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Minimal soil disturbance and increased residue retention on aggregates carbon storage potential and energy relations in Typic Ustochrept soil of Uttar Pradesh: A review

RK Naresh, Vivek, Sunil Kumar, Purushattom, DK Sachan, Lali Jat, NC Mahajan, Richa Tiwari and SS Tomar

Abstract
The conservation treatments were found to significantly improve soil health. The review paper revealed that, all the conservation tillage systems recorded significantly higher soil organic carbon at 0-15 cm depth and 15-30 cm depth higher soil carbon sequestration over conventional systems. However, biological soil quality such as soil microbial biomass carbon and nitrogen were significantly higher in all the tillage systems except conventional tillage without crop residue. Irrespective of the treatments, micro-aggregates were found to be poorer in carbon content, but richer in their capacity to retain it by way of larger activation energies. In surface soil (0–15 cm), the maximum proportion of total aggregated carbon was retained with 0.25–0.106 mm aggregates, and conservation tillage had the greatest ability to hold the organic carbon. However, different forms occurred at higher levels in the 15–30 cm soil layer under the conventional tillage. Compared to conventional tillage, macro-aggregates in conservation tillage was increased by 50.13% and micro-aggregates of the later decreased by 10.1% in surface soil. 50% surface residue retention caused a significant increment of 15.65% in total aggregates in surface soil (0–5cm) and 7.53% in sub-surface soil (5–10 cm). In surface soil, the maximum (19.2%) and minimum (8.9%) proportion of total aggregated carbon was retained with >2mm and 0.1–0.05 mm size fractions, respectively. Conservation agriculture practices secure good soil health by improving soil aggregation (53.8%) and increased energy output with respect to the conventional tillage.

Keywords: Conservation tillage, aggregate-size distribution, straw return mode

Introduction
Tillage is an oldest art associated with the development of agriculture. It includes all operations and practice that are followed for the purpose of modifying the physical characteristics of soil so as to provide favourable conditions. Tillage of soil is the most difficult and time consuming work in production of crops. It has been estimated that on an average about 30 per cent of the total expenditure of crop production is towards tillage operations. There is plenty of scope in reducing this expenditure if the objectives of tillage are understood and if the operations are carried out at the right time with proper implement (Rangaswamy, 2000) [41]. This intensive soil cultivation has worldwide resulted in the degradation of agricultural soils with decrease in soil organic matter, loss of soil structure, thus adversely affected soil health and caused a long term threat to future yields and soil health (Bujarbaruah, 2004) [8].
Carbon is an important part of life on earth. It is found in all living organisms and is the major building block for life on earth and moves through the atmosphere, oceans, plant, soil and earth in short and long term cycles over a time. Carbon pools act as storage houses for large amount of carbon. Any movement of carbon between these carbon pools is called a flux. Soil plays a major role in maintaining balance between global carbon cycle through sequestration of atmospheric carbon as soil organic carbon. Soils store about three times as much carbon as the terrestrial vegetation. Soil C pool comprises soil organic carbon (SOC) and soil inorganic carbon (SIC) pool (Lal, 2004) [23]. Soil organic carbon builds soil fertility, improves soil quality, improves agronomic productivity, protect soil from compaction and nurture soil biodiversity. Increased organic matter in soil, improves soil aggregation, which in turn improves soil aeration, soil water storage, reduces soil erosion, improves infiltration, and generally improves surface and groundwater quality. This enhanced soil health, facilitates use of agricultural inputs in an efficient manner and helps in sustaining agricultural productivity at higher level. It is also helpful in the protection of streams, lakes, and rivers from sediment,

runoff from agricultural fields, and enhanced wildlife habitat. Research reported no-tillage practices improve soil aggregation, C storage (sequestration), and aggregate stability (Zhang *et al*., 2007) [48, 55]. The increase in aggregate stability contributes to increased soil water infiltration and resistance to wind and water erosion (Zhang *et al*., 2007) [48, 55]. Macro-aggregate stability (> 250 µm diameter) is particularly sensitive to changes in management practices (Zibilske and Bradford, 2007) [58]. The loss of macro-aggregate occluded organic matter is a primary source of C lost due to changes in management practices (Mikha and Rice 2004; Jiao *et al*., 2006) [30, 21]. Continuous cropping with reduced fallow frequency and no-tillage has a positive effect on macro-aggregate formation and stabilization, as well as particular organic matter (POM) and SOC (Mikha *et al*., 2010) [31].

Globally, soils contain about 3 times more C than the atmosphere and 4.5 times more C than all living things. Thus, a relatively small increase in agricultural soils can make a significant contribution to reducing atmospheric CO_2 concentrations. It is estimated that increasing SOM contents in soils up to a 2-meter depth by 5-15% could decrease atmospheric CO_2 concentrations by 16-30% (Kell, 2011) [27]. These ideas have led to substantial attention to quantifying stocks of C in soils, mechanisms for stabilizing C in soils, and agricultural management practices including use of recycled organic materials such as compost, biosolids, and biochar to increase SOM stocks (Lal, 2002) [22]. Conservation tillage includes minimum tillage, direct drill, and no-tillage systems. In general, SOC levels are higher in no till systems than conventional till systems. When soil is tilled, soil aggregates are disturbed, which leads to increased decomposition rates of slow turnover SOC pools (Balesdent *et al*., 2000) [5]. However, formation of the slow-turnover SOC pools may be much slower than losses, thus accumulation of SOC may not be as rapid as losses of SOC (Balesdent *et al*., 2000) [5].

Addition of crop residue plays an important role in SOC sequestration in improving soil structure, soil water-holding capability, and soil erosion prevention (Lal, 2009) [24]. Crop residue is important to soil nutrient cycling and soil fertility. Crop residue removal will cause the depletion of soil nutrition (such as N, P, and K) which could decrease agronomic productivity and increase soil degradation (Blanco-Canqui *et al*., 2008). Lal (2009) [24] estimated that residue contained 18 to 62 kg Mg^{-1} of agronomically important nutrients, depending on the type of residue produced and its nutrient content, which would be equivalent to 83% global fertilizer consumption in 2001. However, the effect of surface residue on SOC sequestration was limited in no-tillage. Gale and Combadellar (2000) distinguished the beneficial effects of no-tillage on SOC sequestration from residue- and root-derived C by a stimulated experiment. They found only 16% ^{14}C in the surface residue was in the soil after 360 d; in contrast, 42% of root-derived ^{14}C was still in the soil. Kochsiek *et al*. (2009) [28] found that irrigation could increase the rate of litter-C decomposition which indicated that residue-derived C would be encouraging in respiring as CO_2 in irrigation no-tillage field.

West and Post, (2002) [52] indicate, on average, that a change from conventional tillage (CT) to no-till (NT) can sequester 57 ± 14 g C m^{-2} yr^{-1}. Enhancing rotation complexity can sequester an average 20± 12 g C m^{-2}2 yr^{-1} [Fig. 1a & 1b]. Carbon sequestration rates, with a change from CT to NT, can be expected to peak in 5 to 10 yr with SOC reaching a new equilibrium in 15 to 20 yr (Fig. 2a & 2b]. Following initiation of an enhancement in rotation complexity, SOC may reach a new equilibrium in approximately 40 to 60 yr. Soil C sequestration rates, with a change to NT practices, can be expected to have a delayed response, reach peak sequestration rates in 5 to 10 yr, and decline to near zero in 15 to 20 yr, based on regression analyses [Fig. 2c].

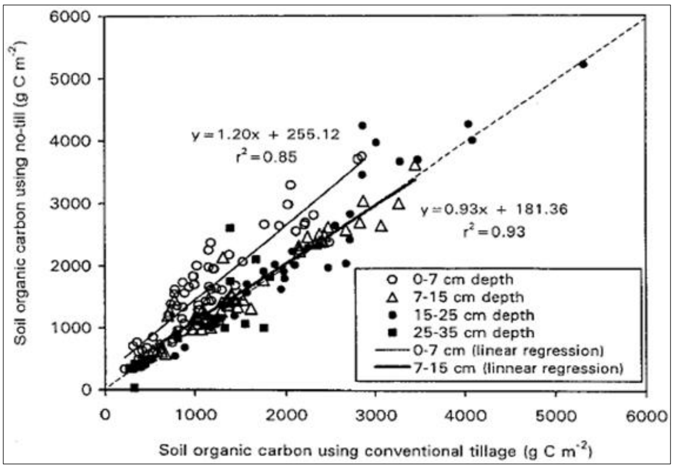


Fig 1(a): Soil organic C (SOC) at different soil depths as a result of changing from conventional tillage to no-till

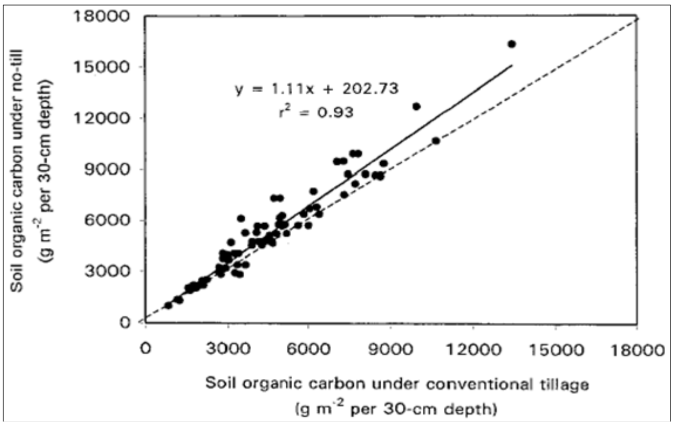


Fig 1(b): Comparison of soil organic C (SOC) between conventional tillage and no-till

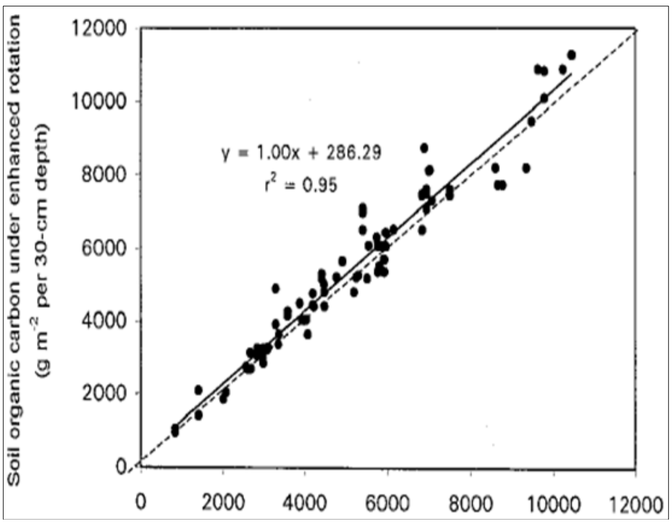


Fig 2(a): Comparison of soil organic C (SOC) between initial and enhanced rotation cropping systems

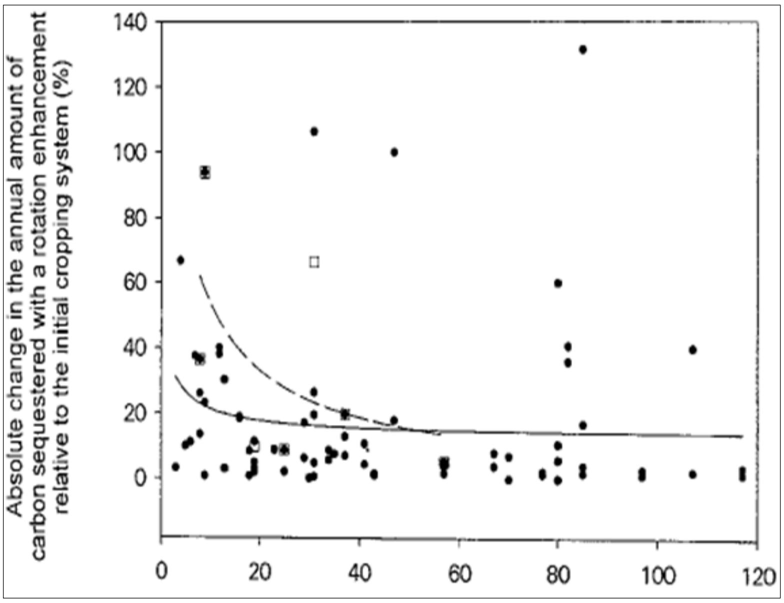


Fig 2(b): The percentage change in annual soil organic C (SOC) sequestration rates under enhanced rotation

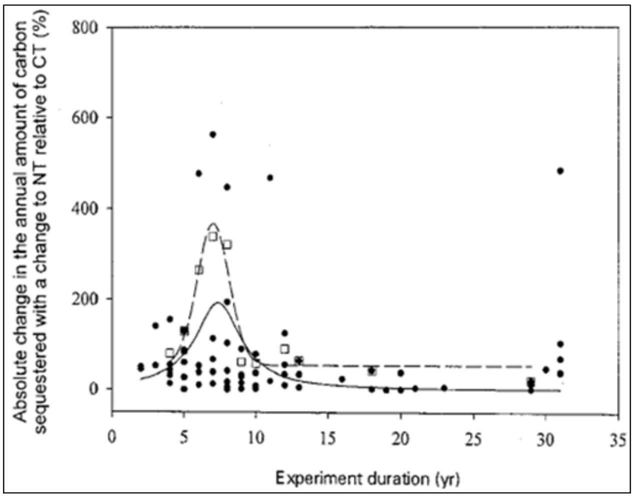


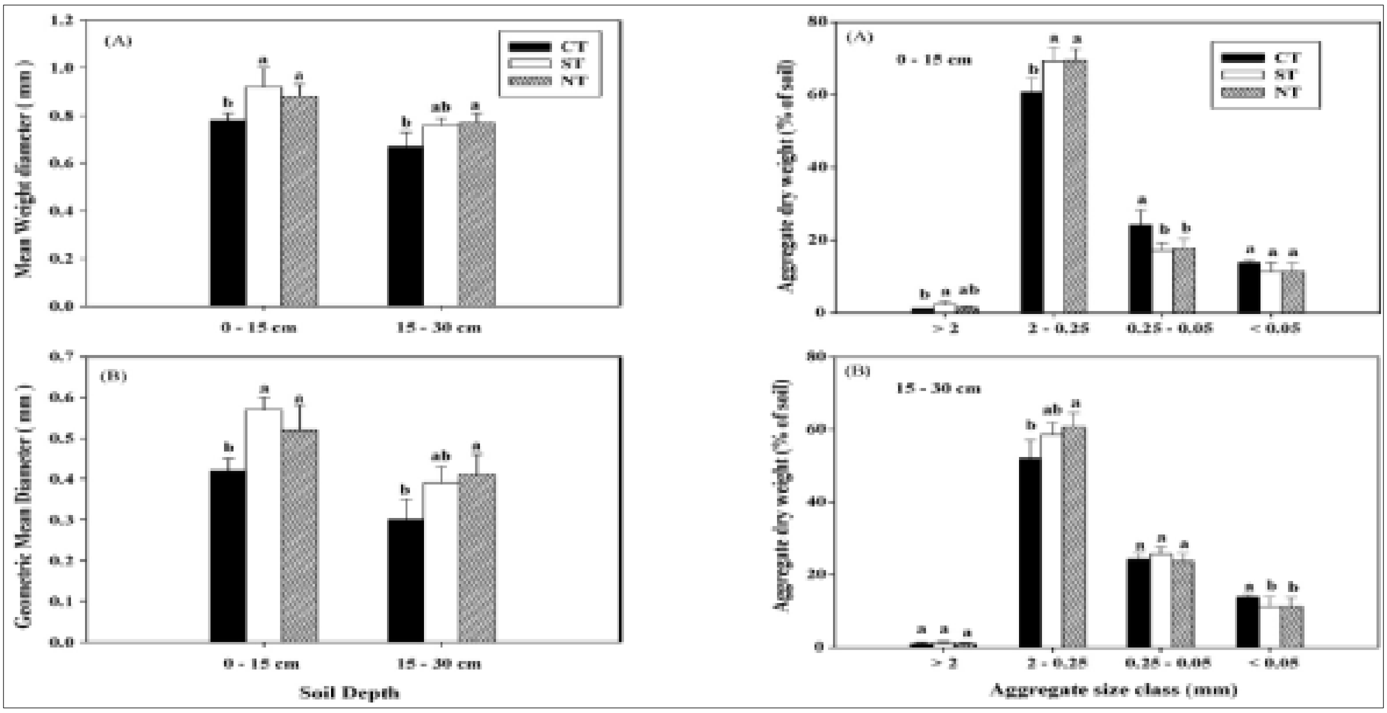
Fig 2(c): The percentage change in annual soil organic C (SOC) sequestration rates under NT, relative to CT

Adoption of no-tillage following conventional tillage generally results in SOC increases, but in some instances little or no increases are observed. Gollany *et al*. (2006) [17] found that increased SOC storage in the fine organic matter fraction with reduced tillage ranged from 0.16 to 0.18 Mg C ha^{-1} at N fertilizer rates of 15 and 180 kg N ha^{-1} under long-term wheat-fallow system, compared to mouldboard ploughed soils. However, a few studies reported that no-tillage and reduced tillage has more SOC compared to the conventional tillage counterpart (Rasmussen and Rhode, 1988). In a global analysis of long term experiments, West and Post (2002) [52] found the average relative increased SOC stock was 0.57 ± 0.14 Mg C $ha^{-1}yr^{-1}$, with 75% of the studies showing increased SOC stocks. Similarly, Baker *et al*. (2007) [4] found that 37 of 51 studies reported positive results in no-tillage with sampling depth < 30 cm, while 35 studies with depths > 30 cm reported losses.

The majority of SOC increase under no-tillage was observed to be in the top of 10-15 cm, with insignificant changes or even decreases relative to conventional tillage at deeper depths (Angers and Eriksen-Hamel, 2008; Naresh *et al*., 2012) [2]. Angers and Eriksen-Hamel (2008) [2] found there was a small, but significant increase in total SOC stocks under no-tillage, but all of this increase was observed in the upper 10 cm. This can be explained by residue burial to a greater depth due to tillage and shows that limited depth of soil sampling could result in over- or under-estimation of SOC stocks.

Gollany *et al*. (2012) [18] reported that no significant changes in SOC in the top 30 cm of the sweep-tillage winter wheat (*Triticum aestivum* L.)-tillage fallow rotation and no till spring wheat-chemical fallow rotation, whereas SOC increased in the no-till spring barley (*Hordeum vulgare* L.) spring wheat rotation. The apparent increase in measured SOC with continuous no-till spring cropping was the result of accumulated un-decomposed crop residue that contributed to the labile C pool.

Chen *et al*. (2009) reported that the portion of 0.25–2 mm aggregates, mean weight diameter (MWD) and geometric mean diameter (GMD) of aggregates from ST and NT treatments were larger than from CT at both 0–15- and 15–30-cm soil depths. At both depths, the content of large macro-aggregates (>2 mm) was very low (around 1% of the soil weight) [Fig. 3a &3b]. Small macro-aggregates (2–0.25 mm) represented the greatest portions (52–70% of whole soil) in all treatments at both 0–15 and 15– 30 cm. At 0–15 cm, CT contained significantly less small macro-aggregates (2–0.25 mm) than ST or NT, which were not different from each other [Fig. 3 a &3b]. The reduction in macro-aggregates and MWD and GMD with CT could be mainly due to mechanical disruption of macro-aggregates from frequent tillage operations and reduced aggregate stability. Tillage increases the effect of drying–rewetting and freezing–thawing, which increase macro-aggregate susceptibility to disruption (Mikha and Rice, 2004) [30]. The ST and NT treatments had 14.2 and 13.7% higher SOC stocks than CT in the upper 15 cm, respectively [Fig.4a & 4b]. Chen *et al*. (2009) reported that reduced tillage (RT) contained 7.3% more SOC than plough tillage (PT) in the 0–20-cm depth, respectively, and estimated that RT accumulate an average 0.32 Mg C ha^{-1} yr^{-1} more than PT over an average period of 11 years, respectively. The results clearly showed that adoption of conservation tillage with residue cover increased SOC and soil aggregation which in turn could improve soil infiltration, promote water retention, increase biological activity and nutrient storage, subsequently increase soil quality and productivity, and eventually reduce soil erosion.



(a) **(b)**

Fig 3 (a): Mean weight diameters (A) and geometric mean diameters (B) of soil from two depths among aggregate-size fractions under conventional tillage with residue removal (CT), shallow tillage with residue cover (ST), and no-tillage with residue cover (NT)
Fig 3(b): Aggregate-size distribution as determined by wet sieving for (a) the 0–15-cm and (b) the 15–30-cm layers under conventional tillage with residue removal (CT), shallow tillage with residue cover (ST), and no-tillage with residue cover (NT)

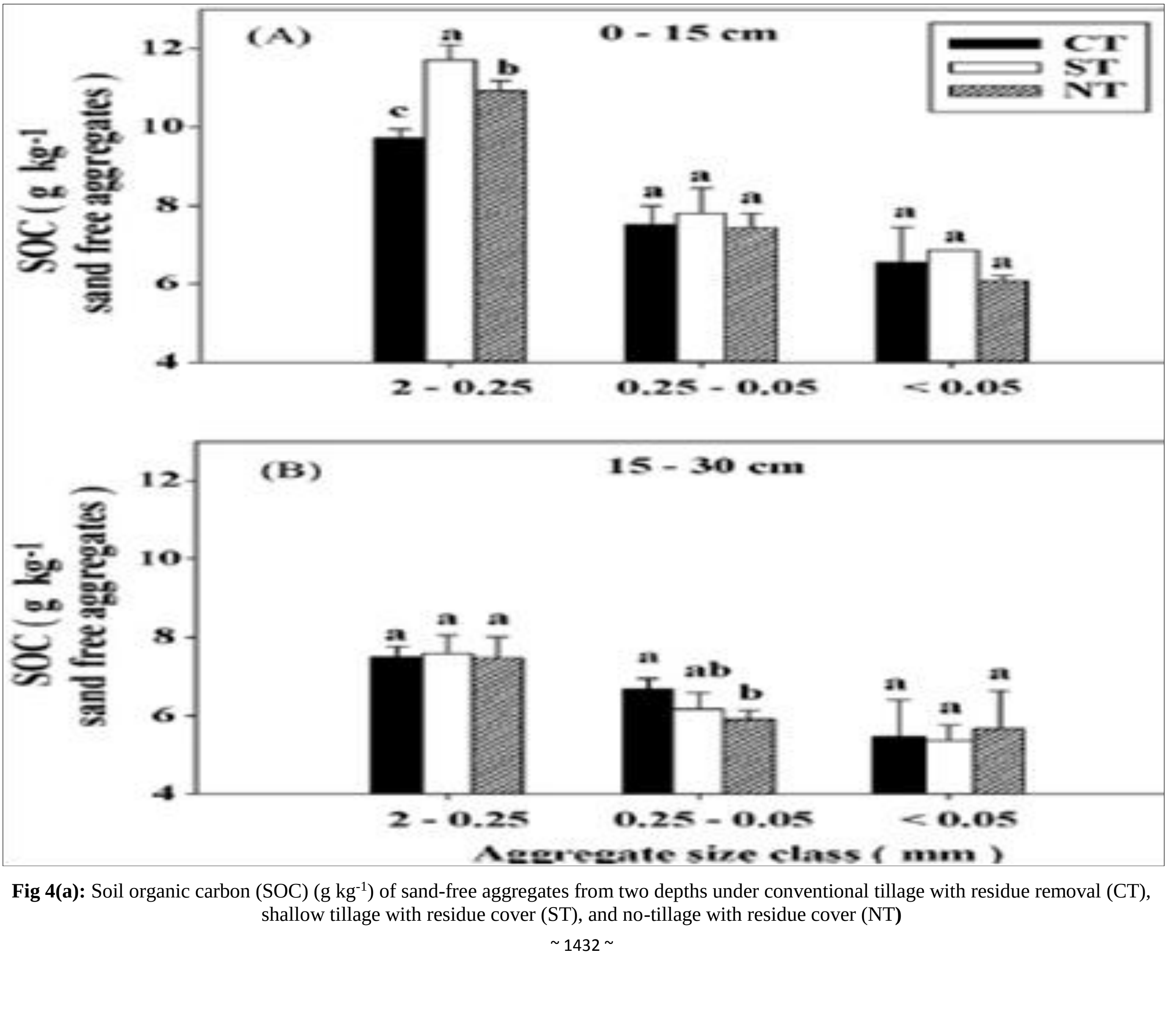


Fig 4(a): Soil organic carbon (SOC) (g kg^{-1}) of sand-free aggregates from two depths under conventional tillage with residue removal (CT), shallow tillage with residue cover (ST), and no-tillage with residue cover (NT)

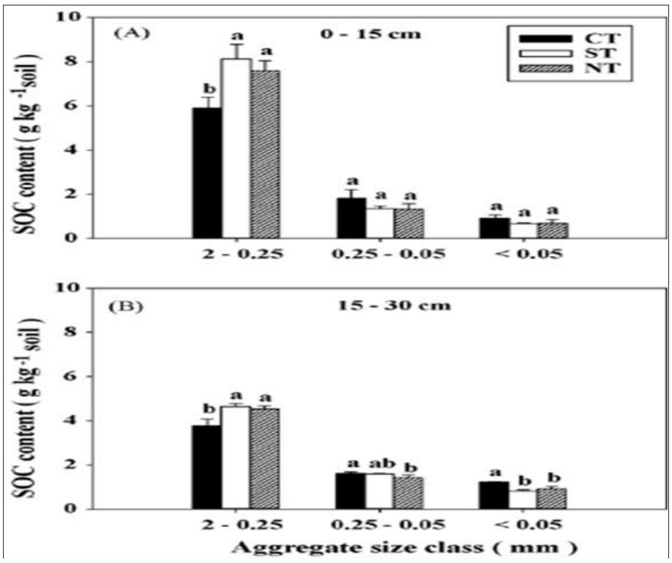


Fig 4(b): Soil organic carbon (SOC) of aggregates in g kg^{-1} soil from two depths under conventional tillage with residue removal (CT), shallow tillage with residue cover (ST), and no-tillage with residue cover (NT)

Naresh *et al*. (2017) [33] revealed that in the turning jointing stage, compared with CT, the ZT and FIRB treatments significantly increased nitrifying bacteria [Gn] by 77% and 229%, respectively. At the booting stage, the Gn rates in ZT and FIRB soils were 2.16 and 3.37 times greater than that in CT soil, respectively. At the milking stage, the Gn rates in ZT and FIRB soils were 1.96 and 3.08 times greater than that in CT soil, respectively. Significantly highest phosphatase activity of 33.90, 46.08, 24.65µg of PNP g^{-1} soil h^{-1} was found at jointing, booting and milking stage of wheat in treatment F_5 (100%RDF +VC @ 5 t ha^{-1}). However, the values were on par with F_3 (50%RDF +VC @ 5 t ha^{-1}) and F_4 (75%RDF +VC @ 5 t ha^{-1}) and significantly different from all other treatments [Table 1]. Singh and Ghosal (2013) concluded that application of FYM and wheat straw along with inorganic fertilizer significantly increased the activity of alkaline phosphatase in 0-10 cm soil layer as compared with the application of inorganic fertilizer alone in a double no-till rice-wheat system. Mathew *et al*. (2012) [29] reported that acid and alkaline phosphatase activity was higher under NT than CT soil at 0-5 cm soil depth in a long term tillage experiment in continuous corn system in a silt loam soil.

Table 1: Change in nitrifying and denitrifying bacteria and phosphatase enzyme activity in soil profile as affected by tillage crop residue practices and nutrient management practices [Naresh *et al*., 2017].

Treatments	Nitrifying bacteria ($\times 10^3$/g)			Denitrifying bacteria ($\times 10^4$/g)			Phosphatase(µg PNP g^{-1} h^{-1})		
	Jointing stage	Booting stage	Milky stage	Jointing stage	Booting stage	Milky stage	Jointing stage	Booting Stage	Milky stage
Tillage crop residue practices									
T_1	2.0 ± 0.4^{c}	4.2 ± 6.5^{a}	35.4 ± 4.1^{c}	35.6 ± 10.3^{cd}	42.0 ± 8.5^{c}	59.7 ± 5.3^{bc}	20.5 ± 4.1^{c}	34.8 ± 4.3^{cd}	16.1 ± 4.1^{c}
T_2	5.9 ± 1.0^{b}	7.2 ± 0.6^{c}	48.6 ± 9.2^{bc}	41.2 ± 8.8^{bc}	63.8 ± 10.7^{bc}	95.1 ± 20.6^{b}	24.9 ± 5.7^{cd}	46.3 ± 9.3^{a}	17.3 ± 8.5^{c}
T_3	6.5 ± 0.7^{b}	13.9 ± 1.3^{b}	64.3 ± 6.2^{b}	69.3 ± 6.6^{a}	110.8 ± 10.7^{b}	137.1 ± 9.9^{a}	25.8 ± 6.6^{a}	49.1 ± 10.7^{b}	17.9 ± 8.8^{bc}
T_4	3.9 ± 1.4^{bc}	11.6 ± 0.8^{bc}	48.2 ± 8.2^{bc}	23.8 ± 0.9^{d}	32.8 ± 2.4^{d}	57.3 ± 20.1^{a}	24.5 ± 5.7^{cd}	38.3 ± 8.4^{a}	21.3 ± 7.1^{a}
T_5	9.9 ± 0.7^{a}	19.6 ± 1.0^{b}	107.8 ± 4.1^{a}	34.5 ± 5.7^{cd}	54.3 ± 4.3^{cd}	82.2 ± 11.6^{a}	29.8 ± 8.8^{bc}	50.8 ± 9.9^{a}	27.1 ± 6.6^{a}
T_6	10.1 ± 1.7^{a}	19.9 ± 0.8^{b}	119.3 ± 8.4^{a}	60.9 ± 3.9^{ab}	82.5 ± 11.8^{b}	114.5 ± 9.3^{a}	31.2 ± 9.2^{bc}	52.3 ± 11.8^{b}	29.1 ± 10.3^{cd}
T_7	1.80 ± 0.6^{c}	3.9 ± 0.7^{c}	29.8 ± 3.4^{c}	17.6 ± 2.4^{c}	23.8 ± 3.9^{c}	28.7 ± 4.1^{c}	17.9 ± 3.9^{ab}	26.2 ± 3.4^{c}	15.7 ± 2.4^{c}
Fertilizer Management Practices									
F_1	3.06 ± 0.21	12.05 ± 1.78	17.74 ± 3.24	19.6 ± 2.6^{c}	21.8 ± 3.3^{c}	26.7 ± 4.1^{c}	20.65 ± 2.7^{a}	35.66 ± 3.24^{c}	16.53 ± 2.90^{b}
F_2	5.91 ± 0.13	14.08 ± 1.84	22.02 ± 2.70	44.2 ± 5.3	53.8 ± 7.7^{bc}	65.1 ± 9.6^{b}	24.30 ± 4.0^{b}	39.87 ± 6.2^{b}	19.85 ± 5.1^{a}
F_3	7.36 ± 0.22	15.36 ± 1.29	24.48 ± 3.84	56.3 ± 6.6^{a}	78.8 ± 8.7^{b}	97.1 ± 9.9^{a}	32.75 ± 5.4^{bc}	44.97 ± 7.8^{bc}	22.54 ± 6.3^{bc}
F_4	4.55 ± 0.14	18.57 ± 1.79	20.10 ± 1.17	53.8 ± 5.9^{d}	62.8 ± 7.4^{d}	87.3 ± 8.1^{a}	27.92 ± 4.7^{a}	41.95 ± 6.6^{a}	21.48 ± 5.9^{a}
F_5	6.77 ± 0.15	16.54 ± 2.18	23.39 ± 1.01	74.5 ± 7.7^{cd}	84.3 ± 8.3^{cd}	92.2 ± 11.6^{a}	33.90 ± 5.6^{c}	46.08 ± 9.9^{a}	24.65 ± 7.6^{a}
F_6	8.92 ± 0.38	20.13 ± 1.80	26.23 ± 4.59	80.9 ± 8.9^{ab}	92.5 ± 9.8^{b}	98.5 ± 10.3^{a}	34.60 ± 6.29^{a}	47.26 ± 10.7^{b}	26.16 ± 8.3^{a}

Shahbaz, (2016) [44] reported that the residue addition caused a significant increase in total soil CO_2 efflux compared to the control without additions. At low additions, the amount of total CO_2 efflux was higher in leaves and stems (for both, up to 1.9 g C kg^{-1}) than in roots (1.5 g C kg^{-1}) [Fig. 5a]. At the high residue addition level, absolute CO_2 efflux also increased. The total amount of SOM-mineralized C in the control was 0.65 g C kg^{-1} soil over 120 days of incubation. Mineralization of SOM significantly increased with residue addition depending on the type and amount of residue. At the doubled amount of residue addition, the cumulative SOM mineralization remained similar between low and high addition levels of leaves (up to 0.9 g C kg^{-1}) and stems (1.1 g C kg^{-1}). The decrease of PE at high C additions highlights the relation of PE with residue decomposition (Wang *et al*., 2015) [51]. The PE was lowest during the intensive phase of residue mineralization and thereafter increased strongly. This residue decomposition and PE phenomena indicated a changing microbial substrate utilization pattern (Nguyen and Marschner 2016) [34], which may result is a variable amount of apparent and real PE.

Shahbaz, (2016) [44] also found that the consistent with the CO_2 efflux, adding residues significantly (28-85%) increased MB-C compared with control. This highlights the microbial demands for C and nutrients. The MB-C significantly increased (compared to the control) during the intensive decomposition phase of the residues (during the first two weeks), with an average of 42-85, 42-53 and 28-54% due to leaf, stem and root addition, respectively [Fig. 5b]. Remarkably, the increase of MB-C was solely (intensive phase) or mainly (slow phase) due to residue-feeding microorganisms, because the differences in SOM-decomposed biomass were insignificant (except at day 120). The amount of residue-derived C present as MB (Res_C_{MB}) was the highest under leaves (0.07 to 0.37 g C kg^{-1} soil) and the lowest under root additions (0.02-0.17 g C kg^{-1} soil) across all sampling periods [Fig. 5b]. Xiao *et al*. (2015) also found that high rates of residue mineralization reflect great substrate C availability, which did not cause an increase in SOM decomposition. Microorganisms preferably utilize substrates if their availability is high and therefore SOM decomposition is not necessarily to be increased.

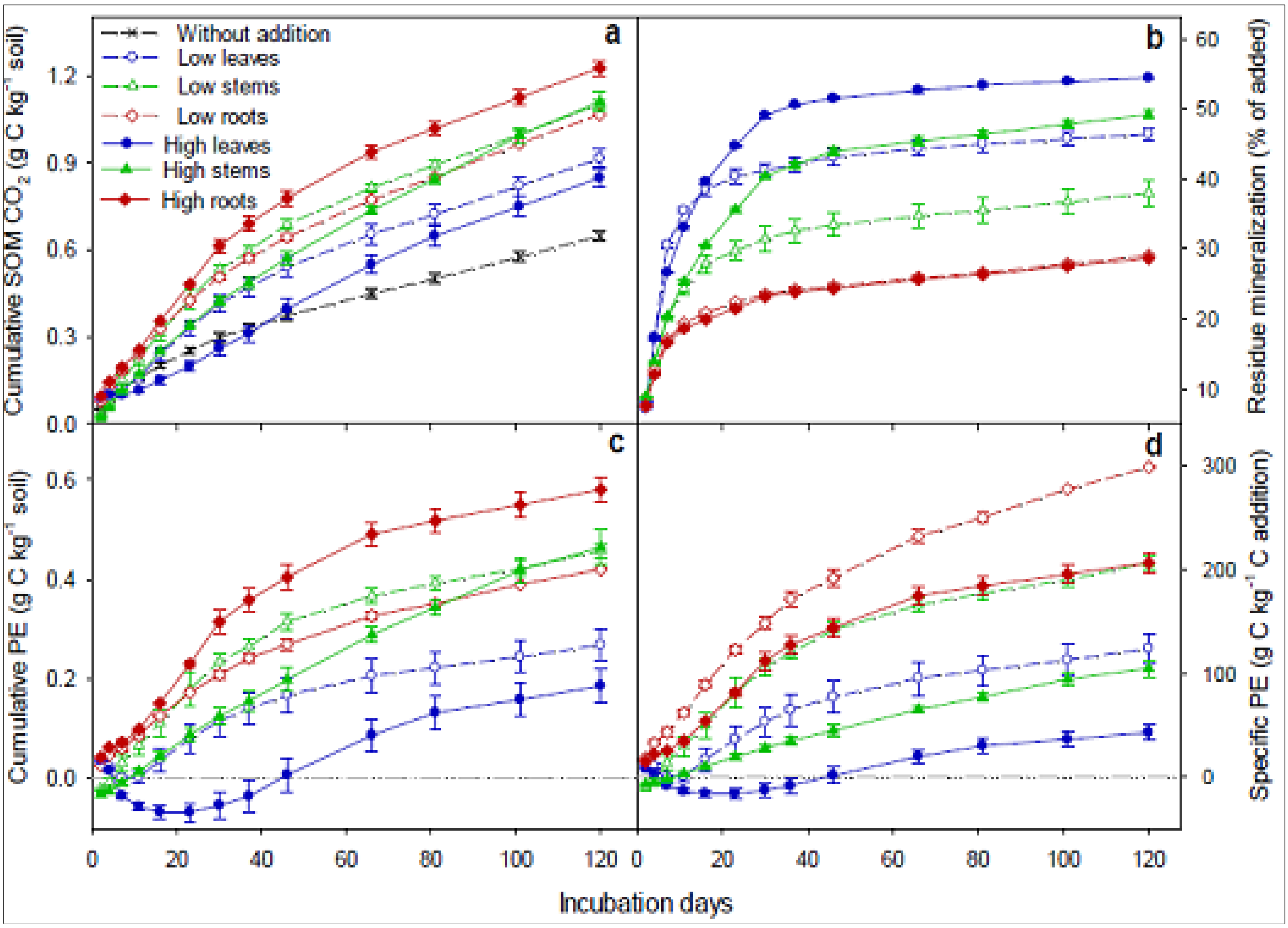


Fig 5 (a): Cumulative CO_2 release originated from soil organic matter (SOM, a), crop residue decomposition (% of initial addition, b), total priming effect (PE, c), and specific PE (d) over 120 days of incubation, depending on the residue type and addition level.

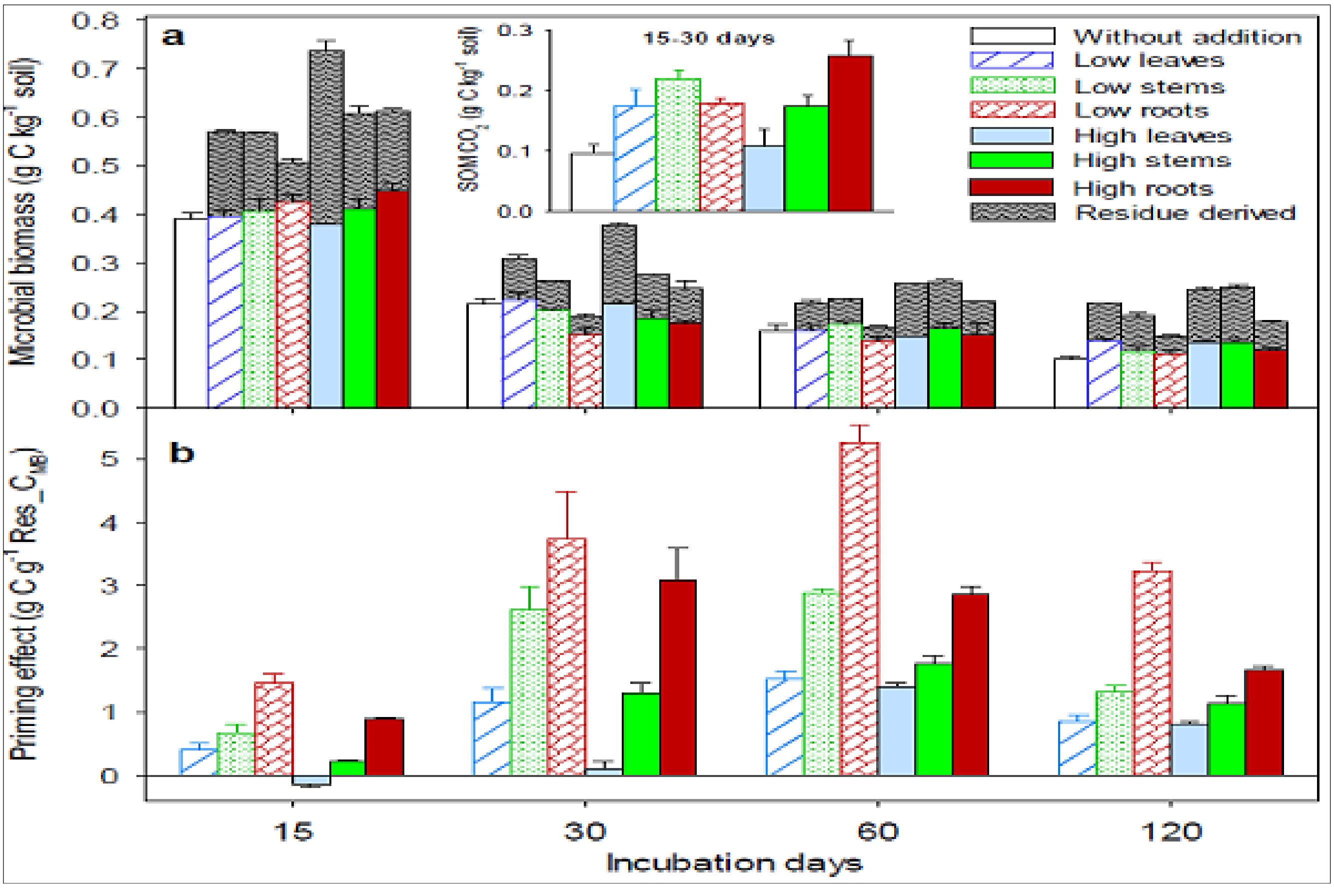


Fig 5 (b): The contribution of soil organic matter (SOM) and crop residues originated C (Res_C_{MB}) to total microbial biomass (a); and the amount of priming effect per unit of Res_C_{MB}, (b), depending on the residue type, addition level and time of sampling.

Naresh *et al*. (2017) [33] reported that plots receiving VC alone or in combination with CR showed the highest stimulation of β-glucosidase activity in the RWCS. The magnitude of increase in β-glucosidase activity at jointing, booting and milky stage over the control ranged from 34.1, 51.1 and 86.2%, respectively. A significant increase in the activity of urease was realized with ZT and FIRB treatments, and with residue retention of 4 and 6tha^{-1}[Table 2]. Mohammadi (2011) [32] concluded that the effect of organic amendments on enzyme activities is probably a combined effect of a higher degree of stabilization of enzymes to humic substances and an increase in microbial biomass with increased soil carbon concentration. Zhang *et al*., (2016) [56] observed that activity of the enzymes (urease and sucrase) increased with the amount of straw applied. Incorporation of maize straw was more effective to increase enzyme activities as compared with wheat straw incorporation because of narrow C: N ratio of maize straw than wheat straw which facilitates faster decomposition of maize straw.

Table 2: Effect of tillage crop residue practices and nutrient management practices on the soil enzymatic activities [Naresh *et al*., 2017].

Treatments	β-glucosidase(μg PNP $g^{-1}h^{-1}$)			Urease (μg NH_3 $g^{-1}h^{-1}$)			Dehydrogenase(μg INTF $g^{-1}h^{-1}$)		
	Jointing stage	Booting stage	Milky stage	Jointing stage	Booting stage	Milky stage	Jointing stage	Booting stage	Milky stage
Tillage crop residue practices									
T_1	4.58 ± 0.14	4.23 ± 0.66	0.46 ± 0.04	14.08 ±1.84	19.97 ±0.94	16.82± 2.42	4.21 ± 0.28	4.83 ± 0.34	3.55 ± 0.17
T_2	4.94 ± 0.58	4.75 ± 0.84	0.60 ± 0.05	15.36 ±1.29	22.02 ±2.70	18.90 ± 1.33	5.91 ± 0.13	5.40 ± 0.12	4.83 ± 0.07
T_3	5.15 ± 0.21	4.96± 0.56	2.88± 0.19	18.57±1.79	24.48±3.84	19.36 ± 1.01	7.36 ± 0.22	6.46 ± 0.27	5.06 ± 0.54
T_4	4.48 ± 0.43	4.38 ± 0.05	0.23 ± 0.03	14.02 ±2.72	20.10 ±1.17	17.41 ±0.85	4.55 ± 0.14	4.91 ± 0.51	4.74 ± 0.17
T_5	4.98 ± 0.59	4.85 ± 0.59	0.84 ± 0.26	16.54 ±2.18	23.39 ±1.01	19.19 ± 1.22	6.77 ± 0.15	6.56 ± 0.03	4.96 ± 0.18
T_6	5.75 ± 0.41	5.14 ± 0.46	3.25 ± 0.09	20.13 ±1.80	26.23 ±4.59	20.79 ± 2.71	8.92 ± 0.38	7.71 ± 0.37	6.41 ± 0.15
T_7	3.28 ± 0.15	2.31 ± 0.68	0.19±0.09	12.05 ±1.78	17.74 ±3.24	14.38 ± 1.54	3.06± 0.21	2.86± 0.23	1.97± 0.28
Fertilizer Management Practices									
F_1	2.66± 0.19^{a}	3.28± 0.36^{b}	0.41± 0.04^{c}	14.4± 0.65	17.3± 0.84^{a}	13.1± 0.21^{bc}	4.06± 0.21	3.86± 0.23	1.97± 0.08
F_2	4.25± 0.21^{d}	4.57± 0.56^{a}	0.68± 0.06^{c}	16.3± 1.05	23.5^{d}± 1.14	14.9± 0.59^{a}	5.21 ± 0.28	4.83 ± 0.34	3.55 ± 0.17
F_3	5.35± 0.43^{c}	5.96± 0.59^{e}	0.85± 0.09^{a}	18.1± 1.19	27.9^{a}± 1.21	19.5± 0.78 ^{ab}	5.91 ± 0.13	5.60 ± 0.12	3.83 ± 0.27
F_4	5.48± 0.46^{e}	6.29± 0.68^{d}	0.93± 0.12^{e}	19.9± 1.41	30.3± 1.56^{cd}	24.2± 0.84^{b}	6.13± 0.15	6.02± 0.03	3.96 ± 0.28
F_5	6.39± 0.58^{b}	6.94± 0.84^{c}	1.o4± 0.36^{b}	20.2± 1.59	36.4^{b}±1.84^{c}	30.1± 0.89^{b}	6.92 ± 0.38	6.71 ± 0.37	4.41 ± 0.35
F_6	5.67± 0.48^{b}	6.41± 0.76^{c}	0.98± 0.19^{b}	21.8± 1.68	39.4± 2.05	34.6± 1.15^{b}	7.77± 0.22	7.56 ± 0.27	4.96 ± 0.31

Enzyme activity highly depended on residue type and the amount of addition (generally increasing with addition level) and sampling time [Fig. 6a]. Overall, the specific enzyme activities (nmol μg^{-1} Res C_{MB} h^{-1}) were lowest on incubation day 15 [Fig.6 a]. At both addition levels, the activities involved in the C-cycle (ß-glucosidase, ß-cellobiohydrolase, chitinase, xylanase) remained stable. The acid phosphomonoesterase and leucine aminopeptidase activity increased until day 60 and then decreased again [Fig.6 a]. Enzyme specific activity was significantly higher under root than under both leaf and stem addition at all sampling periods. With the increase of residue addition level, however, the specific activity significantly decreased compared with low residue addition [Fig.6 a]. No significant differences in enzyme activities between leaf and stem additions were observed at both addition levels. The lower amount of root- than leaf- or stem-originated C in MB confirms that root-C was relatively less labile and its decomposition was slower (Cotrufo *et al*. 2013; Stewart *et al*. 2015) [10, 47]. The MB peaked due to residue additions at day 15, without an increase in SOM-originated C compared to the control. Paterson and Sim (2013) [37] revealed that the specific PE and enzyme activities mainly correlated with residue-metabolizing microbial biomass, indicating the link of the residue-feeding microbial fraction to PE.

Total C contents in f-LF ranged from 0.26 to 0.74 g C kg^{-1} and in α-LF from 0.35 to 0.54 g C kg^{-1} of soil [Fig. 6b].The C content of the f-LF was affected by both N fertilization and organic addition. C contents of the α-LF depended mainly on organic additions. The highest occlusion was found when slurry (alone or in combination with straw) or manure was applied. The effect of N fertilization on α-LF varied depending on the organic addition [Fig. 6b], indicated no response (control, slurry), increased (manure, straw) and decreased (slurry+ straw). Strongly increasing C contents in the f-LF under straw removal reflect an enrichment of root C (Schrumpf *et al*., 2013) [43] due to its slower mineralization rates compared to straw (Shahbaz *et al*., 2016) [44]. f- LF is known to be most responsive to C input, especially derived by cattle manure additions (Yagüe *et al*., 2016) [54]. The HF-C decreased with increasing C additions and N fertilization when straw was removed. On the one hand, root-derived C was retained in the f-LF and thus directly reflected the amount of C input and explained the often observed minor increase of SOM with N fertilization in cropland soils (Lu *et al*., 2011) [26].

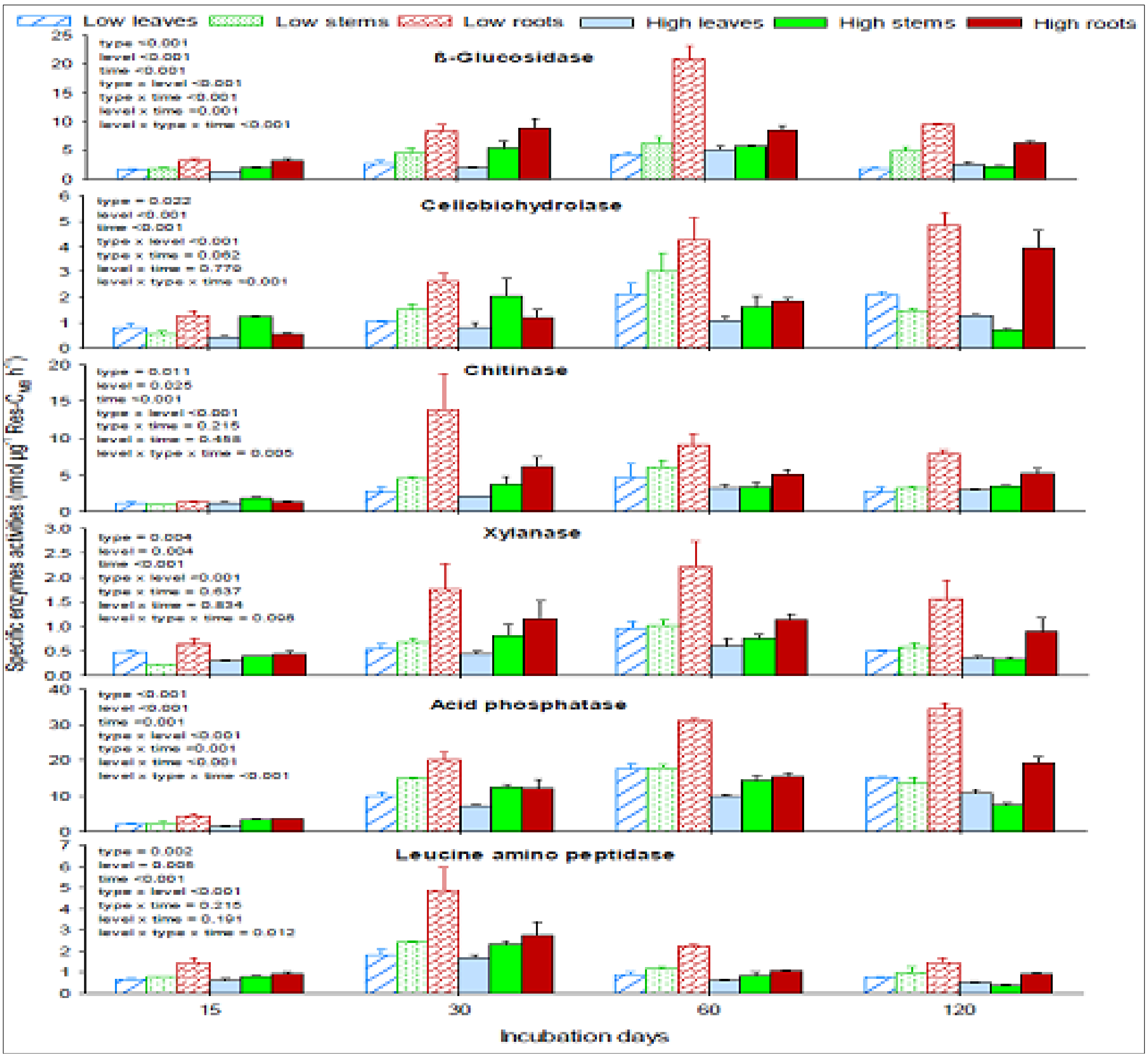


Fig 6 (a): Specific enzyme activities (enzyme activities per unit of residue originated microbial biomass (Res_CMB)), depending on the residue type, addition level and time of incubation

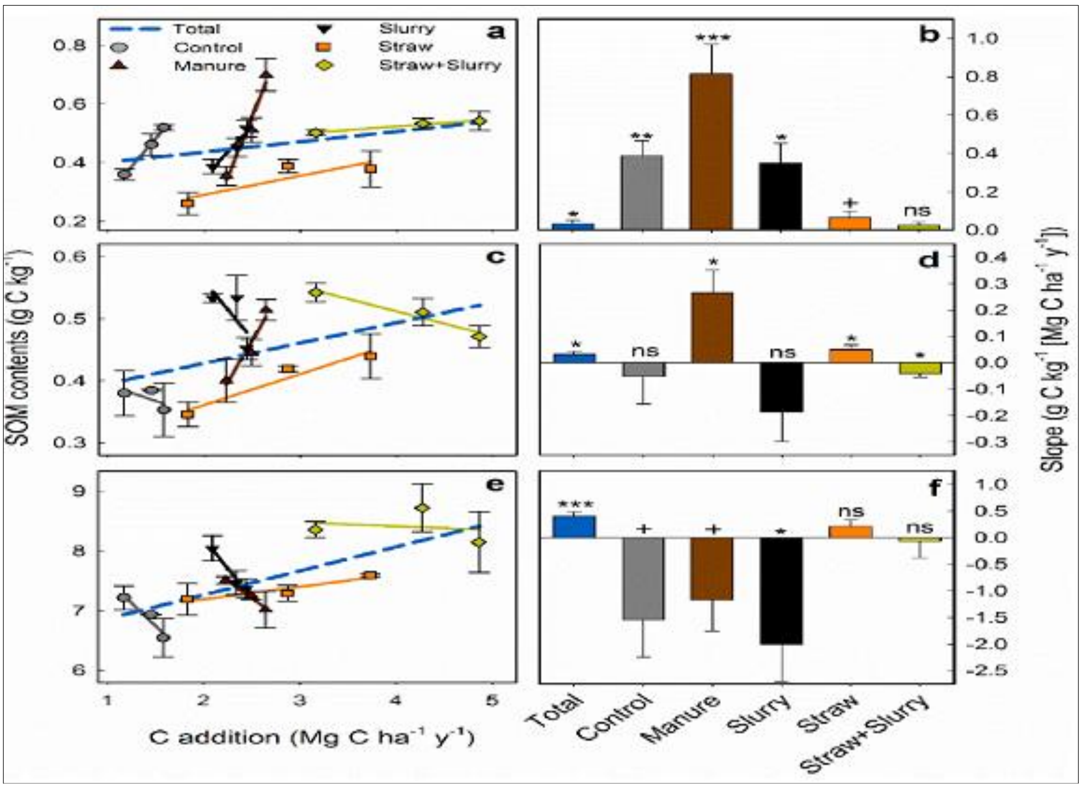


Fig 6 (b): Soil organic matter (SOM) contents and their relationships with mean annual C addition

Zhao *et al*. (2018) [57] also found that relative to the control, the proportion of large and small macro-aggregates in the 0–20 cm soil layer increased the most in MR-WR (32% and 24%), followed by MR (22% and 13%), and WR (11% and 10%). Straw return significantly increased the SOC content in each soil aggregate size class relative to no straw return. The order of SOC fractions with respect to SOC content was mSOM > fine iPOM > coarse iPOM > free LF. Straw return significantly increased the C stock in iPOM and mSOM relative to the control. Coarse iPOM was the most sensitive indicator of C change and mSOM was the main form of SOC under long-term straw return [Fig. 7a & 7b], [Fig.8a & 8b]. Soil depth had a significant influence on almost all measurements, with greater values observed in the 0–20 cm layer than in the 20–40 cm layer. All three straw return treatments (MR-WR, MR and WR) largely improved the SOC stock in each aggregate fraction in the 0–20 cm depth; increases were highest in MR-WR, followed by MR, and finally WR [Fig. 7b]. In the 20–40 cm layer, the SOC stock of small macro-aggregates significantly increased in MR-WR, but the SOC stock in the silt plus clay fraction decreased relative to other three treatments. Higher OC content of micro-aggregates due to straw return may be beneficial to long-term SOC sequestration because micro-aggregates have a longer turnover time and higher stability relative to macro-aggregates (Qiao *et al*., 2015) [35] [Fig. 7a]. The carbon content of soil aggregates was much lower in the 20–40 cm layer than in the 0–20 cm layer because the field machinery used mainly distributed straw within the topsoil. Fine particulate OC of small macro-aggregates tended to increase with increasing straw input in the 0–20 cm layer [Fig. 8a], indicating that increased straw input is conducive to the formation of micro-aggregates due to the positive role of intra-POM on the formation and stability of micro-aggregates (Six and Paustian, 2014) [45]. The proportions of mSOM (29.1–32.9%) and iPOM (8.9–13.2%) [Fig. 8b] suggest that mSOM and iPOM promote a longer turnover time and preferential storage conditions, resulting in a long-term C stock (Li *et al*., 2016) [25, 38].

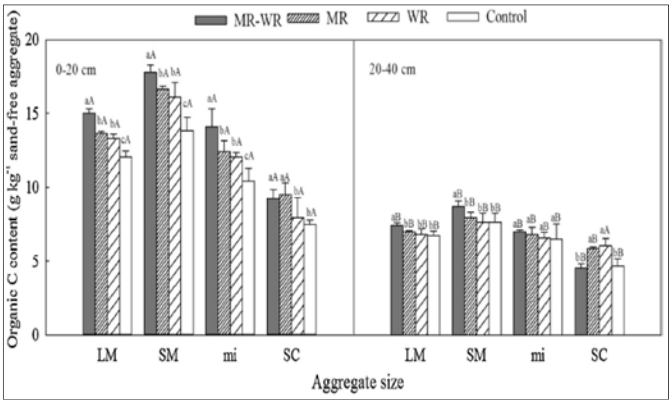


Fig 7 (a): Organic C content (g kg^{-1} aggregate) of aggregates: LM, SM, mi, and SC in the 0–20 cm and 20–40 cm soil layers under MR-WR, MR, WR, and Control.

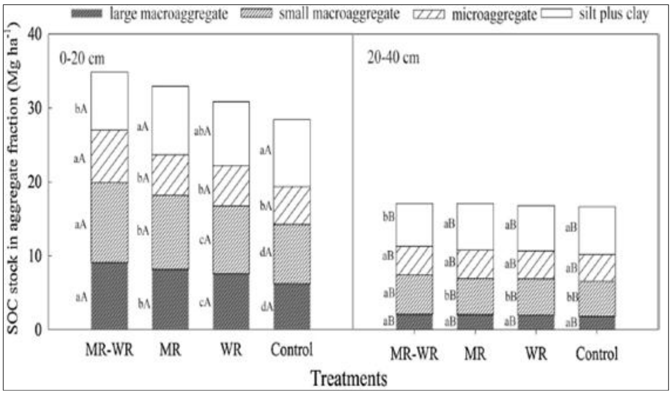


Fig 7 (b): SOC stock of aggregate fractions (Mg ha^{-1}): large macro-aggregates, small macro-aggregates, micro-aggregates, and silt plus clay in the 0–20 cm and 20–40 cm soil layers under MR-WR, MR, WR, and Control.

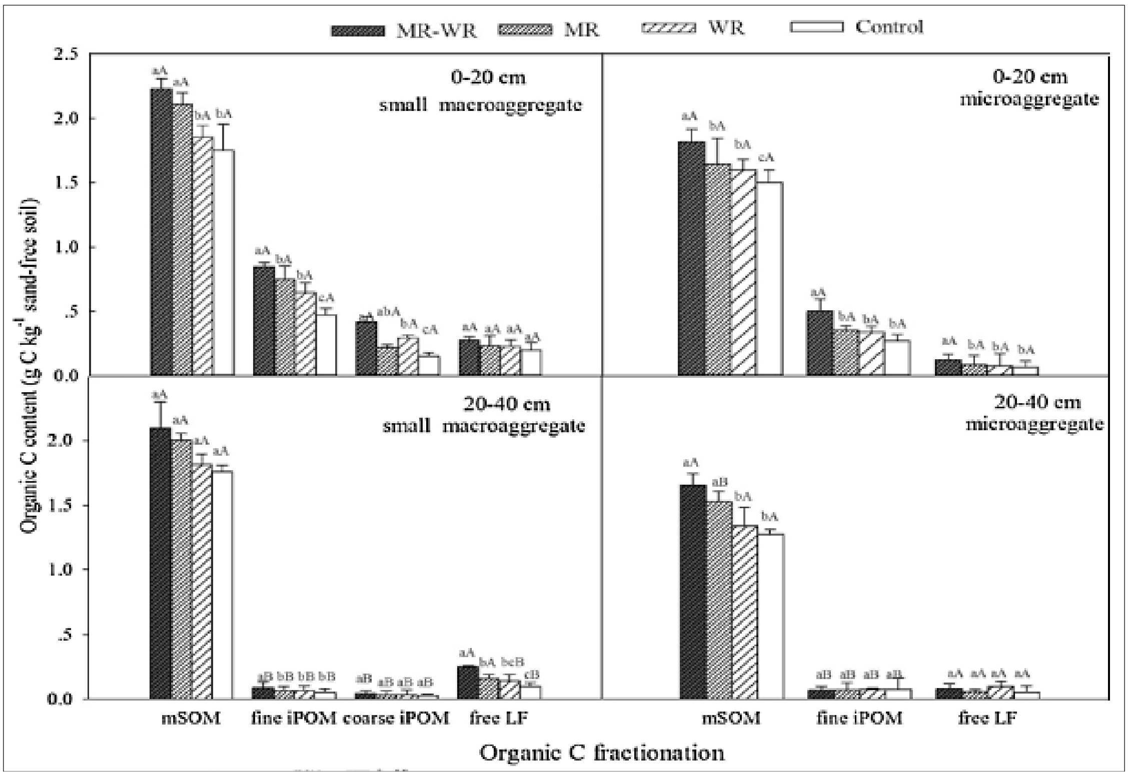


Fig 8 (a): Organic C content (g kg^{-1} soil) of the SOC fractions: coarse $_{i}$POM, fine $_{i}$POM, $_{m}$SOM, and free LF of small macro-aggregates and micro-aggregates in the 0–20 cm and 20–40 cm soil layers under MR-WR, MR, and WR.

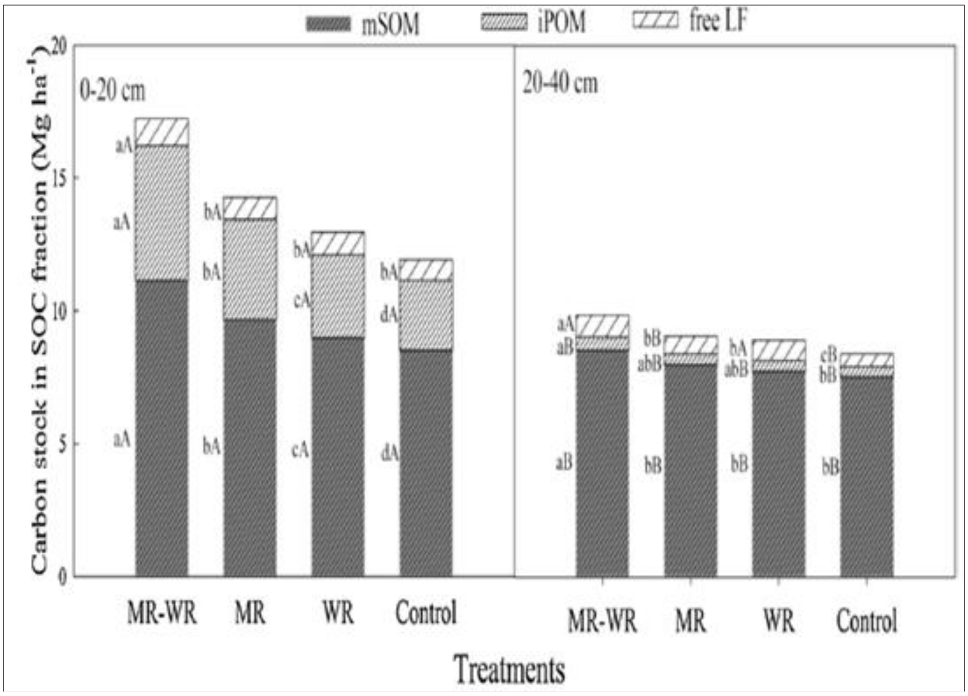


Fig 8 (b): Carbon stock of $_m$SOM, $_i$POM, and free LF (small macro-aggregates and micro-aggregates) in the 0–20 and 20–40 cm soil layers under MR-WR, MR, WR, and Control.

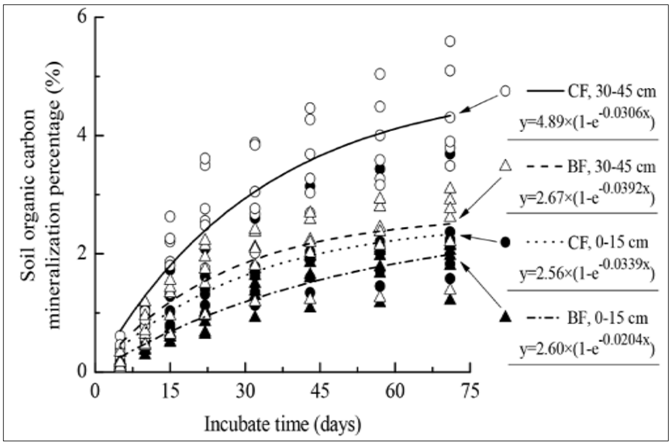


Fig 9 (a): The weighted mean of soil organic carbon mineralized percentage in various aggregates vary with incubation days in two soil depths

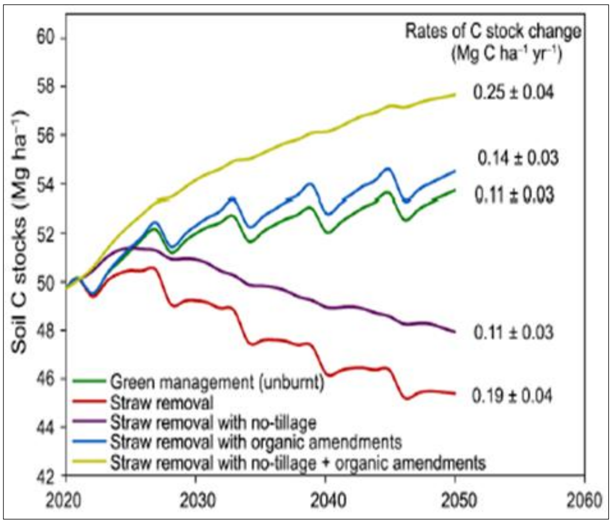


Fig 9 (c): Simulated soil C stocks at 0-0.3 m layer in sugarcane areas under green management, straw removal, and best management practices

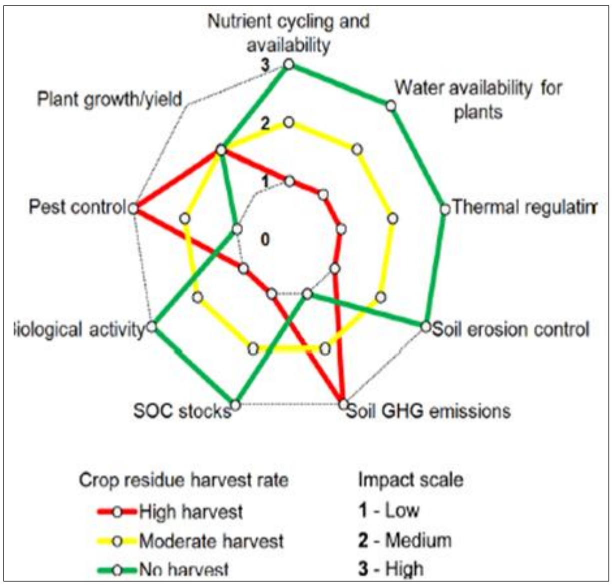


Fig 9 (b): Impacts of crop residue management on soil functions and plant growth

Fang *et al*. (2015) reported that the cumulative carbon mineralization (C $_{min}$, mgCO$_2$-C kg^{-1} soil) varied with aggregate size in BF and CF top soils, and in deep soil, it was higher in larger aggregates than in smaller aggregates in BF, but not CF. The percentage of soil OC mineralized (SOC $_{min}$, % SOC) was in general higher in larger aggregates than in smaller aggregates. Meanwhile, SOC $_{min}$ was greater in CF than in BF at topsoil and deep soil aggregates [Fig. 9a]. Cherubin *et al*. (2018) [9] showed that crop residue harvest and the consequent lower input of organic matter into the soil led to C storage depletions over time, reducing cycling, supply and availability of soil nutrients, directly affecting the soil biota. Although the biota regulates key functions in the soil, crop residue can also cause proliferation of some important agricultural pests. In addition, crop residues act as physical barriers that protect the soil against raindrop impact and temperature variations. Therefore, intensive crop residue harvest can cause soil structure degradation, leading to soil compaction and increased risks of erosion [9b & 9c].

Absolute amounts of residue C were higher at high level throughout all size classes. However the portion of residue derived C (% of initial input) incorporated into aggregates was smaller at high addition level in macro- and micro-aggregates [Fig. 10a]. Moreover, the portion of root-derived C in micro-aggregates was significantly higher compared to stalk and leaves [Fig. 10a]. The proportion of protected residue-derived C was smaller at high addition level for all types of residue. Thus, increasing addition level promotes macro-aggregate formation. However, the low proportion of physically protected residues at high addition levels leads a decreasing C-stabilization rate within SOM. Andruschkewitsch *et al*. (2014) [1] revealed that the micro-aggregates may be more effective in stabilising C because sorption instead of physical occlusion may be the prevailing process.

Residue quality and amount strongly influenced the MB and microbial activity (high MB under leaf, low under root additions) involved in crop residue and SOM decomposition [Fig 11b]. (Blagodatskaya *et al*. 2014) [6]. the increase in MB after residue addition was mainly due to crop residue feeding microbial fraction. During intensive phase, crop residues preferably decomposed due to accelerated enzyme production (specific), which mainly correlated with the residue-feeding microbial population.

SOM formation and soil structural development the C content with N fertilization, particularly when straw was absent [Fig. 11c]. In addition to the positive impact on mineral-associated SOM fraction, straw incorporation also provides soil physical protection against raindrop impact, resulting in reduced sediment detachment (Prosdocimi *et al*., 2016) [38]. Although, the overall effect of straw removal on bulk SOM was minor. However, the potential benefits of straw incorporation to protect decadal mineral-associated SOM from loss, and so may improve soil quality. Mineralisation of SOM [Fig. 11b] increased with the level of residue addition. Consequently, SOM mineralisation was 50 to 90% increased due to the addition of field equivalent amounts of 5 and 18 Mg ha^{-1} crop residue [Fig. 11b]. The priming of added residues was evident from increased mineralization of SOM which mainly depended upon the amount of addition. [Fig. 11b] Regardless of residue type, mineralization of SOM increased up to from 50 to 90% due to addition of low and high levels, respectively, whereas residue addition was increased 3.6 times. Therefore, the amount of primed CO_2 decreased per unit of applied residue. This was also reported by Guenet *et al*. (2010) [19].

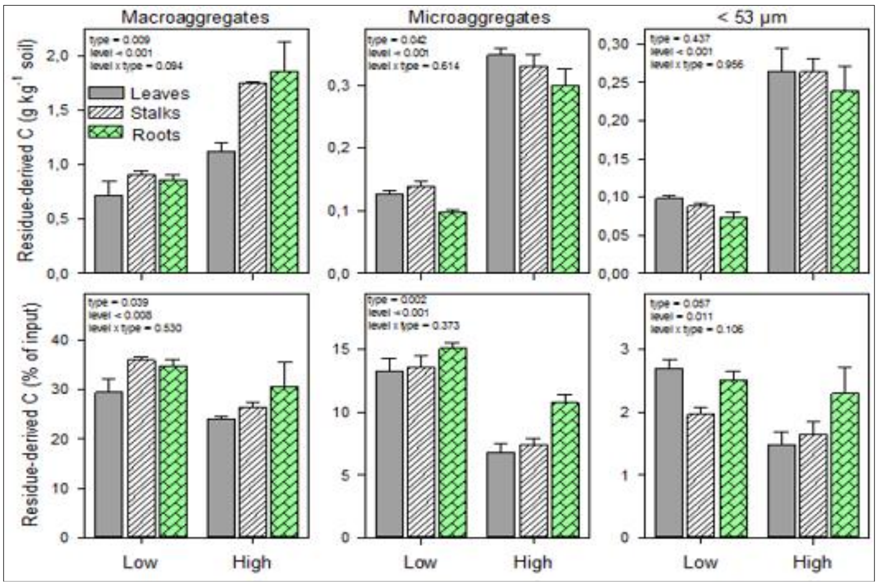


Fig. 10 (a): Residue-derived C in the soil aggregate size classes (Macro >250 µm, Micro 53-250 µm and silt plus clay <53 µm).

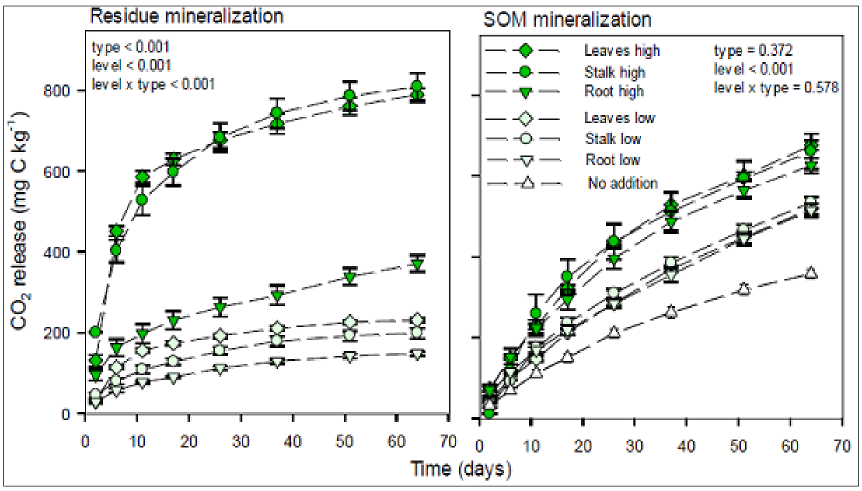


Fig. 10 (b): Cumulative CO_2-C release during 64 days of incubation depending on type and level of crop residue additions

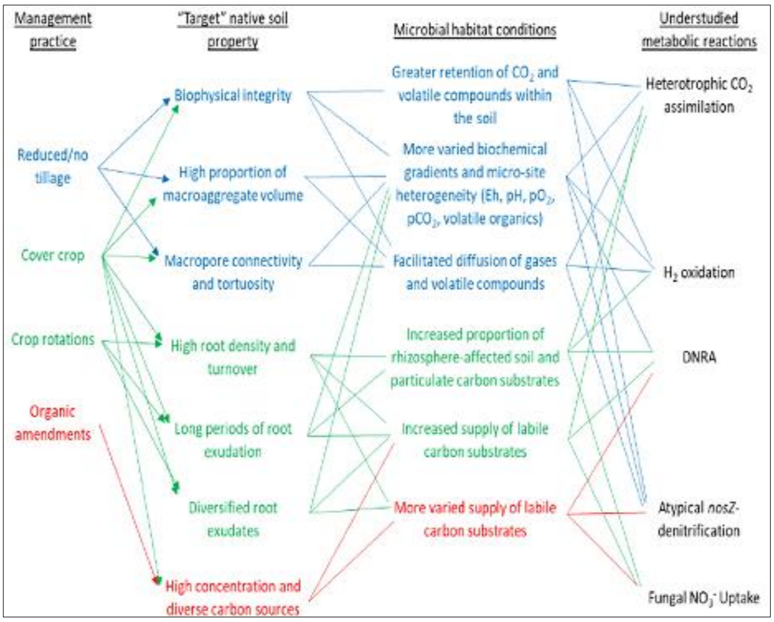


Fig 11(a)

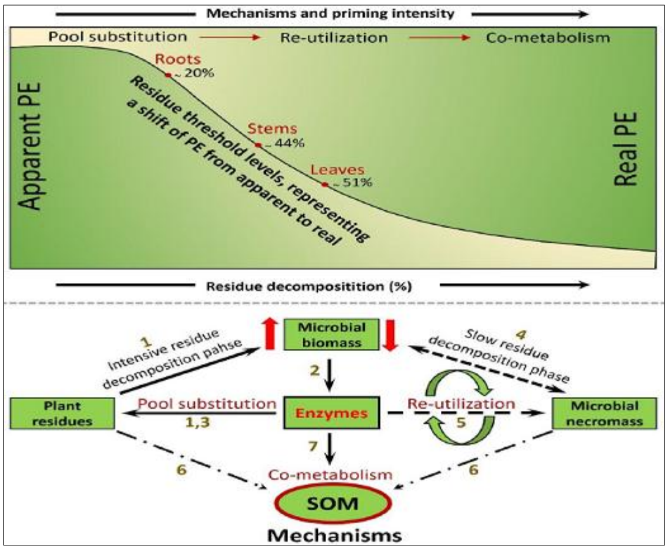


Fig 11(b): Conceptual scheme of apparent and real priming effect (PE) in soil after residue addition, explained by three main mechanisms: pool substitution, re-utilization and co-metabolism

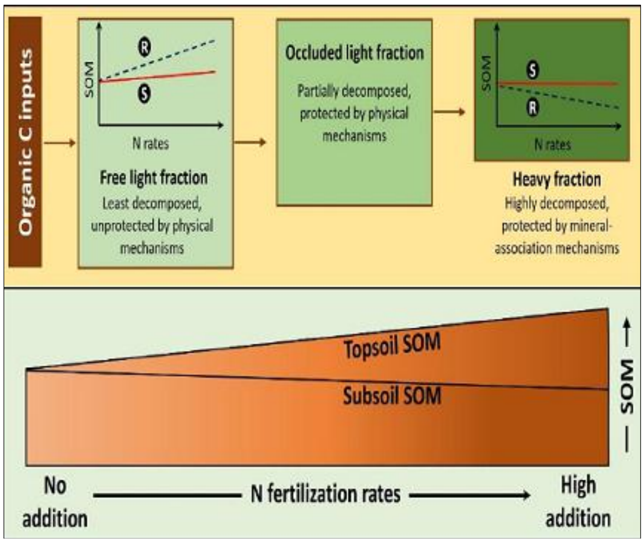


Fig 11(c): The stabilization of top- and subsoil soil organic matter (SOM) under long term organic C inputs and N fertilization rate

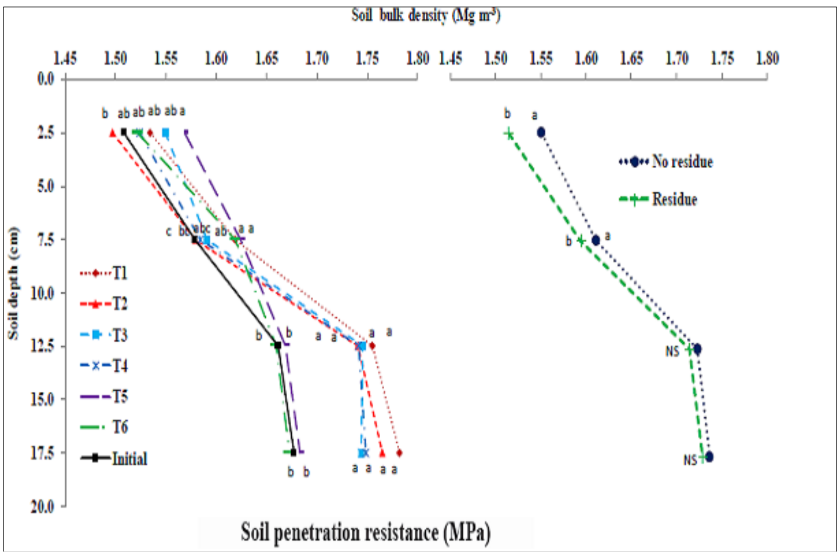


Fig 12 (a): Effect of different tillage/crop establishment and residue retention on soil bulk density at wheat harvest in rice-wheat cropping. T_1, CT-PTR (–S,–WR)/ZT-DSW (–RR); T_2, CT-PTR (+S,+WR)/ ZT-DSW (+RR); T_3, CT-DSR (–S,–WR)/ZT-DSW (–RR); T_4, CT-DSR (+S,+WR)/ZT-DSW (+RR); T_5, ZT-DSR (–S,–WR)/ZT-DSW (–RR); T_6, ZT-DSR (+S,+WR)/ZT-DSW (+RR).

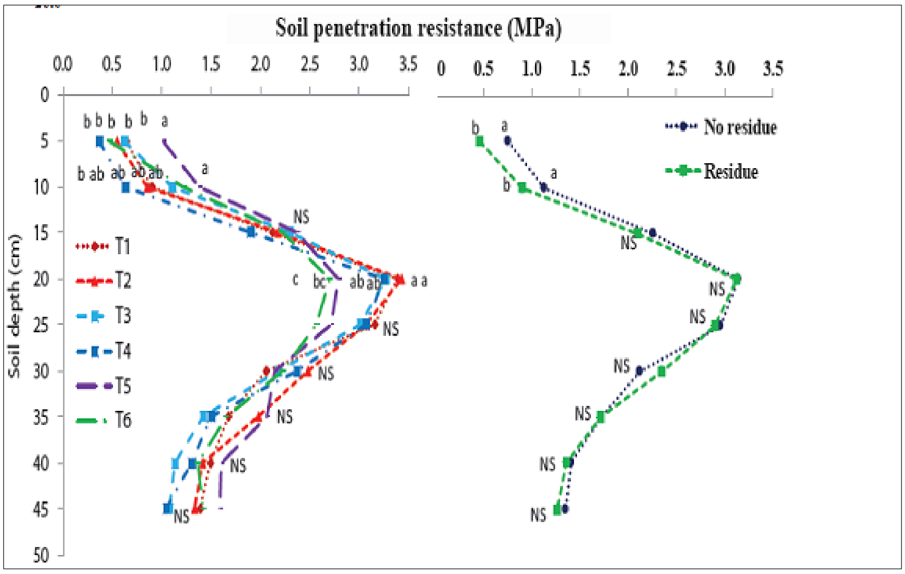


Fig 12 (b): Effect of different tillage/crop establishment and residue retention on soil penetration resistance at wheat harvest of rice-wheat cropping.

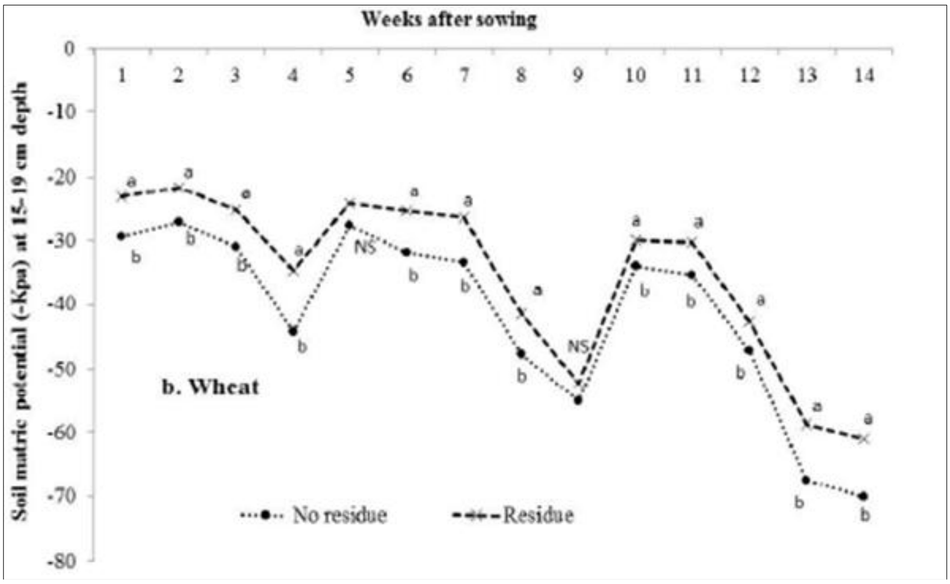


Fig 12 (c): Effect of crop residue mulch on soil matric potential during wheat crop season in rice-wheat system.

Gathala *et al*. (2017) [17] reported that the effect of tillage, CE, and residue management on bulk density (D_b) was significant at all depths [Fig. 12a]. Generally, irrespective of treatments, D_b increased with an increase in depth. At the 0–5-cm and 6–10-cm soil depths, D_b was higher in T_5 (ZT-DSR (–S,–WR)/ZT-DSW (–RR)) than in T_2 (CT-PTR (+S,+WR)/ZT-DSW (+RR)), whereas it was not significantly different from the rest of the treatments except T_4 (CT-DSR (+S,+WR)/ZT-DSW (+RR)) at 6–10 cm depth [Fig.12a]. The difference in D_b between CT-DSR and ZT-DSR was not significant at 0–5 cm and 6–10 cm soil depths, whereas, at both 11–15 cm and 16–20 cm soil depths, T_3 and T_4 had 4–5% higher D_b than T_5 and T_6 [Fig.12a]. Tripathi *et al.* (2007) [49] reported that puddling is known to increase D_b in soil immediately below the plow layer due to (i) destruction of soil aggregates The greater D_b in 15-30 cm layer of the CT treatment indicates the development of a compacted "hard pan" beneath tillage depth, caused by the compacting and shearing action of tillage implements Dolan *et al*. (2006) [11] (ii) filling of macro pores with finer soil particles, which ultimately reduces the porosity; and (iii) direct physical compaction caused by implements.

Soil penetration resistance (SPR) was significantly influenced by tillage, CE methods, and residue management up to 25 cm depth, except at 15 cm depth [Fig. 12b]. Irrespective of treatment, SPR increased with the increase in depth up to 20 cm. In surface soil (5 cm depth), SPR was significantly higher in T_5 [ZT-DSR (–S, –WR)/ZT-DSW (-RR)] compared to the other treatments. At 10-cm depth, SPR was significantly lower in T_4 (CTDSR (+S, +R)/ZT-DSW (+RR)) than in T_5 (ZT-DSR (–S, WR)/ZTDSW (–RR), whereas the rest of the treatments did not differ from either T_4 or T_5. This differs from the results of Saha *et al*. (2010) [42] who reported lower SPR in ZT, than in CT, in the surface (0–15 cm) layer.

The effect of residue mulch on SMP in wheat was significant ($P<0.05$). SMP was higher by 3 to 8 MPa (average of 5.7 MPa) with residue than without residue throughout the 14-week period after the sowing of wheat [Fig. 12c]. The effect of mulch on soil matric potential (SMP) was stronger during the early growth period than in the latter part of the season. This is expected because the mulch had a greater effect in conserving soil moisture during the initial growth period in comparison with the latter part of the crop season. Decomposition of rice residue over time and the application of a first post-sowing irrigation (75 mm) at 3–4 weeks after sowing possibly decreased the positive effect of residue retention on SMP. Soil management practices that increase the soil organic matter content could have a positive impact on the soil water holding capacity Hatfield *et al*. (2001) [20]. Therefore, replacement of traditional tillage with conservation tillage will improve soil water storage and increase water use efficiency Su *et al*. (2007) [48].

Verhulst *et al*. (2011) reported that the PB-straw burned had high electrical conductivity, Na concentration and penetration resistance and low soil resilience and aggregation, showing that the combination of PB with the burning of residues is not a sustainable management option. The CTB-straw incorporated was distinguished from the PB practices by the soil physical variables, especially the low direct infiltration and aggregate stability, indicating degradation of physical soil quality in this system. The practice of PB, where all or part of the residue is retained in the field, seems to be the most sustainable option for cereal cropping system [Table 3]. The mean weight diameter (MWD) obtained through dry sieving was significantly higher in PB-straw retained and CTB-straw incorporated than in PB straw burned [Table 3]. The MWD obtained through wet sieving was significantly higher in PB where straw was not burned than in PB-straw burned and CTB-straw incorporated and significantly lower in CTB-straw incorporated than in PB-straw burned [Table 3]. The dispersion index was significantly higher in CTB-straw incorporated than in all PB treatments [Table 3]. The soil resilience was significantly lower in PB-straw burned than in CTB-straw incorporated, PB-straw removed and PB-straw retained [Table 3]. The time-to-pond was the highest in PB with all or part of the straw retained the lowest in CTB-straw incorporated and PB-straw burned and intermediate in PB-straw removed. At all four depths, the penetration resistance was significantly higher in PB straw burned than in the other tillage-straw treatments, with exception of the PB-straw partly retained at 0–15 cm. At 0–15 cm, the CTB-straw incorporated had lower penetration resistance than the PB treatments [Table 3]. At 15–30 cm, CTB-straw incorporated had significantly lower penetration resistance than PB-straw removed and PB-straw partly retained [Table 3], but not than PB-straw retained.

When no N fertilizer was applied, the plots with PB-straw burned were separated from the other plots by high positive scores on the first PC, because of the high electrical conductivity and Na concentration in these plots [Fig. 13a]. With 150 kg N ha^{-1}, again the plots with PB-straw burned are separated from the other plots by their high electrical conductivity and Na concentration, this time resulting in high negative scores on the first PC [Fig. 13b]. The plots with PB-straw retained are separated by high positive loadings on the first PC associated with high SMB C and total N and low electrical conductivity and Na concentration [Fig. 13b]. Also with 300 kg N ha^{-1}, the plots with PB-straw burned were distinguished from the other plots, but the separation was less clear [Fig. 13c]. At all three fertilizer levels, three groups of plots were distinguished: plots with PB-straw burned, plots with CTB-straw incorporated and PB straw not burned. The separation resulted mainly from the high penetration resistance and low soil resilience in PB-straw burned and the high dispersion index and low time-to-pond and MWD after wet sieving in CTB-straw incorporated. Only without N fertilizer, the PCA with the physical data showed the PB-straw retained separated from the PB-straw partly retained and PB-straw removed because of the higher time-to-pond and aggregation and lower penetration resistance of the former. Gál *et al*. (2007) [14] observed higher bulk density in the 0–30 cm layer under zero than under conventional tillage on a silty clay loam in Indiana after 28 years, but no difference in the 30–100 cm layer. In a side by-side comparison of zero and mouldboard tillage for 19 years across a variable-landscape in southern Ontario, bulk density measured before spring tillage was dependent upon depth and tillage. Averaged across soil textures varying from sandy loam to clay loam, bulk density was greater under zero than under mouldboard tillage in the top 20 cm of the soil profile.

Table 3: Soil characteristics as affected by tillage-straw practice in the long-term sustainability trial [Verhulst *et al*., 2011]

Variable	CTB-straw incorporated	PB-straw burned	PB-straw removed	PB-straw partly retained	PB-straw retained
Chemical					
Total N (%)	0.062 c[a]	0.064 bc	0.064 bc	0.066 ab	0.068 a
pH	7.89 ab	7.74 c	7.76 c	7.83 bc	7.97 a
EC (dS m^{-1})	0.95 b	1.39 a	0.91 bc	0.92 b	0.81 c
Na (mgkg^{-1} soil)	669 bc	839 a	690 b	691 b	598 c
Fe (mgkg^{-1} soil)	3.84 b	3.69 b	4.31 a	3.88 b	4.30 a
Biological					
SMB-C[b] (mgkg^{-1} soil)	596 b	540 b	617 ab	681 a	687 a
Physical					
MWD dry sieving[b] (mm)	1.99 a	1.34 d	1.74 b	1.56 c	1.89 ab
MWD wet sieving[c] (mm)	0.49 c	0.56 b	0.61 a	0.62 a	0.64 a
Dispersion index	43.4 a	35.6 b	28.7 b	29.7 b	35.3 b
MWD resilience (mm)	18.34 b	23.13 a	17.06 b	19.66 ab	16.96 b
Time-to-pond (s)	22.4 c	11.6 c	59.2 b	86.7 a	91.1 a
Pen Res 0–15 cm (MPa)	0.21 c	0.63 a	0.46 b	0.52 ab	0.47 b
Pen Res 15–30 cm (MPa)	0.62 c	1.09 a	0.80 b	0.85 b	0.71 bc
Pen Res 30–45 cm (MPa)	0.79 b	1.15 a	0.88 b	0.95 b	0.82 b
Pen Res 45–60 cm (MPa)	0.93 c	1.25 a	0.98 bc	1.06 b	0.93 c

CTB = conventionally tilled raised beds, PB = permanent raised beds, EC = electrical conductivity, SMB = soil microbial biomass, MWD = mean weight diameter, Pen Res = penetration resistance

[a]Tillage-straw treatments with the same letter are not significantly different for the considered soil quality parameter at the 0.05 significance level. [b]data from Limon-Ortega *et al*. (2006); [c]data from Six and Pulleman (2007)

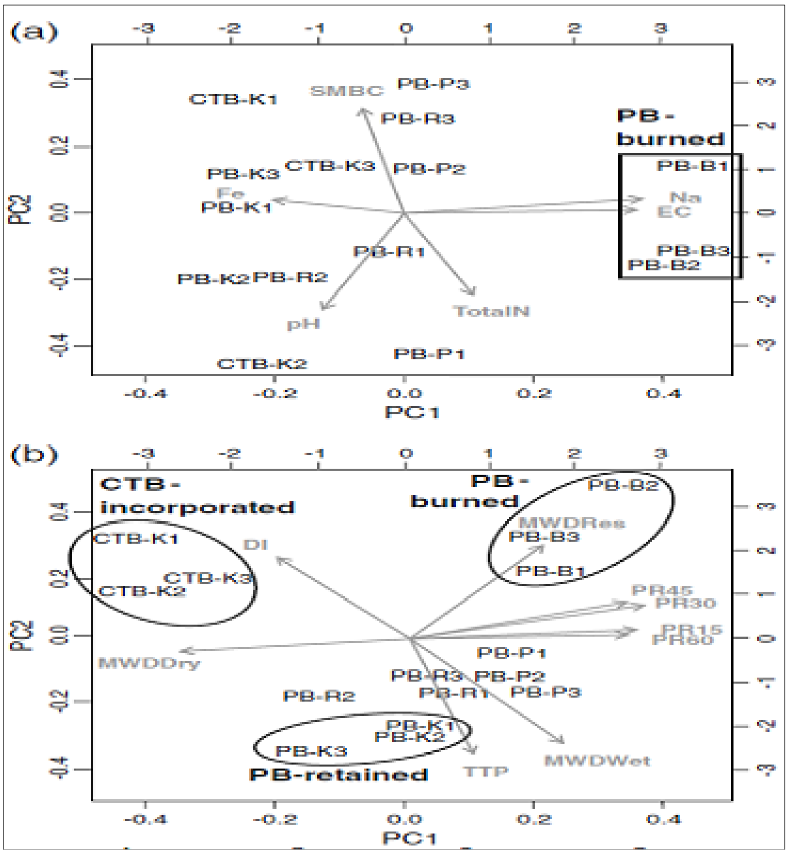


Fig 13 (a): Biplot of principal components 1 and 2 of the principal component analysis for plots with 0 kg N ha⁻1of (a) chemical and biological data and (b) physical data of the long-term trial with CTB = conventionally tilled raised beds; PB = permanent raised beds; K = residue is kept in the field; B = residue is burned; R = residue is removed from the field; P = residue is partly retained; EC = electrical conductivity; SMB = soil microbial biomass; MWD = mean weight diameter; Dry = dry sieving; Wet = wet sieving; Res = soil resilience; PR = penetration resistance; 15=0–15 cm; 30=15–30 cm; 45=30–45 cm; 60= 45–60 cm; DI = dispersion index

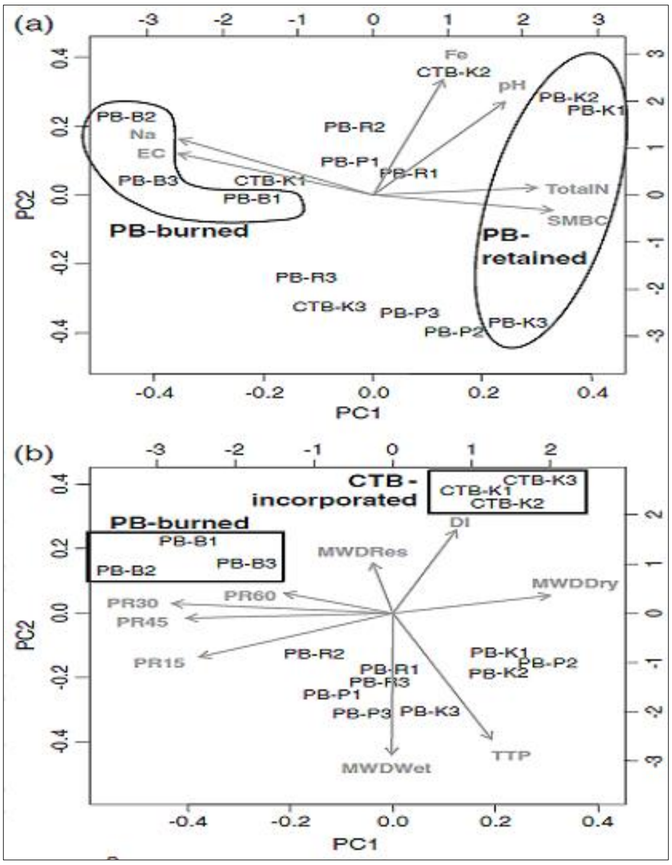


Fig 13 (b): Biplot of principal components 1 and 2 of the principal component analysis for plots with 150 kgN ha^{-1} of (a) chemical and biological data and (b) physical data of the long-term trial

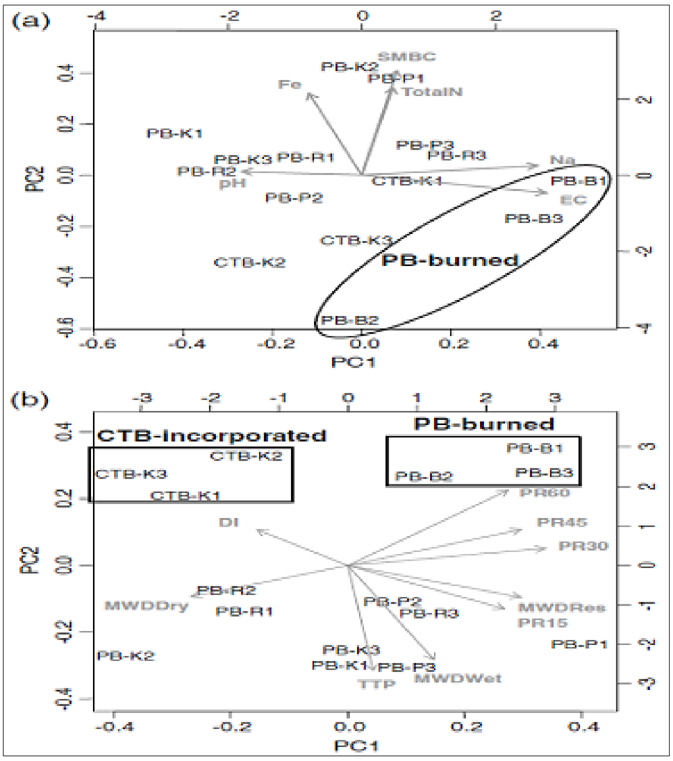


Fig 13 (c): Biplot of principal components 1 and 2 of the principal component analysis for plots with 300 kgN ha^{-1} of (a) chemical and biological data and (b) physical data of the long-term trial

Quintero and Comer ford, (2013) [36] indicated that reduced tillage increased the soil C concentration and average C content in the whole profile (≈117 cm depth) by 50 and 33%

(1636 t C ha^{-1} vs. 1224 t C ha^{-1}), respectively, as compared to conventional farming practices. Carbon content increased 177% in the subsoil (A2 horizon, 78 - 117 cm depth, from 215 to 596 tha^{-1}) [Fig.14a], although most of the soil C was in the A1 horizon (between 0 - 78 cm average thickness, 1097 tha^{-1}) [Fig 14b]. These increases show that reduced tillage enhances C stores in Andisols which are already high in organic matter. In addition, C in aggregates represented more than 80% of the total organic matter and it was positively affected by conservation practices. The C increase was preferential in the smaller macro-aggregates (<2 mm). The aggregate dispersion energy curves further suggested that C increase was occurring in micro-aggregates within the smaller macro-aggregate fraction. Data suggested that smaller macro-aggregates can be used in these soils to evaluate the influence of field management practices on soil C sequestration. This is probably related to a positive linear relationship between SOC and the proportion of crop residues returned to soil described by Rasmussen *et al*. (2008). It has been suggested that the increase in soil organic carbon associated with the adoption of conservation tillage will continue for a period of 25 to 50 yr depending on climatic conditions, soil characteristics, and production management practices (Franzluebbe, 1997).

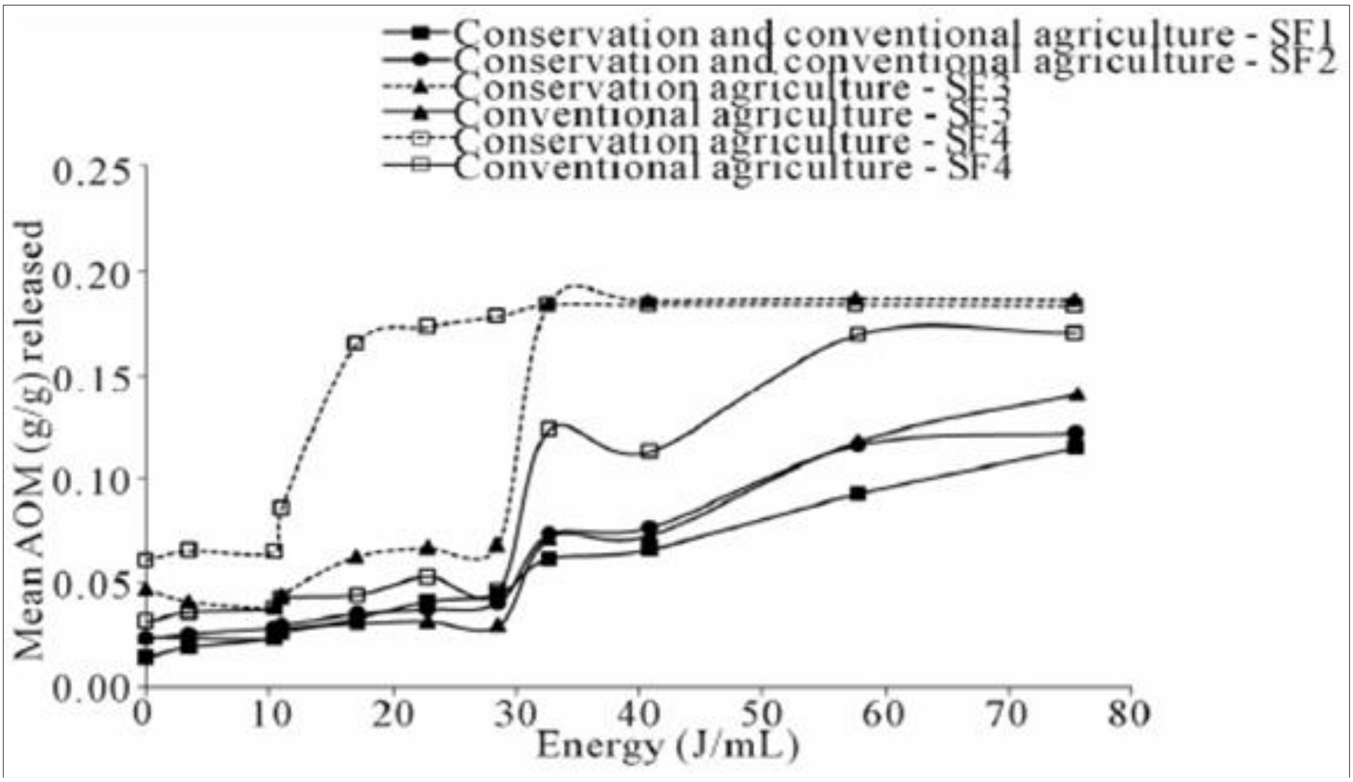


Fig. 14 (a): Aggregated organic matter of all size class aggregates for horizon A2 released with different energy inputs

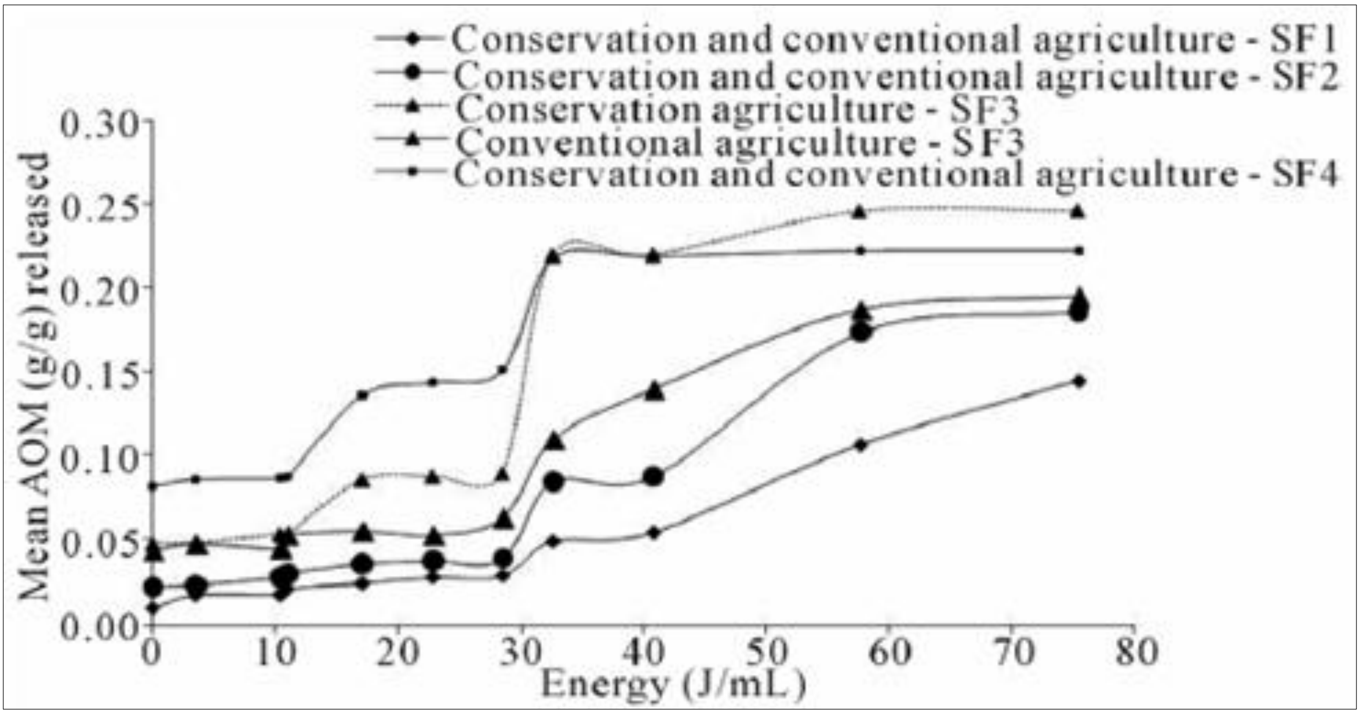


Fig. 14 (b): Aggregated organic matter of all aggregates size classes from horizon A1 (top horizon), released with different energy inputs

Awanish, (2016) [3] reported that the greater variations among carbon fractions were observed at surface layer (0-5 cm). F_1= very labile, F_2 =labile, F_3= less labile and, F_4=non-labile. At this depth, C fraction in vertisols varied in this order: $F_4>F_1>F_2=F_3$. Below 5 cm, the carbon fraction was in the order: $F_4 > F_1 > F_3 > F_2$. For 15-30 cm depth it was in the order $F_4 > F_1 > F_2 > F_3$.At lower depth, almost similar trend was followed as that of 30-45 cm [Fig.15]. Regardless of tillage system, contribution of different fractions of carbon (C) to the TOC varied from, 33 to 41%; 9.30 to 30.11%; 8.11 to 26%; 30.6 to 45.20% for very labile, labile, less labile and non-labile fractions, respectively at 0-5cm depth. For subsurface layer (5-15cm), contribution of different fractions to the TOC varied from 27.8 to 40%; 7.80 to 12.40%; 11.11 to 19.0%; 38.0 to 50.0% for very labile, labile, less labile and non-labile fraction, respectively. In general, C contents decreased with increasing depth, mainly for very labile faction (F_1) which was contributing around 40% or more in surface and surface layers (0–5 and 5–15 cm) as compared to deeper layers (15–30 and 30–45 cm). Moreover, less labile and non-labile fractions contribute more than 50% of TOC, indicating more recalcitrant form of carbon in the soil. Dolan *et al.* (2006) [11] reported that crop residues are precursors of the SOC pool, and returning more crop residues to the soil is associated with an increase in SOC concentration. The effects of conservation tillage on SOC accumulation may vary with the amount and characteristics of residues returned to soil. Moreover, during tillage a redistribution of the soil organic matter takes place. Small changes in soil organic carbon can influence the stability of macro-aggregates.

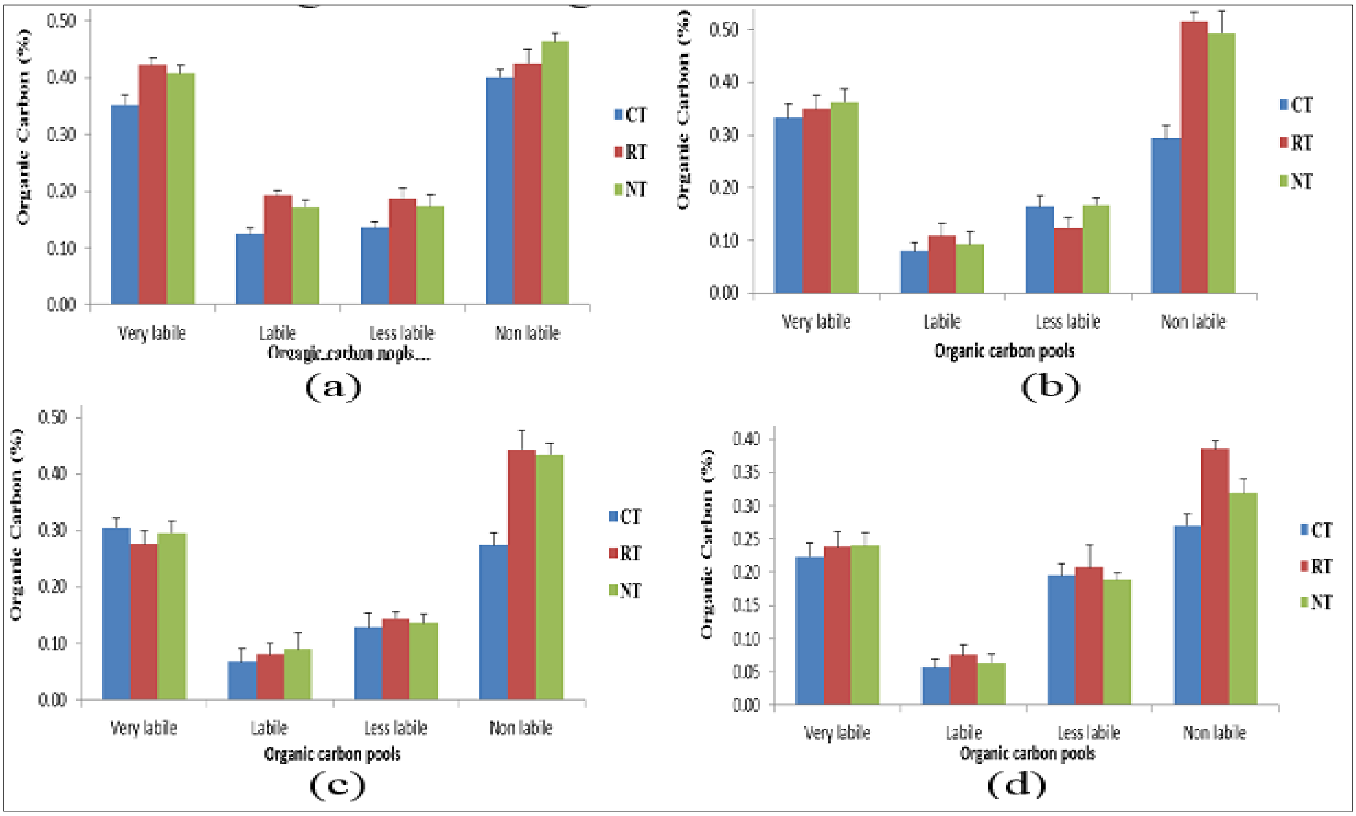


Fig 15: Effect of conservation agriculture on organic carbon pools (%) in **(a)** 0-5 cm **(b)** 5-15 cm **(c)** 15-30 cm and **(d)** 30-45 cm depth under different tillage system

Conclusion

Minimal soil disturbance and increased residue retention in the soil organic matter and carbon storage potential in Typic Ustochrept soil of Uttar Pradesh. The soil carbon concentration in the whole profile was 29% higher under conservation tillage than under conventional tillage and the carbon content was higher by 33%. C content improvement was the greatest in the sub-soil increasing by 177% although most of the C is stored in the top horizon. This may be mostly an effect of residue retention. These improvements reflect that conservation tillage (minimal soil disturbance/ reduced tillage and increased residue retention) is allowing the rehabilitation of soil carbon compared to conventional tillage systems. On croplands, tillage is the most important practice, which can have a major effect on the carbon pool, either negative with conventional plowing or positive, when No-tillage is applied. No-tillage practices claim to reverse historical carbon loss from soils, thereby reducing CO_2 in the atmosphere through storage in soil sinks - a process known as sequestration. Carbon sequestration and an increase in soil organic matter will have a direct positive impact on soil quality and fertility. Higher carbon storage potential SOC or concentrations in the upper soil not only promote a more productive soil with higher biological activity but also provide resilience to extreme weather conditions.

Adoption of

CA systems with crop residue retention may result initially in N immobilization. However, rather than reducing N availability, CA may stimulate a gradual release of N in the long run and can reduce the susceptibility to leaching or denitrification when no growing crop is able to take advantage of the nutrients at the time of their release. Tillage, residue management and crop rotation have a significant impact on micro and macro nutrient distribution and transformation in the soil. The altered nutrient availability may be due to surface placement of crop residues in comparison with incorporation of crop residues with tillage. CA practices increases availability of nutrients near the soil surface where crop roots proliferate. CA induces important shifts in soil fauna and flora communities. The different taxonomic groups of soil microbes respond differently to tillage disturbance and changed residue management strategies. Therefore, to achieve sustainable food production with minimal impact on the soil and the atmosphere, conservation tillage practices become more important now than ever.

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