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Soil organic carbon, dehydrogenase activity and fluorescein diacetate as influenced by contrasting tillage and cropping systems in Vertisols of Central India

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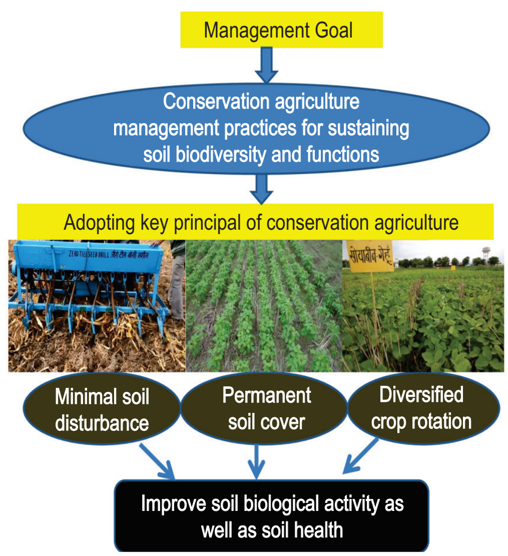
Abstract

Aim : The present study aimed to compare the effects of different tillage systems and cropping systems on soil biological activity in terms of soil organic carbon, labile carbon, dehydrogenase activity, fluorescein diacetate activity and crop productivity.

Methodology : The yield data of different cropping systems were converted in soybean grain equivalent yield using minimum support price based on 2015 and expressed in q ha^{-1}. Soil samples were collected randomly from 2-3 locations from the plots at the end of 3rd crop cycles at 0-5 and 5-15 cm depths during April 2014 with the help of core sampler and processed. The soil samples were analysed using standard analytical procedures.

Results : Within tillage system, soil organic carbon was recorded higher in reduced tillage (0.67%), compared to no-tillage (0.66%) and conventional tillage (0.62%) at 0-5 cm depth. The labile carbon in surface soil (0-5 cm) followed same trend of soil organic carbon, whereas at 5-15 cm depth, it followed the trend : no-tillage > reduced tillage > conventional tillage. Furthermore, soil enzymatic activity was significantly affected by the imposed tillage systems. The results of dehydrogenase activity reported higher in no-tillage system compared to reduced and conventional tillage; whereas fluorescein diacetate hydrolysis was reported higher in reduced tillage followed by no-tillage and conventional tillage at surface soil (0-5 cm). Pearson correlation (r) showed significant correlations between soil organic carbon and soil biological parameters. It was inferred that cropping system had a significant effect on soybean grain equivalent yield at end of 3rd crop cycles. The results of this study also confirmed effectiveness of studied parameters as soil indicators owing to sensitivity towards management practices.



Interpretation : Soil microbial activities greatly influenced with depth as in the upper layer than 5-15 cm depth. Significantly positive correlation between soil organic carbon and microbial activities indicated enhanced microbial biodiversity, maintaining a better environment for stabilizing soil quality due to tillage and cropping systems applied.

Introduction

Conservation agriculture technology convenes to three key principles: minimal soil disruption, *i.e.* reduced tillage or no-tillage and direct sowing/planting; permanent soil cover, *i.e.* retention of crop residue/cover crops/inter-cropping and; diversified crop rotation to inhibit weeds residents, insects and diseases (Derpsch, 2001). No-tillage, ensures more storage of crop residue on surface of the soil, which results lower temperature and higher soil moisture with in effect to improve microbial activity, better soil aggregation and improvement in soil properties, such as soil organic carbon and nitrogen content and shrinkage C:N ratio than conventional tillage (Derpsch *et al.,* 2010; Benitio, 2010; Celik *et al.,* 2011).

The suitable management practices of soil to perform are sustainable crop productivity and to maintain or increase soil quality (Aziz *et al.,* 2009) and soil quality have to be a combination of physical, chemical and biological properties sensitive to management (Islam and Weil, 2000; Aparicio and Costa, 2007). Soil physical and chemical properties have been extensively used to measure soil quality around the world (Mukherjee and Lal, 2014; Kumar *et al.,* 2017). However, soil functions typically change slowly, and consequently significant variations may occur for several years (Pupin *et al.,* 2009, Gajda *et al.,* 2013). In contrast, soil biological functions as an activity of soil microorganisms and/or activity of enzymes are sensitive to soil management practices and also due to sudden environmental changes, and providing sensitive information on changes in soil quality (Melero *et al.,* 2010).

Soil organic carbon is considered as a key indicator of soil quality as well as soil health and it supports various momentous soil functions by providing energy, substrates and biological diversity to support biological activity, which affects aggregation (important for habitat space, oxygen supply, and preventing soil erosion), infiltration (important for leaching, runoff, and crop water uptake), and decomposition (important for nutrient cycling) (Franzluebbers, 2010). Herrick and Wander (1997) reported that different pool of SOC special functions at different characteristics of soil quality, such as fate of ionic and non-ionic complexes, the increase of cation exchange capacity and long term stability of micro-aggregate. Microbial enzymes have vital role in soil and are used to measure the soil quality and influence of soil management (Mohammadi, 2011; Pupin *et al.,* 2009). Soil enzymes are important in catalyzing numerous essential reactions, necessary for existing processes of micro-organisms in soils and the stabilization of soil structure, decomposition of organic wastes, organic matter formation, and nutrient cycling, hence playing an important role in agriculture.

The soil biological activities are considered as dynamic properties and in continuous change in soil atmosphere. Conditions of soil in different agro-ecosystem are unstable for applied management practices. Hence, the management practices such as tillage, type and amount of fertilizer and crop rotations have great impact on soil biological properties. There is relatively very little information available on the effect of tillage and cropping systems on soil biological properties in tropical/ subtropical environment region, particularly for the Indian Vertisol (Kumar *et al.,* 2017). In view of the above, the present study was carried out to evaluate the effect of different tillage and cropping systems on soil biological properties in terms of soil organic carbon, labile carbon, dehydrogenase activity and fluorescein diacetate.

Materials and Methods

A long-term field experiment (three years old) was started during August, 2011 with three contrasting tillage namely no-tillage, reduced tillage and conventional tillage in combination with crop four cropping systems on crop yield and soil properties under rainfed vertisols of Central India at the experimental station of ICAR- Indian Institute of Soil Science, Bhopal, India. Soils under the research farm was classified as clayey textural class (Vertisols, Isohyperthermic Typic Haplustert) with 58% clay, 22% silt and 20% sand in the first 0-15 cm layer. The climate of the experimental site was characterised as hot sub humid type, with mean annual air temperature, mean annual rainfall and potential evapotranspiration of 25°C, 1130 and 1400 mm, respectively.

The experiment had a split-plot design with three tillage system (No-tillage, Reduce tillage and Conventional tillage) as the main plot and four crop systems namely [Soybean + Pigeon pea (2:1), Soybean – Wheat, Maize + Pigeon pea (1:1), Maize - Gram] as the sub plot with a size of 10 x 5 m (50 m2) replicated thrice. The conventional tillage consisted of deep summer ploughing after residue burning and passed 3 to 4 tillage operations using tine cultivator, followed by sowing in *kharif* and *rabi* crops. The reduced tillage consisted of one pass tillage operation using duck foot cultivator and sowing through zero till seed drill in *kharif* and *rabi* crops and no-tillage consisted of sowing/planting crops into undisturbed soil by opening a narrow slot of sufficient width and depth to cover the seed using zero till seed drill. Soil samples were collected from two incremental depths (0-5 and 5-15 cm) randomly, 2-3 locations in a plot in the month of April 2014 at the end of 3rd crop cycle.

Therefore, at each depth, 36 soil samples [3 tillage (main treatments plots), 3 replicates and 4 cropping systems (sub treatments plots)] and total 72 soil samples were studied. These samples were air dried in a screen house grained with wooden mortal and pestal, passed through a 2.0 mm sieve after removing large plant material, and analysed for soil biological properties. Organic carbon content of the soil sample was determined by the method of Walkley and Black, (1934). The labile soil carbon was determined by potassium permanganate (KM_nO_4) oxidizable method as suggested by Blair *et al.* (1995). Soil dehydrogenase activity was determined by the method of Casida *et al.* (1964) using 3% Triphenyltetrazolium chloride and colour intensity of TPF was recorded at 485 nm with a spectrophotometer. Soil fluorescence diacetate activity was estimated by the method of and Adam *et al.* (2001) using potassium phosphate buffer (pH 7.6) and absorbance of the filtrates were recorded at 490 nm with a spectrophotometer. The soil organic carbon, labile carbon, dehydrogenase activity, fluorescence diacetate activity and yield data were analysed using two way analysis of variance (ANOVA) technique following the split plot design. The data analysis was done with SPSS windows, version 11.0. The significance of the treatment effect was determined by F - test, and to compare the significance difference between two treatments, least significance difference (LSD) was estimated at $p < 0.05$ level of significance.

Results and Discussion

The higher labile carbon and soil organic carbon concentration was recorded at surface layer (0-5cm) and its concentration decreased with increasing depth. Among different tillage system evaluated, reduced tillage and no-tillage registered significantly ($p<0.05$) higher soil organic carbon and labile carbon compared to conventional tillage at 0-5 cm. Similarly, at 5-15 cm depth, reduced tillage and no-tillage registered significantly ($p<0.05$) higher soil organic carbon compared to conventional tillage (Table 1). Regardless the soil depths, tillage had significant effect ($p<0.05$) on labile carbon, soil organic carbon, whereas, cropping systems and interaction (tillage x cropping system) effect on soil organic carbon was non-significant ($p>0.05$), but interaction between tillage and cropping systems had positive ($p<0.05$) effect on labile carbon. Increased soil organic carbon and labile carbon at 0-5 cm depth under reduced tillage and no-tillage than conventional tillage was possibly attributed to minimum soil disturbances and crop residue retention helps in increasing soil carbon in the surface layers. Similarly, Hati *et al.* (2014) and McCarty *et al.* (1998) reported that conservation tillage, particularly no-tillage leads to a higher soil organic carbon concentration in the top layer of the soil (0-5 cm) and alters its distribution within the soil profile. In addition, conservation tillage maintains soil temperature variations, and enhancing soil moisture can also support better microbial activity in surface soil. In contrast under conventional tillage, results findings corroborated with the Bhattacharyya *et al.* (2009) and Dou *et al.* (2008) found conservation tillage namely no-tillage significantly increased the size of soil organic carbon and labile pools of carbon compared with conventional tillage only at surface layer. According to Weil *et al.* (2003), labile or active carbon pool, which is readily available to microbes are different from a highly recalcitrant or passive carbon pool, *i.e.,* slowly altered by microbial activities. This fraction of carbon pool serves as a sensitive indicator like change in microbial biomass cabon, soil quality as influenced by the management practices (Islam and Weil, 2000; Li *et al.,* 2012).

The results revealed that higher labile carbon under reduced tillage and no-tillage at surface layer (0-5 cm), indicated that soil quality improved under these practices compared to conventional practices. Many researchers have reported that soils under long-term no-tillage and reduced tillage systems recorded higher carbon concentration in the soil surface than conventional tillage (Thomas *et al.,* 2007; Lopez-Fando and Pardo, 2009). Results of the present study were congruent with the findings of Bhattacharya *et al.* (2012), who concluded from a 6 years study that reduction in tillage intensity led to a significantly

Table 1 : Oxidizable soil organic carbon, labile carbon in soils under contrasting tillage and cropping systems of rainfed Vertisols of Central India

Tillage system (TS)	**Cropping systems (CS)**	**Soil organic carbon (%)**		**Labile carbon**	
		0-5 cm	**5-15 cm**	**0-5 cm**	**0-15 cm**
CT	Soybean + P. Pea (2:1)	0.64	0.55	353.86	146.63
	Soybean - Wheat	0.59	0.48	324.35	94.72
	Maize + P. Pea (1:1)	0.61	0.52	309.70	116.24
	Maize - Gram	0.64	0.54	339.28	119.12
	Mean	**0.62**	**0.52**	**331.80**	**119.18**
RT	Soybean + P. Pea (2:1)	0.68	0.58	423.74	257.77
	Soybean - Wheat	0.66	0.53	397.47	135.32
	Maize + P. Pea (1:1)	0.67	0.60	364.82	145.74
	Maize - Gram	0.67	0.55	428.40	150.18
	Mean	**0.67**	**0.57**	**403.61**	**172.25**
NT	Soybean + P. Pea (2:1)	0.66	0.59	398.03	263.09
	Soybean - Wheat	0.66	0.56	376.30	169.26
	Maize + P. Pea (1:1)	0.63	0.58	317.22	181.02
	Maize - Gram	0.68	0.59	334.52	179.46
	Mean	**0.66**	**0.58**	**356.52**	**198.21**
LSD					
(p<0.05)	TS	0.003*	0.002*	S*	S*
	CS	0.266^{NS}	0.42^{NS}	S*	S*
	T X CS	0.830^{NS}	0.755^{NS}	0.389^{NS}	0.15^{NS}

NT-no tillage; CT-conventional tillage; RT-reduced tillage; TS-tillage system; CS-cropping system; NS- non significant at $p>0.05$; S*-significant at $p<0.05$

higher soil organic carbon accumulation in the surface soil layer (0-5 cm), in the Indian Himalayas.

Among the cropping systems compared, soybean+ pigeon pea (2:1) recorded significantly higher soil organic carbon and labile carbon followed by maize- gram than maize+ pigeon pea (1:1) at 0-5 cm depth and almost similar trend was observed at 5-15 cm depth at the end of third crop cycle. The higher carbon under both cropping systems is possible due to less soil disruption, addition of above (leaf litter) and below (higher root biomass) ground biomass, legume in rotation/intercropping coupled with crop residue management in the top layer (0-5cm). Further, above all these involvements help in net mineralization of carbon. Salinas-Darcia *et al.* (1997) reported that increase in soil organic carbon concentration in reduced tillage could make these systems more sustainable over long term carbon sequestration in soil. A global data analysis indicated that carbon sequestration rates peak in 5 to 10 years with a change from mouldboard plough to no-tillage and soil organic carbon reaching a new equilibrium in 15 to 20 years (West and Post, 2002).

Tillage systems had significant ($p<0.05$) effect on dehydrogenase activity and fluorescence diacetate enzyme activity (Table 2). In general, conservation agriculture practices retaining crop residue, to protect soil surface from direct sun light and maintaining temperature and moisture in soil can also contribute positive effect on soil enzymatic activity. Parihar *et al.* (2016) was reported that long-term tillage and crop rotations and their interactions had significant effect on soil dehydrogenase activity and fluorescein diacetate hydrolysis enzyme activity for 0–30 cm soil depth. The higher fluorescence diacetate hydrolysis indicates contribution of several enzymes, involved in decomposition of soil organic matter/ crop residue. In general, surface layer (0-5cm) recorded significantly higher microbial activity as compared to lower soil depth. Irrespective of soil depths, significantly higher dehydrogenase activity and fluorescence enzyme activity were recorded under reduced tillage compared to no tillage than conventional tillage practices.

The data inferred that enzymatic activity decreased with increasing soil depths. It was further inferred that cropping systems showed significant ($p<0.05$) effect under 0-5 and 5-15 cm depth in both crop cycles. Among the cropping systems compared, significantly higher dehydrogenase and fluorescenc activity was recorded in soybean + pigeon pea (2:1) followed by maize - gram cropping system in both the depth. Brandan *et al.* (2012) and Gajda *et al.* (2013) also reported that higher soil microbial enzymatic activities due to conservation agriculture with legume crop in rotation as compared to conventional tillage. The enzyme activity is commonly used as an indicator of biological activity in soils. This enzyme is considered to exist as an integral part of intact cells but does not accumulate extracellularly in the soil. Oxidation of soil organic matter by dehydrogenase is achieved by transferring protons and electrons from substrates to acceptor and is considered to be linked with respiration pathway of microorganisms (Das and Verma, 2011). Availability of organic matter, soil temperature and soil moisture significantly affect the dehydrogenase activity of soil. Madejon *et al.* (2007) and Tao *et al.* (2009) reported higher dehydrogenase activity in conservation agriculture with legume crop in rotation as compared to

Table 2 : Oxidizable soil organic carbon, labile carbon in soils under contrasting tillage and cropping systems of rainfed Vertisols of Central India

Tillage system (TS)	**Cropping systems (CS)**	**Dehydrogenase activity (DHA)**		**Fluorescein diacetate (FDA)**	
		0-5 cm	**5-15 cm**	**0-5 cm**	**5-15 cm**
CT	Soybean + P. Pea (2:1)	146.63	35.64	35.64	10.31
	Soybean - Wheat	94.72	35.33	35.33	14.17
	Maize + P. Pea (1:1)	116.24	36.74	36.74	8.40
	Maize - Gram	119.12	32.11	32.11	10.55
	Mean	**119.18**	**34.96**	**34.96**	**10.86**
RT	Soybean + P. Pea (2:1)	257.77	46.79	46.79	15.11
	Soybean - Wheat	135.32	50.25	50.25	10.68
	Maize + P. Pea (1:1)	145.74	45.27	45.27	10.65
	Maize - Gram	150.18	45.88	45.88	22.17
	Mean	**172.25**	**47.05**	**47.05**	**14.65**
NT	Soybean + P. Pea (2:1)	263.09	51.12	51.12	9.24
	Soybean - Wheat	169.26	45.61	45.61	7.36
	Maize + P. Pea (1:1)	181.02	42.25	42.25	8.09
	Maize - Gram	179.46	46.95	46.95	12.96
	Mean	**198.21**	**46.48**	**46.48**	**9.41**
LSD					
($p<0.05$)	TS	S*	S*	S*	S*
	CS	S*	0.201^{NS}	0.201^{NS}	S*
	T X CS	0.15^{NS}	0.137^{NS}	0.137^{NS}	S*

NT-no tillage; CT-conventional tillage; RT-reduced tillage; TS-tillage system; CS-cropping system; NS- non significant at $P>0.05$; S*-significant at $p<0.05$

Table 3 : Relationship between soil organic carbon (SOC) and biological properties of soil under different tillage and cropping systems

Related soil parameters	Correlated coefficient (r)	Linear equation
SOC-LC	0.72*	Y=1043.1x – 313.36
SOC-DHA	0.64*	Y=11478.8x -582.09
SOC-FDA	0.77**	Y=176.19 x -7158

SOC – Soil organic carbon, LC – Labile carbon, DHA- Dehydrogenase activity; FDA – Fluorescence diacetatehydrolysis activity, Statistical significance: *p≤0.05, **p≤0.01.

conventional tillage. High soil organic matter/carbon in surface layer soil ensures availability of substrate for microbes and adequate aeration facilitates active aerobic decomposition, hence higher soil enzyme activity in top soil (0-5 cm). Higher dehydrogenase activity in deeper layer of conventional tillage compared to other system may be attributed to better aeration as frequent soil disturbance provides congenial condition to aerobic microbial community for growth and decomposition.

The inter-relationship of soil organic carbon and labile carbon were confidently inter-correlated with each other (Table 3). At surface layer (0-5 cm), organic carbon and labile carbon was significantly correlated (r= 0.72**), indicating that under reduced tillage and no-tillage with residue retention/incorporation improved soil carbon in surface layer (0-5 cm depth). The decrease in labile carbon under conventional tillage was accountable for intensive tillage. On the other hand, destruction of macro-aggregates has adverse effect on labile carbon resulting in loss of soil organic carbon (Madejon *et al.,* 2007; Kumar *et al.,* 2017). The soil organic carbon and dehydrogenase activity were significantly ($p<0.05$) and positively correlated (r= 0.64**) with each other at surface layer (Table 3). Higher enzymatic activity in conservation tillage with legume crop in rotation as compared to conventional tillage has been reported earlier (Madejon *et al.,* 2007; Tao *et al.,* 2009). Soil organic carbon and fluorescein activity were also significantly correlated (r= 0.77**). The higher fluorescein activity under conservation tillage quantifies for involvement of numerous enzymes, involved in decay of soil organic matter/residue decomposition in soil.

Yield parameters recorded during third crop cycle and yield data were converted into soybean equivalent yield (q ha^{-1}) (Table 4). It was inferred that tillage had no significant effect ($p>0.05$) on soybean grain equivalent even after completion of 3rd crop cycles. However, cropping system had a significant effect during 3rd crop cycles. Among the cropping systems studied, maize-gram recorded significantly ($p< 0.05$) higher yield followed by maize+ pigeon pea (1:1), soybean+ P. pea (2:1) and soybean-wheat at end of 3rd crop cycles. Moreover, the interaction effect between tillage and cropping system did not show significant effect on crop yields. A slight increase in crop yield was observed under RT and NT compared to CT after completion of three crop cycles. Similarly, Tomar, (2008) concluded from ten year study that adoption of no-tillage had a slight advantage in terms of yield as compared to conventionally tilled plots in rice-wheat system in Vertisols. No-tillage, thus, not only resulted in slight improved yields, it also involved lower cost of production and account of saving in terms of fuel cost etc. The adoption of conservation agriculture, the beneficial effects are likely to increase over time due to improvement in soil quality (Tomar, 2008). The results of long term tillage experiment conducted during 2000-2010 at Indian Institute of Soil Science, Bhopal revealed that yield levels of conservation tillage soybean–wheat system was on par with conventional tillage, besides, greater saving of energy and labour under conservation tillage in Vertisols of Central India.

It was found that conservation tillage coupled with

Table 4 : Soybean grain equivalent yield (q ha^{-1}) under contrasting tillage and cropping systems in Vertisols of Central India after 3rd crop cycles

	2014-15			
	Tillage systems (TS)			
Cropping systems (CS)	CT	RT	NT	Mean
Soybean + P pea (2:1)	33.90	32.76	34.65	33.77
Soybean- Wheat	34.05	37.79	37.42	36.42
Maize + P pea (1:1)	43.45	42.12	44.56	43.38
Maize - Gram	49.24	52.67	53.10	51.67
Mean	40.16	41.34	42.43	41.31
LSD (p< 0.05)	Tillage = NS Cropping System = S T X CS = NS			

TS-Tillage systems; CS-Cropping systems; NT-no tillage; CT-conventional tillage; RT-reduced tillage; NS- non significant at p> 0.05; S*-significant at p<0.05, Crop yields were converted into soybean grain equivalent yield using minimum support price based on MSP 2015 residue management had a positive effect of microbial activity and also, enhancing the biological health of the soil. In addition, conservation agriculture practices not only sustained/increased organic carbon and microbial biodiversity but also favoured the crop. Indeed, the outcome of this study would be helpful in improving soil biodiversity, crop productivity as well as improving soil health in Verisols of Central India and similar agro-ecological region in South Asia.

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