Original Research Article

Residue Retention in a Maize-Chickpea Cropping System under Conservation Agriculture Influence Soil biochemical attributes in Vertisolof Central India

Comment [FO1]: Please rewrite this title as follows:
"Assessing the impact of residue retention on soil biochemical properties of Vertisols in a Maize-Chickpea cropping system under different tillage practices in Central India"

ABSTRACT

This study examined the biochemical properties of vertisol under residue retention (RR) practices of 0%, 30%, and 90% in a maize-chickpea cropping system under conventional tillage (CT). The parameters assessed were total organic carbon (TOC), β-glucosidase activity, dehydrogenase activity (DHA), fluorescein diacetate hydrolysis activity (FDA), and stratification ratio. Soil samples were collected from 0–15 cm and 15–30 cm depths at the end of the cropping cycle to evaluate the effects of different residue management strategies. At the surface soil (0–15 cm), TOC was significantly higher under 90% RR (15.24 g kg^{-1}) and 30% RR (12.16 g kg^{-1}) compared to CT (9.39 g kg^{-1}). Enzymatic activities also showed significant improvements with increased residue retention. DHA at 0–15 cm was highest under 90% RR (103.57 µg TPF g^{-1} day^{-1}), followed by 30% RR (84.63 µg TPF g^{-1} day^{-1}) and CT (70.75 µg TPF g^{-1} day^{-1}). A similar trend was observed for FDA, where 90% RR recorded 26.13 µg fluorescein g^{-1} h^{-1}, exceeding CT by 3.22% (22.91 µg fluorescein g^{-1} h^{-1}). β-glucosidase activity was also highest under 90% RR (169.60 µg PNG g^{-1} soil h^{-1}), but with reduced values at greater soil depths. TOC and enzymatic activities ~~demonstrated~~ revealed strong positive correlations, confirming their sensitivity to management practices. Stratification ratios did not vary significantly across the various residue retention levels, which could likely due to the high clay content protecting TOC and enzymes. These findings highlight the potential of residue retention to enhance soil health and serve as reliable indicators of soil quality in sustainable croppingsystems.

Keywords: Residue retention, Tillage, cropping system, Total organic carbon, soil enzymatic activity,

INTRODUCTION

Crop residue retention is a key element of conservation agriculture (CA), alongside (a) minimal mechanical soil disturbance, (b) permanent soil cover, and (c) crop rotation, as highlighted by Ojeda *et al.* (2015) and Ye *et al.* (2019). Crop residues help mitigate the negative impacts of conventional farming practices and enhance soil quality, facilitating better adaptation to climate-related risks (Das *et al.,* 2020; Thierfelder *et al.,* 2018). Land degradation continues to be a significant global issue, particularly in India, where approximately 44~~%~~ per centof the total land area is affected (Bhattacharyya *et al.,* 2015; Mythili & Goedecke, 2016). The incorporation of crop residues enhances soil organic matter (SOM), conserves soil moisture, and fosters biological activity (Huang, Xu, & Chen,2008).Residues, especially from staple crops like maize and chickpea, provide a vital source of organic carbon that can stimulate microbial populations involved in soil carbon cycling. Maize (*Zea mays L.*) is~~,~~ an emerging versatile crop with wider adaptability and photo-insensitivity under the different ecological scenario. It has the potential to address issues such as~~,~~ water scarcity and climate

change(Parihar ~~*et al.*~~*et al*.,(2018). Similarly, chickpea (*Cicer arietinum*), is a protein-rich and best among all legume proteins, with the most production centered in India. Maize-based rotations with improved soil management practices enhanced soil properties(Aulakh *et. Al*.,(2008).

Concerns regarding soil deterioration and quality losses have recently increased the significance of soil quality indices, which enable the evaluation of patterns and modifications in various soil management techniques. The agroecosystem's productivity and sustainability are determined by the quality of the soil. To get empirical data on how conservation techniques impact soil qualities, a residue retention management experiment is consequently required. To ascertain the impact of various soil management strategies, a number of indices that combine the physical, chemical, and biological characteristics of soil have been employed (Doran *et al.* 1994). Analyzing soil biological processes is crucial for assessing soil quality. A good short-term predictor of soil biological and biochemical fertility is microbial activity (Melero *et al.,* 2008; Nannipieri *et al*., 1990). Soil enzymes play a crucial role in driving numerous reactions related to the breakdown of soil organic matter, nutrient cycling, and the formation of soil structure. They are also considered as indicators of soil health~~, as~~ because they respond quickly to changes in soil management practices (Gianfreda *et al*., 1996). The stratification ratio serves as a useful measure for assessing the variation of soil nutrients with depth. The distribution of soil organic carbon across different depths has gained significance due to its role in nutrient retention, boosting biological activity, preventing erosion, and supporting agricultural productivity (Franzluebbers *et al*., 2007).

~~We~~ In this study, we hypothesize that by improving soil microbial activity and soil fertility, residue retention would be beneficial. The total organic carbon (TOC), dehydrogenase (DHA), fluorescein diacetate (FDA), and β-glucosidase in Vertisols of Central India were evaluated ~~in soils~~using ~~with~~ varying levels of residue retention ~~in comparison to soils managed using~~and conventional tillage practice.

MATERIALS AND METHODS

Experimental Site

The study was conducted at the research farm of the Indian Institute of Soil Science (IISS) in Bhopal, India. The experimental site is geographically situated at coordinates 23°18'28.26"N and 77°24'26.00"E, with an elevation of 500 meters above sea level. The area receives an average annual rainfall of 1,146 mm, with more than 80% of it occurring between June and September. The region experiences an average annual air temperature of 25°C and has a generally humid subtropical climate. The summer season starts in the latter half of March and lasts until mid-June, while winter peaks in January, with temperatures occasionally dropping close to freezing at night. The soil at the experimental site is classified as Vertisols (black soils) from the montmorillonite isohyperthermic family of typic haplustert, and is characterized by its alkaline nature and distinct swell-shrink properties (Aher *et al.,* 2018).

The experiment was conducted using a Randomized Block Design (RBD), with each treatment replicated five times ~~and randomized~~. Each plot measured 7m × 6m. The treatments included residue retention (RR)of(0%), 30%, and 90% in a maize and chickpea cropping system under zero tillage, and conventional tillage management.All required agronomic practices were strictly followed. After harvesting both maize and chickpea, the residues were collected, chopped, and left on the soil surface prior to planting the next crop in each cycle. Nutrient supply was primarily through urea (46% N), Di-ammonium Phosphate (DAP: 18% N and 46% P), and Muriate of Potash (MOP: 60% K). The recommended fertilizer doses were 120:24:33 kg of N:P:K per hectare for maize and 40:26:24 kg of N:P:K per hectare for chickpea, applied during each cropping season.

Comment [FO2]: Please mention the varieties of maize and chickpea grown and some basic characteristics including why you chose these varieties over the others.

Soil Sampling and Chemical Analysis

At the end of second year experiment, soil samples were collected from two different depths: 0-15 cm and 15-30 cm, after the harvest of each maize and chickpea crop in 2022-2024. The freshly collected soil samples were passed through a 2 mm sieve and immediately stored in plastic bags, loosely tied to allow proper aeration and prevent moisture loss, at 4°C until microbiological and enzyme activity assessments. The remaining soil was air-dried for chemical analysis, which was conducted within two weeks.

Soil pH and electrical conductivity (EC) were assessed using the 1:2.5 soil-to-water ratio method. Total organic carbon content in the soil was analysed through dry combustion with a TOC analyser.

Soil Enzymatic Analysis

β-glucosidase activity was evaluated following the method of Eivazi and Tabatabai (1988), by incubating soil with p-nitrophenyl β-D-glucopyranoside and measuring p-nitrophenol absorbance at 400 nm. Dehydrogenase activity was assessed using the procedure described by Thalmann (1968), through soil incubation with 2,3,5-triphenyl-tetrazolium chloride (TTC) and measuring the absorbance of triphenyl formazan (TPF) at 546 nm. Fluorescein diacetate (FDA) hydrolysis was determined based on the method of Adams and Duncan (2001), by incubating soil with fluorescein diacetate and recording fluorescein absorbance at 490 nm.

The stratification ratio for total organic carbon and enzymatic activities was determined as the ratio of their values in the surface soil layer (0–15 cm) to those in the deeper layer (15–30 cm), following the method outlined by Franzluebbers (2002). All microbial analyses were performed in triplicate for each sample, and the results were expressed on an oven-dry weight basis.

Statistical Analysis

Statistical analysis was conducted using MS-Excel, and the results were reported as mean values. Significant differences between residue retention management practices were determined using the student's t-test at (p = 0.05). Analysis of covariance (ANOVA) was performed to evaluate the variability of all parameters for each treatment across different soil depths. A correlation matrix for the various properties was constructed based on Pearson correlation coefficients (p = 0.05).

RESULT

Soil Chemical Parameters

At the end of the 2022–2024 cropping season, soil pH, EC, and TOC in residue retention practices were measured at both depths (0–15 cm and 15–30 cm). Across all treatments in both cropping years, the pH and EC of the soil were found to be significant at the surface and non-significant in the subsurface (Table 1). The mean soil pH range at the surface (0–15 cm) ranged ranges from 7.5 to 7.9, with a the lower lowest value (7.5) seen under 90% per cent crop residue retention treatment. Although there was a slight rise increase in the pH in of subsurface soil, however, the residue retention treatments did not noticeably affect this parameter. The average soil EC ranges was from 0.13 dS/m to 0.23 dS/m at the surface (0-15 cm), with the 90% per cent crop residue retention treatment having the lowest value (0.13 dS/m). However, the mean values of pH and EC at both depths do not significantly differ in the case of no residue and CT.

The distribution of total organic carbon (TOC) varied under different residue retention (RR) levels and conventional tillage (CT) (Table 1). Residue retention significantly increased the TOC at both 0–15 cm and 15–30 cm soil depths in the maize-chickpea cropping system. The increase in TOC due to residue retention management ranged ranges from 38.4% percent to 10.3% per cent at the 0–15 cm depth and from 18.0% per cent to 4.2% per cent at the 15–30 cm depth. After two years of conservation agriculture, the TOC levels under 90%, per cent, 30%, per cent, and 0% per cent RR were 38.4%, per cent, 22.8%, per cent, and 10.3% per cent higher, respectively, than those under CT at the 0–15 cm depth. The TOC values ranged from 15.24 g kg^{-1} (0–15 cm) to 8.66 g kg^{-1} (15–30

cm) under 90% per centRR, 12.16 g kg^{-1} (0–15 cm) to 7.88 g kg^{-1} (15–30 cm) under 30% per centRR, 10.47 g kg^{-1} (0–15 cm) to 7.41 g kg^{-1} (15–30 cm) under 0% per centRR, and 9.39 g kg^{-1} (0–15 cm) to 7.10 g kg^{-1} (15–30 cm) under CT. The mean TOC values showed a decreasing trend with increasing soil depth, with the highest TOC concentration recorded at the 0–15 cm depth under 90% per centRR.

Dehydrogenase (DHA), Fluorescein Diacetate (FDA)and B-Glucosidase Activity

Significant variations in dehydrogenase activity (DHA) waswereobserved in both surface and subsurface soils under the different levels of residue retention (RR) compared to conventional tillage (CT) (Fig 1). At the 0–15 cm depth, DHA activity rangeed from 103.57 to 70.55 µg TPF g^{-1} soil 24 h^{-1}, while at the 15–30 cm depth, it varied variesfrom 64.19 to 44.77 µg TPF g^{-1} soil 24 h^{-1}. The increase in DHA rangeed from 31.88% per centto 4.14% per centat 0–15 cm and from 30.3% per centto 2.9% per centat 15–30 cm. The DHA levels under 90%, per cent, 30%, per cent, and 0% per centRR were 31.8%, per cent, 19.07%, per cent, and 4.14% per centhigher, respectively, than those under CT at the 0–15 cm depth. The DHA values rangeed from 103.57 µg TPF g^{-1} soil 24 h^{-1} (0–15 cm) to 64.19 µg TPF g^{-1} soil 24 h^{-1} (15–30 cm) under 90% per centRR, 87.18 µg TPF g^{-1} soil 24 h^{-1} (0–15 cm) to 53.06 µg TPF g^{-1} soil 24 h^{-1} (15–30 cm) under 30% per centRR, 73.60 µg TPF g^{-1} soil 24 h^{-1} (0–15 cm) to 46.12 µg TPF g^{-1} soil 24 h^{-1} (15–30 cm) under 0% per cengtRR, and 70.55 µg TPF g^{-1} soil 24 h^{-1} (0–15 cm) to 44.77 µg TPF g^{-1} soil 24 h^{-1} (15–30 cm) under CT. The mean DHA values showed a decreasing trend with increasing soil depth, with the highest DHA concentration recorded under 90% per centRR at the 0–15 cm depth. In the subsurface soils, the DHA activity was significantly higher under 90% per centRR, showing a 59.6% per centincrease compared to CT.

Statistical analysis revealed a significant effect of the different residue retention (RR) practices on fluorescein diacetate (FDA) activity (Fig. 1). The FDA activity ranged rangesfrom 26.13 to 16.27 µg fluorescein g^{-1} soil h^{-1} at the 0–15 cm depth and from 11.97 to 8.57 µg fluorescein g^{-1} soil h^{-1} at the 15–30 cm depth. The increase in FDA activity due to RR management ranged from 37.8% per centto 17.2% per centat 0–15 cm and from 28.4 per cent% to -4.4% per centat 15–30 cm. The FDA activity under 90%, per cent, 30 per cent%, and 0% per centRR was 37.8%, per cent, 12.6%, per cent, and 17.2% per centhigher, respectively, than under CT at the 0–15 cm depth. The FDA ranged rangesfrom 26.13 µg fluorescein g^{-1} soil h^{-1} (0–15 cm) to 11.97 µg fluorescein g^{-1} soil h^{-1} (15–30 cm) under 90% per centRR, 18.62 µg fluorescein g^{-1} soil h^{-1} (0–15 cm) to 8.81 µg fluorescein g^{-1} soil h^{-1} (15–30 cm) under 30% per cengtRR, 19.64 µg fluorescein g^{-1} soil h^{-1} (0–15 cm) to 8.21 µg fluorescein g^{-1} soil h^{-1} (15–30 cm) under 0% per centRR, and 16.27 µg fluorescein g^{-1} soil h^{-1} (0–15 cm) to 8.57 µg fluorescein g^{-1} soil h^{-1} (15–30 cm) under CT. The mean FDA values exhibited a decreasing trend with increasing soil depth, with the highest FDA concentration recorded under 90% per centRR at the 0–15 cm depth. In the subsurface (15–30 cm), the FDA activity was significantly higher under 90% per centRR, showing a 28.4% per centincrease compared to CT.

The β-glucosidase, a key enzyme in the soil carbon cycle, showed showsactivity levels ranging from 169.6 to 83.7 µg PNG g^{-1} soil h^{-1} in surface and subsurface soils. The increase in β-glucosidase activity due to residue retention (RR) management ranged rangesfrom 16.7% per centto 12.6% per centat the 0–15 cm depth and from 19.9% per centto -4.7% per centat the 15–30 cm depth. At the 0–15 cm depth, the β-glucosidase activity was 16.7%, per cent, 12.6%, per cent, and 7.9% per centhigher under 90%, per cent, 30%, per cent, and 0% per centRR, respectively, compared to conventional tillage (CT). The β-glucosidase activity ranged rangesfrom 169.60 µg PNG g^{-1} soil h^{-1} (0–15 cm) to 104.62 µg PNG g^{-1} soil h^{-1} (15–30 cm) under 90% per centRR, 161.58 µg PNG g^{-1} soil h^{-1} (0–15 cm) to 89.47 µg PNG g^{-1} soil h^{-1} (15–30 cm) under 30% per centRR, 153.36 µg PNG g^{-1} soil h^{-1} (0–15 cm) to 79.99 µg PNG g^{-1} soil h^{-1} (15–30 cm) under 0% per centRR, and 141.29 µg PNG g^{-1} soil h^{-1} (0–15 cm) to 83.75 µg PNG g^{-1} soil h^{-1} (15–30 cm) under CT. The mean β-glucosidase activity showed showsa declining trend with increasing soil depth. The highest activity was recorded at the 0–15 cm depth under 90% per centRR. At the subsurface level (15–30 cm), the

β-glucosidase activity was significantly higher under 90% per centRR, with a 19.9% per centincrease compared to CT.

No significant differences were observed in the stratification ratios of total organic carbon and enzymatic activities between the different residue retention levels and conventional tillage (CT) treatments (Fig 2). Generally, enzymatic activities (β-glucosidase, DHA, and FDA) exhibited a strong correlation ($p < 0.01$) with total organic carbon content and were also strongly correlated (Table 3).

Table1. Mean values of pH, electrical conductivity (EC) and total organic carbon (TOC) in soil under different Residue Retention (RR) level and Conventional tillage (CT) at the different depths.

		Residue Retention				
Soil parameters	Soil depths (cm)	RR-0%	RR-30%	RR - 90 %	CT	C.D value (p=0.05)
pH	0-15	7.81	7.64	7.54	7.92	0.19
	15-30	7.74	7.64	7.54	7.87	N/S
EC (dS m^{-1})	0-15	0.23	0.19	0.13	0.23	0.02
	15-30	0.15	0.14	0.15	0.15	N/S
TOC (g kg^{-1})	0-15	10.47	12.16	15.24	9.39	2.74
	15-30	7.41	7.88	8.66	7.10	1.05

RR- residue retention, CT- conventional tillage

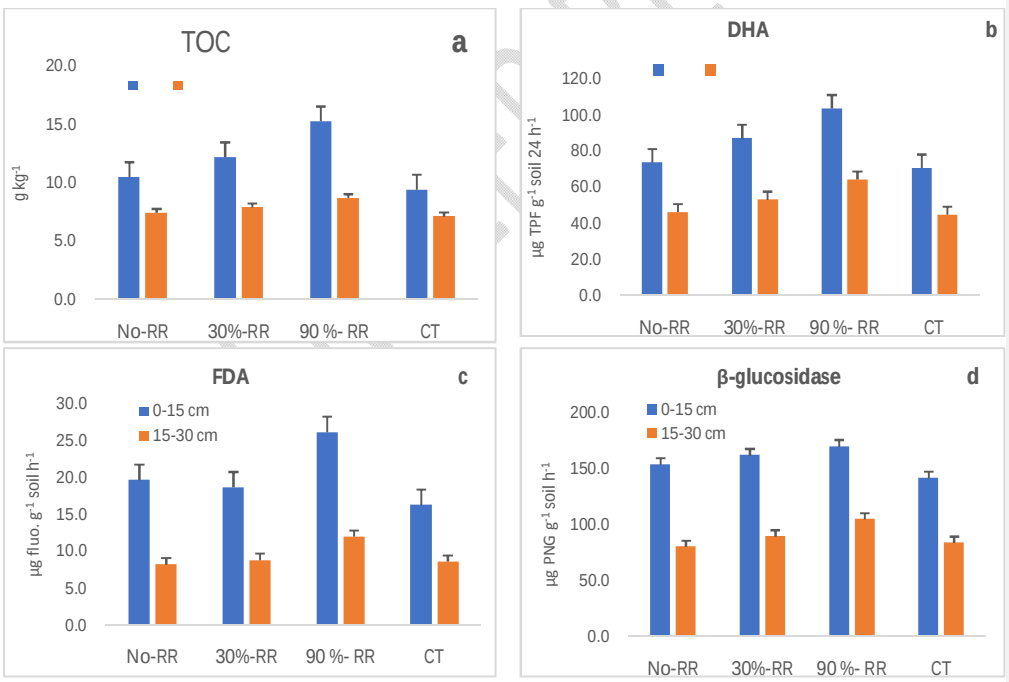

Figure 1. Total organic carbon (TOC) in soil samples collected from fields under different residue retention and tillage practices.

Soil enzymatic activities (b) DHA, (c) FDA, (d) β-glucosidase were estimated under different residue retention (RR) and conventional tillage at the different depth 0-15 cm and 15-30 cm. The residue retentions are no residue retention (0%), 30% per centresidue retention and 90% per centresidue

retention. Each data point represents an average with error bar as standard error of three replicated observations. Significant difference between treatments was indicated with p<0.05.

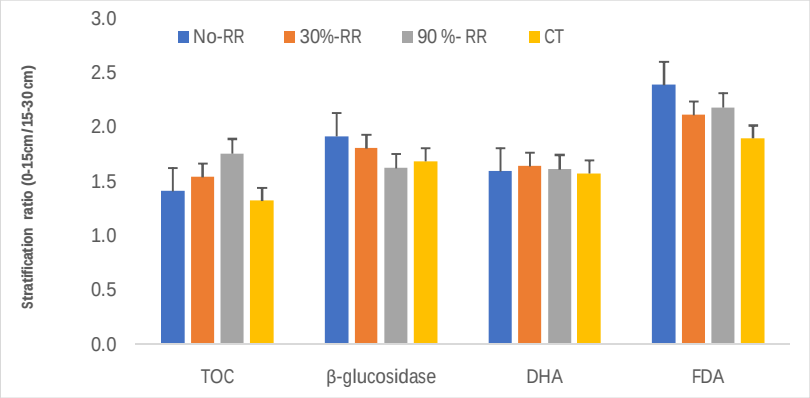

Figure 2. Stratification ratio (0-15 cm/15-30cm) for total organic carbon (TOC) and soil enzymatic activities (DHA, dehydrogenase activity; β -glu, β-glucosidase activity; FDA, Fluorescein diacetate activity) under residue retention (RR); 0%, per cent, 30% per centand 90% per centand conventional tillage (CT). Vertical bar represents a standard error. Significant difference between treatment is indicated with p<0.05.

Table2. correlation coefficient between biochemical (DHA and FDA)and chemical properties (TOC) in soil samples (n=40)

	TOC	DHA	FDA	β-glucosidase
TOC	-			
DHA	0.84**	-		
FDA	0.78*	0.94**	-	
β-glucosidase	0.78*	0.95**	0.92**	-

Correlation is significant at *p= 0.05 level, ** p=0.01 level

DISCUSSION

Climate-smart agricultural practices influence soil enzyme activities to varying degrees. Significant variations in enzyme activities were observed under different levels of crop residue retention (90%, 30%, 0%) compared to conventional tillage. Notable differences in SOC and enzyme activities were recorded in both surface and subsurface soils among the residue retention treatments. Our findings showed that SOC was significantly higher under 90% per centcrop residue retention in the surface soil compared to CT. This is consistent with studies by Kumar *et al.,* (2017), Hati *et al.,* (2015), and McCarty *et al.,* (1997), who reported that conservation tillage, particularly no-till (NT), results in higher SOC concentrations in the topsoil and alters its distribution throughout the soil profile. The greatest differences in SOC concentration between tillage treatments were observed in the surface soilsuppermost soil layer, with the following order:in the order of RT > NT > CT. Several studies have shown that long-term conservation tillage systems (NT and RT) maintain higher SOC levels in the surface soils compared to CT (Conant *et al*., 2007; Lopez-Fando*et al.,* 2009). Increased The

Comment [FO3]: What could be the reason for this significantly higher SOC?

increased SOC concentrations are typically attributed to a variety of interacting factors, including minimal soil disturbance, enhanced residue retention and addition, reduced surface soil temperatures, improved soil moisture, and lower erosion risks (Ismail *et al*., 1994). Crop residues contribute to the SOC pool, and returning more crop residues to the soil is linked to higher SOC concentrations (Dolan *et al.,* 2006). SOC is one of the soil biological properties most influenced by tillage practices (Somasundaram *et al*., 2014).

The DHA activity in 90%, per cent, 30%, per cent, and conventional tillage varied from 70.55 to 103.57 µg TPF g^{-1} day^{-1} in the surface layer. Residue The residue retention in no-tillage systems had a significant effect on the DHA activity. A similar finding was reported by Parihar *et al*., (2016), where surface soils under no-tillage (NT) practices showed significantly higher DHA (122.35 µg TPF g^{-1} day^{-1}) compared to CT (77.07 µg TPF g^{-1} day^{-1}). The decomposition of retained maize residues releases carbon, which can be available to soil microbes, leading to higher DHA activity in the surface soils under a maize-chickpea cropping system. Kumar *et al*., (2017) reported significantly higher DHA in soybean + pigeon pea rotations, followed by maize-gram systems.

Dehydrogenase activity is a well-established indicator of biological activity in soils, as the enzyme exists as an integral part of microbial cells but does not accumulate extracellularly. The oxidation of soil organic matter by dehydrogenase involves the transfer of protons and electrons from substrates to acceptors, and is considered to be linked to the respiration pathways of microorganisms (Das *et al.,* 2011). The DHA activity was significantly influenced by the availability of organic matter, soil temperature, and soil moisture. This is in conformity with the findings of Madejon*et al.,* (2007) and Tao *et al.,* (2009), who observed higher DHA activity under conservation agriculture systems with legume rotations compared to CT.

The mean FDA activity values for 90%, per cent, 30%, per cent, 0%, per cent, and conventional tillage ranged from 22.91 to 30.85 µg fluorescein g^{-1} h^{-1} in both the surface and subsurface layers. Residue It is noted that residue retention management practices had a significant effect on the surface layer during the cropping cycle. Similar findings were reported by Perez-Brandan *et al.,* (2012) and Gajda *et al.,* (2013), who observed higher soil microbial enzymatic activities under conservation agriculture with legume rotations compared to conventional tillage. A significant influence of soil organic matter (SOM) on various biological properties of soil has been documented (Askari *et al.,* 2014; Sinha *et al.,* 2014; Sinha NK, 2014; Marinari *et al.,* 2006). In this study, SOM concentration significantly influenced the total organic carbonTOC, DHA, FDA, and β-glucosidase activities, as supported by the strong correlations between soil biological properties and soil organic carbonSOM content.

Higher β-glucosidase activity was observed in surface soils compared to subsurface soils in the maize-chickpea cropping system, which could likely be due to the increased carbon input from the fibrous root mass of maize in the previous year. This finding wasis consistent with the higher soil carbon concentration under 90% per centresidue retention compared to conventional tillage, and the significant positive correlations observed between β-glucosidase activity, residue load, and total organic carbon. Martin-Lammerding *et al.,* (2015) and Acar *et al.,* (2018) noted that β-glucosidase activity was highest under no-tillage (NT), followed by reduced tillage (RT), with CT showing the lowest levels of β-glucosidase activity. In addition, Jat *et al.,* (2021) and Acar *et al*., (2018) also reported that β-glucosidase activity was significantly higher in rhizospheric soils compared to bulk soils.

CONCLUSION

The soil biological parameters in theofthe Vertisols of central India under the maize-chickpea cropping system were significantly impacted by varying levels of crop residue retention management. The results clearly demonstrated that higher residue retention, particularly 90% per centand 30%, per

cent, supported greater biological activity compared to conventional tillage. Residue retention, as a key component of conservation tillage, triggered a rapid response in soil microbial activity. Biological activities in the soil were predominantly concentrated in the upper layer (0–15 cm), where TOC, DHA, FDA, and β-glucosidase activities were notably higher. This increase could be attributed to the accumulation of ~~organic matter~~SOM from crop residues, litterfall, root biomass, and root and soil biota exudates, as well as the enhanced interaction between the soil surface and atmospheric conditions, fostering soil biodiversity. The strong correlations observed between ~~total organic carbon~~TOC and enzymatic activities (DHA, FDA, and β-glucosidase) in the surface layer highlight the critical role of organic carbon in promoting microbial activity and sustaining soil biodiversity.

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