasons. Under PB, DHA was 49.2 and 50.1% higher compared to CT in 0-5 cm and 5-15 cm soil depths, respectively, during the *rabi* season (Table 4). Soil DHA was lower in lower depths, irrespective of treatments. Across the seasons, DHA was highest in *kharif* followed by summer and *rabi* with a range of 31.8-63.8, 31.0-61.5 and 29.3-57.0 $\mu\text{g TPFg}^{-1} 24 \text{ h}^{-1}$, respectively. In respect to cropping systems, DHA values decreased in the order: MCS>MWMb>MMS>MMuMb irrespective of soil depths and seasons. Dehydrogenase activity was 39.6 and 24.5% higher in MCS over MMuMb in 0-5 cm and 5-15 cm soil depths, respectively in the *kharif* season. Similar trend was recorded for *rabi* and summer seasons. Interaction of tillage practices and cropping systems was not significant for either soil depths or seasons.

In the present investigation, long-term effect of CA practices *viz.* PB, ZT *vis-à-vis* CT was evaluated on WBC and DHA activity under different maize-based cropping systems. WBC contents under PB and ZT were greater than CT in the present case (Table 3). These results are expected in the light of C input through retention of crop residues and minimum soil disturbance. The CA has high potential for C-sequestration and conversion to no-till farming helps sequestering C in soil (Dey *et al.*, 2016). A few reports contradicted the claims made regarding improvement in SOC content owing to adoption of CA (Yang and Wander 1999; Halvorson *et al.*, 2002; Thomas *et al.*, 2007). The present study

however did not substantiate such reports. Earlier studies further suggest only small changes in WBC content of soil when measured over short-term because of large quantity of background organic matter present in soil (Lal, 2015). Contrarily there has been significant change in WBC content in the present study. Such changes in WBC may be attributed due to adoption of CA which involves substantial amount of residue retention (30% of the above ground residues of *kharif* and *rabi* crops) *vis-à-vis* CT with residue removal. Averaged across soil depths, MCS and MWMB accumulated relatively higher WBC compared with MMuMb and MMS which indicate that inclusion of chickpea or wheat as *rabi* crop appeared to be a superior option compared to mustard or winter maize as far as SOC accumulation is concerned. The finding of present study is in

line with the published literature on depth-wise distribution of SOC in crop lands (Mandal *et al.*, 2013; Singh *et al.*, 2015). This study corroborated the findings of Bhattacharyya *et al.*, (2012) suggesting thereby the advantage of minimum soil disturbance (PB and ZT) and crop wise residue retention on soil surface.

Dehydrogenase activity (DHA) measured during different seasons was invariably higher under CA (PB and ZT) compared with CT irrespective of soil depth (Table 4). An improvement in DHA content under CA practices is very much explainable in the light of possible flux in the microbial activity owing to less soil disturbance and retention of crop residues on the soil surface (Liu *et al.*, 2014).

Table.1 Some important initial physicochemical properties of the experimental soil

Parameter	Values	Reference
Mechanical composition		Bouyoucos (1962)
Sand (%)	64.1	
Silt (%)	12.6	
Clay (%)	23.4	
Texture	Sandy loam	
pH	7.8	Jackson (1973)
EC (dSm ⁻¹)	0.32	Jackson (1973)
Bulk density (Mg m ⁻³)	1.58	Veihmeyer and Hendrickson (1948)
KMnO ₄ Oxidizable N (kg ha ⁻¹)	158	Subbiah and Asija (1956)
0.5 M NaHCO ₃ -extractable P (kg ha ⁻¹)	11.6	Olsen <i>et al.</i> , (1954)
Neutral 1 N NH ₄ OAc-extractable K (kg ha ⁻¹)	248	Hanway and Heidel (1952)

Table.2 Treatments details of long-term experiment

S. No.	Notations	
Main-plot: <i>Tillage and crop establishment techniques (03)</i>		
1.	Zero tillage permanent bed planting	1. Permanent bed (PB)
2.	Zero tillage flatbed	2. Zero tillage (ZT)
3.	Conventional tillage flat	3. Conservation tillage (CT)
Sub-plot: <i>Cropping systems (04)</i>		
1.	Maize-Wheat-Mungbean	1. MWMB
2.	Maize-Chickpea- <i>Sesbania</i>	2. MCS
3.	Maize-Mustard-Mungbean	3. MMuMb
4.	Maize-Maize- <i>Sesbania</i>	4. MMS

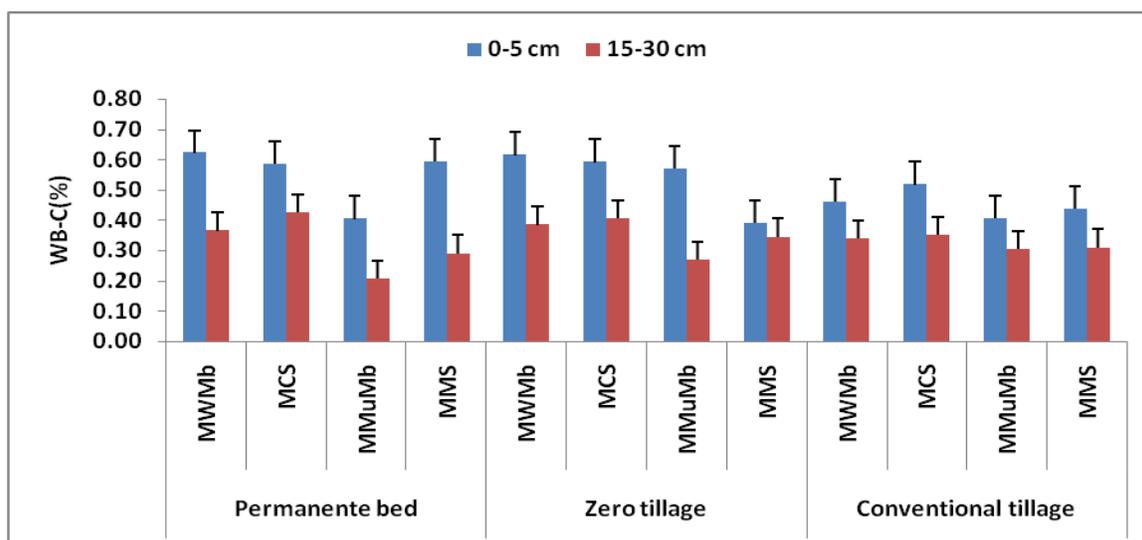
Table.3 Long-term effect of different tillage and cropping systems on depth-wise distribution of Walkley- Black C (WBC) after harvest of *rabi* crops

Treatment	WBC (%)			
	0-5 cm	5-15 cm	15-30 cm	Mean
<i>Tillage practices</i>				
Permanent bed	0.552	0.443	0.322	0.439
Zero tillage	0.542	0.472	0.351	0.455
Conventional tillage	0.455	0.396	0.326	0.393
LSD ($p<0.05$)	0.038	0.049	NS	
<i>Cropping systems</i>				
MWMb	0.566	0.444	0.363	0.458
MCS	0.565	0.479	0.394	0.479
MMuMb	0.461	0.370	0.260	0.363
MMS	0.475	0.455	0.315	0.415
Mean	0.517	0.437	0.333	
LSD ($p<0.05$)	0.042	0.050	0.035	
Interaction (LSD, $p<0.05$)	0.074	NS	0.060	

Table.4 Season-wise changes in dehydrogenase activity ($\mu\text{g TPF g}^{-1} 24 \text{ h}^{-1}$) under different treatment options

Treatment	<i>Kharif</i>			<i>Rabi</i>			Summer		
	0-5 cm	5-15 cm	Mean	0-5 cm	5-15 cm	Mean	0-5 cm	5-15 cm	Mean
<i>Tillage practices</i>									
Permanent bed	63.8	48.7	56.3	57.0	44.0	50.5	61.5	47.3	54.4
Zero tillage	59.3	46.7	53.0	52.7	42.4	47.6	56.7	45.5	51.1
Conventional tillage	42.2	31.8	37.0	38.2	29.3	33.8	40.7	31.0	35.9
LSD ($p<0.05$)	8.2	5.5		6.5	4.2		6.5	4.2	
<i>Cropping system</i>									
MWMb	55.5	42.0	48.8	49.6	38.3	44.0	53.3	40.8	47.1
MCS	65.9	48.2	57.1	57.3	42.9	50.1	62.8	46.8	54.8
MMuMb	47.2	38.7	43.0	43.5	36.0	39.8	45.9	37.9	41.9
MMS	51.9	40.6	46.3	46.7	37.1	41.9	49.9	39.5	44.7
Mean	55.1	42.4	48.8	49.3	38.6	44.0	53.0	41.3	47.1
LSD ($p<0.05$)	6.5	5.2		5.9	3.4		5.9	3.4	
Interaction (LSD, $p<0.05$)	NS	NS		NS	NS		NS	NS	

Fig.1 Interaction effect of long-term tillage practices and cropping systems on Walkley- Black C in different soil depths [Error bar shows LSD ($p < 0.05$)]



Adoption of CA significantly improved SOC status, and *vis-à-vis* soil biological activity. Relatively higher levels of WBC under long-term CA suggested greater possibility of C sequestration under PB and ZT over CT. Soil microbes flourished under CA practices resulting in higher DHA. Cropping systems like MWMb and MCS could be successfully adopted under CA to enhance SOC status which is the ultimate reservoir of plant nutrients and soil microbes and thus improvement of overall soil health can be achieved.

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