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Effect of Conservation Tillage on Changes in Soil Aggregate-associated Organic Carbon and Biological Pools to Nitrogen and Straw Alters in RWCS in North-Western India: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

To manage this issue, understanding the mineralization process of crop leftovers is helpful. C and N mineralization kinetics in surface-applied and soil-integrated rice and wheat residues were investigated. Rice and wheat residues bind nitrogen in the soil. The use of the residue increased soil organic carbon by 18% and aggregate stability by 55% compared to the control. This study concludes that instead of simply leaving agricultural wastes on the surface, it is best to work them into the soil, where they will decompose more quickly, the mineral N will be released more quickly, more organic matter will be produced, and the soil structure will be improved. Compost amendment was more effective in decreasing macro-aggregate and silt+clay fraction-specific activities than fertilizer NPK. Tillage and residue levels had a significant impact on soil organic carbon accumulation between 0 and 15 centimeters, but not between 15 and 30 centimeters. The SOC content of plots that used raised beds permanently and retained residue was 19.44 g kg^{-1}, but the SOC content of plots that used zero-tilling was only 18.53 g kg-1. SOC levels in puddled rice grafts and conventionally tilled wheat were both 15.86 g kg-1. When compared to plots where the residue was removed, those where it was left but not tilled sequestered 0.91 g $kg^{-1}yr^{-1}$ SOC. After receiving NT treatments, the concentration of DOC in three different soil depths (bulk, >0.25 mm aggregate, and 0-5 cm soil) increased by 15.5%, 29.5%, and 14.1%, respectively. Increases in MBC ranged from 11.2% to 11.5% to 20%. The 0-50 cm depth SOC stock increased from 49.89 Mg ha-1 to 53.03 Mg ha-1 when the residue was removed. SOC stock was grown by 50 centimeters by rotational farming, but by just 5.35 percent through no-till farming. Bulk soil SOC was 12.9% higher in S treatments compared to NS treatments that removed crop residue, as were >0.25 mm aggregate (11.3%) and 0.25 mm aggregate (14.1%). While NT treatments increased DOC by 15.5%, 29.5%, and 14.1% in bulk soil, >0.25 mm aggregate, and 0.25 mm aggregate in the 0-5 cm soil layer, respectively, CT treatments increased MBC by 11.2%, 11.2%, and 20%. The 0-5 cm soil layer, bulk soil, and >0.25 mm aggregate all saw increases in DOC content of 23.2%, 25.0%, and 37.5% after receiving S treatments compared to NS treatments, while MBC increased by 29.8%, 30.2%, and 24.1%.

Keywords: Carbon fractions; soil aggregation; aggregate-associated C; microbial biomass carbon.

1. INTRODUCTION

Soil organic carbon (SOC) is like the "skin" of the Earth, protecting it from harmful elements [1]. A high level of soil organic carbon (SOC) is an excellent measure of soil quality [2] and is essential for soil fertility and function [3]. Zheng et al. [4] found that soil organic carbon impacted both the total number and distribution of aggregates. Aggregates, or "cells" in the soil, improve carbon sequestration and soil fertility [5]. Stable soil aggregates limit the degradation of SOC by bacteria and enzymes and prevent the loss of SOC due to soil erosion. Since physical fraction evaluates three aggregate sizes at three levels, it is frequently used to investigate SOC storage and turnover. It has been shown that soil texture and particle size influence the quality of SOC pools. Aggregates larger than 1 mm in diameter that are resistant to water have the highest SOC concentrations [6]. The combination of chemical fertiliser and straw results in aggregates of this size, which are water-stable and therefore ideal for the accumulation of SOC [7].

Tillage and residue management enhanced soil structure, SOM protection, and biological activity [8,9]. Increases agricultural productivity, nitrogen retention, and soil organic matter. Traditional tilling harmed soil LMAs [10]. Because long-term no-tillage reduced MA turnover and produced stable MIs, it aided in C stability and sequestration [11]. Aggregates are often physically broken up by this impact [12]. Organic matter (OM) can be oxidised and released thanks to bacteria's ability to deconstruct aggregates. The ratio of organic matter to aggregates that are less water-stable decreases as a result [13]. Compared to MI-rich soils, no-tillage LMAs had greater SOC and macro-pore contents, which meant better water penetration and aeration [14]. Extensive ploughing, which alters soil macro-aggregates, is the primary driver of soil organic carbon loss [15]. Protecting labile soil OC from enzymatic and microbial assault is made possible by LMAs [16]. Increasing soil MAs has been shown to boost soil OC [17]. Slow crop residue decomposition in a no-till system leads to a rise in soil organic carbon (SOC) levels. It has been found that the breakdown of residue helps to stabilize soil aggregates [18]. Several studies have shown that no-till farming practices change the soil's aggregation. After converting from conventional tillage to no-till and straw-returning, we hypothesized that the OC in LMA soil would grow if we were able to preserve the MI fractions in the soil.

“The appropriate management of soil organic carbon is crucial for agricultural production systems due to the alarmingly high quantities of carbon in the soil. Because of its high starting point and inherent soil variability, SOM is unaffected by the short-term changes in soil quality caused by crop or soil management practices” (Haynes, 2005). “Dissolved organic carbon (DOC), microbial biomass carbon (MBC), and particulate organic matter carbon (POC) are examples of labile soil organic carbon pools that are more sensitive to soil management practices and serve as excellent indicators of soil quality that affect soil function (such as immobilization-mineralization). These factors are good early predictors of the effect of land use on SOM quality because of their rapid responsiveness to supply changes” [19]. This study analysed the effects of tillage and straw returning management on organic carbon (OC) sequestration in soil aggregates of varying sizes and soil quality in the intensive agroecosystem of Western Uttar Pradesh. We are interested in the third relationship between SOC inside aggregates and the metabolic diversity of soil microorganisms in the Rice-Wheat Cropping System. Tillage systems (straw systems), SOC, organic C fractions, and microbial metabolic activity were all linked factors. Water-Resistant Aggregate Materials and Soil: The Importance of Organic Carbon.

Soil organic carbon (SOC) in water-stable aggregates (WSA) was discovered to be significantly influenced by soil management practices [20]. Across the size fractions > 5 mm, 5-3 mm, 2-1 mm, 1-0.5 mm, and 0.5-0.25 mm, SOC in WSA ma increased by 1.33, 1.18, 0.97, 1.22, and 0.76 $gkg^{-1}yr^{-1}$under the T treatment (Fig. 1). Wagner et al. [21] observed that MT and NT resulted in much more water-stable macro-aggregates in surface soil than CT. Under NT, significant changes in the soil were only observed between 25 and 40 centimeters below the surface (Fig. 2a). Reduced tillage increased macro-aggregate turnover by increasing micro-aggregate carbon content. Soil carbon content and macro-aggregate production were not affected negatively by CT at 5–25 and 25–40 cm. CT's soil mixing and litter assimilation, which generates binding agents as nucleation sites for macro-aggregates, may help reduce the detrimental physical consequences of tillage. In the top five centimeters of soil, Corg concentrations in macro-aggregates were greatest in the reduced-tillage treatments compared to the CT treatment (Fig. 2b). When the total number of Corg in macro-aggregates decreased, the differences between the CT and MT/NT treatments shrank to the depth range of 5-25 cm. Significant differences were found between CT and NT for Corg content in macro-aggregates at 25-40 cm soil depth, with the highest concentration found in CT. Corg concentration in macro-aggregates shifted under NT only at the 0-5 and 25-40 cm soil depths (Fig. 2b).

Tillage crop residue practices were shown to significantly affect the distribution of soil mass among WSC size classes in two soil depths (0-15 cm and 15-30 cm) [22]. As can be shown in Table 1, topsoil has a WSC that is 5.48 percentage points higher than subsoil. T6 treatments achieved the highest WSC in both study depths. When comparing CR to CT, FIRB, ZT, and 6tha-1, the WSC of the soil at the surface was raised by 35.6%, while the WSC of the soil at the subsurface was raised by 33.1%. When compared to the other treatments, T6 had a 19.73% increase in WSC. Both the topsoil and subsoil WSC increased by 22.56% and 25.61%, respectively, due to residue retention with or without tillage. The F5 treatment, which included 100% RDN as CF+ VC@ 5tha-1, had the highest WSC concentration in the surface soil (0-15 cm), followed by the F4 treatment, which included 75% RDN (29.8 mgkg1), and the F1 treatment, which did not include any fertilizer, which had the lowest WSC level (21.9 mgkg1). Soil depths between 15 and 30 centimeters experienced a similar, but less severe, impact. Treatment with 100% RDN as CF+ VC@ 5tha-1 (F5) resulted in a 37.2% rise in WSC in the top 15 centimeters of the soil, while treatment with 75% RDN (F4) resulted in a 28.4% increase in WSC. The nutrient cycle and crop production are both influenced by WSC, an active pool of organic C because it acts as a source and sink for mineral nutrients and organic substrates in the near term and as an accelerator for plant nutrient conversion from the stable organic form in the long run.

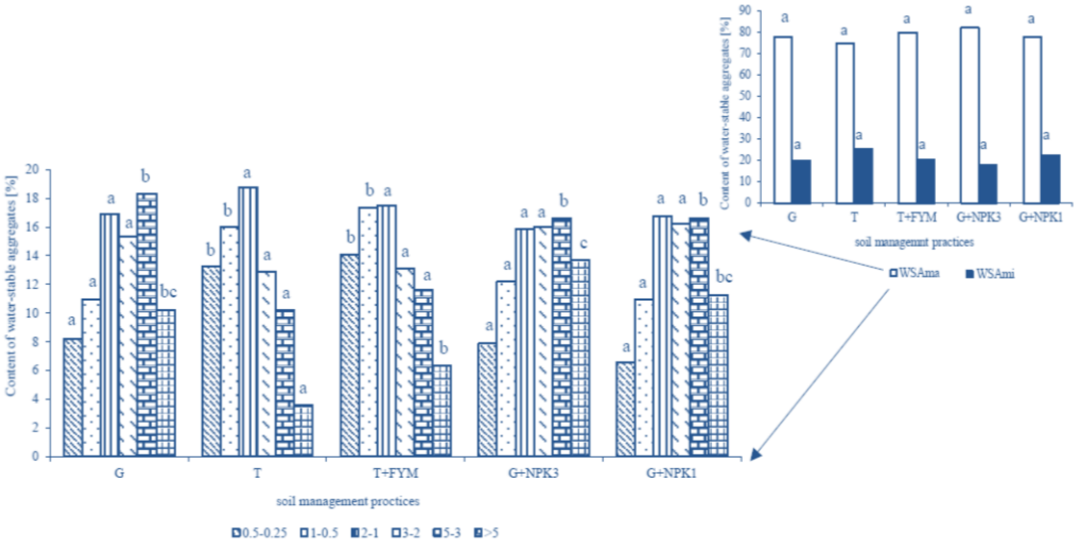

Fig. 1. Water-stable aggregates under diverse soil-management practises: G – control; T – tillage; T+FYM – tillage+ farmyard manure; WSAma and WSAmi are water-stable macro- and micro-aggregates, respectively

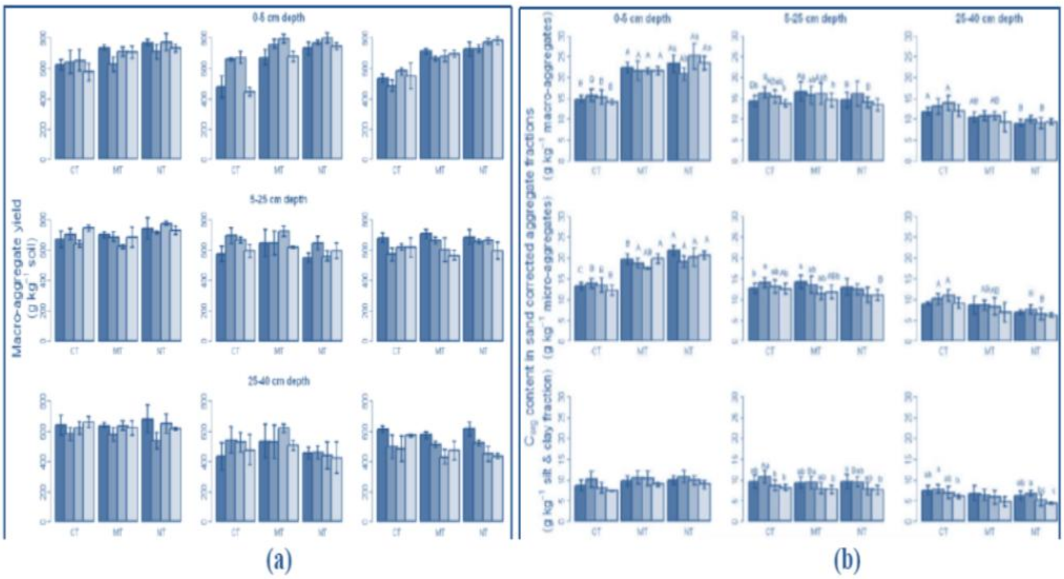

Fig. 2(a). Average dry matter yields of macro-aggregate (>250µm) fractions of different tillage treatments. CT with annual mould-board ploughing to 25-30 cm, MT with cultivator or disc harrow 10-15 cm deep, and NT with direct drilling
Fig. 2(b). Average Corg concentration in sand corrected macro-aggregate (>250µm) and micro-aggregate (250-53 µm) fractions and silt and clay (<53 µm) fractions of different tillage treatments

Changes in MBC could provide insight into how management affects the biophysical characteristics of the soil. The ZT and FIRB residue retention plots under the RWCS had greater MBC than the CT plot, suggesting that the accumulation of organic C compounds at the soil surface after abandonment had aided microbial activity. It's feasible that MBC can be maintained and bacteria fed without any actual plant formation occurring thanks to additional labile C components. Soil that is too wet could also play a role. At wheat maturity, the CT treatment's high biomass output would drastically reduce soil moisture, stressing the in-field microorganisms. In the SOM, MBC controls how nutrients are transformed and stored. Soil MBC is the principal active component of the SOM pool and controls all SOM transformations. Compared to 100% CF (F2) fertilizer and unfertilized control plots, MBC levels in both the surface and sub-surface soil were significantly higher in the 100% RDN as CF+ VC@ 5tha^{-1} (F5) and 75% (F4) plots [Table 1]. The top 15-30 cm of soil included concentrations of MBC ranging from 116.8 mgkg1 in unfertilized control plots to 424.1 mgkg^{-1} in integrated nutrient use with 100% RDN as CF+ VC@ 5tha^{-1} areas, while the deeper soil layer contained concentrations of MBC ranging from 106.6 mgkg1 in the control to 324.9 mgkg1 in the F5 plots. MBC increased by 72.5 and 58.4 percent, respectively, after the CF+ VC@ 5tha^{-1} (F5) and 75% RDN (F4) treatments were sprayed to the top soil. When using CF(F2) fertiliser instead of 100% RDF, MBC increased by 34.4%. An integrated FYM and RDN fertilizer, which increases root biomass turnover, may be necessary to achieve the greatest MBC value. It has been found that using fertilizer made entirely of RDN CF increases crop yields and promotes microbial cellular component synthesis. Therefore, relative to other treatments, 100% RDN as CF+ VC@ 5tha^{-1} fertilizer resulted in the highest root biomass and consequently, MBC. LFC can also be used to characterize SOC from agricultural systems and treatments with organic and inorganic fertilizers. LFC values in surface soil (0-15 cm) were 81.3, 95.7, 107.8, 128.1, 155.2, 1778, and 52.7 mgkg1 for ZT and FIRB without residue retention, 4 & 6 tha-$^{-1}$ residue retention, and C T treatments, respectively (Table 1). Fertilizers and VC both contributed to a higher soil LFC (Table 1). Compared to the control treatment, the organic treatment's surface layer contained significantly higher concentrations of LFC (183.9 mg kg-1), integrated (160.5 mg kg-1), and RDN (123.5 mg kg-1) than the former.

Tillage and fertilizer management alter fPOM and cPOM concentrations at different soil depths in a continuous RW cropping system, as shown in Table 1 [23]. Incubation for 7 and 28 days revealed that macro-aggregates contained more C than undisturbed soil (Fig. 1). (3a). The initial macroaggregates disperse quickly. Soils supplemented with organic C might have been deficient in free organic material because of the high rate of aggregate formation during the first few days of incubation, which increased microbial biomass but reduced substrate availability. As can be seen in (Fig.3b), the microbial biomass used up some of the organic C present in the newly produced macro-aggregates. Insufficient SOC is stabilized in soil because macro-aggregates are oversaturated with SOC after formation. Hui-Ping Ou et al. [24] found that the fraction of >2 mm aggregates in the 0.00-0.05 m layer of NT+S was 7.1% higher than in NTS. Both the 0.05-0.20 m and 0.20-0.30 m layers had the same NT+S and NT-S aggregate fraction levels. For all soil layers, the percentage of >2 mm aggregate in NT+S and NT-S was higher than in MP+S and MP-S (Fig. 4), while the percentage of 0.053 mm aggregate was lower in MP+S by 11.5-20.5%.

In all treatments, the greatest SOC concentration was recorded between 0 and 5 cm deep, and it declined with greater subsurface depth. SOC levels between 0 and 5 centimeters and 5 to 15 centimeters were both increased by the addition of GM/SPM or farmyard manure. The 50% RDN as CF+50% RDN as FYM (F5) and GM/SPM (F6) treatments had the highest SOC in the 0-5 and 5-15 cm soil depths, while the Control (no manure and fertilizer) F1 treatment had the lowest. In the 0-15 cm depth zone, soils treated with 50% RDN as CF+50% RDN as FYM had significantly higher SOC stocks, at 35.17 Mgha-1, than either 100% RDN as CF plots or unfertilized controls (Table 2). 50% RDN as CF+50% RDN as FYM plots had 16% greater 0-15 cm soil organic C content than 75% CF+25% FYM plots. In contrast to CF+50% GM/SPM (21.47 g kg1), 50% RDN as CF+50% FYM (23.65 g kg1) was discovered in the top layer of soil. The RDN in CF (75%) and FYM (25%; 19.64 gkg^{-1}) was higher than the unfertilized control (10.99 gkg^{-1}). Refer to Table 2 to examine the 15-year shift in TOC, TN, and SOC. See [19] for further details.

Table 1. Concentrations of different soil organic matter carbon fractions IPOM and cPOM at different soil depths as affected by tillage and nutrient management to the continuous RW cropping system (Source: Naresh *at al.,* 2018)

Treatments	0-15 cm layer					15-30 cm layer				
	WSC (Ingkg-1)	**MBC (Ingkg-1)**	**LFC (Ingkg-1)**	**rPOIVI (g Ckg-1)**	**ePOM (g Ckg-1)**	**WSC (Ingkg-1)**	**MBC (mgkg-1)**	**LFC (lingkg-1)**	**MOM (g Ckg-1)**	**cPO1VI (g Ckg-1)**
	Tillage Crop Residue Practices									
Ti	16.9d	311.4’	81.3^{0}	0.44^{0}	0.92ed	15.7^{0}	193.9’	65.1”	0.32^{cd}	0.58^{bc}
T2	18.9’	345.2be	107.8k	0.62bal	1.82th’	17.8’d	219.8’	94.1be	0.55$^{0'}$	1.31but
T3	20.8th	481.7’	155.2’	0.88th	2.54’	19.6tc	294.8ab	132.6’	0.83c	1.93’
T4	18.7’’	306.5c	95.7’	0.53$^{''1}$	1.03’’	17.6c^{d}	187.5a	87.6’	0.35^{b}c	0.94th
T5	^{1}1.4^{b,}	398.6^{13}	128.8b	0.86be	2.21a	20.3a	240.9be	102.9b	0.72a	1.64’
T6	23.2’	535.8’	177.8	1.30’	2.38*	21.6’	361.8’	141.2’	1.19e	1.89^{01}
T7	14.2’	266.7’	52.7’	0.38^{0}	0.94^{0}	13.8’	145.9^{0}	49.8’	0.26f	0.61^{0}
	Fertilizer Management Practices									
FT	21.9e	116.8’	89.2’	0.41^{4}	0.64^{0}	15.1’	106.0	47.9f	0.28	0.48d
F2	28.4^{0}	189.2’	123.5$^{b'}$	0.60$^{''0}$	093^{0}	18.8^{0}	166.10	66.7’	0.45	0.59
F3	29.2’	239.9’	146.4’	0.71’	1.52^{0}	20.2’	196.8k	85.9^{0}	0.52	0.74”^{0}
Fs	29.8’	280.7b	160.5b	1.33ab	2.81ab	^{2}1.9^{13}c	219.9bc	103.2bc	0.72	1.64*
Fs	32.5’	2424.1’	183.9’	1.89’	3.78’	26.4’	324.9’	152.9’	0.92	2.34’
F6	28.9	210.3	133.2’	0.66	1.19	19.8	178.2	76.4	0.51	0.63

Table 2. Effect of 15 years of application of treatments on total organic C (TOC), total N (TN), and soil organic carbon (SOC) [19]

Treatments	0-5 cm layer				5-15 cm layer			
	TOC (g kg-1)	**TN (mg kg-1)**	**SOC (g kg-1)**	**SOC Stock (Mg ha-1)**	**TOC (g kg-1)**	**TN (mg kg-1)**	**SOC (g kg-1)**	**SOC Stock (Mg ha-1)**
	Tillage Crop Residue Practices							
T1	19.30c	539c	5.9c	19.79e	14.37d	489c	4.5d	14.91c
T2	23.00b	590b	6.5b	30.05c	17.98c	561bc	5.8bc	27.70b
T3	25.68a	696ab	7.2a	35.40a	21.63a	643ab	6.6a	30.97a
T4	18.50c	516c	4.5d	22.18d	14.32d	483c	4.6d	16.79c
T5	23.01b	584bc	6.1bc	31.63bc	18.89bc	546bc	5.4c	25.99b
T6	23.87ab	845a	6.8ab	33.52ab	19.98ab	765a	6.1ab	29.26ab
T7	9.28d	422c	3.6e	14.91f	7.36e	328d	3.2e	9.46d
	Nutrient Management Practices							
F1	10.99d	406cd	7.9c	29.16c	9.01d	349d	6.8c	23.74c
F2	17.78b	577c	8.4bc	30.70c	15.13c	554bc	7.3bc	26.15c
F3	19.64b	621bc	8.5b	31.97bc	15.64bc	568bc	7.5bc	27.75bc
F4	13.56c	544cd	8.1c	29.67c	13.37c	514c	7.0bc	29.55c
F5	23.65a	896a	9.6a	36.14a	19.08a	783a	8.3a	34.19a
F6	21.47a	737ab	9.0ab	34.59a	18.80a	694ab	8.1a	31.17ab
F7	21.40ab	645bc	8.6b	32.62b	17.30ab	608b	7.6ab	29.86b

Values in a column followed by the same letter are not significantly different (P<0.05)

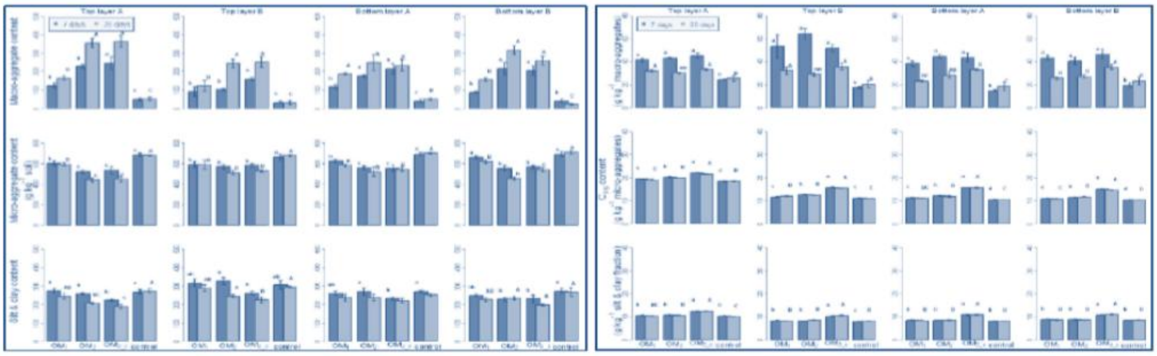

Fig. 3 (a). Mean dry matter yields of macro-aggregate (>250 µm), micro-aggregate (250-53) and silt & clay (<53 µm). components of various soils at 0-5 and 5-25 cm depth and treatments (OM1: 4.1 g C kg-1 soil, OM2: 8.2 g C kg-1 soil, OM2_c: 8.2 g C kg-1 soil, whereat the clay content was increased to 25%, control: no addition) after 7 and 28 days of incubation

Fig. 3 (b). Mean Corg content in macro-aggregate (>250 µm), micro-aggregate (250-53 µm), and silt & clay (<53 µm). components of different soils at 0-5 and 5-25 cm depth and treatments

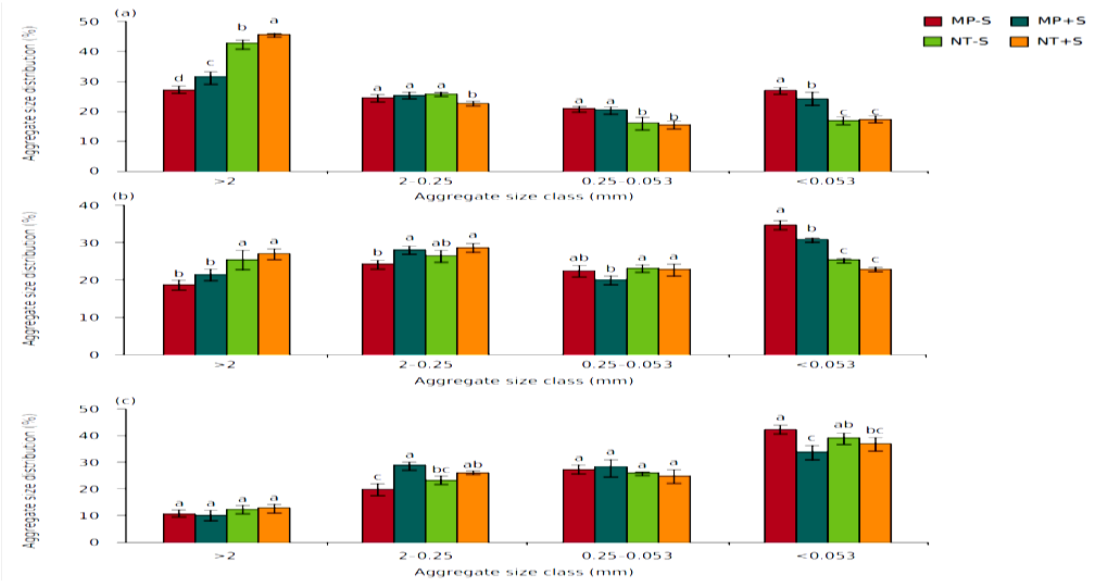

Fig. 4. Tillage treatments affect water-stable aggregate size distribution (%) in soil layers. 0.00-0.05, 0.05-0.20, and 0.20-0.30 m. MP-S: mouldboard plough without straw; MP+S: with straw; NT-S: no-tillage without straw; NT+S: with straw

Carbon from plants and animals is kept in the soil in aggregates that can endure soaking and draining:

Soil organic matter (SOM) is the bedrock of soil quality and function and a key indicator of soil health and fertility. Fertility, crop output, and aggregate stability in the face of water are all greatly influenced by soil organic carbon (SOC) levels. Table 3 shows that the amount of SOC contained in macro-aggregates reduced significantly with increasing soil depth across all treatments, as documented by Zheng et al. [25]. However, the ability to store C in micro-aggregates was not affected by depth. SOC storage shrank from 1-2 to > 2mm as aggregate size increased. Greater SOC storage was observed across all macro-aggregate sizes (0-30cm) in ST, compared to other treatments. Micro-aggregate storage of SOC was enhanced by the CT treatment from the surface to 30cm, but not below. Maximum SOC was found in the

0-10cm depth range for the 0.25-1.00mm aggregate size range in all tillage treatments. There was a reduced effect from MP and CT compared to the much larger effect from ST and NT treatments (34.7–45.7% of the whole). The 0.002mm aggregates increased SOC by 1.5%-13.4%, but the ST and NT treatments contributed very little. According to the SOC contribution rates, macroaggregates NT > ST > CT > MP and micro-aggregates MP > ST > CT > NT.

Soil structure was enhanced by reduced erosion, evaporation, and organic matter loss due to increased straw cover in the NT and ST treatments. Straw mulch slows water loss and helps microbes break down SOC more quickly. Sub-soiling promotes root system growth, and decomposition and humification can convert a lot of root system and stubble into SOC, thus the SOC content and C accumulation of deep soil increase with ST treatment. The soil's composition and the depth of its tilling were essential. Compared to the MP and CT treatments, the NT and ST treatments had higher aggregate-associated C at a depth of 0-10cm due to organic matter and soil structure. While C decreased with soil depth in the NT treatment, it remained elevated in the ST treatment because it was associated with the aggregates. Compared to the MP and CT treatments, the NT and ST treatments had higher aggregate-associated C at a depth of 0-10 cm due to organic matter and soil structure. While C decreased with soil depth in the NT treatment, it remained elevated in the ST treatment because it was associated with the aggregates.

According to Zheng et al. [25] (Fig. 5a), the fractal dimension (D) of aggregates changed with soil depth for different treatments. The ST and NT had significantly lower aggregate D than the MP and CT did between 0 and 10 centimeters. While ST's effect on lowering D persisted at 10-20 and 20-30cm of soil depth, NT's effect waned with deeper soil. Up to about 50–60cm, D was lowest for CT, and then it was roughly the same for ST, NT, and MP. SOC was found to be much higher in the topsoil than in the subsoil (Fig. 5b). Conservation tillage (ST and NT) produced a considerably greater mean SOC between 0 and 10 centimeters compared to conventional tillage (CT). The ST was highest between 10 and 30 centimeters. The average SOC for ST was between 20 and 30 centimeters, followed by MP, CT, and NT in that order. The ability of 0.25-1 and 1-2mm aggregates to store water was increased due to the buildup of SOC. In contrast, the MP and CT treatments saw fewer macro-aggregates than the ST and NT ones. The rate of turnover was directly related to the amount of SOCs they were able to store. Long-term soil fertility relies on the consistency and ratio of macro-aggregates. As soils are dug deeper, they become less able to store carbon in their aggregates and SOC.

According to Six et al. [26], tillage had no effect on free LF C, but they did observe that it was 45% lower in cultivated regions than in NV. Micro-aggregates from NT had three times as much crop-derived C as those from CT. CT also reduces the stability of SOM in mobile micro-aggregates, preventing them from breaking apart and forming new aggregates (Fig. 6a). The SOC content of the 0-20 cm layer was higher for each aggregate class than the 20-40 cm layer, as shown in Fig. (55) by Zhao et al. [31]. It has been established that colloids and mineral matter acquired from crops bind micro-aggregates into macro-aggregates [27]. “The SOC content of MRWR aggregate fractions was the highest, followed by MR and WR. Straw input can alter SOC distribution and boost aggregate SOC content, particularly in macroaggregates [28], and it serves as a substrate for microorganisms” [29].

Mazumdar et al. [30] found that macro-aggregates had more C than micro-aggregates. 1-2 mm macro-aggregates had the most C, followed by 0.5-1mm (Fig. 7a). Organic manures degrade organic waste, where roots hyphae and polysaccharides link mineral particles into micro-aggregates and form C-rich macroaggregates (Fig.7a). Zhao et al. [31] found that straw return treatments, especially MRWR, increased mSOM and fine iPOM in small macro- and micro-aggregates in the 0–20 cm layer (Fig. 7b). 20–40 cm iPOM has less carbon than 0–20 cm (Fig. 7b).

Table 3. Soil organic carbon storage in water-stable aggregates across soil layers and tillage treatments [25]

Depth (cm)	Treatments	Macro-aggregate (t ha^{-1})				Micro-aggregate (t ha^{-1})		
		>2 mm	2-1 mm	1-0.25 mm	Sum	0.25-0.053 mm	0.053-0.002 mm	<0.002 mm
0-10	ST	2.65±0.74a'	5.87±0.34a	7.75±0.23a	16.28±0.85a	1.38±0.11c	0.26±0.02c	0.26±0.08b
	NT	1.40±0.07b	5.82±0.36a	7.78±0.40a	15.00±0.11a	1.26±0.10c	0.23±0.02c	0.25±0.04b
	MP	0.35±0.01b	3.98±0.29b	5.91±0.43b	10.24±0.17b	2.44±0.06b	0.73±0.05b	0.69±0.07a
	CT	0.44±0.04b	4.43±0.22b	6.11±0.54b	10.99±0.37b	2.88±0.08a	1.96±0.23a	0.44±0.14ab
10.-20	ST	2.43±0.03a	6.85±0.19a	9.14±0.16ab	18.42±0.29a	0.61±0.01ab	1.54±0.10c	0.72±0.01ab
	NT	1.62±0.02b	5.04±0.25b	8.49±0.10b	15.15±0.22b	0.49±0.10b	1.40±0.03c	0.67±0.14b
	MP	0.59±0.03d	4.02±0.31c	7.67±0.31c	12.28±0.16c	0.82±0.01a	3.27±0.06b	0.97±0.02ab
	CT	1.35±0.09c	4.69±0.09bc	9.42±0.19a	15.46±0.36b	0.73±0.11ab	3.56±0.08a	1.05±0.17a
20-30	ST	3.06±0.10a	6.77±0.51a	9.92±0.17a	19.75±0.47a	1.70±0.56a	0.96±0.28b	0.21±0.11bc
	NT	1.41±0.03b	6.32±0.47a	8.30±0.10ab	16.02±0.34c	1.99±0.13a	0.98±0.10b	0.54±0.11bc
	MP	2.15±0.26b	6.52±1.23a	9.03±1.10ab	17.71±0.38b	2.03±0.22a	0.59±0.21b	0.59±0.06b
	CT	2.09±0.46b	3.48±0.36b	7.76±0.11b	13.33±0.07d	1.88±0.07a	1.73±0.09a	2.12±0.14a
30-40	ST	1.92±0.03a	5.74±0.61a	7.01±0.57a	14.67±0.09a	1.29±0.26a	0.68±0.24a	0.33±0.04a
	NT	1.06±0.25ab	4.00±0.54a	4.43±0.15b	9.50±10.34b	1.27±0.15a	0.93±0.34a	0.26±0.10a
	MP	1.12±0.45ab	4.71±0.42a	7.72±0.57a	13.56±0.23a	1.20±0.06a	0.56±0.14a	0.31±0.12a
	CT	0.60±0.23ab	2.87±1.53a	5.83±1.19ab	9.30±1.01b	2.00±0.58a	0.95±0.26a	0.10±0.02a
40-50	ST	0.66±0.23ab	3.29±0.90a	4.60±0.55a	8.55±0.39a	0.79±0.35a	0.48±0.18a	0.26±0.06a
	NT	0.23±0.07b	1.66±0.24a	4.02±0.36ab	5.90±0.23c	1.09±0.26a	0.16±0.04a	0.21±0.06a
	MP	0.87±0.24a	2.97±0.60a	3.35±0.26b	7.18±0.27b	0.93±0.16a	0.25±0.19a	0.34±0.07a
	CT	0.55±0.19ab	1.71±0.20a	4.85±0.04a	7.11±0.33b	1.35±0.29a	0.33±0.11a	0.15±0.06a
50-60	ST	0.23±0.15a	1.99±0.21a	3.48±0.31a	5.69±0.05a	0.80±0.04b	0.22±0.04b	0.33±0.06a
	NT	0.34±0.07a	1.06±0.06b	3.50±0.17a	4.90±0.06b	1.33±0.08a	0.19±0.04b	0.17±0.03a
	MP	0.31±0.11a	2.21±0.25a	3.20±0.35ab	5.72±0.14a	1.29±0.03a	0.20±0.06b	0.23±0.07a
	CT	0.15±0.03a	1.83±0.10a	2.38±0.06b	4.36±0.05c	1.21±0.02a	0.96±0.06a	0.26±0.04a

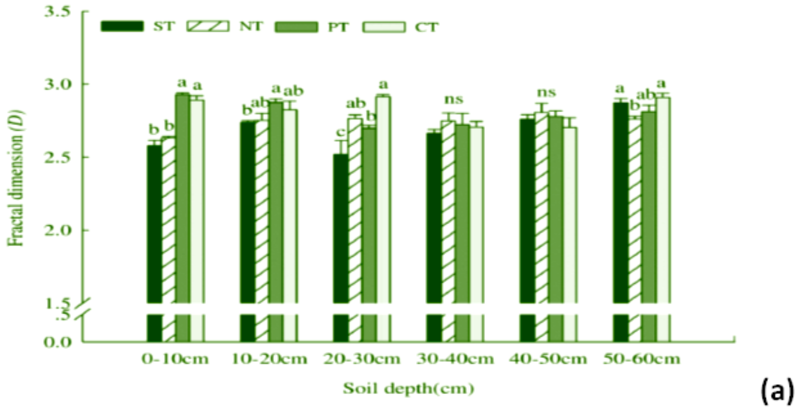

Fig. 5a. Effect of tillage methods on fractal dimension (*D*) of water-stable aggregates

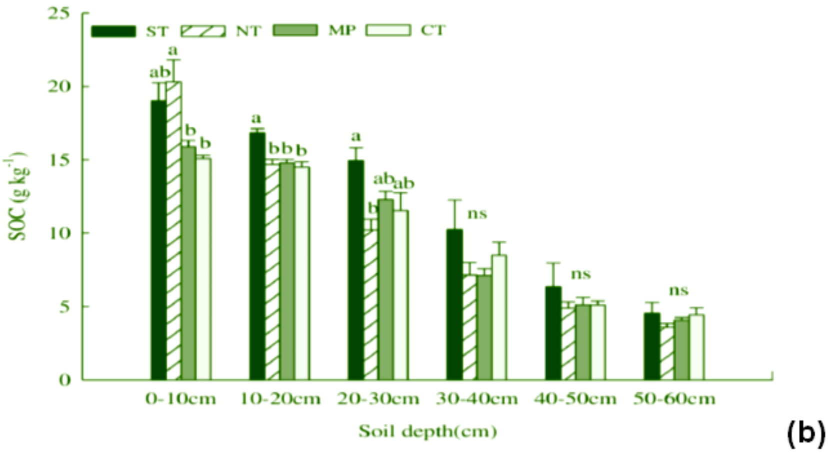

Fig. 5b. Effect of tillage methods on soil organic carbon

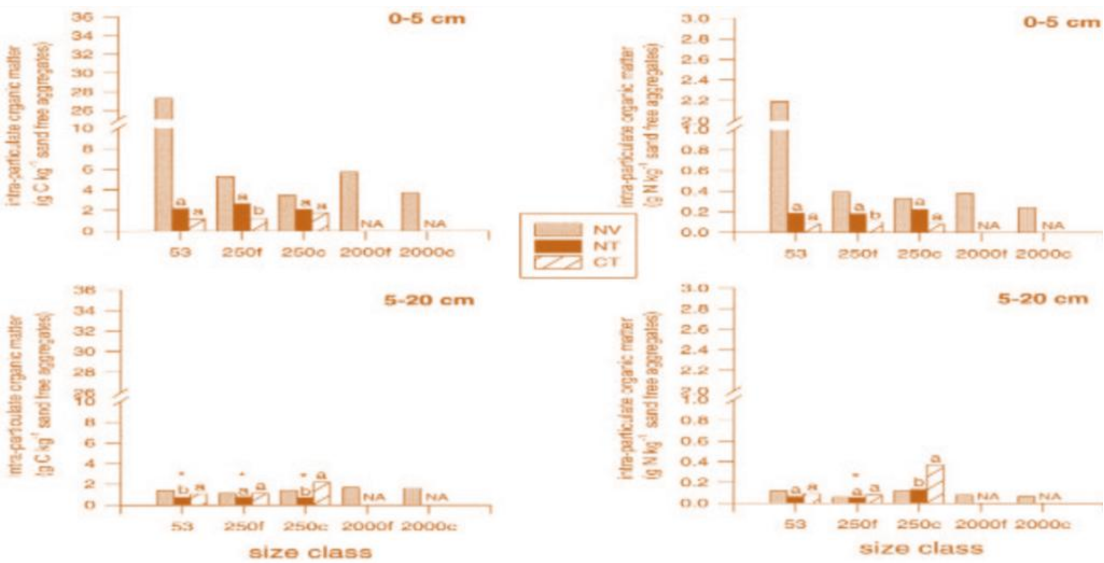

Fig. 6 (a). Aggregate and Soil Organic Matter Dynamics under Conventional and No-Tillage Systems

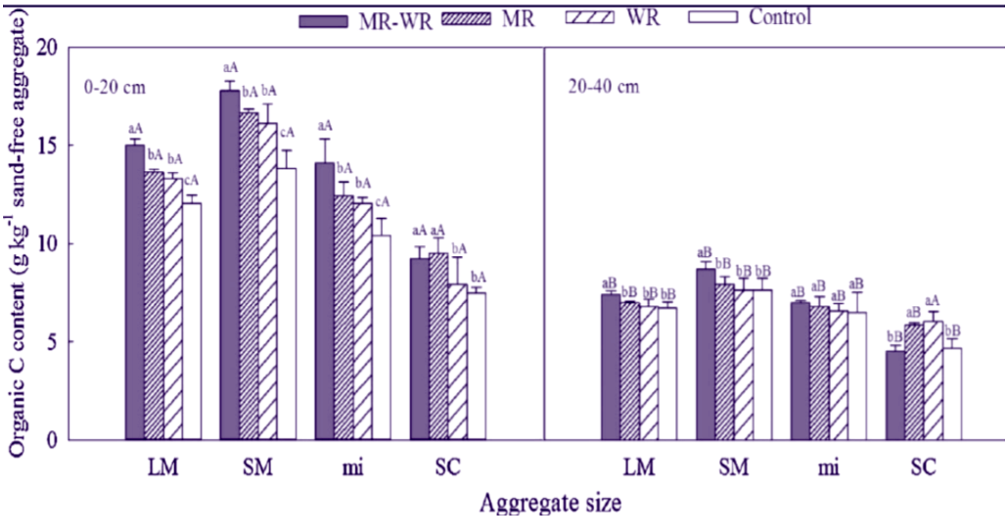

Fig. 6 (b). Organic C content (g kg−1 aggregate) of aggregates: LM, SM, mi, and SC in the 0–20 cm and 20–40 cm soil layers under MR-WR, MR, WR, and Control

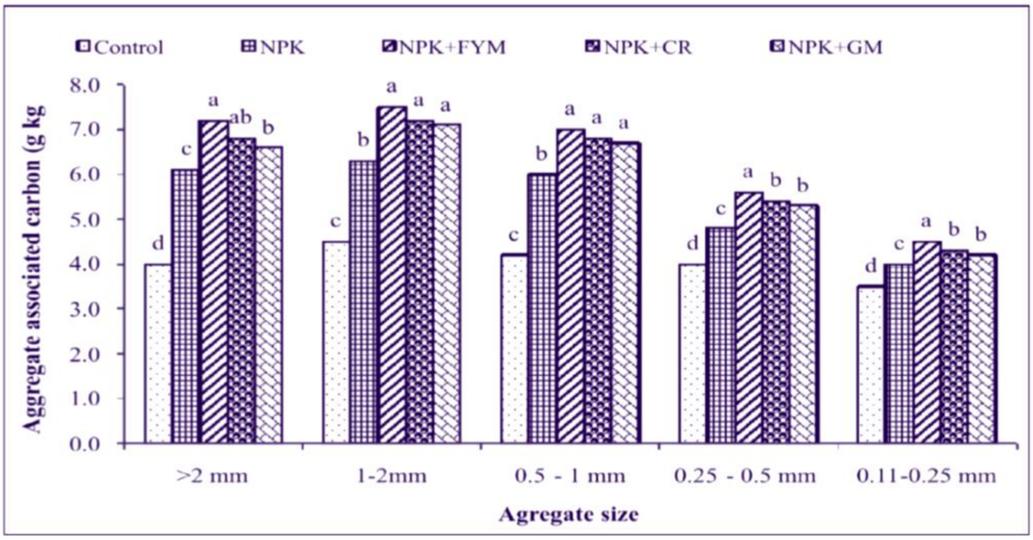

Fig. 7 (a). Effects of long term integrated nutrient management practices on aggregate associated carbon in the soil

Conservation tillage practices have been demonstrated to significantly alter the top 15 cm of soil in terms of total soil carbon (TC), total inorganic carbon (TIC), total soil organic carbon (SOC), and oxidizable organic carbon (OC) [32]. Wheat cultivated with zero till on large raised beds (T9) and rice grown in transplanted beds (T8) had significantly higher total carbon (TC) and soil organic carbon (SOC). Wide-raised beds with zero-till wheat increased TIC, TC, SOC, and OC at the surface by 40.5%, 34.5%, 36.7%, and 34.6%, respectively, compared to CT with transplanted rice growth. These results were true regardless of residue incorporation/retention. The BC, WSOC, SOC, and OC contents of the ZTR (zero till with residue retention) (T1) and RTR (reduced till with residue retention) (T3) treatments were determined to be 24.5%, 21.9%, 19.37 g kg^{-1}, and 18.34 g kg^{-1}, respectively. The surface soil BC, WSOC, SOC, and OC in zero-tilled wheat fields were 22.7 percent, 15.7 percent, 36.7 percent, and 28.8 percent greater than in conventionally tilled wheat fields, respectively. The retention of zero tillage residue led to increases of 22.3% in BC, 14.0% in WSOC, 24.1% in SOC, and 19.4% in OC compared to no residue management. Soil carbon in its various forms below the surface (15-30cm) also increased as a result of conservation efforts, albeit to a lesser extent.

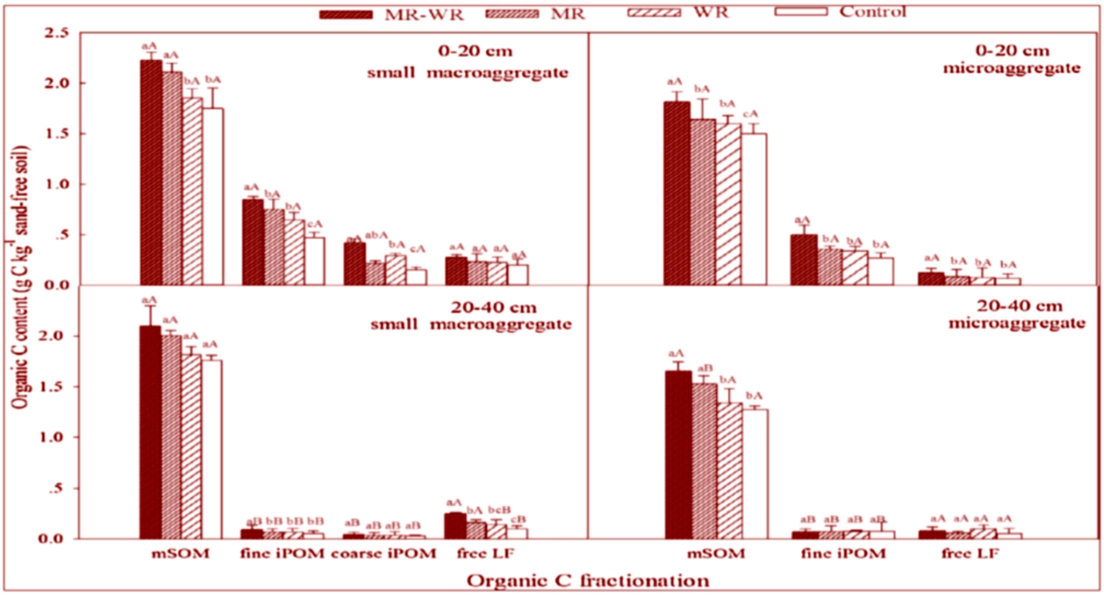

Fig. 7(b). Organic C content (g kg−1 soil) of SOC fractions: coarse iPOM, fine iPOM, mSOM, and free LF of tiny macro- and micro-aggregates in the 0–20 cm and 20–40 cm soil layers under MR-WR, MR, and WR

1.1 Percentages of C-stabilizing Elements

The WSC of topsoil was 3.74 percentage points greater than that of subsoil, as reported by Naresh et al. [19]. T6 treatments achieved the highest WSC in both study depths. PRB and ZT with 6tha^{-1} CR improved surface soil WSC by 39.6 percent compared to conventional tillage, and subsurface soil WSC by 37.5 percent. The highest WSC (20.15%) was seen with T6 compared to the other treatments. ZT plots had 32% more surface soil POC (840 mg kg^{-1}bulk soil) than CT plots (620 mg kg^{-1}bulk soil). POC content in the 0-5 cm soil layer increased from 620 mgkg1 in CT (T7) to 638 and 779 mgkg1 without residue retention and to 898, 1105, 1033, and 1357 mgkg^{-1} in ZT and PRB with residue retention (T2, T3, T5, and T6). Development slowed in the subsoil depths of 5-15 cm. At all depths, POC levels in the soil were greater in F5 plots than in F6 and F1. In the ZT and PRB without residue retention, 4 and 6 tha^{-1} residue retention, and CT treatments, the LFOC of the surface soil was 81.3%, 95.7%, 107.8%, 155.2, 128.1, 178.1, and 52.7%, respectively. Tillage and residue retention raised the LFOC content in the 0-5 cm layer, although not as much as in the 5-15 cm layer. Plots that received 50% RDN as CF+50% as FYM (F5) and integrated use of 50% as CF+50% as GM/SPM (F6) fertilizer maintained a significantly higher LFOC in the top 5 cm of soil compared to unfertilized control plots (F1). Fertiliser, organic sources, and residue retention led to larger increases in WSC, POC, PON, LFOC, and LFON in the 0-5 cm soil layer than in the 5-15 cm soil layer in ZT, PRB, and CT.

Nandan et al. [33] found that tillage-based crop establishment and residue management significantly influenced TOC and soil C-fractions, C-pools, and C-management indicators. There was an increase in Cfrac1, Cfrac2, Cfrac3, Cfrac4, and TOC when residue was not removed. To a larger extent than in the CTTPR-CT, Cfrac1, Cfrac2, Cfrac3, and Cfrac4 as well as TOC were increased in the conservation tillage treatments. ZTDSR-ZT and ZTTPR-ZT both resulted in greater amounts of active C-pool, LI, and CMI compared to CTTPR-CT. The total organic carbon (TOC) in soils treated with either ZTDSR-ZT or ZTTPR-ZT with crop residue retention was 29-30% greater than in soils treated with CTTPR-CT. ZTDSR-ZT performed better than ZTTPR-ZT, NPTPR-ZT, and CTTPR-CT in terms of stabilizing soil carbon.

It was found that compared to Sc1 (16.2 Mg C ha^{-1}), Sc4, Sc3, and Sc2 (all CSA-based scenarios) increased SOC in the top 15 cm of soil by 69.7 percent, 40.7 percent, and 9.0 percent, respectively. Surface soil active and passive pool carbon in Sc4 was substantially greater than in Sc1, at 9.8 and 6.4 Mg C ha^{-1}, respectively. Sc4 had the highest CVL of all of the study areas, at 12.4 Mg C ha1; this is 82% higher than Sc3's CVL of 10.6 Mg C ha^{-1} and 56% higher than Sc1's CVL of 6.8 Mg C ha1. Sc4 was more effective in conserving CNL, CLL, and CL in topsoil than Sc1. Maximum CPP (47%) and CAP (72%) coverage. occurred in both Sc3 and Sc2. Sc3 had a higher concentration of carbon from CVL (45-47%), while Sc3 had a higher concentration of carbon from CL (23-25%). CLL (18%) and CNL (29% of all cancers) are two of the most frequent types of the disease. Sc2 (12.5 Mg C ha^{-1}), which puddled agricultural wastes into the soil, had 8% greater SOC than Sc3 and Sc4 at 15-30 cm depth. Sc2 exhibited the highest CAP, CPP, and CVL between 15 and 30 centimetres down.

Maharjan et al. [34] discovered that in organic farming, total soil organic C (24 mg C g^{-1}soil) is highest in the topsoil (0-10 cm depth). Forested and conventional farming both contributed 9 and 15 milligrams, respectively. Organic farming soil has the highest total C concentration, regardless of depth. (Fig. 8a) Overall, the soil used for organic farming had the highest content of N. C and N microorganisms in organically farmed topsoil were shown to increase by 350 and 46 mg g^{-1}soil, respectively (Fig. 8a). Forest soils have the same levels of microbial biomass as regular farm soils. Organic Farming > Conventional Farming > Forest Soil, disputing H2 > H1. The use of animal manure and vermicomposting in organic farming increases soil carbon and nitrogen (Fig. 8b). Manure's readily available N boosts plant biomass.

Organic carbon and microbial biomass in soil: a study of the impact of different tillage techniques:

Carbon dioxide and plant-available nutrients from plant and animal wastes and soil organic matter are released by microbial biomass, which is measured in terms of "biomass." Soil microbes decompose plant matter, store excess nutrients for the short term, and provide plants with a minuscule nutrient boost. Microorganisms rule the planet. The capacity of the soil to take in and then release nutrients is directly related to its capacity for C immobilization and mineralization. According to the research of Dou et al. [35], the composition of SOC is as follows: 5%-8% SMBC, 2% mineralized C, 14%-31% POM C, 53%-71% hydrolyzable C, and 1-2% DOC. In a no-till crop, the SMBC in the top 5 cm increased from 0 to 30. The SMBC of CW, SWS, and WS was higher under NT from 0 to 5 cm by 25, 33, and 22%, but lower under NT from 5 to 15 cm by 20 and 8%, respectively. Tillage did not change the top 15-30 centimetres of the soil. The greater cropping intensity in NT resulted in 31% and 36% higher SMBC for SWS and WS, respectively, compared to CW at 0-30 cm. Bhattacharya et al. [36] observed that tillage only affected the top five cm of soil in terms of soil organic matter (POM) C changes. Compared to CT plots, where the surface soil POM C was 3.61 g kg^{-1}, the ZT plots had 4.08 g kg^{-1}.

According to Paudel et al. [37], tillage and residue levels from 0 to 20 cm significantly influenced soil organic carbon building, but not from 20 to 40 cm. The SOC content of plots that used raised beds permanently and retained residue was 19.44 g kg-1, but the SOC content of plots that used zero-tilling was only 18.53 g kg^{-1}. SOC levels of 15.86 g kg^{-1} were found in both puddle-transplanted rice and hand-tilled wheat. Moharana et al. [38] found that in FYM + NPK plots, TOC (11.48 g kg^{-1}), WBC (7.86), LBC (1.36), and MBC (273 mg kg^{-1}) were all greatest. The amount of SOC that changed hands in the subsurface soil (15-30cm) was much less than that in the surface soil (0-15cm). Organic manure, such as FYM, increases all pools of soil organic carbon (SOC) and serves to conserve it.

Potentially mineralizable nitrogen (PMN) and microbial biomass nitrogen (MBN) increased from 6.7 and 11.8 $mgkg^{-1}$ in conventional tillage (T6) to 8.5, 14.4, 7.6, 14.1 $mgkg^{-1}$in ZT and RT without residue retention, and from 12.4, 10.6, 9.3 to 20.2, 19.1, 18.2 mg kg^{-1}in ZT with residue retention and CT with residue incorporation (T1, T3, T5). The total SOC is regulated by the microbial communities in the soil, as Zhang et al. (2013) found. These colonies receive C both directly and indirectly through MBC. Xu et al. [39] discovered 129.32 Mg C ha1 of SOC in the 0-80 cm layer under NT, significantly greater than under PT or RT. Soil organic carbon (SOC) stocks were highest in the 0-80 cm soil layer and in SCB in NT, and in the 0-20 cm soil layer and in RT, respectively.

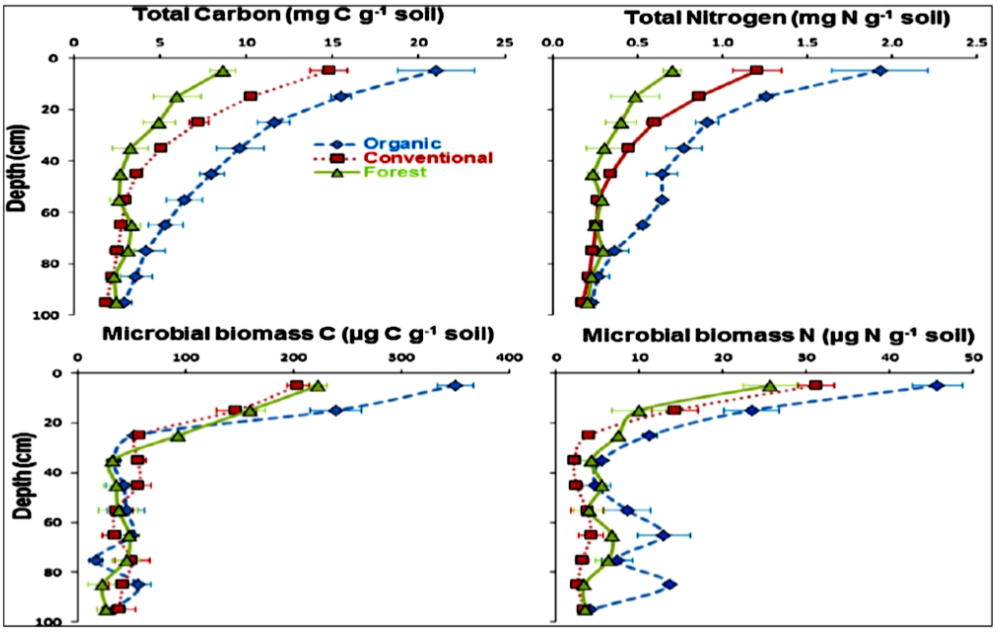

Fig. 8(a). Total C, N, and microbial biomass C and N depending on land use and depth

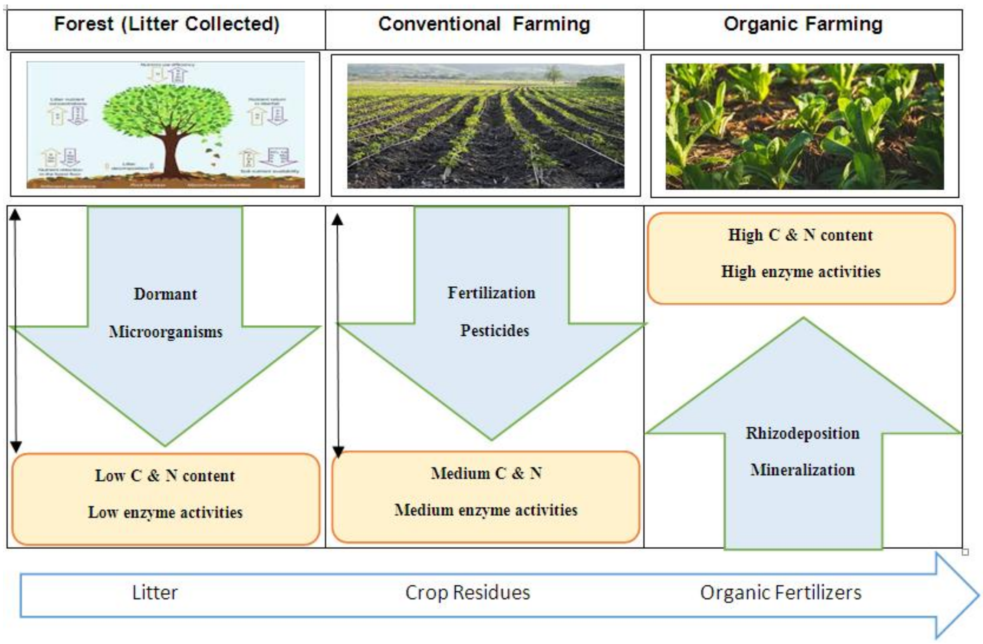

Fig. 8(b). Conceptual diagram representing the effect of land use on carbon and nitrogen content in soil

Wang et al. [40] found that SOC content was higher in NT, ST, and BT than in CT. The standard of living in NT is 12.5% higher than BT and 11.6% higher in ST. Increased SOC stratification occurs in both BT and NT when tillage practices are altered. As a result, the storage and dispersion of SOC in loess soil can be greatly enhanced by adjusting tillage practices. Surface SOC stocks were raised by 50 kg m-2 due to ZT and PRB, but by 50-200 and 200-400 kg m-2 due to residue retention [40]. Surface SOC was consistently reduced by 400 kg m^{-2} after CT was applied. The SOC, microbial biomass, and enzyme activity of macro-aggregates are more strongly influenced by conservation tillage (CT) than those of micro-aggregates. It was shown that as SOC concentrations increased, straw return reactions increased on average. Both the amount of straw-C ingested and the clay content had significant effects on the SOC response. Sirisha et al. [41] reported that NT treatments increased MBC by 11.2%, 11.5%, and 20% and DOC by 15.5%, 29.5%, and 14.1% in the 0-5 cm soil layer. The 0-5 cm soil layer's MBC was increased by 29.8%, 30.2%, and 24.1% under the S treatments, while the DOC concentration increased by 23.2%, 25.0%, and 37.5% over the NS treatments. Conservation tillage (NT and S) improved microbial metabolism in finer and coarser soil aggregates, respectively, between 0 and 5 centimeters deep. After 10 days of incubation, T4 demonstrated the highest and most significant improvement in microbiological parameters compared to T3, with increases of 44.6% in total N, 27.2% in MN, 24.6% in MBN, and 24.6% in MBC in the topsoil, and 10.2%, 21.0%, 24.0%, and 24.2% in the subsoil, respectively [42-49].

2. CONCLUSIONS

Conservation tillage (ST/NT) improved soil structure and aggregate stability in respect to water. When compared to MP and CT, they increased SOC storage capacity and increased SOC content across multiple aggregates. Years of conservation tillage increased water-stable macro-aggregate concentration, SOC ratio, and storage. In addition to increasing the SOC, ST also increased the macro-aggregate C. Tillage has a negative effect on soil aggregation because it disrupts macro-aggregates and, by extension, biological and chemical processes. Crop residues provide a source of organic materials for the soil. Reduced tillage and residue retention increased the microbial biomass of the soil. Early crop microbial immobilization of available-N enhanced synchronization between crop demand and N supply. Due to residue retention and lower soil disturbance, organic carbon levels were found to be greater in no-till and reduced-till systems than in conventional tillage. In no-till systems, soil organic carbon levels rose. Conventional tillage decreased organic C stocks and labile fractions in soil both at the surface (20 cm) and at greater depths (100 cm). The fine POC and DOC levels in the soil surface decreased. Fine POC, LFOC, and microbial biomass can all indicate shifts in the organic C content of topsoil. Western Uttar Pradesh's rice and wheat farming have depleted SOC, putting agriculture in the region at risk. Reduced and no-tillage practices, as well as crop residue, raised SOC and improved agricultural sustainability. No-till farming, on the other hand, enhanced soil structure, aggregation, and SOC build-up. In low-till agriculture, crop residue is a common by-product. This review study also highlighted many obstacles and research opportunities for alternate tillage and crop residue management, all with the goal of increasing SOC concentration and stock and soil carbon pools.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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