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Manure addition influences the effect of tillage on soil aggregation and aggregate associated carbon in a Vertisol of Central India

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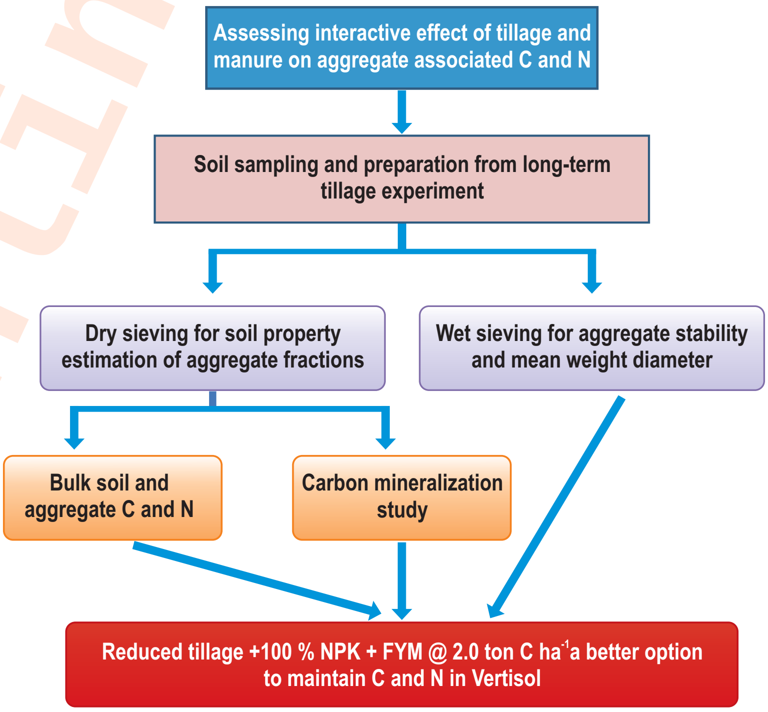
Abstract

Aim: To study the combined effect of tillage and manure addition on bulk soil and aggregate associated carbon and nitrogen in Vertisol.

Methodology: The study was conducted in a long-term tillage experiment having two tillage treatments (reduced tillage and no-tillage) together with100% NPK fertilizer without (T_1) and with addition of farm yard manure (T_2) @ 2.0 ton C ha^{-1} to soybean in a soybean-wheat cropping system in a Vertisol of Central India, with three replicates in a split plot design. The parameters studied were aggregate size distribution, mean weight diameter, water stable aggregates, bulk soil and aggregate associated organic carbon, available nitrogen and rate of carbon mineralization.

Results: The results indicated significantly higher SOC in reduced tillage (0.87%) than no-tillage (0.71%) under100% NPK fertilization in the bulk soil for 0-15 cm depth. However, 100% NPK + FYM showed a significant increase in the bulk soil organic carbon in the no-tillage treatment only. Available nitrogen content in the bulk soil and aggregate fractions were significantly lower under no-tillage than the corresponding reduced tillage treatments. Manure addition led to significantly higher available N content and proportion of WSA in both the tillage practices. The carbon mineralization was significantly higher by 1.4 to 1.6 times under reduced tillage than no-tillage.

Interpretation: Long-term tillage study in Vertisol of Central India indicated reduced tillage to be a better option than no-tillage in maintaining organic carbon and nitrogen availability in soil.



Key words: Nitrogen, Soil aggregate carbon, Tillage, Vertisol, Water stable aggregates

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Introduction

Physical protection of soil organic carbon (SOC) in aggregate fractions is a key process governing the turnover of SOC and mitigation of greenhouse gas emission. Understanding the management and environmental factors influencing soil aggregation and distribution of SOC in aggregate fraction is imperative to elucidate the underlying mechanisms of soil carbon storage (Cai *et al*., 2016; Dhaliwal *et al*., 2020; Piazza *et al*., 2020).Among the soil management practices, tillage and nutrient management strongly influence soil structure, SOC accumulation and soil aggregation (Blanco-Canqui and Lal 2007; Zhang *et al.* 2017). Improvement in soil structure and accretion in SOC due to reduced tillage contributes to soil quality improvement and sequestration of carbon in soil. However, the overall effect of tillage is decided by soil type and climate (Zibilske and Bradford 2007; Lenka *et al.,* 2019) and may also be influenced by external carbon input in the form of manure. Conservation tillage has been advocated to be a part of solution to mitigate climate change effects and to ensure sustainable agriculture, which has been adopted with numerous benefits to soil functioning and processes. Most studies indicate better soil aggregation and higher soil organic carbon (SOC) in the surface soil as twin benefits of conservation tillage (Six *et al*., 2000; Wright and Hons 2005). Among several models of SOC, turnover in soil pools of physically protected SOC describes the binding of primary mineral particles into micro-aggregates (<0.250 mm size) and micro-aggregates in macro aggregates (>0.250 mm size). In addition, carbon incorporated with different aggregates also differs in their molecular structures and stability. The more persistent organic matter that binds micro-aggregates are generally characterized as older, more humified having recalcitrant SOC (Six *et al*., 2000). Roots, fungal hyphae and polysaccharides that bind micro-aggregates into macro aggregates are generally more labile to microbial decomposition (Kumar *et al*., 2013).

Reduced tillage and no-tillage are two common forms of conservation tillage practiced in agriculture production systems. The two tillage systems differ with respect to residue management. In no tillage, all the residue retained is found on the soil surface, while in reduced tillage, the residue is incorporated at ploughing depth (Lenka *et al*., 2015; Lenka and Lenka, 2014; Singh *et al*., 2020).On the contrary, crop residue remain on the surface in case no-tillage is more vulnerable to different losses like decomposition and erosion. Thus, carbon input to the soil in the initial years of adoption is higher under reduced tillage than no- tillage. A difference in the net carbon input and intensity of soil manipulation under two different forms of conservation tillage is likely to influence SOC mineralization, soil aggregation and carbon content in soil and aggregate fractions. The situation is different on adding manure and fertilizer in agriculture production systems. A considerable amount of research has been conducted to study the influence of tillage and crop residue management on soil aggregation and SOC accumulation (Martens 2000; West and Post 2002; Wright and Hons 2005). In India, many researchers have investigated the effect of conservation tillage and nutrient management on soil health, quality, crop yield and productivity in rice-wheat systems in the Indo-Gangetic regions (Brar *et al*., 2015; Dhaliwal *et al*., 2020; Lenka and Lenka, 2014; Parihar *et al*., 2020; Singh *et al*., 2020; Tripathi *et al*., 2014). However, few studies have addressed the combined effect of tillage, residue and manure management on soil aggregation and distribution of carbon and nitrogen in soil aggregates in the soybean-wheat systems of India. The information is meager for Vertisols, particularly in India. Hence, this study was conducted with the hypothesis that aggregation and aggregate associated carbon and nitrogen will be higher under no-tillage and further improved with manure addition. The objectives of the investigation were: to assess the effect of tillage and manure management on 1) soil aggregation and SOC accretion, 2) soil aggregate carbon and nitrogen and 3) SOC mineralization.

Materials and Methods

Study area : Soil samples were collected for this study from the research farm of Central Institute of Agricultural Engineering, Bhopal. The area falls under semi-arid and sub-tropical zone, characterized by hot summer and cold winter. The mean annual precipitation is about 650 mm, most of which is received during the monsoon period from July to September. The average maximum temperature during summer is 35 °C and 21 ºC during winter. The soil of the experimental field was non-calcareous Vertisol (Isohyperthermic Typic Haplustert) with 52% clay content, bulk density of 1.34 mg m^{-3} at 0.27 g g^{-1} soil water content, and available water capacity of 10.16 cm at 0-15 cm soil layer. Soil was neutral to alkaline with 7.0 g kg^{-1} soil organic carbon, electrical conductivity of 0.3 dS m^{-1} and Ca^{2+} as the dominant exchangeable cation in the Ap horizon.

Soil sampling and preparation : The soil used in this study was collected from a long-term experiment under conservation tillage in soybean-wheat system, initiated in the year 2008. The surface soil samples were collected before sowing of soybean in June, 2016 from 0-15 cm soil depth. A core auger was used to randomly sample the soil from each treatment. The treatment detail consisted of tillage as the main plot at two levels: no tillage (no-tillage; direct sowing by no till drill); reduced tillage (reduced tillage; one pass rotavator + sowing by seed cum fertilizer drill)) and nutrient as subplot with two levels100% NPK fertilizer without (T_1) and with addition of farm yard manure (T_2) @ 2.0 ton $Cha^{-1}$to soybean in a soybean-wheat cropping system in a Vertisol of Central India, with three replicates in a split plot design.

Estimation of aggregate fractions: From each plot, five number of soil cores were collected from 0-15 cm depth using soil cores. Extracted cores were mixed together to generate a single well-mixed sample. All visible roots and fresh litter materials were removed from the collected soil, and the samples were passed through a 4-mm sieve to remove large litter fragments and particles. The 4-mm sieved soil was dry sieved by passing through a nest of 2 mm and 0.250 mm sieve to obtain aggregates of> 2 mm (large macro aggregate), 2-0.250 mm (small macro aggregate) and < 0.250 mm (micro aggregate and silt clay) size. Aggregates were separated by placing 500 g of 4-mm sieved soil in a nest of sieves (20-cm diameter) containing 2 mm and 0.250 mm sieves. Sieves were shaken at 200 oscillations min^{-1} for 3 min and aggregates retained and passed through the sieves were then thoroughly mixed with spatula and air-dried. The soil samples and aggregate fractions were stored in airtight container for future analysis.

The processed soil samples of different size fractions were analyzed for organic carbon and available nitrogen content. A portion of the aggregate size was finely ground for total carbon analysis, following the method of the Walkley and Black (1934). Soil moisture content of the sample was determined by weighing the soil prior and after oven drying at 105 °C for 48 hrs. Available nitrogen content was estimated by alkaline $KMnO_4$ method, where organic matter in soil was oxidized with hot alkaline $KMnO_4$ solution (Subbiah and Asija, 1956).

Soil respiration study : Twenty gram of each aggregate fraction and bulk soil (dry weight equivalent) were incubated in 300 ml glass jars at a water potential of -0.033 MPa. Before starting the incubation process, residues visible to naked eye were removed from the soil followed by 15 days of pre-incubation at 15 °C and at -0.033 MPa field capacity moisture content to avoid pulsing effect. This was followed by incubation in 300 ml glass jars in three replications at 25 °C (±1°C) for 122 days. Controls (without soil samples) were also incubated for same number of days. Small vials (20 ml, with no lids) containing 5 ml of 1.0 M NaOH solution were kept inside each glass jar to trap respired CO_2 (De Neve and Hofman, 2002). The glass jars were tightly capped with lids to keep constant water potential throughout the experiment, and were opened at each sampling date to allow air exchange. To ensure constant moisture regime, samples were weighed periodically and deionized water was added to maintain moisture at -0.03 M Pa. Sampling was done after 0, 1, 3, 7, 12, 17, 22, 27, 34, 41, 48, 55, 62, 71, 79, 96 and 122 days by removing small NaOH vials. Soil respiration was estimated by alkaline NaOH (Anderson, 1982) method. To calculate the carbon mineralization rate, the amount of CO_2 was determined by titrating NaOH with 0.2 N HCl to pH 8.3 in the presence of 3.0 nitrogen$BaCl_2$, using phenolphthalein indicator.

Mineralization of carbon was computed by the following equation:

$$CO_2\text{- C mineralized (mg g}^{-1}\text{ soil)} = \frac{(B - S) * N * 6}{W}$$

Where, B is the volume of HCl used in blank sample (ml); S is the volume of HCl used in soil sample (ml); N is the normality of HCl; W is the weight of soil sample taken (g). The quantity of carbon mineralization at each sampling date was summed over 122-d incubation period and the value was expressed as cumulative CO_2-C mineralization.

Analysis of aggregate fraction : A wet sieving procedure (Kemper and Chepil, 1965) was used to segregate the aggregates into four categories, viz. large macro-aggregates (>2 mm diameter), small macro-aggregates (2-0.250 mm), micro-aggregates (0.250-0.053 mm) and mineral or silt+clay size (<0.053 mm) fraction. Also, the mean weight diameter (MWD) of soil samples was estimated by wet sieving technique. Briefly, the composite soil samples collected from field were air dried and passed through 8 mm and 4 mm sieves to remove debris, dry roots and other parts. One hundred gram of air-dried soil aggregates retained on 4mm sieve was spread evenly on the top of uppermost sieve in the set of graduated sieves, having openings of 2.000, 0.250 and 0.053 mm. The sieves were of 20 cm in diameter and 5 cm height. The samples were pre-wetted with an atomizer. The stroke length of sieving apparatus was 3.5 cm and sieving was carried out for 15 min at 35 rotations per minute. The material retained on each sieve was removed and oven dried at 105 °C for 48 hr. The weight of soil aggregates retained on each size fraction was recorded for computation of mean weight diameter and per cent aggregate size fraction. The portions of aggregates > 0.25 mm size was considered as water stable aggregates. The per cent WSA was determined by multiplying the proportion of weight of such aggregates with100.

The mean weight diameter (MWD) was used as an index of aggregate stability (Van Bavel, 1949). The MWD is equal to the sum of the products of (a) mean diameter (d_i) of each size fraction and (b) proportion of total sample weight (w_i) in the corresponding size fraction, where the summation is carried out over all 'n' size fractions including the one that passes through the finest sieve.

$$MWD = \sum_{i=1}^{n} d_i w_i$$

Statistical analyses : The data obtained from the studied parameters were analyzed by two way analysis of variance (ANOVA) followed by Tukey's test ($\alpha = 0.05$) using a statistical software SAS 9.2. With respect of soil OC, available nitrogen and carbon mineralization rate, the analysis was carried out by using a factorial treatment structure, taking tillage and aggregate size as two factors. For a significant F-value, the treatment means were separated with least significant difference (LSD) at 95% confidence value ($P < 0.05$).

Results and Discussion

The SOC content was significantly affected by tillage practice but not by aggregate size (Table 1). Without manure, the SOC content in the bulk soil was significantly higher under reduced than no-tillage. The effect of tillage treatment on SOC content was significantly influenced on adding manure under no-tillage treatment only. Addition of manure in reduced tillage did not show any significant increase in the bulk soil SOC content where as it was significant in no-tillage. This indicated, if manure is not added, reduced tillage practice shall result in higher SOC in the bulk soil than no-tillage. Among the aggregate fractions, a trend of higher SOC was observed in large macro aggregate size (>2 mm size), though the effect of aggregate size was not significant. On the other hand, addition of manure led to significant increase in the SOC content in the large (>2 mm size) and small macro-aggregate fractions (2-0.25 mm) in both reduced tillage and no-tillage. In case of large macro aggregates (>2 mm size), addition of manure led to significant increase in SOC from 0.79 to 0.92% under reduced tillage and from 0.80 to 0.98% under no-tillage. In small macro aggregates, the increase in SOC content due to manure addition was also significant with the values increasing from 0.83 to 0.89% under reduced tillage and from 0.78 to 0.88% under no-tillage. In the absence of manure, the large macro aggregates associated SOC was statistically at par under reduced tillage and no-tillage. On the other hand, small macro aggregate associated SOC was significantly higher under reduced tillage than no-tillage. Increase in aggregation concomitant with increases in SOC has been observed in no-tillage and reduced tillage systems (Paustian *et al.* 2000; Six *et al.* 2000; Lenka and Lal 2013; Lenka *et al*. 2015; Yadav *et al*., 2020). Further, the influence by tillage on SOC seems to depend on the depth to which the tillage/ploughing operation incorporates plant material. Below the plough depth, SOC would be dependent on long-term vegetation and cropping history of a field. The effect of tillage under a particular cropping system and management practice depends on the input-output balance of carbon into or out of the soil system (Zhang *et al.,* 2017). In no-tillage, the output in form of oxidative loss of soil carbon was minimum due to absence of tillage. The input was also lower due to no incorporation of residues(Singh *et al*., 2020; Singh *et al*., 2020; Wang *et al*., 2019; Yadav *et al*., 2020).

Tillage and residue management are two key determinants affecting soil carbon, aggregate turnover and aggregate associated carbon in arable soils (Guo *et al.* 2016). Tillage strongly influences SOC distribution and storage by physically mixing soil and by distributing crop residues in the soil, though excessive tillage has adverse effect on soil carbon. As compared to no-tillage, higher OC in bulk soil as well as in the macro aggregates under reduced tillage was in the line of expectation. Even though the quantity of residue retention was same across tillage, under no-tillage, the crop residue was on the surface. On the other hand, reduced tillage provided scope for incorporation of the residues, and subsequent decomposition and mineralization of residue increases SOC in the bulk soil and macro aggregate fractions (Lehtinen *et al*., 2014). Incorporation of residue provides congenial thermal and moisture regime as well as acts as substrate for the microbial community to aid in faster decomposition and better aggregation. Reduced tillage with inorganic fertilizer alone was reported to induce a loss of macro aggregates and a gain of micro-aggregates (Six *et al.* 2000). In this study, addition of manure along with chemical fertilizers resulted in significantly higher SOC content in no-tillage treatment only. Application of organic manure with inorganic fertilizer increased the soil organic carbon content and better aggregate formation that could be attributed to enhanced crop yield, larger below ground biomass and greater pore space. The results are in conformity with the previous reports (Cai *et al*., 2016; Conant *et al*., 2011; Naresh *et al*., 2020; Yadav *et al*., 2020).

Soil available nitrogen content was significantly influenced by tillage management, aggregate size and their interaction effects (Table 2). The available nitrogen content in the bulk soil was significantly higher under reduced than no-tillage, with or without addition of manure. The effect of tillage treatment on available nitrogen content was significantly influenced by the addition of manure under both reduced tillage and no-tillage treatments. In general, available nitrogen content in aggregate fractions was higher than in the bulk soil. The available soil nitrogen content in the bulk soil ranged from 146 kg ha^{-1} under NT-T$_1$ to 215 kg ha^{-1} under RT-T$_2$. Among the two tillage practices, higher soil available nitrogen was observed under reduced tillage. Similar to the trend observed in SOC, addition of manure led to significant increase in the available nitrogen content in the bulk soil as well as in the aggregate size fractions in both reduced tillage and no-tillage. Higher available nitrogen was also observed under RT-T$_2$ treatment in the aggregate size fractions. Similar effect of organic manure addition with inorganic fertilizer in increasing the nitrogen content in aggregate fraction over inorganic fertilizer have also been reported (An *et al*., 2010; Sainju, 2006; Tripathi *et al*., 2014; Yadav *et al*., 2020). On an average, the available soil nitrogen content in the bulk soil was higher by 19% in the reduced than no tillage. Among all the treatments, significantly higher available nitrogen content was observed in RT-T$_2$ followed by NT-T$_2$ and RT-T$_1$ treatment. Among the aggregate fractions, significantly higher available nitrogen content was observed in the smallest (<0.250 mm) fraction under RT whereas in small macro aggregates under no-tillage. Across tillage, higher available nitrogen in micro-aggregates (<0.250 mm) fraction than macro-aggregate indicated greater stabilization of soil nitrogen in micro-aggregates.

A possible higher carbon balance in the soil system under reduced tillage led to significantly higher SOC and available nitrogen in the bulk soil and in aggregate fractions. Application of crop residues with wider C : N ratio, such as wheat straw may result in prolonged immobilization of mineral nitrogen (Benbi and Khosa, 2014; Blagodatskaya *et al*., 2016). Significantly lower nitrogen availability under no-tillage as observed in the present investigation is attributed to slow residue decomposition and thus possible nitrogen mining from the soil (Angás *et al.,* 2006; Verachtert *et al.,* 2009). Across the treatments, soil available

Table 1 : Effect of tillage management on SOC (%) in bulk soil and in different aggregate size fractions at 0-15 cm soil depth

Land management	Aggregate size class				
	bulk	**>2 mm**	**2-0.250 mm**	**<0.250 mm**	**Mean**
RT-T_1	0.87	0.79	0.83	0.86	0.84
RT-T_2	0.90	0.92	0.89	0.90	0.90
NT-T_1	0.71	0.80	0.78	0.90	0.80
NT-T_2	0.91	0.98	0.88	0.86	0.91
Mean	0.85	0.87	0.85	0.88	
	Land management (A)		**Aggregate size class (B)**		**Interaction (AxB)**
LSD (p=0.05)	0.034		ns		0.068
SEm±	0.012		0.012		0.023

ns : Not significant; Note: RT-T_1: Reduced tillage + RDF in soybean and wheat; RT-T_2: Reduced tillage + RDF + 2.0 t FYM-C ha^{-1} every year in soybean; NT-T_1: No tillage + RDF in soybean and wheat; NT-T_2: No tillage + RDF in soybean and wheat + 2.0 t FYM-C ha^{-1} every year in soybean.

Table 2 : Effect of tillage management on soil available N (kg ha^{-1}) in bulk soil and in different aggregate size fractions at 0-15 cm soil depth

Land management	Aggregate size class				
	bulk	**>2 mm**	**2-0.250 mm**	**<0.250 mm**	**Mean**
RT-T_1	177.71	211.16	209.07	232.06	207.50
RT-T_2	215.34	229.97	217.43	234.15	224.22
NT-T_1	146.35	175.62	177.71	173.53	168.30
NT-T_2	183.98	175.62	188.16	186.07	183.46
Mean	180.84	198.09	198.09	206.45	
	Land management (A)		**Aggregate size class(B)**		**Interaction(AxB)**
LSD (p=0.05)	3.08		3.08		6.16
SEm±	1.061		1.061		2.123

Note: RT-T_1: Reduced tillage + RDF in soybean and wheat; RT-T_2: Reduced tillage + RDF + 2.0 t FYM-C ha^{-1} every year in soybean; NT-T_1: No tillage + RDF in soybean and wheat; NT-T_2: No tillage + RDF in soybean and wheat + 2.0 t FYM-C ha^{-1} every year in soybean

nitrogen was significantly greater in <0.250 mm fraction indicating a major portion of active nitrogen pool is preferentially being stored in microaggregates and silt + clay size fractions (Sainju, 2006).

Distribution of four different aggregate fractions was significantly ($p<0.05$) influenced on adding tillage and manure (Table 3). Small macroaggregates (2-0.250 mm) constituted the largest fraction followed by micro-aggregates (0.250-0.053 mm), silt + clay size fraction (<0.053 mm) and large macroaggregates (> 2.0 mm). The proportion of both large and small macro aggregates was significantly higher under NT-T_2 treatment. In all the management treatments, small macro- (2-0.250 mm) and micro-aggregates (0.250-0.053 mm) dominated the aggregate size distribution accounting for 85-90% of dry soil weight. Without addition of manure, the large macro aggregates were at par under RT and no-tillage. Similar trend was also observed in case of other aggregate fractions. Addition of manure showed significantly higher large macro- and small macro aggregates only under no-tillage.

The proportion of water stable aggregates and MWD were significantly ($p<0.05$) affected by the tillage and manure management treatments (Table 4). The values of both WSA and MWD were significantly higher under NT-T_2 only. The proportion of water stable aggregates (> 0.250 mm) varied from 64 to 72%, with higher values under NT-T_2 followed by NT-T_1, RT-T_2 and RT-T_1 in order. Without addition of manure, the WSA and MWD values were at par in RT and no-tillage. However, manure addition significantly increased the WSA and MWD only under no-tillage. Despite, lowest values of both the parameters under RT-T_1, all the three treatments, viz. RT-T_1, RT-T_2 and NT-T_1, were statistically at par. A trend of higher soil bulk density was observed under no-tillage than reduced tillage, though the effect was non-significant (Table 4). The volumetric soil moisture content at 0.033 MPa was not significantly affected by tillage and manure addition, though higher values were observed under manure treatments than no-manure treatments.

Tillage significantly ($p<0.05$) influenced the cumulative soil carbon mineralization in bulk soil as well as in the aggregate fractions (Table 5). Carbon mineralization was significantly higher

Table 3 : Effect of tillage management on aggregate size distribution, as determined by wet sieving procedure, for soil of 0-15 cm depth

Tillage management	Aggregate size distribution (%)			
	Large macroaggregates (>2 mm)	Small macroaggregates (2-0.250 mm)	Microaggregates (0.250-0.053 mm)	Silt + clay size (<0.053 mm)
RT-T_1	3.73	60.41	25.88	8.76
RT-T_2	3.25	64.87	24.62	6.38
NT-T_1	3.87	63.43	25.92	7.13
NT-T_2	4.35	68.02	18.89	5.99
LSD (p=0.05)	0.58	3.34	3.13	1.66
SEm±	0.24	1.34	1.25	0.67

Note: RT-T_1: Reduced tillage + RDF in soybean and wheat; RT-T_2: Reduced tillage + RDF + 2.0 t FYM-C ha^{-1} every year in soybean; NT-T_1: No tillage + RDF in soybean and wheat; NT-T_2: No tillage + RDF in soybean and wheat + 2.0 t FYM-C ha^{-1} every year in soybean

Table 4 : Effect of tillage management on soil properties in the 0-15 cm soil depth

Tillage management	Water stable aggregates	Mean Weight Diameter (mm)	Bulk Density (Mg m^{-3})	θ at 0.033 MPa (%, v/v)
RT-T_1	64.14	0.91	1.38	42.75
RT-T_2	68.12	0.93	1.34	45.17
NT-T_1	67.3	0.95	1.42	42.27
NT-T_2	72.37	1.01	1.41	45.78
LSD (p=0.05)	3.693	0.05	ns	ns
SEm±	1.047	0.01	0.023	2.014

ns : Not significant; Note: RT-T_1: Reduced tillage + RDF in soybean and wheat; RT-T_2: Reduced tillage + RDF + 2.0 t FYM-Cha^{-1} every year in soybean; NT-T_1: No tillage + RDF in soybean and wheat; NT-T_2: No tillage + RDF in soybean and wheat + 2.0 t FYM-C ha^{-1} every year in soybean

Table 5 : Effect of tillage management on cumulative soil C mineralized (CO_2-C µg g^{-1} soil) after 122 days incubation period in bulk soil and aggregate fractions at 25° C incubation temperature

Land management	Aggregate size class				
	bulk	>2 mm	2-0.250 mm	<0.250 mm	Mean
RT-T_1	401	422	359	525	427
RT-T_2	449	461	428	491	457
NT-T_1	246	280	230	326	271
NT-T_2	337	298	308	376	330
Mean	358	365	331	430	
	Land management(A)		**Aggregate size class(B)**		**Interaction(AxB)**
LSD (p=0.05)	8		8		16
SEm±	3		3		6

Note: RT-T_1: Reduced tillage + RDF in soybean and wheat; RT-T_2: Reduced tillage + RDF + 2.0 t FYM-C ha^{-1} every year in soybean; NT-T_1: No tillage + RDF in soybean and wheat; NT-T_2: No tillage + RDF in soybean and wheat + 2.0 t FYM-C ha^{-1} every year in soybean

under reduced tillage than no-tillage treatments. In bulk soil, the carbon mineralization followed the order: RT-T_2> RT-T_1> NT-T_2> NT-T_1. Similar trend was observed in two aggregate size fractions (> 2 mm and 2-0.25 mm aggregate size). In all tillage treatments, manure application enhanced carbon mineralization significantly.

Soil aggregation is a key indicator of soil quality and environmental sustainability of agricultural management practices. Aggregate formation stabilizes organic material within soil micro sites, physically protecting soil organic matter from microbial decomposition and increasing the mean residence time relative to inter-aggregate (unprotected) organic matter. The MWD and WSA were significantly higher under no-tillage with addition of manure (NT-T_2). Even under RT system, manure addition did not show significant higher effect on MWD and WSA. This indicated that in this clay rich soil, effect of no-tillage in improving soil structure is manifested only with application of FYM. These findings are consistent with the results of Choudhury *et al.* (2014) and Bottinelli *et al.* (2017). Increase in relative proportion of macro aggregates under no-tillage plus FYM application are due to cementing action of the organic acid and polysaccharides formed during decomposition of organic residues by enhanced microbial activity (Paustian *et al.,* 2000; Six *et al.,* 2000).

No tillage increases the turnover time of macro aggregate formation. Tillage reduces the stability of macro aggregates as macro aggregates disintegrates with tillage and proportion of micro-aggregates increases (Beare *et al.,* 1994; Six *et al.,* 2000). Reduced and zero tillage in wheat coupled with direct seeded rice increased macro aggregates by 50% than conventional tillage (Choudhury *et al.,* 2014). Favorable effect of no tillage in increasing the macro-aggregates and reducing the micro-aggregates has been reported by Beare *et al.* (1994). Effect of organic manures in enhancing the proportion of macro aggregates has been reported by Su *et al.* (2006), Rasool *et al.* (2008) and Padbhushan *et al.* (2016).

The increase in water stability of aggregates due to addition of FYM has been earlier reported by Benbi *et al.* (1998), Singh *et al.* (2014) and Padbhushan *et al.* (2016). Increase in MWD with no-tillage and addition of FYM is due to higher percentage of macro aggregates in the soil. Similar increase in MWD by no tillage and FYM was observed by Choudhury *et al.* (2014), Bottinelli *et al.* (2017) and Mikha and Rice (2004).

The study indicated that in Vertisols under soybean-wheat cropping system, conservation tillage with integrated use of inorganic and organic fertilizer improved soil aggregation, accumulation of soil organic carbon in the macro-aggregates and available nitrogen in microaggregates. Therefore, study recommends minimum tillage with residue return and integrated use of nutrient as sustainable soil management strategy for the farmers of Central India.

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References

An, S., A. Mentler, H. Mayer and W.E.H. Blum: Soil aggregation, aggregate stability, organic carbon and nitrogen in different soil aggregate fractions under forest and shrub vegetation on the Loess Plateau, China. *Catena,* **81**, 226–233 (2010).

Anderson, J.P.: Soil Respiration. In: Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties (Eds.: A.L. Page, R.H. Miller and D.R. Keeney). *Soil Sci. Soc. America Inc*., pp. 831-871 (1982).

Angás, P., J. Lampurlanés and C.C. Martínez: Tillage and nitrogen fertilization effects on nitrogen dynamics and barley yield under semiarid Mediterranean conditions. *Soil Tillage Res.,* **87**, 59-71 (2006).

Beare, M.H., P. F. Hendrix and D.C. Coleman: Water-stable aggregates and organic matter fractions in conventional-and no-tillage soils. *Soil Sci. Soc.* Am. *J.,* **58**, 777-786 (1994).

Benbi, D.K., C.R. Biswas, S.S. Bawa and K. Kumar: Influence of farmyard manure, inorganic fertilizers and wed control practices on some soil physical properties in a long-term experiment. *Soil Use Manage.,* **14**, 52-54 (1998).

Benbi, D.K. and M.K. Khosa: Effects of temperature, moisture, and chemical composition of organic substrates on carbon mineralization in soils. *Commun Soil Sci Plant Anal.,* **45,** 2734–2753 (2014).

Blagodatskaya, E., S. Blagodatsky, N. Khomyakov, O. Myachina and Y. Kuzyakov: Temperature sensitivity and enzymatic mechanisms of soil organic matter decomposition along an altitudinal gradient on Mount Kilimanjaro. *Sci. Rep*., **6**, 1–11 (2016).

Blanco-Canqui, H. and R. Lal: Soil structure and organic carbon relationships following10 years of wheat straw management in no-till. *Soil Tillage Res.,* **95**, 240–254 (2007).

Bottinelli, N., D.A. Angers, V. Hallaire, D. Michot, C. Le Guillou, D. Cluzeau, D. Heddadj and S. Menasseri-Aubry: Tillage and fertilization practices affect soil aggregate stability in a humic Cambisol of Northwest France. *Soil Tillage Res.,* **170**, 14-17 (2017).

Brar, B., J. Singh, G. Singh and G. Kaur: Effects of long term application of inorganic and organic fertilizers on soil organic carbon and physical properties in maize–wheat rotation. *Agronomy*, **5**, 220–238 (2015).

Cai, A., H. Xu, X. Shao, P. Zhu, W. Zhang, M. Xu and D.V. Murphy: Carbon and nitrogen mineralization in relation to soil particle-size fractions after 32 years of chemical and manure application in a continuous maize cropping system. *PLoS One*, **11**, 1–14 (2016).

Choudhury, S.G., S. Srivastava, R. Singh. S.K. Chaudhari, D.K. Sharma, S.K. Singh and D. Sarkar: Tillage: Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice–wheat cropping system under reclaimed sodic soil. *Soil Tillage Res.,* **136**, 76-83 (2014)

Conant, R.T., M.G . Ryan, G.I. Ågren, H.E. Birge, E.A. Davidson, P.E. Eliasson, S.E. Evans, S.D. Frey, C.P. Giardina, F.M. Hopkins, R. Hyvönen, M.U.F. Kirschbaum, J.M. Lavallee, J. Leifeld, W.J. Parton, J.M. Steinweg, M.D. Wallenstein, J.Å. Martin Wetterstedt and M.A. Bradford: Temperature and soil organic matter decomposition rates - synthesis of current knowledge and a way forward. *Glob. Chang. Biol*., **17**, 3392–3404 (2011).

De Neve, S. and G. Hofman: Quantifying soil water effects on nitrogen mineralization from soil organic matter and from fresh crop residues. *Biol. Fert.. Soils.,* **35**, 379-386 (2002).

Dhaliwal, S.S., R.K. Naresh, R.K. Gupta, A.S. Panwar, N.C. Mahajan, R. Singh and A. Mandal: Effect of tillage and straw return on carbon footprints, soil organic carbon fractions and soil microbial community in different textured soils under rice–wheat rotation: A review. *Rev. Environ. Sci. Biotechnol*., **19**, 103–115 (2020).

Guo, L., S. Zheng, C. Cao and C. Li: Tillage practices and straw-returning methods affect topsoil bacterial community and organic carbon under a rice-wheat cropping system in central China. *Sci. Rep.,* **6**, 33155 (2016).

Kemper, W.D. and W.S. Chepil: Size distribution of aggregation. In: Methods of Soil Analysis (Eds.: CA Black). American Society of Agronomy, pp. 499–510 (1965).

Kumar, R., K.S. Rawat, J. Singh, A. Singh and A Rai: Soil aggregation dynamics and carbon sequestration. *J. Appl. Nat. Sci.,* **5**, 250–267 (2013).

Lehtinen, T., N. Schlatter, A. Baumgarten, L. Bechini, J. Krüger, C. Grignani, L. Zavattaro, C. Costamagna and H. Spiegel: Effect of crop residue incorporation on soil organic carbon and greenhouse gas emissions in European agricultural soils. *Soil Use Manag.,* **30**, 524–538 (2014).

Lenka, N.K. and R. Lal: Soil aggregation and greenhouse gas flux after 15 years of wheat straw and fertilizer management in a no-till system. *Soil Tillage Res.,* **126**, 78-89 (2013).

Lenka, S. and N.K. Lenka: Conservation tillage for climate change mitigation – The reality. *Clim. Chang. Environ. Sustain*., **2**, 1–9 (2014).

Lenka, S., N.K. Lenka, R.C. Singh, M.C. Manna, A.K. Misra and S.K. Rautaray: Tillage and manure induced changes in carbon storage and carbon management index in soybean–wheat cropping system in the Vertisols of Central India. *Natl. Acad. Sci. Lett.,* **38**, 461-464 (2015).

Lenka, S., P. Trivedi, B. Singh, B.P. Singh, E. Pendall, A. Bass and N.K. Lenka: Effect of crop residue addition on soil organic carbon priming as influenced by temperature and soil properties. *Geoderma,* **347**, 70-79 (2019).

Martens, D.A.: Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. *Soil Biol. Biochem.,* **32**, 361-369 (2000).

Mikha, M.M. and C.W. Rice: Tillage and manure effects on soil and aggregate-associated carbon and nitrogen. *Soil Sci. Soc. Am. J.,* **68**, 809-816 (2004).

Naresh, R.K., N.C. Mahajan, R.S. Rathore and M.S. Chandra: Effect of tillage with organic and inorganic fertilizer management practices on soil aggregation and aggregate associated carbon fractions to a sub-tropical soil under rice-wheat rotation: A review. *Int. J. Curr. Microbiol. Appl. Sci*., **9**, 939–959 (2020).

Padbhushan, R., A. Das., R. Rakshit., R.P. Sharma, A. Kohli and R. Kumar: Long-term organic amendment application improves influence on soil aggregation, aggregate associated carbon and carbon pools under scented rice-potato-onion cropping system after the 9th crop cycle. *Commun. Soil Sci. Plan.,* **47**, 2445-2457 (2016).

Parihar, C.M., A.K. Singh, S.L. Jat, A. Dey, H.S. Nayak, B.N. Mandal, Y.S. Saharawat, M.L. Jat and O.P. Yadav: Soil quality and carbon sequestration under conservation agriculture with balanced nutrition in intensive cereal-based system. *Soil Tillage Res*., **202**, 104653 (2020).

Paustian, K., J. Six, E.T. Elliott and H.W. Hunt: Management options for reducing CO_2 emissions from agricultural soils. *Biogeochemistry,* **48**, 147-163 (2000).

Piazza, G., E. Pellegrino, M.C. Moscatelli and L. Ercoli: Long-term conservation tillage and nitrogen fertilization effects on soil aggregate distribution, nutrient stocks and enzymatic activities in bulk soil and occluded microaggregates. *Soil Tillage Res*., **196**, 104482 (2020).

Rasool, R., S.S. Kukal and G.S. Hira: Soil organic carbon and physical properties as affected by long-term application of FYM and inorganic fertilizers in maize–wheat system. *Soil Tillage Res.,* **101**, 31-36 (2008).

Sainju, U.M.: Carbon and nitrogen pools in soil aggregates separated by dry and wet sieving methods. *Soil Sci.,* **171**, 937-949 (2006).

Singh, D., S. Lenka, N.K. Lenka, S.K. Trivedi, S. Bhattacharjya, S. Sahoo, J.K. Saha and A.K. Patra: Effect of reversal of conservation tillage on soil nutrient availability and crop nutrient uptake in soybean in the Vertisols of Central India. *Sustainability,* **12**, 6608 (2020).

Singh, R.C., S. Lenka and C.D. Singh: Conservation tillage and manure effect on soil aggregation, yield and energy requirement for wheat in Vertisols. *Indian J. Agric. Sci.,* **84**, 267-271 (2014).

Singh, S., A. Nouri, S. Singh, S. Anapalli, J. Lee, P. Arelli and S. Jagadamma: Soil organic carbon and aggregation in response to thirty-nine years of tillage management in the southeastern US. *Soil Tillage Res*., **197**, 104523 (2020).

Six, J., E.T. Elliott and K. Paustian: Soil macro-aggregate turnover and micro-aggregate formation: A mechanism for carbon sequestration under no-tillage agriculture. *Soil Biol. Biochem.,* **32**, 2099–2103 (2000).

Su, Y.Z., F. Wang, D.R. Suo, Z.H. Zhang and M.W. Du: Long-term effect of fertilizer and manure application on soil-carbon sequestration and soil fertility under the wheat–wheat–maize cropping system in northwest China. *Nutr. Cycl. Agroecosys.,* **75**, 285-295 (2006).

Subbiah, B.V. and G.L. Asija: A rapid procedure for the determination of available nitrogen in soils. *Curr. Sci.,* **25**, 259-260 (S1956).

Tripathi, R., A.K. Nayak, P. Bhattacharyya, A.K. Shukla, M. Shahid, R. Raja, B.B. Panda, S. Mohanty, A. Kumar and V.K. Thilagam: Soil aggregation and distribution of carbon and nitrogen in different fractions after 41 years long-term fertilizer experiment in tropical rice-rice system. *Geoderma,* **213**, 280–286 (2014).

Van Bavel, C.H.M.: Mean weight-diameter of soil aggregates as a statistical index of aggregation. In: *Soil Sci. Soc. Am. Proc.,* **14**, 20-23 (1949).

Verachtert, E., B. Govaerts, K. Lichter, K.D. Sayre, J.M. Ceballos-Ramirez, M.L. Luna-Guido, J. Deckers and L. Dendooven: Short term changes in dynamics of carbon and nitrogenin soil when crops are cultivated on permanent raised beds. *Plant Soil,* **320**, 281-293 (2009).

Walkley, A. and I.A. Black: An examination of degtjareff method for determination of soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci*., **34**, 29-38 (1934).

Wang, B., L. Gao, W. Yu, X. Wei, J. Li, S. Li., X. Song, G. Liang, D. Cai and X. Wu: Distribution of soil aggregates and organic carbon in deep soil under long-term conservation tillage with residual retention in dryland. *J. Arid Land*., **11,** 241–254 (2019).

West, T.O. and W.M. Post: Soil organic carbon sequestration rates by tillage and crop rotation. *Soil Sci. Soc. Am. J.,* **66**, 1930-1946 (2002).

Wright, A.L. and F.M. Hons: Soil carbon and nitrogen storage in aggregates from different tillage and crop regimes. *Soil Sci. Soc. Am. J.,* **69**, 141-147 (2005).

Yadav, S., R.K. Naresh, Vivek, M.S. Chandra and N.C. Mahajan: Soil carbon pools, carbon and nitrogen storage pattern in soil aggregate fractions under long-term application of organic and synthetic fertilizers in rice-wheat system: A review. *Curr. J. Appl. Sci. Technol.*, **39**, 53–65 (2020).

Zhang, X., X. Xin, A. Zhu, Z. Zhang and W. Yang: Effects of tillage and residue managements on organic carbon accumulation and soil aggregation in a sandy loam soil of the North China Plain, *Catena,* **156**, 176-183 (2017).

Zibilske, L.M. and J.M. Bradford: Soil aggregation, aggregate carbon and nitrogen, and moisture retention induced by conservation tillage. *Soil Sci. Soc. Am. J.,* **71**, 793–802 (2007).