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Effect of conservation tillage on biological activity in soil and crop productivity under rainfed Vertisols of central India

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Abstract
The investigation was pointed to compare the effects of three tillage systems *viz.* conventional tillage (CT), reduced tillage (RT) and no-tillage (NT) and four cropping systems namely, Soybean + P. Pea (2:1), Soybean – Wheat, Maize + P. Pea (1:1), Maize – Gram) on soil living environs in terms of dehydrogenase activity (DHA), fluorescein diacetate hydrolysis activity (FDA), liable carbon ($KMNO_4$ extractable) and soil organic carbon (SOC). Soil samples were collected at the end of 3rd crop cycles from the layer of 0-15 cm depth. Within tillage systems, SOC were reported higher in RT (0.63%) and NT (0.62%) as compared to CT (0.57%) at surface soil (0-15cm). At 0-15cm depth, RT and NT registered significantly (P<0.05) higher SOC concentration compared to CT. The liable carbon (LC) content in surface soil (0-15 cm) was followed same trends of SOC, it follows the trend of RT > NT > CT. Further, cropping systems (CS) significantly affect this fraction of carbon at the surface layer. Moreover, soil enzymatic activity was significantly (P<0.05) affected by the imposed tillage systems. The results of DHA reported that significantly (P<0.05) higher in NT (122.35 µg TPF g^{-1} day^{-1}) system compared to RT (109.65 µg TPF g^{-1} day^{-1}) and CT (77.07 µg TPF g^{-1} day^{-1}). The FDA was reported significantly (P<0.05) higher in RT (30.85 µg fluorescein g^{-1} h^{-1}) followed by NT (27.95 µg fluorescein g^{-1} h^{-1}) and CT (22.91 µg fluorescein g^{-1} h^{-1}) at 0-15cm depth. Pearson correlation (r) showed significant correlations between soil organic carbon and studied soil biological parameters. The results of this study also confirmed effectiveness of studied parameters as soil indicators owing to sensitiveness towards management practices.

Keywords: Tillage, cropping system, soil organic carbon, soil enzymatic activity, crop productivity

1. Introduction

The ideal soil micro-biological and bio-chemical to determine the soil quality [1]. Soil quality as defined by Karlen *et al.* [2] is the capacity of a soil to perform their function, within ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation [3]. Soil physical and chemical properties have been widely used to quantity soil quality around the world [4]. However, these soil properties usually change very slowly, and therefore significant changes may occur only over many years [5, 6]. The modern agriculture system used huge amount of chemical fertilizers and pesticides, resulting decreased microbial diversity in soil [7-9]. By contrast, biological activity of soil microorganisms and activity of enzymes are sensitive to management practices and also due to sudden environmental changes, and providing sensitive information on changes in soil quality [10]. Soil micro-organism can respond quickly and reflect harmful atmosphere, and to soil organism activity can recover after harsh environs and comes to in good physical form over again [11, 12]. Soil organic carbon have been considered as a key indicator of soil quality as it supports many important soil functions by providing the 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) [13, 14]. Herrick and wander [15] shown that different pool of soil organic matter influences different aspects of soil quality, such as fate of ionic and non-ionic compounds, the increase of soil cation exchange capacity and long term stability of micro aggregate. Microbial enzymes have essential functions in the soil and have been used to measure the soil quality and the influence of soil management [16, 3].

Soil enzymes are important in catalyzing several crucial reactions necessary for the life processes of micro-organisms in soils and the stabilization of soil structure, the decomposition of organic wastes, organic matter formation, and nutrient cycling, hence playing an important role in agriculture.
The soil biological properties are considered as very dynamic and in constant flux due to change in soil environment. Soil conditions/environment of agro-ecosystem at the given time is the manifestation of imposed management practices. Hence, the management practices such as tillage practices, type and amount of fertilizer application and crop rotation supposed to have great impact on soil biological properties. In temperate soils, increases in various soil enzyme activities have been associated with decreases in tillage intensities, and were highly correlated with carbon contents in Alfisols [17], Entisols [18], Mollisols [19], and Ultisols [20]. There is relatively very little information available on tillage and cropping systems effects on soil biological properties for tropical/ subtropical environment region articulately for the Indian *Vertisol* [21]. The objective of the present studies was to evaluate the effect of different tillage and cropping systems on soil biological properties as soil organic carbon, labile carbon, dehydrogenase activity and fluorescein diacetate.

2. Materials and Methods

2.1 Description of experimental site

A field experiment was started during Aug 2011 with three tillage systems *viz.* no-tillage (NT), reduced tillage (RT) and conventional tillage (CT) in arrangement with four cropping systems namely (Soybean + P. Pea (2:1), Soybean – Wheat, Maize + P. Pea (1:1), Maize – Gram) on crop productivity and soil properties under rainfed *Vertisols* of Central India at the experimental research farm of ICAR- Indian Institute of Soil Science, Bhopal, India. Soils under the research farm is classified as clayey *Vertisol* (*Vertisols*, *Isohyperthermic Typic Haplustert*) with 58% clay, 22% silt and 20% sand in the first 0-15 cm layer. The geographic co-ordinate of experimental site is 23°18' N, 77°24' E, and located 485 m above mean sea level. The climate of the experimental site is characterised as hot sub humid type, with mean annual air temperature, mean annual rainfall and potential evapotranspiration are 25ºC, 1130 mm and 1400 mm, respectively.

2.2 Soil sampling and processing

The experiment had a split-plot design with three tillage system (NT, RT, CT) as the main plot and four cropping systems as the subplot with a size of plots 10 x 5 m replicated thrice. The CT consists of deep summer ploughing after residue burning at the harvest of *rabi* crops and 3 to 4 pass tillage operations using tine cultivator followed by sowing in *kharif* and *rabi* crops. The RT consist of one pass tillage operation using duck foot cultivator and sowing through zero till seed drill in kharif and rabi crops and NT consisted of planting/sowing crops into undisturbed soil by opening a narrow slits of sufficient width and depth to cover the seeds. Surface soil samples (0-15cm) were collected randomly 2 locations/sets (mixed both) within the plot, with the help of core samplers during in the May 2015 at the end of 3rd cropping system. Thus, 36 soil samples (3 tillage, 4 cropping systems and 3 replicates) were examined in this studied. After collection, these samples were mixed, air dried in screen house and processed wooden mortal and petal, passed sieved through a 2-mm for liable carbon, DHA and FDA and 0.25 mm for soil organic carbon after removing large plant material and analysed for soil biological properties.

2.3 Methodology applied

The oxidizable soil organic carbon was determined by wet digestion method [22]. One-half gram of soil samples were placed in a 500 ml of Erlenmeyer conical flask and added 10 ml 1.0*N* potassium dichromate ($K_2Cr_2O_7$), followed 20 ml concentrated sulphuric acid (24.0*N* H_2SO_4). After the completion of the reaction (30 minute), the excess $K_2Cr_2O_7$ was determined by titrating agent 0.5*N* ferrous ammonium sulphate [$(NH_4)_2SO_4.FeSO_4.6H_2O$)]. The amount of $K_2Cr_2O_7$ consumed by oxidizable soil carbon calculated the theoretical value of 1.0 ml 1.0*N* $K_2Cr_2O_7$ oxidises 3.0 gm of carbon. Liable soil organic carbon ($KMnO_4$ extractable) was determined by the method as suggested [23]. The soil Dehydrogenase Activity (DHA) and Fluorescence Diacetate (FDA) were estimated by the method of Casida *et al.* [24] and Adam [25].

3. Results and Discussion

3.1 Effect of conservation tillage on SOC

The higher SOC concentration was recorded under RT. Among different tillage system evaluated, RT (0.62%) and NT (0.62%) registered significantly (P<0.05) higher SOC compared to CT (0.57%) at surface layer Table I. the result indicated that the tillage had significant effect (P<0.05) on SOC, whereas, cropping systems (CS) and interaction between tillage x cropping system (T x CS) did not showed any effect significant (P>0.05) on SOC. The increased SOC concentration at surface soil under RT and NT than CT was possibly attributed to minimum soil disturbances and crop residue retention helps in increasing SOC. Similarly, Hati *et al.* [26] and McCarty *et al.* [27] reported that conservation tillage particularly NT leads to a higher SOC concentration in the top layer and alters its distribution within the soil profile. The differences in SOC concentration between tillage treatment were highest in the upper most soil layer where they were in the order as follows: RT > NT > CT. Many researchers have reported that soils under long-term conservation tillage (NT and RT) systems recorded higher SOC in the soil surface than CT [28-30]. It is often indicated that an increase in SOC concentration is a result of different interacting factors, such as minimum soil disturbances, increased residue retention/addition, reduced surface soil temperature, higher soil moisture content and decreased risk of erosion [31, 32]. Our study results were congruent with the results reported by Bhattacharya *et al.* [33], who concluded from a 6 years study that reduction in tillage intensity led to a significantly larger SOC accumulation in the surface soil layer in the Indian Himalayas. It is evident from the perusal of data that to bring significant changes in SOC especially under rainfed situations require a minimum soil disturbance coupled with residue addition for at least 6-10 years. Similarly, no-tillage farming systems usually help to maintain soil organic matter [34].
Among the cropping systems compared, maize + P.pea (1:1) recorded significantly higher OC (0.64%) followed by soybean + P.pea (0.63%) under RT and maize- gram (0.64%) followed by soybean + P.pea (0.63%) in NT. It is also evident from the data that the SOC content under RT and NT is significantly higher than CT after three years of crop-cycles. Salinas-Darcia *et al.* [35] was reported that increase of SOC concentration in RT systems could make these systems more sustainable over the long term as thereby CO_2 is sequestered.

The soil biological property most affected by tillage is SOC [20]. Crop residues are precursors of the SOC pool, and returning more crop residues to the soil is associated with an increase in SOC concentration [36]. The effects of conservation tillage on SOC accumulation may vary with the amount and characteristics of residues returned to soil. Moreover, during tillage a redistribution of the soil organic matter takes place.

Table 1: Oxidizable soil organic carbon (SOC) and liable carbon (LC) in soils under contrasting tillage and cropping systems.

Tillage System (T)	Cropping Systems (CS)	Organic Carbon (%)	Liable Carbon (mg C kg $^{-1}$)
		0-15 cm	0-15 cm
CT	Soybean + P. Pea (2:1)	0.60	250.25
	Soybean - Wheat	0.54	209.54
	Maize + P. Pea (1:1)	0.57	212.97
	Maize - Gram	0.59	229.20
	Mean	0.57	225.49
RT	Soybean + P. Pea (2:1)	0.63	340.76
	Soybean - Wheat	0.60	266.40
	Maize + P. Pea (1:1)	0.64	255.28
	Maize - Gram	0.61	289.29
	Mean	0.62	287.93
NT	Soybean + P. Pea (2:1)	0.63	330.56
	Soybean - Wheat	0.61	272.78
	Maize + P. Pea (1:1)	0.61	249.12
	Maize - Gram	0.64	256.99
	Mean	0.62	277.37
LSD (*P*<0.05)	T	S*	S*
	CS	NS	S*
	T X CS	NS	NS

CT - conventional tillage; RT - reduced tillage; NT - no tillage; T- tillage; CS - cropping system; T X CS – interaction between tillage and cropping systems; NS - non significant at *P*>0.05; S*- significant at *P*<0.05

3.2 Effect of conservation tillage on active or labile carbon (LC)

An effort was complete to enumerate of LC fraction influenced by contrasting cropping systems and tillage practices Table 1. LC recorded significantly higher under RT and NT than the CT after completion of three crop cycles. It was further inferred from data that cropping systems showed significant (*P*<0.05) effect on LC at 0-15 cm depth. This fraction of carbon is often termed as active or labile fraction of carbon, which is very sensitive to management practices. According to Weil *et al.* [37] a small change in labile fractions of SOC gives an early indication of soil degradation or improvement with respect to farm management practices. Among the tillage system studied, RT recorded significantly (*P*<0.05) higher value (287.93 mg C kg $^{-1}$) compared to NT (277.37 mg C kg $^{-1}$) and CT (225.49 mg C kg $^{-1}$) at surface soil depth. Tillage systems and cropping were significant (*P*<0.05) effect on labile carbon. Among the cropping systems compared, soybean +pigeon pea (2:1) followed by maize-gram recorded significantly higher LC under RT than other cropping system after completion of third crop cycles. This was mainly due to better mixing of residue with minimum soil disturbances under reduced tillage, which provide more substrate for microbes to decompose the fresh residue results in higher labile carbon under these treatments. Whereas, under NT, less opportunity for mixing of crop residue. In contrast under CT, our results corroborated with the findings of Bhattacharyya *et al.* [38] and Dou *et al.* [39] found conservation tillage namely no-tillage significantly increased the size of SOC and all labile SOC pools compared with CT only at surface layer. According to Weil *et al.* [37], labile or active C pool - this is readily available to microbes which are different from a highly recalcitrant or passive C pool that is only very slowly altered by microbial activities. This fraction of C pool serves as a sensitive indicator like change in microbial biomass C, soil quality as influenced by the management practices [40-42]. We observed that higher labile carbon under reduced tillage and no-tillage at surface layer (0-5cm), which indicates that soil quality is improved under this practice compared to conventional practices.

3.3 Effect of conservation tillage on DHA

Mean data of DHA value for CT, RT and NT varied from 77.07 to 122.35 µg TPF g $^{-1}$ day $^{-1}$ for surface layer Table 2. Tillage systems were significant (*P*<0.05) effect on DHA. Similar result was reported (Parihar *et al.* [43]. Surface layer, significantly higher DHA was recorded under NT (122.35 µg TPF g $^{-1}$ day $^{-1}$) compared to RT (109.65 µg TPF g $^{-1}$ day $^{-1}$) than CT (77.07 µg TPF g $^{-1}$ day $^{-1}$) practices. The data was inferred that dehydrogenase activity decreased in CT system. Among the cropping systems compared, significantly higher DHA was recorded in soybean + pigeon pea (2:1) followed by maize-gram cropping system. The dehydrogenase 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 extra cellularly in the soil. Oxidation of soil organic matter by dehydrogenase is achieved by transferring protons and electrons from substrates to acceptor and considered to be linked with respiration pathway of microorganisms [44]. Availability of organic matter, soil temperature and soil moisture significantly affect the DHA activity of soil. Madejon *et al.* [45] and Tao *et al.* [46] reported higher DHA under conservation agriculture with legume crop in rotation as compared to CT.

Table 2: Dehydrogenase activity (DHA) and fluorescein diacetate activity (FDA) in soils under contrasting tillage and cropping systems.

Tillage System (T)	Cropping Systems (CS)	DHA (µg TPF g^{-1} day^{-1})	FDA (µg fluorescein g^{-1} h^{-1})
		0-15 cm	0-15 cm
CT	Soybean + P. Pea (2:1)	91.14	22.98
	Soybean - Wheat	65.03	24.75
	Maize + P. Pea (1:1)	76.49	22.57
	Maize - Gram	75.62	21.33
	Mean	77.07	22.91
RT	Soybean + P. Pea (2:1)	152.28	30.95
	Soybean - Wheat	92.79	30.47
	Maize + P. Pea (1:1)	95.51	27.96
	Maize - Gram	98.03	34.03
	Mean	109.65	30.85
NT	Soybean + P. Pea (2:1)	157.11	30.18
	Soybean - Wheat	107.44	26.49
	Maize + P. Pea (1:1)	111.64	25.17
	Maize - Gram	113.21	29.96
	Mean	122.35	27.95
LSD (*P*<0.05)	T	S*	S*
	CS	NS	NS
	T X CS	NS	NS

CT - conventional tillage; RT - reduced tillage; NT - no tillage; T-tillage; CS - cropping system; T X CS – interaction between tillage and cropping systems; NS - non significant at *P*>0.05; S*- significant at *P*<0.05

3.4 Effect of conservation tillage on FDA

Mean data of FDA activity value for CT, RT and NT varied from 22.91 to 30.85 µg fluorescein g^{-1} h^{-1} in surface layer Table 2. Tillage systems were significant (*P*<0.05) effect on FDA. Similar result was reported [43]. In contrast to tillage system, RT (30.85 µg fluorescein g^{-1} h^{-1}) recorded higher activity as compared to NT (27.95 µg fluorescein g^{-1} h^{-1}) than CT (22.91 µg fluorescein g^{-1} h^{-1}). The higher FDA hydrolysis indicating is a measurement for contribution of several enzymes, involve in decomposition of soil organic matter/ crop residue. In general, surface layer recorded significantly higher FDA (microbial activity) as compared to lower soil depth. The NT and RT was significantly (*P*<0.05) higher FDA enzymatic activity than CT. It was inferred that cropping systems not significant (*P*>0.05) effect surface layer in third crop cycle. Among the cropping systems compared, soybean + pigeon pea (2:1) followed by maize-gram recorded significantly higher fluorescein diacetate hydrolysis enzyme activity than other cropping system. Perez-Brandan *et al.* [47] and Gajda *et al.* [6] also reported that higher soil microbial enzymatic activities due to conservation agriculture with legume crop in rotation as compared to conventional tillage. A significant influence of SOM on a range of biological properties of soil has been reported [48-51]. In present investigation, the concentration of SOM significantly influenced the $KMnO_4$ extractable soil carbon, DHA and FDA, as confirmed by the high linear correlations obtained between soil biological properties and soil OM content (Fig.1, 2 and 3).

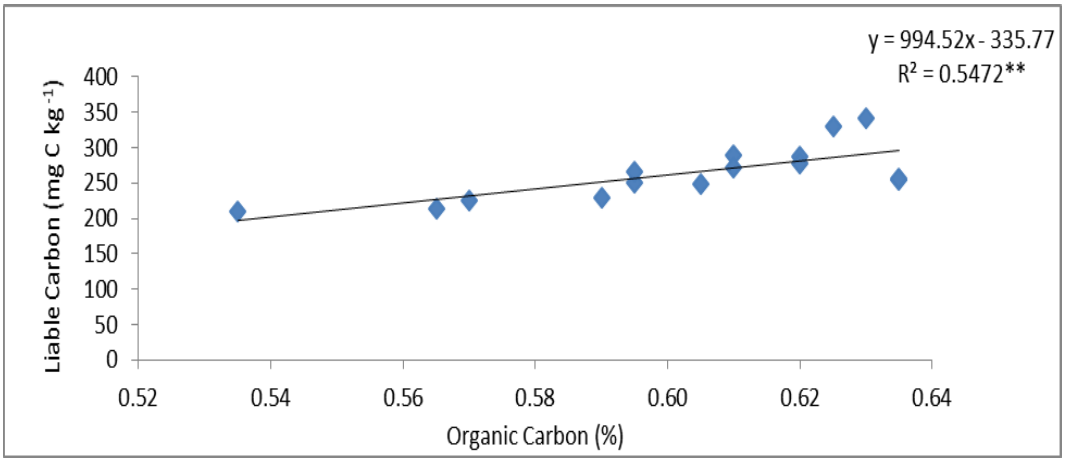

Fig 1: Correlation between soil organic carbon and $KMnO_4$ extractable liable carbon fraction; ** Correlation is significant at the *P*<0.01 level; * Correlation is significant at the *P*<0.05 level.

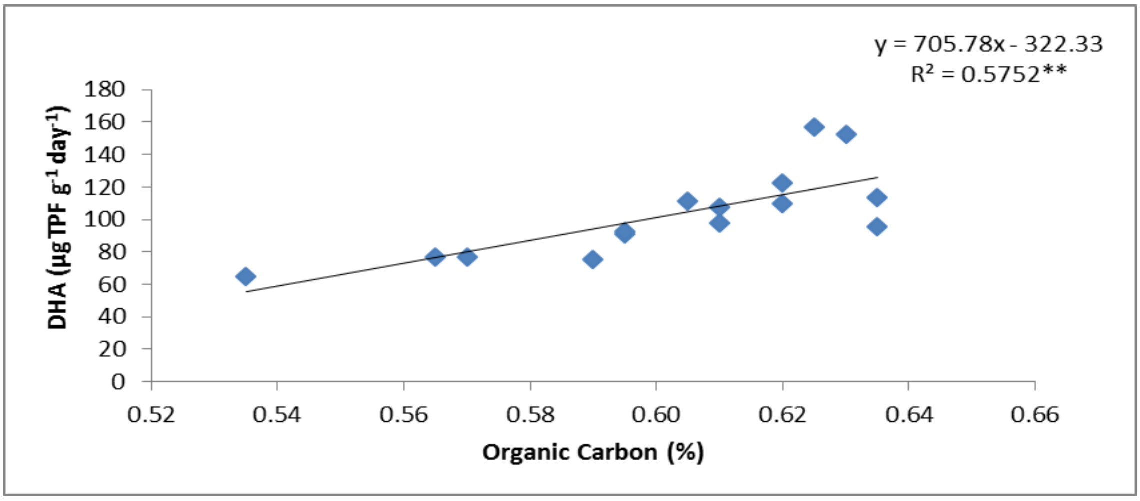

Fig 2: Correlation between soil organic carbon and dehydrogenase activity; ** Correlation is significant at the *P*<0.01 level; * Correlation is significant at the *P*<0.05 level.

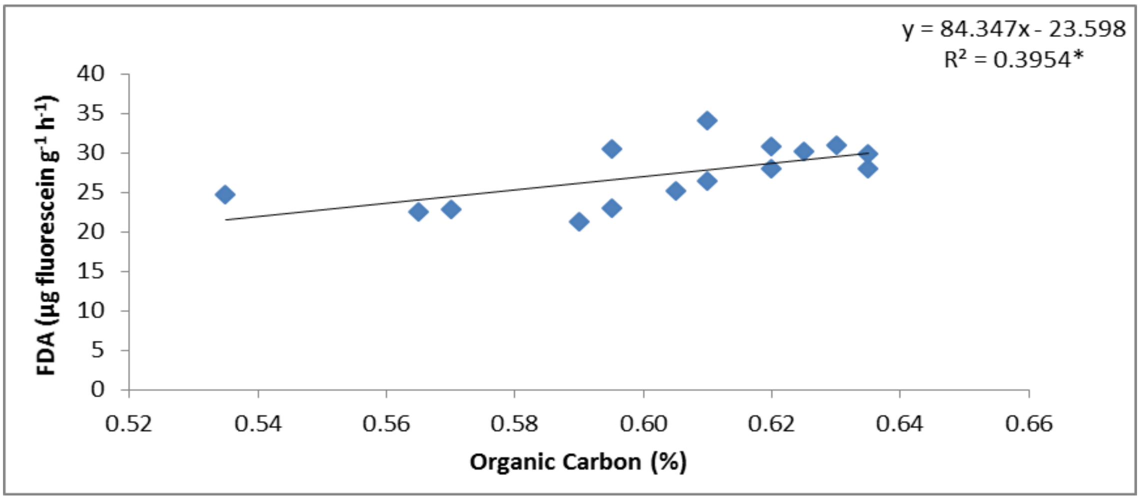

Fig 3: Correlation between soil organic carbon and Fluorescence Diacetate hydrolysis activity; ** Correlation is significant at the *P*<0.01 level; * Correlation is significant at the *P*<0.05 level.

3.5 Correlations between organic carbon and soil biological indicators

As expected, SOC and LC were positively correlated with each other at 0-15 cm depth Fig. 1. At surface layer SOC and $KMnO_4$ extractable liable carbon was significantly (P<0.05) correlated (r^2 = 0.55), its indicating that under RT and NT with residue retention/incorporation increased soil organic carbon and liable fraction of carbon at surface soil. On the other hand, both SOC and LC play significant role in macro-aggregate formation [52]. The reduction of LC under CT system was responsible for intensive tillage. On the other hand, destruction of macro-aggregates could have adverse effect on LC resulting loss of SOC [52-54]. Soil organic carbon and DHA was linear positive correlation with each other at surface layer Fig. 2. At 0-15 cm depth organic carbon and DHA have significantly (P<0.05) correlated (r^2 = 0.58), its indicating that oxidation of soil organic matter by DHA is achieved by transferring protons and electrons from substrates to acceptor and considered to be linked with respiration pathway of microorganisms [44]. Availability of organic matter, soil temperature and soil moisture significantly affect the DHA activity of soil. Madejon *et al.* [55] and Tao *et al.* [46] reported higher enzymatic activity in conservation agriculture with legume crop in rotation as compared to CT. The correlation between SOC and FDA significantly correlated (r^2 = 0.41). The higher FDA under conservation tillage quantifies for involvement of numerous enzymes, involve in decay of soil organic matter/ crop residue. The adaptation of key principles of conservation agriculture practices enhances the living environment in surface soil.

3.6 Effect of different tillage and cropping system on Crop Yield

Yield data was recorded at harvesting of third crop cycle and converted into soybean equivalent yield (t ha^{-1}) Table 3. It was inferred that tillage had no significant effect (P>0.05) on soybean grain equivalent yield (SGEY) 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 seed yield (5.2 t ha^{-1}) followed by maize+ pigeon pea (1:1) (4.4 t ha^{-1}), soybean- wheat (3.6 t ha^{-1}) and soybean+ pigeon pea (2:1) (3.4 t ha^{-1}) at end of three crop cycles. Moreover, the interaction effect between tillage and cropping system did not shown significant effect on crop yields. We observed a slight increase in crop yield under RT and NT compared to CT after completion of three crop cycles. Similarly, Tomar [56] concluded from 10 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 similar of slightly improved yields, it also involved lower cost of production and account of saving in the term of fuel cost etc. Similarly, straw mulch application at the rate of 5 t ha^{-1} was found highly effective in further improving yield. With the adoption of CA, the beneficial effects are likely to increase over time due to improvement in soil quality [56]. Results of long term tillage experiment conducted during 2000-2010 at IISS, Bhopal revealed that yield levels of conservation tillage (i.e. no-tillage and reduced 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. Conservation tillage practices that are no-tillage and reduced tillage were as effective as conventional tillage in terms of crop productivity under soybean and wheat [57].

Table 3: Soybean grain equivalent yield (t ha^{-1}) under different tillage and cropping systems

Cropping systems (CS)	2014-15			
	Tillage systems (T)			
	CT	RT	NT	Mean
Soybean + P pea (2:1)	3.4	3.3	3.5	3.4
Soybean- Wheat	3.4	3.8	3.7	3.6
Maize + P pea (1:1)	4.3	4.2	4.5	4.4
Maize - Gram	4.9	5.3	5.3	5.2
Mean	4.0	4.1	4.2	4.1
LSD (*P*<0.05)	Tillage = NS			
	Cropping System = S*			
	T X CS = NS			

CT - conventional tillage; RT - reduced tillage; NT - no tillage; T- tillage; CS - cropping system; T X CS – interaction between tillage and cropping systems; NS - non significant at $P>0.05$; S* - significant at $P<0.05$, Crop yields were converted into soybean grain equivalent yield (SGEY) based on minimum support price (MSP) 2015.

4. Conclusions

The observed soil biological parameters were significantly influenced by the tillage and cropping system management practices in *Vertisol*. It is evident from the results that no-tillage and reduced tillage maintained greater biological activity than conventional tillage. In contrast, the activities of soil micro-organisms respond rapidly by adoption of conservation tillage principles. Soil biological activities greatly influenced with in the upper layer (0-15 cm) SOC, $KMnO_4$ extractable soil carbon, DHA and FDA were reported higher top soil layer. Because, more organic matter through plant residue, litter fall, root biomass and root and soil biota exudates added in soil surface and interaction between atmosphere with soil bio-diversity in it. Surface layer more Significant correlation value between soil organic carbon and $KMnO_4$ extractable liable fractions of carbon, DHA and FDA indicate role of soil organic carbon to enhance microbial activity and maintaining a better soil bio-diversity for stabilizing and protecting extracellular enzymes.

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