International Journal of Chemical Studies 2019; 7(4): 3047-3065

International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(4): 3047-3065

Received: 19-05-2019
Accepted: 23-06-2019

Saurabh Tyagi
Department of Agriculture; Shobhit University, Meerut, Uttar Pradesh, India

RK Naresh
Department of Agronomy; Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, Uttar Pradesh, India

Satya Prakash
Department of Agriculture; Shobhit University, Meerut, Uttar Pradesh, India

Kanti Tyagi
Syngenta India Limited, India

Lali Jaat
Department of Agronomy, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, Uttar Pradesh, India

NC Mahajan
Institute of Agricultural Sciences, Department of Agronomy, Banaras Hindu University, Varanasi, Uttar Pradesh, India

Correspondence
Saurabh Tyagi
Department of Agriculture; Shobhit University, Meerut, Uttar Pradesh, India

Dynamic of new generation tillage and crop establishment techniques on crop-water productivity and soil health in rice-wheat rotation in North-Western IGP: A review

Saurabh Tyagi, RK Naresh, Satya Prakash, Kanti Tyagi, Lali Jaat and NC Mahajan

Abstract
Conventional tillage and crop establishment methods such as puddled transplanting in the rice–wheat (*Oryza sativa* L.–*Triticum aestivum* L.) system in the Indo-Gangetic Plains (IGP) require a large amount of water and labour, both of which are increasingly becoming scarce and expensive. We attempted to evaluate alternatives that would require smaller amounts of these two inputs. The yields of rice in the conventional puddled transplanting and direct-seeding on puddled or non-puddled (no-tillage) flatbed systems were equal. Yields of wheat following either the puddled-transplanted or no-tillage direct-seeded rice were also equal. Compared with conventional puddled transplanting; direct seeding of rice on raised beds had a 13 to 23% savings of irrigation water, but with an associated yield loss of 14 to 25%. Nevertheless, water use efficiency (WUE) in the rice–wheat system was higher with direct-seeded rice (0.45 g L^{-1}) than with transplanted rice (0.37–0.43 g L^{-1}). Moreover, CT-TPR system, zero till direct-seeded rice (ZT-DSR) consumed 6%–10% less water with almost equal system productivity and demonstrated higher water productivity. Bulk density (Db) of the 10- to 20-cm soil layer was highest under puddled treatments (1.74–1.77 Mg m^{-3}) and lowest under ZT treatments (1.66–1.71 Mg m^{-3}). Likewise, soil penetration resistance (SPR) was highest at the 20-cm depth in puddled treatments (3.46−3.72 MPa) and lowest in ZT treatments (2.51–2.82 MPa). Compared with conventional practice, on average, water-stable aggregates (WSAs) > 0.25 mm were 28% higher in ZT direct-seeding with positive time trend of 4.02% yr^{-1}. Infiltration was higher (0.29–0.40 cm h^{-1}) in ZT treatments than puddled treatments (0.18 cm h^{-1}). Gradual improvement in soil physical parameters in ZT system resulted in improvement in wheat yield and is expected to be superior in long run on system (rice-wheat) basis. Although the labile pools of SOC were positively affected by conservation tillage practices (CT–NT, NT–NT, and NT–CT), the less labile pool was only influenced by the continuous NT and NT–CT in the 0- to 5-cm depth. Plots under NT–NT and NT–CT had about 27 and 19% higher labile SOC pool than CT–CT plots (5.65 g C kg^{-1} soil), and NT–NT and NT–CT plots had about 14 and 11% higher less labile SOC pool than CT–CT plots (2.61 g C kg^{-1} soil) in that soil layer. SOC storage decreased with soil depth, with a significant accumulation at 0-20cm depth. Plots under NT–NT had about 10% higher coarse (250–2000 μm) intra-aggregate particulate organic matter-C (iPOM–C) within >2000 μm sand free aggregates in the 0- to 5-cm soil layer compared with CT–CT plots. The fine (53–250 μm) iPOM–C within the 250- to 2000-μm aggregates was also higher in the continuous NT plots compared with CT within both >2000 and 250 to 2000 μm sand free aggregate size classes in that soil layer. The application of conservation tillage practices to be crucial for maintaining crop, water productivity and soil quality in soils of the North Western IGP.

Keywords: Indo-gangetic plains, soil organic carbon, productivity, crop establishment technique

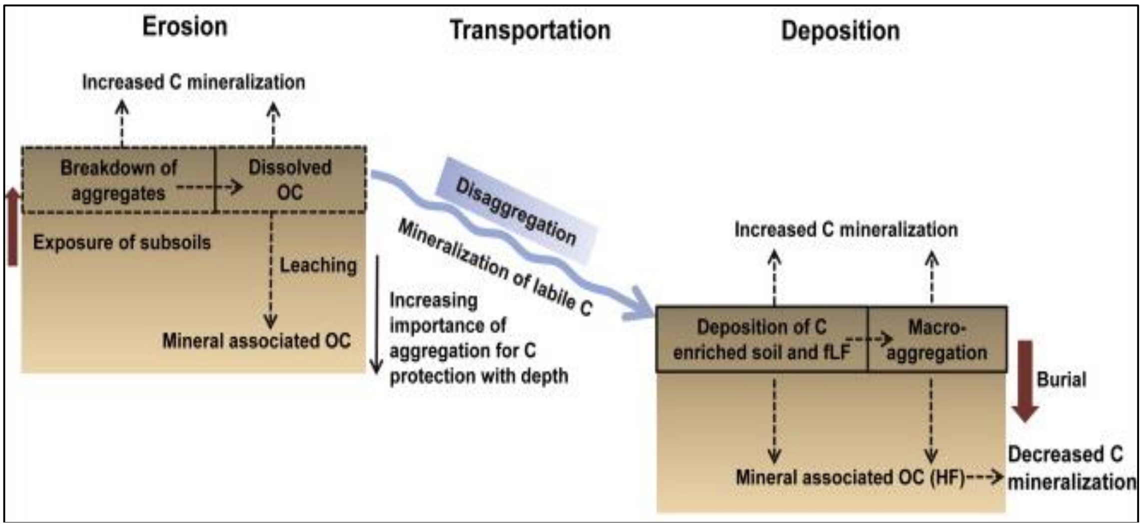
Introduction
India is endowed with rich and diverse natural resources and climatic variations, which enable it to grow many plant species, commonly grown in the tropical, subtropical and temperate regions. In spite of the rich resource base, its burgeoning population makes it difficult to maintain a balance with food production. Self-sufficiency in food is a major challenge for the country. Natural resources are vital to agrarian livelihoods, and for this reason, sustainable use of available natural resources is critical for national food security. In India, natural resources are seen as vehicles of development, employment generation, and poverty alleviation and diversified options for livelihood of millions of people.

Since there are many competing end-uses of land resources in national economy, a multiple range of state and federal laws govern their use across the federal structure of the country. It is a common knowledge that the Indo Gangetic Plains (IGP) produces about 50% of the total food grains to feed 40% of the population of the country1. Of the 610 administrative districts in India, 185 are located in the IGP. The IGP occupies a total area of approximately 52.01 m ha and represents eight agro ecological regions (AER) and 14 agro-ecological sub regions (AESRs). The area of the IGP is nearly 13% of the total geographical area of the country, and more than 280 million rural inhabitants reside in this area.

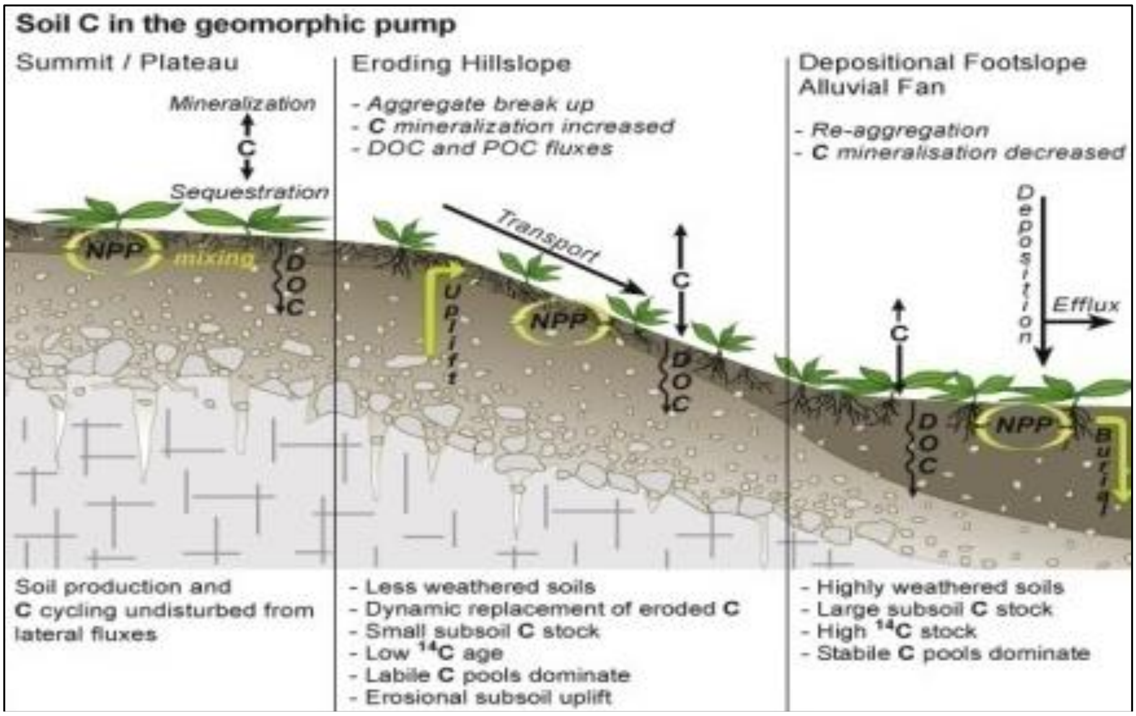
Rice and wheat are staple food crops of the world cultivated on an area around 370.4 m ha. A large proportion of world population relies on rice and wheat for daily caloric intake, income and employment. Rice-wheat cropping system is one of the major cropping systems in South Asia and is practiced in 14 million hectares area (Singh *et al*., 2010) [27] providing food for more than 400 million people. The rice–wheat production systems are fundamental to employment, income, and livelihoods for hundreds of millions of rural and urban population of South Asia (Saharawat *et al*., 2010) [27]. This system covers about 10.5 million hectares in India contributes 26% of total cereal production, 60% of total calorie intake and about 40% of the country's total food basket (Sharma *et al*., 2015 [30]; (Mondal *et al*., 2016) [21]. In India rice occupies nearly 44.1 million hectares area, 105.5 million tonnes total production with a productivity of 2291 kg/ha productivity for the year 2014-15 (Anonymous, 2016) [1]. Naresh *et al*. (2017) [27] reported 7% yield reduction in wheat yield when grown after puddled transplanted rice in comparison to wheat grown after direct seeded rice under unpuddled condition. Conventionally grown rice-wheat leads to depletion of SOC at the rate 0.13 t ha^{-1} yr^{-1} from 0 to 0.6 m depth of eastern IGP (Sapkota *et al*., 2017) [29]. Declining soil health, decreasing water use efficiency and environmental pollution are major sustainability issues of RWCS (Bhatt *et al*., 2016) [26]. Sequestering soil organic carbon (SOC) is the key strategy to improve soil health and mitigating climate change. Furthermore, increased allocation of SOC into passive pools of longer residence time helps to achieve higher carbon sequestration in soils (Mandal *et al*., 2008) [20].

Tillage is one of the basic inputs of crop production, actually tillage alters the rhizosphere environment by modifying most of the physical properties of the soil, *viz*. bulk density and soil strength, hydraulic conductivity and aggregates stability, infiltration rate and porosity due to formation, destruction and rearrangement of soil particles and aggregates and alternation in clod size distribution (Guzha, 2004). In the conventional systems involving intensive tillage, there is gradual decline in soil organic matter by quicker oxidation and burning of crop residues causing pollution, greenhouse gases emission, and loss of valuable plant nutrients. However, the extent of the impacts of tillage is variable depending upon the inherent soil characteristics and climatic conditions. Efficient management of costly input like diesel, at present having substantial subsidy, can help in reducing the cost of production, and thereby making, the produce more competitive. In conventional practice of rice growing with manual transplanting of rice seedlings in random geometry after intensive dry, wet tillage and puddling contributes significantly to these challenges, making this system unsustainable. Resource Conserving Technologies (RCTs) include any new technologies (cultivars; more efficient implements; reduced or minimal tillage; soil, water, and crop management practices) that are more efficient, use less inputs, improve production and income, and attempt to overcome emerging problems (Gupta and Seth, 2007). Jat *et al*. (2014) [13] reported significantly higher rice-wheat system grain yield in conservation tillage as compared to conventional tillage (CT) practice in IGP of India. Carbon is the central element that determines soil fertility through mediating the release of various plant available nutrients in soil, thus determines yield of crops. Simultaneously, it improves the soil resilience through buffering various soil properties, which provide good soil environment for plant growth (Chan, 2010) [4]. In addition to this, higher SOC improves microbial activity and better physical environment in soil, thus ensures better health of soil. The review paper was made to address the issues of declining soil health and yield stagnation in conventional rice-wheat cropping system and we have tried to answer the following questions: (1) Is CA superior over farmer's practice in terms of crop-water productivity and carbon stabilization? (2) Is intensive cultivation practice with new tillage and crop establishment practices in RWCS can be adopted as an alternate superior technology in terms of TOC build up and crop yield? and (3) to propose reasonable CA strategies to improve the associated organic carbon fractions in intensively managed soil on the North Western IGP.

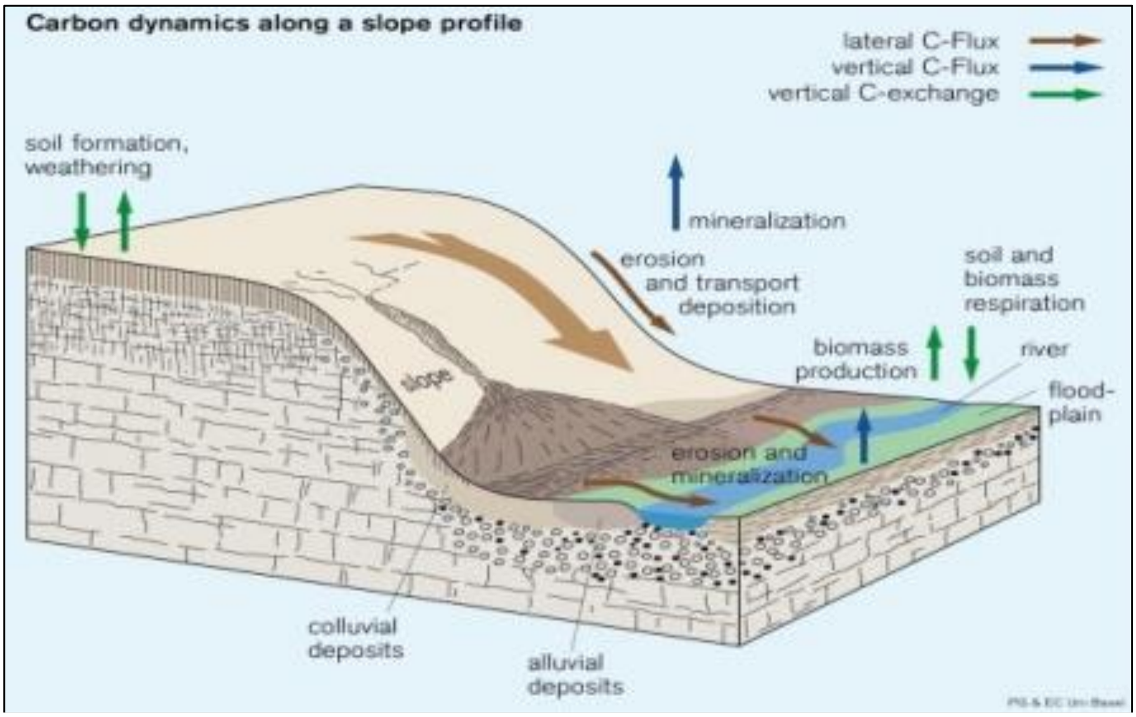
Naresh *et al*. (2014) [23] revealed that the relative yields of transplanted rice on permanent beds decreased progressively over the years, from 6.6% of CT-TPR in the first rice crop year (2009) to 9.8% of CT-TPR in the fourth crop cycle (2012). Whether this was a direct effect of soil water availability or an indirect effect on other factors such as redox and nutrient availability is not known. In addition to tillage and crop establishment practices, distribution of rainfall had an effect on the rice yield in the four years. Rice yields were higher in 2010 as compared to 2009, 2011 and 2012 in Table 1, due to favorable distribution of rainfall, that is, more rains at particular intervals during the crop establishment. Rice yields in zero till transplanted rice (ZT-TPR), reduced till direct-seeded rice (RT-TPR) and transplanted rice on wide raised beds (WBed-TPR) were on at par with CT-TPR. On average, the highest rice yields (5.76, 5.53, 5.33 and 5.13 t/hm^2) were obtained in CT-TPR, followed by ZT-TPR, WBed-TPR and RT-TPR. In direct seeded rice (DSR), yields were 16.3%–25.2% less than ZT-TPR, RT-TPR, WBed-TPR and CT-TPR. This indicated that water and labor intensive operation of puddling can be avoided without yield penalty in rice. WBed-TPR yielded 6.6%, 7.4%, 8.0% and 9.8% lower in 2009 to 2012, respectively, than in CT-TPR. Moreover, WBed-TPR suffered from water stress compared to when planted on flat land resulting in lower yields.



Erosion
Transportation
Deposition
Increased C mineralization
Breakdown of aggregates
Dissolved OC
Exposure of subsoils
Leaching
Mineral associated OC
Disaggregation
Mineralization of labile C
Increasing importance of aggregation for C protection with depth
Increased C mineralization
Deposition of C enriched soil and fLF
Macro-aggregation
Burial
Mineral associated OC (HF)
Decreased C mineralization



Soil C in the geomorphic pump
Summit / Plateau
Eroding Hillslope
Depositional Footslope Alluvial Fan
Mineralization
C
Sequestration
- Aggregate break up
- C mineralization increased
- DOC and POC fluxes
- Re-aggregation
- C mineralisation decreased
Transport
Deposition
Efflux
NPP
mixing
DOC
Uplift
C
Burial
Soil production and C cycling undisturbed from lateral fluxes
- Less weathered soils
- Dynamic replacement of eroded C
- Small subsoil C stock
- Low 14C age
- Labile C pools dominate
- Erosional subsoil uplift
- Highly weathered soils
- Large subsoil C stock
- High 14C stock
- Stabile C pools dominate



Carbon dynamics along a slope profile
lateral C-Flux
vertical C-Flux
vertical C-exchange
soil formation, weathering
mineralization
erosion and transport deposition
soil and biomass respiration
biomass production
river
flood-plain
slope
erosion and mineralization
colluvial deposits
alluvial deposits

Table 1: Yield, water application and water productivity under various crop establishment techniques

Crop establishment technique	Water application (mm/hm^2)				Yield (t/hm^2)				Water productivity (kg/m^3)			
	2009	2010	2011	2012	2009	2010	2011	2012	2009	2010	2011	2012
CT-TPR	2 995	2 890	2 950	2 745	5.73	6.10	5.65	5.60	0.191	0.211	0.192	0.204
CT-BCR	2 950	2 735	2 885	2 695	4.25	4.35	4.20	4.15	0.144	0.159	0.146	0.154
ZT-DSR	2 790	2 595	2 765	2 535	4.30	4.45	4.25	4.10	0.154	0.171	0.154	0.162
ZT-TPR	2 835	2 663	2 795	2 590	5.50	5.90	5.45	5.25	0.194	0.222	0.195	0.203
RT-DSR	2 895	2 710	2 845	2 645	4.20	4.50	4.10	4.05	0.145	0.166	0.144	0.153
RT-TPR	3 075	2 950	3 025	2 790	5.25	5.45	5.18	4.65	0.170	0.185	0.171	0.167
WBed-DSR	2 575	2 155	2 395	2 245	4.25	4.35	4.15	3.95	0.165	0.202	0.173	0.176
WBed-TPR	2 615	2 210	2 465	2 330	5.35	5.65	5.25	5.05	0.205	0.256	0.213	0.217
CD at 5%	-	-	-	-	0.56	0.68	0.49	1.08	-	-	-	-

CT-TPR, Conventional-till puddled transplanted rice; CT-BCR, Conventional-till puddled broadcast seeded rice; ZT-DSR, Zero till direct-seeded rice; ZT-TPR, Zero till transplanted rice; RT-DSR, Reduced till direct-seeded rice; RT-TPR, Reduced till transplanted rice; WBed-DSR, Direct seeded rice on wide raised beds; WBed-TPR, Transplanted rice on wide raised beds.

Naresh *et al*. (2014) [23] also found that soil on the top of permanent raised beds retained lower bulk density than that in conventional puddle transplanted rice (Fig. 1). The differences arose presumably because there was less structural disruption of aggregates and settlement in the unsaturated condition of the raised beds compared to the saturated condition of the conventional puddled transplanted rice. With the passage of time, the differences between soil physical parameters get narrowed (Limon *et al*., 2006) because the height of bed gets reduced and become compacted. The infiltration rate was greater under WBed-DSR than under CT-TPR, which was similar to those under ZT-DSR and CT-DSR. WBed-DSR and ZT-DSR had significantly higher soil aggregates (> 0.25 mm) than CT-TPR. Further, under conventional-tillage, soil aggregation was static across the seasons, whereas it improved over time under zero-till and permanent beds (Fig. 1).The mean weight diameters of aggregates (average of all size groups) were significantly higher under ZT-DSR and WBed-DSR and increased over time compared with conventional-tillage (Fig. 1).

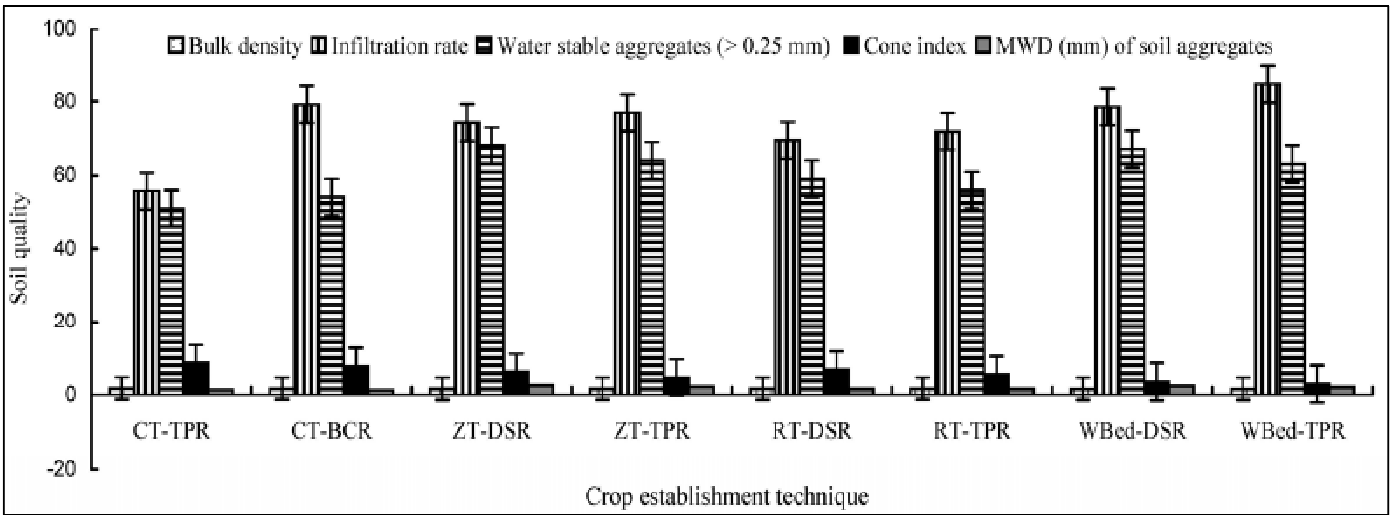


Fig 1: Effects of crop establishment on soil properties of rice crop [bulk density, water stability of aggregates, clod breaking strength and soil organic carbon (%)]

Gathala *et al*. (2011) [9] revealed that the soil penetration resistance (SPR) increased with the increase in depth up to 20 cm, irrespective of treatment. In surface soil (5-cm depth), SPR was highest (1.3–1.4 MPa) in ZT flat beds (T_5 and T_6) and the differences from other treatments (T_1–T_4) ranged from 26 to 51%. The T_2 (puddled TPRAWD/ZT wheat) had 20% higher SPR than T_1 (puddled TPR/CT wheat) and T_5 and T_6 (ZT flat) had 28% higher SPR than T_3 and T_4 (raised beds). In subsurface soil (15- and 20-cm depth), the trend of SPR was reverse to surface soil, and it was higher in puddled (T_1 and T_2) than in the rest of the treatments (T_3–T_6) (Fig. 2a). At 15 and 20 cm, SPR was 9 to 25% and 24 to 33% lower in T_3–T_6 than T_1 and T_2, respectively.

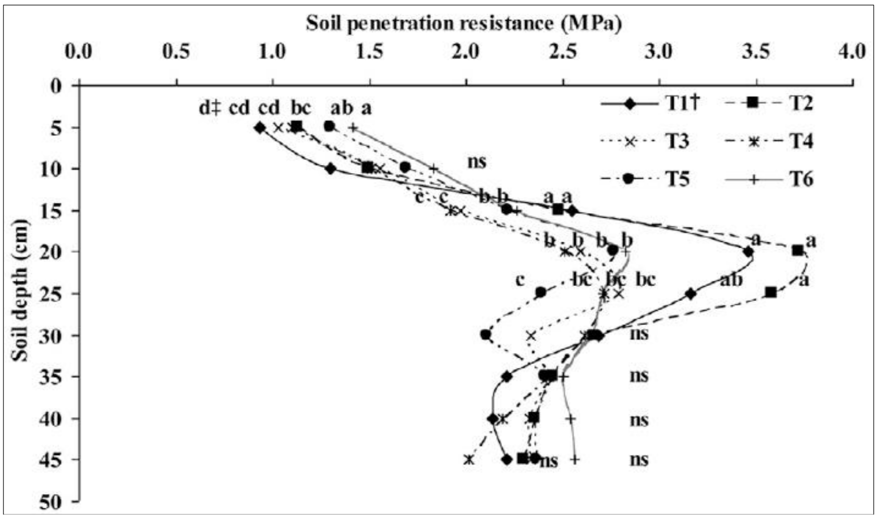


Fig 2(a): Effect of tillage and crop establishment methods on soil penetration resistance (4-yr average, 2005–2006 to 2008–2009) in 7-yr rice–wheat rotation

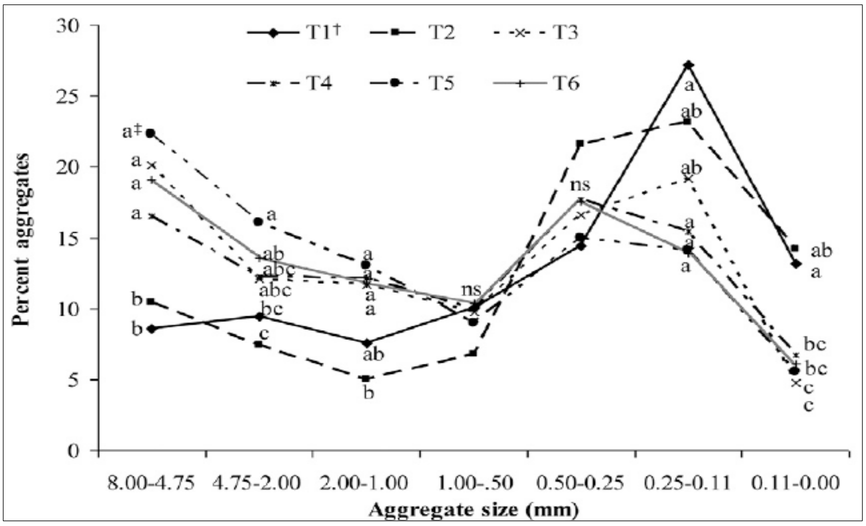


Fig 2(b): Effect of tillage and crop establishment methods on water-stable aggregate size distribution after 7-yr rice–wheat rotation

Gathala *et al*. (2011) [9] reported that the size distribution of WSA after seven rice–wheat cropping cycles differed in different treatments (Fig. 2b). The T_1 and T_2 had lower (about half) WSA > 1.00 mm, but higher WSA <0.25 mm than T_3–T_6. However, the aggregate size distribution in T_3–T_6 was not different. According to these data, conventional puddling decreased macro-aggregates (>1.00 mm) in favour of micro-aggregates (<0.25 mm), and ZT and raised beds increased macro-aggregation by either binding the micro-aggregates or protecting them against destruction, or both. Tillage operations break soil aggregates and expose soil organic carbon (SOC) for decomposition. Zero-till increases soil aggregation by reducing soil disturbance and increasing soil organic matter, and possibly the growth of fungi that bind soil particles and micro-aggregates together (Naresh *et al*., 2017; Sainju *et al*., 2009) [27, 28].

Causarano *et al*. (2008) [3] reported that pastures contained significantly greater SOC than cropland at 0- to 5-cm depth (1.9 times greater than CsT and3.1 times greater than CvT), but there were no differences among management systems at lower depths (5–20 cm). A similar management effect was observed for POC, SMBC, and CMIN [Fig.3a]. Pastures and CsT had less soil disturbance, which allowed SOC fractions to accumulate at the surface. Above ground residues decompose more slowly than incorporated residues because reduced contact with the soil increases drying and rewetting and reduces interactions with soil fauna and microbes. However, the average concentrations of total SOC, POC, SMBC, and CMIN within the surface 20 cm followed the order: pasture >CsT>CvT ($P \leq 0.05$) [Fig.3b].The POC/total SOC ratio decreased with soil depth in pasture and CsT, but remained fairly constant in CvT. This suggests that POC was a larger portion of total SOC at the soil surface, probably as a result of the accumulation of plant and animal residues, root fragments, and other labile organic materials where soil remained undisturbed by tillage operations. Potential C mineralization (CMIN) decreased with depth and was different among management systems in the order: pasture >CsT>CvT [Fig.3b]. Moreover, the impact of management on water-stable MWD and ASD, however, following the order: pasture >CsT>CvT [Fig.3c]. Comparing dry to wet ASD, differences occurred mainly among large macro-aggregates (1000–4750 µm). Pasture soils withstood disruptive forces during wet sieving better than CsT soils, which were more stable than CvT soils. Large macro-aggregates under pasture were 24% of the whole soil with dry and wet sieving, while large macro-aggregates under CsT were 24%of the whole soil with dry sieving and 17% with wet sieving; in CvT, the same aggregate-size class was 22% with dry sieving and 10% with wet sieving. Disruption of macro-aggregates with wet sieving increased the <53-µm aggregate-size class, i.e., silt- and clay-size micro-aggregates.

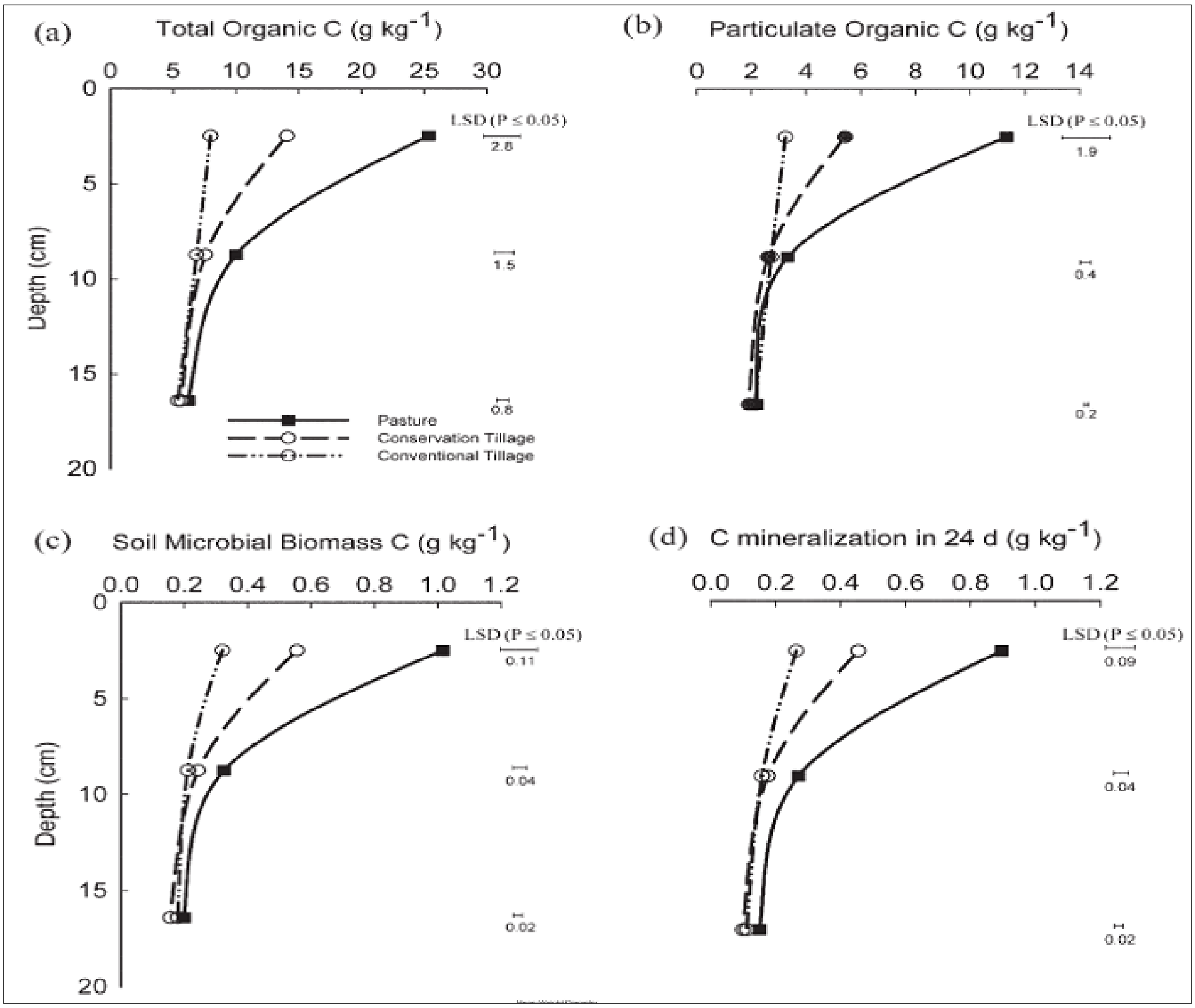


Fig 3(a): Depth distribution of (a) total soil organic C, (b) particulate organic C, (c) soil microbial biomass C, and (d) C mineralized

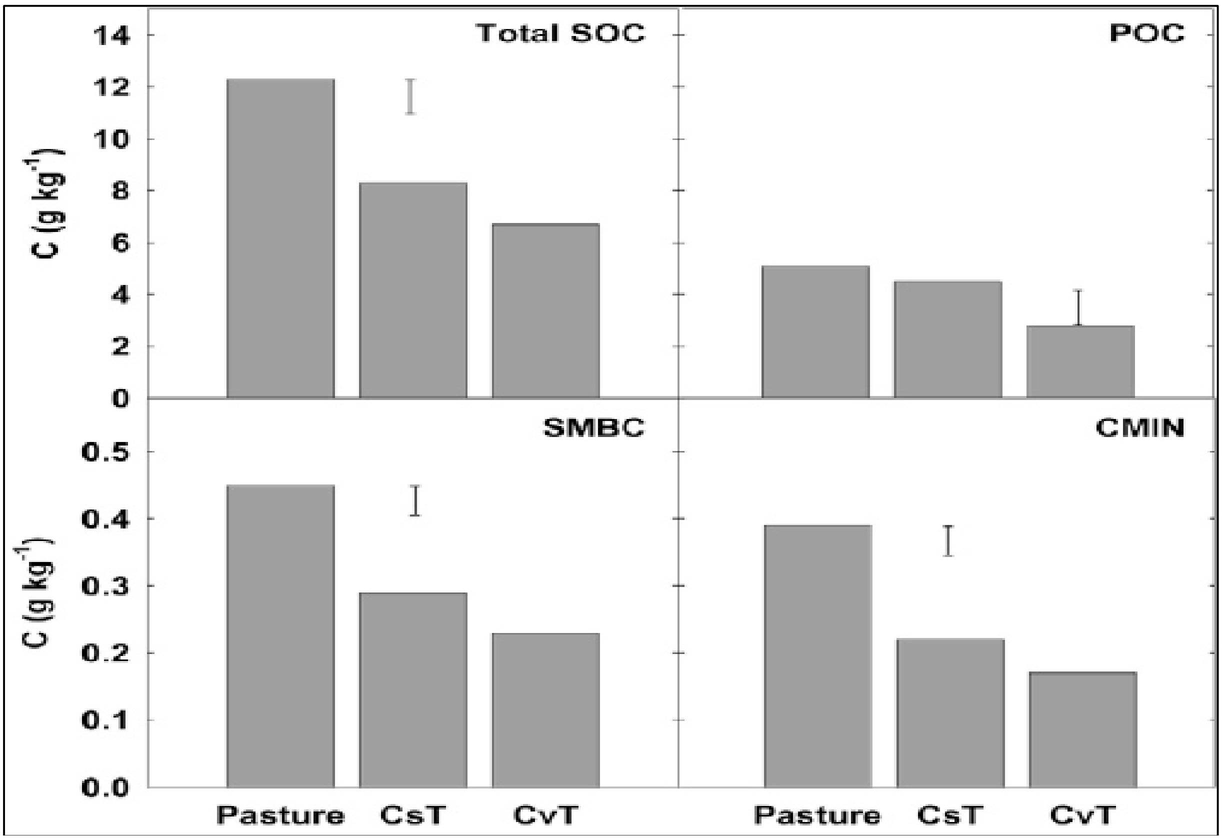


Fig 3(b): Effect of pasture, conservation tillage (CsT), and conventional tillage (CvT) on total soil organic C (SOC), particulate organic C (POC), soil microbial biomass C (SMBC), and C mineralized in 24 d (CMIN) at 0- to 20-cm depth

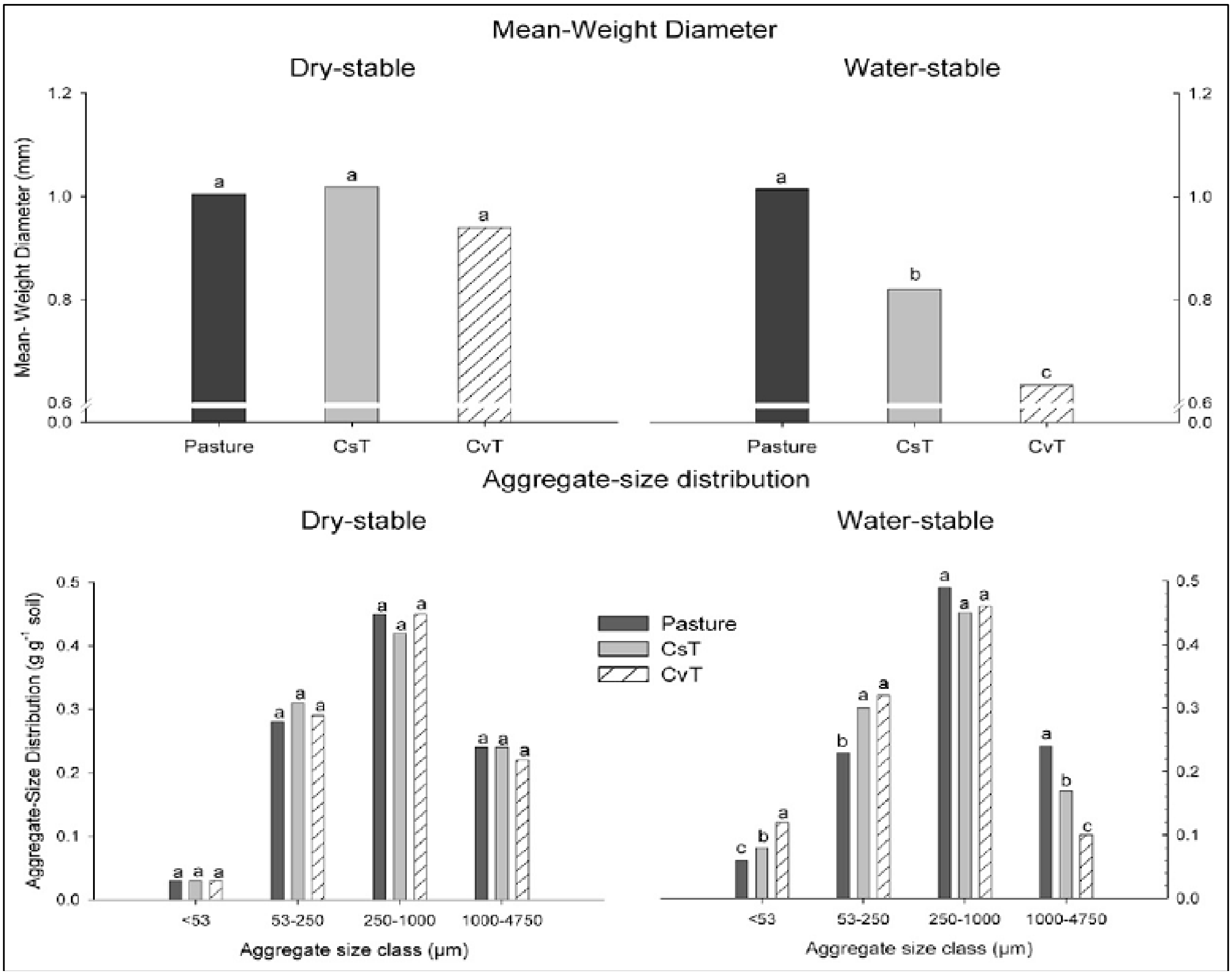


Fig 3(c): Dry-stable and water-stable mean-weight diameter and aggregate-size distribution (0–5 cm) under pasture, conservation tillage (CsT), and conventional tillage (CvT) systems

Zhao *et al*. (2018) [40] also found that the straw return treatments, particularly MR-WR, increased the proportions of mSOM and fine iPOM within small macro-aggregates and micro-aggregates, especially in the 0–20 cm layer [Fig. 4a]. The carbon content of iPOM was much lower at 20–40 cm than at 0–20 cm [Fig.4a]. Six *et al*. (1998) [34] revealed that the concentration of free LF C was not affected by tillage, but was on average 45% less in the cultivated systems than NV. Proportions of crop-derived C in macro-aggregates were similar in NT and CT, but were three times greater in micro-aggregates from NT than micro-aggregates from CT. Moreover, the rate of macro-aggregates in CT compared with NT leads to a slower rate of micro-aggregate formation within macro-aggregates and less stabilization of new SOM in free micro-aggregates under CT [Fig.4b].

Naresh *et al*. (2017) [24] observed that the macro-aggregates are less stable than micro-aggregates, and therefore more susceptible to the disruption forces of tillage. The influence of tillage on aggregate C and NT content is shown in [Fig. 4c]. At 0–15 cm, tillage effect was confined to the 2–0.25 mm size fraction, in which the conservation tillage treatments contained significantly higher SOC contents than CT, ST had significantly higher NT contents than CT, and NT tended to have higher NT contents than CT [Fig. 4c]. No significant differences were detected in SOC and NT contents in the 0.25– 0.05 mm and <0.05 mm classes among all treatments [Fig.4c]. The highest SOC and NT contents were found in the 2–0.25 size fraction. Data from the 15- to 30-cm samples show generally diminished effect of tillage treatments [Fig.4c]. Soil organic C and NT contents in the aggregate-size fractions generally decreased with increase in soil depth for all treatments [Fig. 4c]. Chen *et al*. (2009) [5] reported that reduced tillage (RT) contained 7.3% more SOC and 7.9% more N stocks 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} and 0.033 Mg N ha^{-1} yr^{-1} more than PT over an average period of 11 years, respectively.

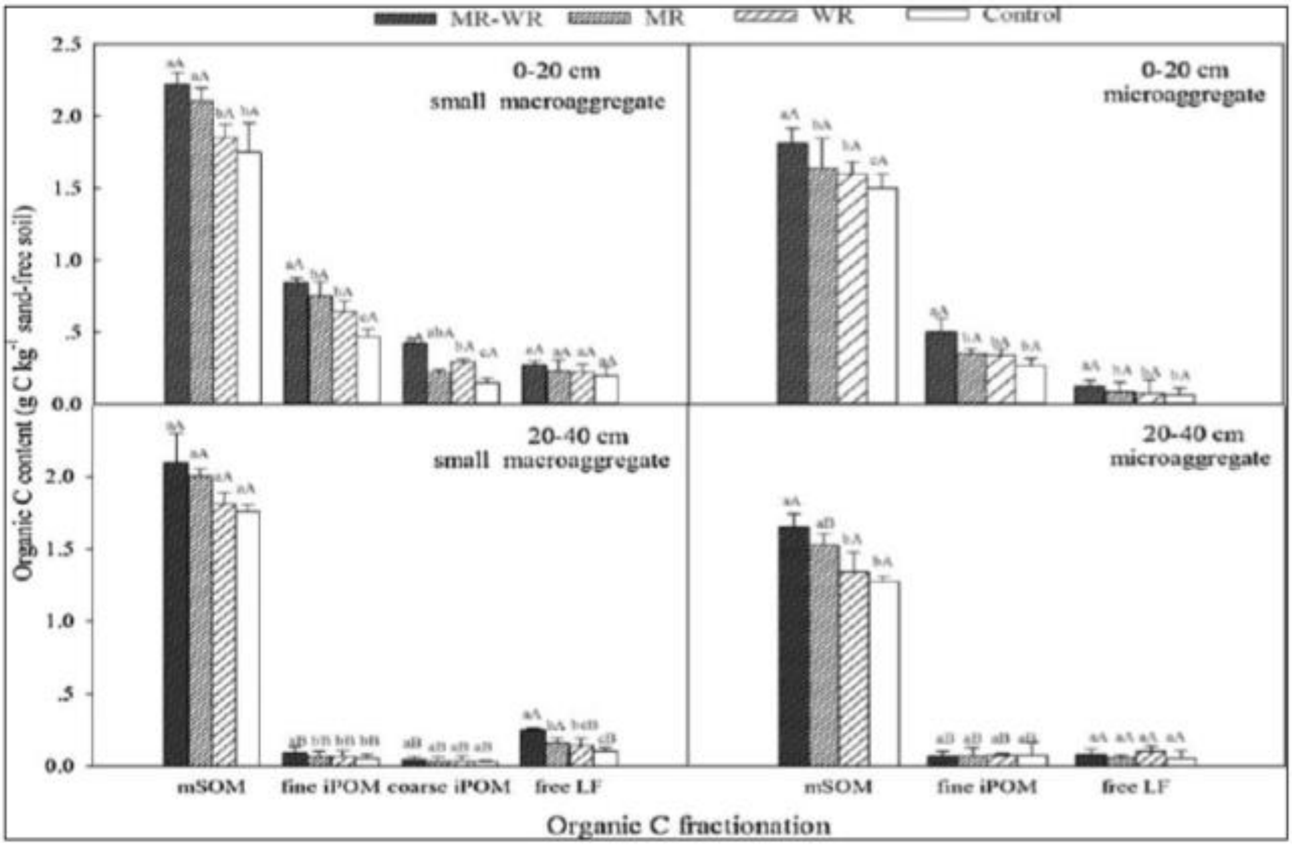


Fig 4(a): Organic C content (g kg^{-1} soil) of the SOC fractions: coarse iPOM, fine iPOM, mSOM, and free LF of small macro-aggregates and micro-aggregates in the 0–20 cm and 20–40 cm soil layers under MR-WR, MR, and WR

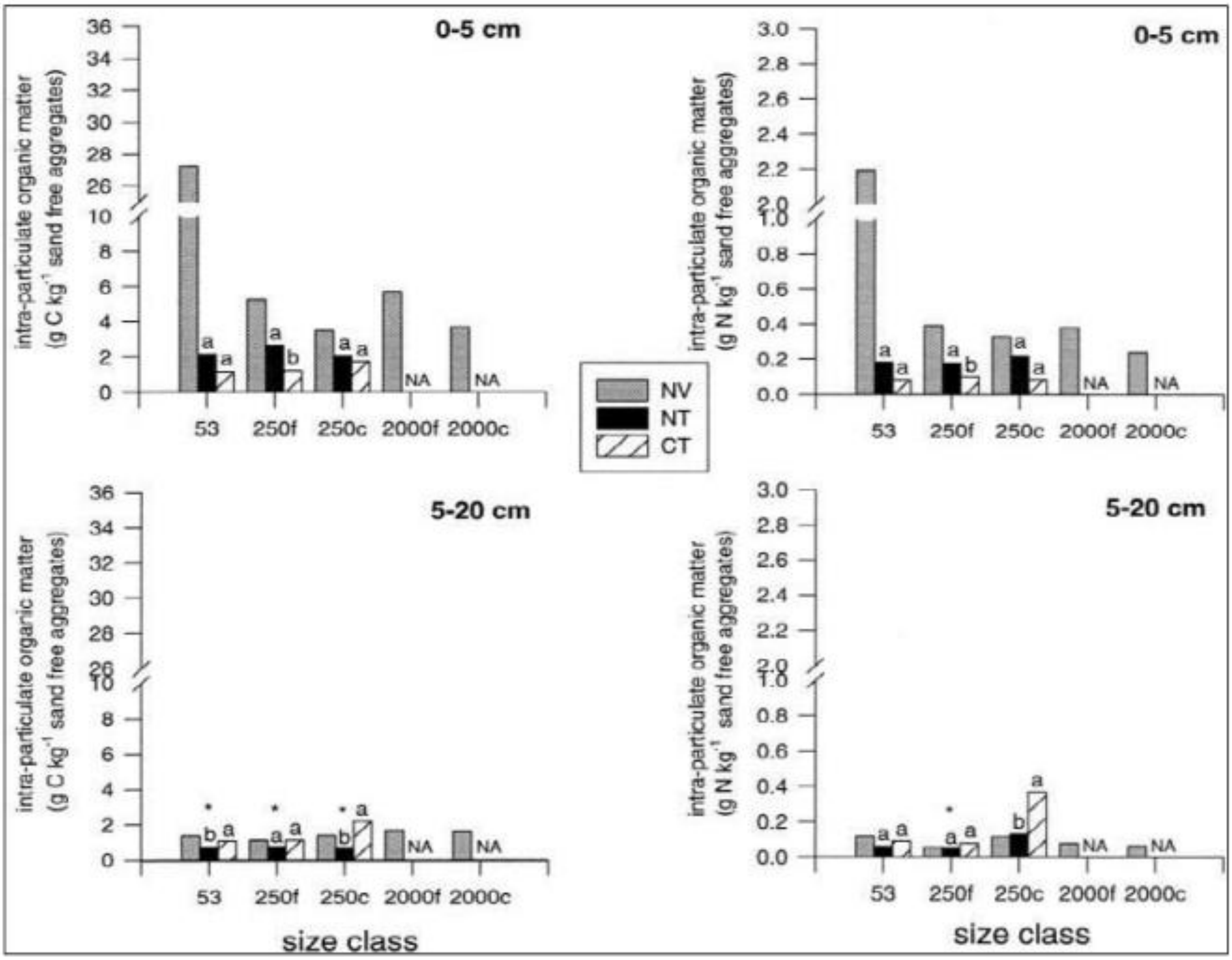


Fig 4(b): Aggregate and Soil Organic Matter Dynamics under Conventional and No-Tillage Systems

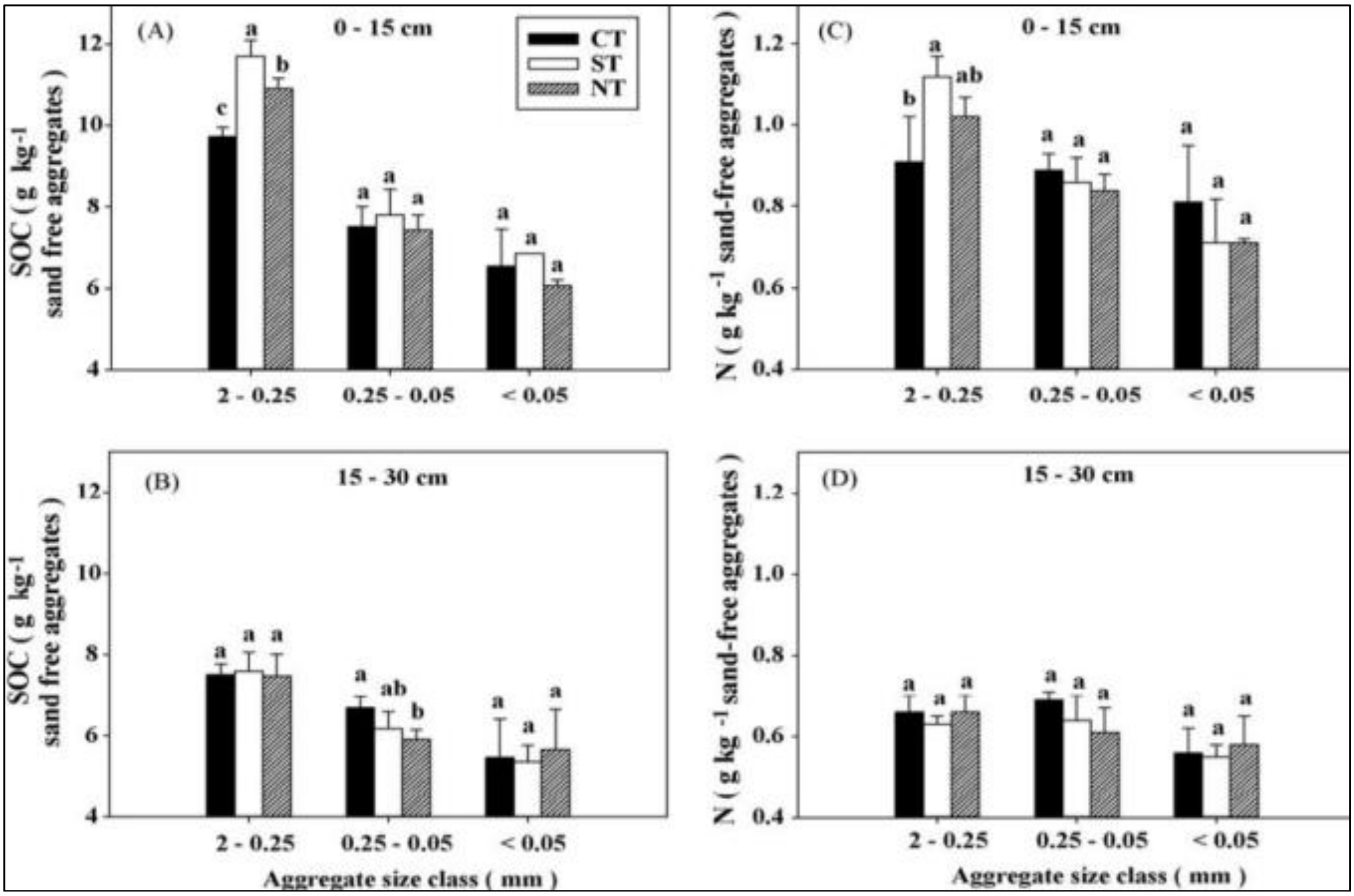


Fig 4(c): Soil organic carbon (SOC) and nitrogen content (g kg-1) of sand-free aggregates from two depths under conventional tillage with residue removal (CT), shallow tillage with residue cover (ST), and no-tillage with residue cover (NT)

Gu *et al*. (2016) [10] revealed that SOC concentration in all treatments decreased with soil depth. The significant differences of SOC among treatments were solely at depths of 0-40 cm, where soil physicochemical properties changed. Further changes would have occurred following activity by microorganisms. Average SOC content at depths of 0-40cm in ST and GT were 6.26 g kg^{-1} and 6.59 gKg^{-1} respectively, significantly higher than that of 5.44 g kg^{-1} in CK [Fig 5a.]. The use of ST and GT increased SOC by 15.15% and 21.14% respectively. In the course of the growing season, SOC concentrations in all treatments presented substantial changes with seasons. The maximum SOC was recorded in the dry and cold season, and the minimum in the warm and wet season.

Gu *et al*. (2016) [10] also found that compared to the control without cover (CK), ST and GT treatments increased the contents of SOC,LOC, DOC, POC and EOC by 14.73%, 16.5%, 22.5%, 41.5% and 21%, respectively, in the 0-40 cm soil layer, and by 17%, 14%, 19%, and 30%, respectively, in the 0-100 cm soil layer [Fig.5b]. The contents of organic carbon and its active fractions decreased with increasing soil depth in all of the treatments. SOC was accumulated in the period of December to the following March. The contents of soil DOC and LOC were high in January to March, while the contents of soil POC and EOC were high in June to September. The relative contents of soil organic carbon fractions were POC > EOC > LOC > DOC over the four years. However, ST and GT treatments significantly increased soil DOC concentrations at depths of 0-40 cm, by 28.56% and 23.33% respectively, [Fig.5c] compared to CK, but there was no difference between ST and GT treatments at each layer of the soil profile. The increase in DOC with ST may be due to the soluble decomposed organic materials of the straw, while the increase in DOC with GT could possibly be attributed to an increase in organic acids and water-soluble carbohydrates from rhizo-deposition and root exudates. In addition, a decrease in surface runoff under GT and ST was an important reason for the increased DOC, as DOC may be lost with runoff. Compared with CK, the DOC in GT and ST was favorably leached, deposited and absorbed into the subsoil layer, resulting in higher concentrations of DOC at depths of 20-40 cm [Fig.7c]. This was probably because of low soil bulk density in ST, and in GT lower pH would have increased DOC adsorption by soil (Jardine *et al*., 1989] [11].

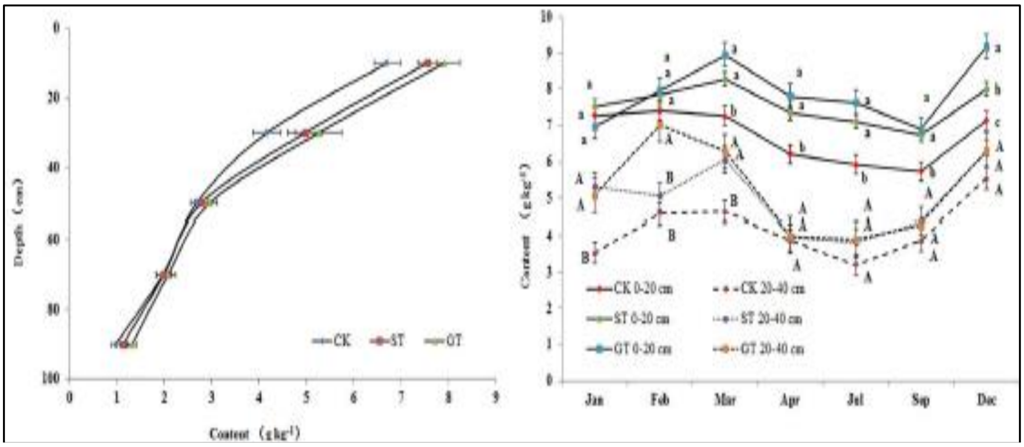


Fig 5(a): Changes of soil total organic carbon

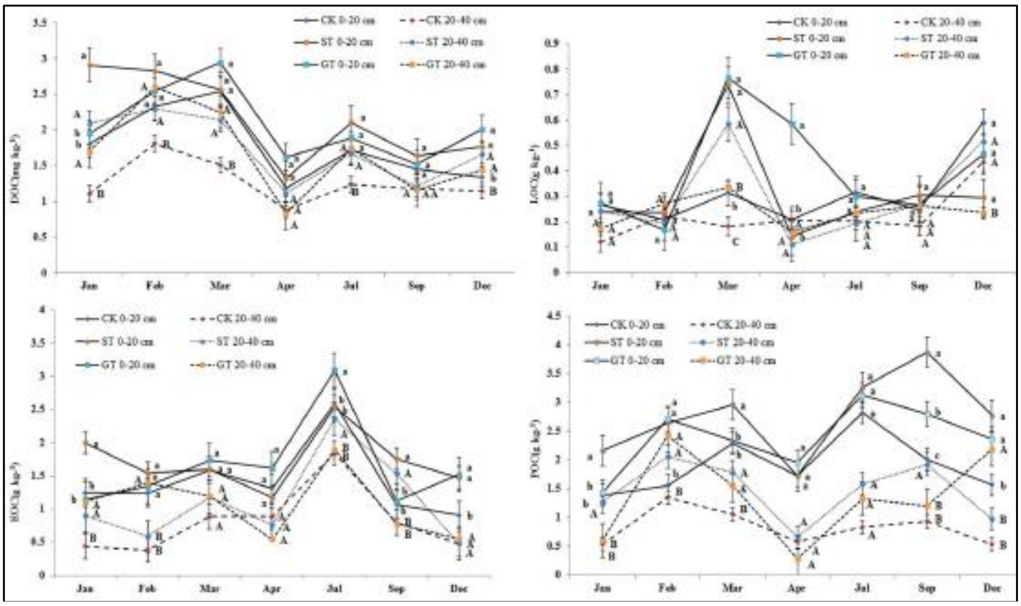


Fig 5(b): Dynamic changes of carbon fractions

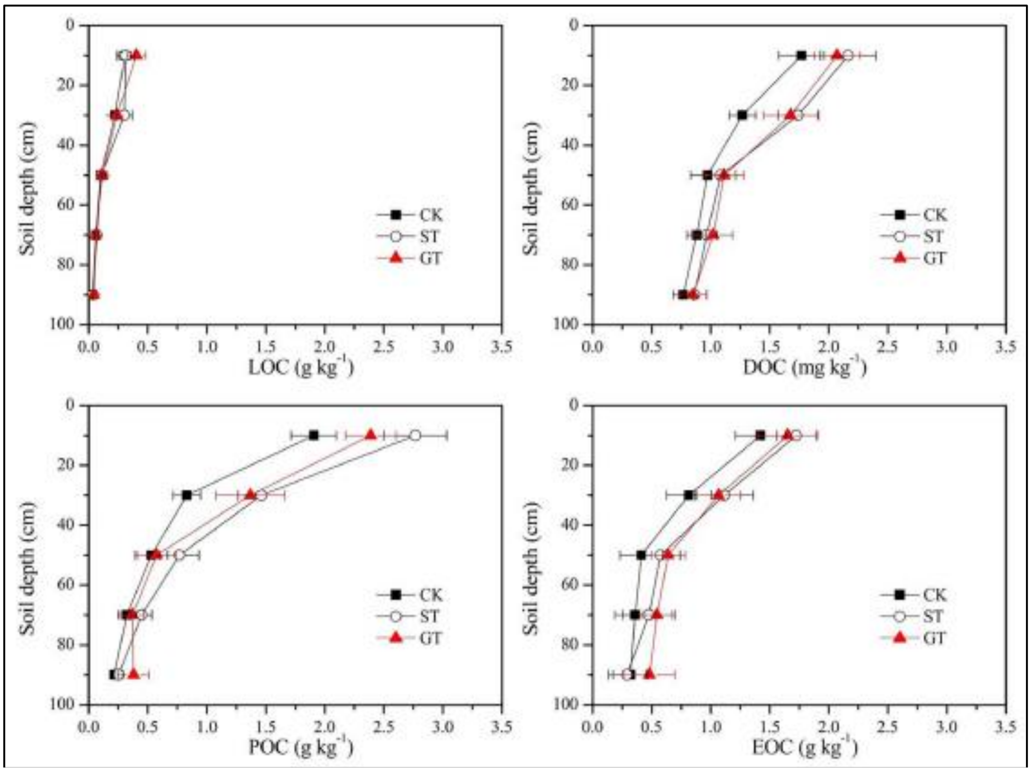


Fig 5(c): Content of Carbon fractions at different depths

Liu *et al*. (2016) [19] showed that the mass proportion both of coarse-sand (2000–200 μm) and clay (< 2 μm) fractions increased with prolonged rice cultivation, but the aggregate size fractions were dominated by fine-sand (200–20 μm) and silt (20–2 μm) fractions across the chronosequence. SOC was highly enriched in coarse-sand fractions (40–60 g kg^{-1}) and moderately in clay fractions (20–25 g kg^{-1}), but was depleted in silt fractions (~10 g kg^{-1}). The recalcitrant carbon pool was higher (33–40% of SOC) in both coarse-sand and clay fractions than in fine-sand and silt fractions (20–29% of SOC). However, the ratio of labile organic carbon (LOC) to SOC showed a weakly decreasing trend with decreasing size of aggregate fractions [Table 2A]. The divergence of the uncultivated marsh soil to the rice soils could be attributed to the land use impact as a determinant factor for SOC turnover (Qian *et al*., 2013) [26]. The increased allocation of SOC to clay-sized fraction could be attributed to the accelerated formation of clay and hydroxyl Fe/Mn minerals (Wissing *et al*., 2013) [38] due to long-term paddy management (Kölbl *et al*., 2014) [16].Total soil DNA (deoxyribonucleic acid) content in the size fractions followed a similar trend to that of SOC. Despite the largely similar diversity between the fractions, 16S ribosomal gene abundance of bacteria and of archaeal were concentrated in both coarse-sand and clay fractions. Being the highest generally in coarse-sand fractions, 18S rRNA gene abundance of fungi decreased sharply but the diversity gently, with decreasing size of the aggregate fractions [Table 1B]. In the clay sized fractions of aggregates, DNA content was independent of SOC, which could be either inaccessible to microbes or non-degradable due to binding to minerals or as inert carbon (Kögel-Knabner *et al*., 2008) [15]. In contrast, the DNA of microbes, here mainly as bacterial or archaeal in the soils, could be mostly adsorbed on clay minerals or hidden in small micro pores within the fine aggregates (Chiu *et al*., 2006) [6]. Naresh *et al*. (2018) [25] revealed that as compared to conventional tillage, the percentages of >2 mm macro-aggregates and water-stable macro-aggregates in rice-wheat double conservation tillage (zero-tillage and straw incorporation) were increased 17.22% and 36.38% in the 0–15 cm soil layer and 28.93% and 66.34% in the 15–30 cm soil layer, respectively. Zero tillage and straw incorporation also increased the mean weight diameter and stability of the soil aggregates. In surface soil (0–15 cm), the maximum proportion of total aggregated carbon was retained with 0.25–0.106 mm aggregates, and rice-wheat double-conservation tillage had the greatest ability to hold the organic carbon (33.64 g kg^{-1}). In the NPK + FYM treatment, LOC was ~16% significantly higher in topsoil than the sub-surface soil.

Table 2: (A) SOC, total N and LOC in g kg^{-1} and SMBC in mg kg^{-1} of the size fractions (PSFs) of the soil chronosequence and (B) DNA content (μg g^{-1}), and the copy numbers of bacterial (BA; copies $x10^9 g^{-1}$), fungi (FA;copies $x10^7 g^{-1}$) and archaeal (ArA;copies $x10^8 g^{-1}$) of the size fractions [Liu *et al*., 2016] [19].

Fraction	Soil	DNA	BA	FA	ArA
Coarse sand (2000–200 μm)	*P*0	3.32 ± 0.07Ae	5.86 ± 0.75Ad	8.92 ± 1.50Ab	0.81 ± 0.03Ce
	*P*50	35.33 ± 0.42Aa	46.18 ± 9.21Aa	15.50 ± 2.60Aa	6.37 ± 0.81Bd
	*P*100	24.72 ± 2.14Ac	31.45 ± 5.79Ab	10.49 ± 0.87Ab	13.54 ± 0.73Bc
	*P*300	16.20 ± 0.05Ad	10.12 ± 2.39Ac	8.12 ± 0.32Ab	16.01 ± 1.06Ab
	*P*700	31.95 ± 0.64Ab	14.25 ± 1.03Ac	9.40 ± 0.71Ab	21.17 ± 0.48Ba
Fine sand (200–20 μm)	*P*0	3.63 ± 0.28Ab	4.90 ± 0.45Ab	3.23 ± 0.27Bc	2.83 ± 0.18Ac
	*P*50	4.35 ± 0.40Db	8.42 ± 1.75Ba	8.04 ± 0.25Ba	5.27 ± 1.12Bd
	*P*100	13.63 ± 3.30Ba	7.75 ± 1.18Ca	8.37 ± 0.67Aa	8.16 ± 2.27Cab
	*P*300	9.97 ± 0.33Ba	4.92 ± 1.10Bb	6.23 ± 0.23Bb	3.57 ± 0.24Cb
	*P*700	12.83 ± 0.33Ca	8.16 ± 1.64Ba	2.43 ± 0.19Cd	7.68 ± 0.66Ca
Silt (20–2 μm)	*P*0	1.57 ± 0.28Bc	1.78 ± 0.15Bc	3.98 ± 0.57Ba	0.29 ± 0.02Dd
	*P*50	10.02 ± 1.58Ca	10.64 ± 2.95Ba	4.25 ± 0.30Ca	2.48 ± 0.44Cc
	*P*100	8.25 ± 0.12Cab	5.78 ± 0.36Cb	2.17 ± 0.20Bb	8.65 ± 0.09Ca
	*P*300	7.78 ± 0.31Cb	5.91 ± 0.81Bb	2.47 ± 0.45Bb	6.60 ± 0.27Bb
	*P*700	9.25 ± 0.64Da	6.16 ± 0.29Bb	3.68 ± 0.19Ba	9.44 ± 1.41Ca
Clay (< 2 μm)	*P*0	4.00 ± 1.89Ad	5.27 ± 0.61Ac	0.52 ± 0.03Cd	1.83 ± 0.10Bc
	*P*50	17.62 ± 0.26Bb	38.05 ± 4.92Aa	1.31 ± 0.07Dc	14.08 ± 2.13Ab
	*P*100	16.20 ± 0.38Bb	15.86 ± 3.31Bb	1.94 ± 0.30Bb	44.66 ± 13.68Aa
	*P*300	11.17 ± 0.90Bc	13.03 ± 2.58Ab	1.39 ± 0.40Cb	22.16 ± 6.17Aa
	*P*700	25.67 ± 0.57Ba	15.63 ± 2.24Ab	2.48 ± 0.31Ca	36.00 ± 3.82Aa

PSF	Soil	SOC	Total N	LOC	SMBC
Coarse sand (2000–200 μm)	*P*0	11.07 ± 1.20Ad	1.04 ± 0.11Ad	6.22 ± 0.18Ac	not determined
	*P*50	53.44 ± 1.09Ab	4.15 ± 0.49Aa	27.85 ± 1.61Aa	794.7 ± 47.0Ac
	*P*100	41.74 ± 1.31Ac	3.37 ± 0.38Ab	19.69 ± 1.16Ab	1052 ± 73.7Ab
	*P*300	40.64 ± 1.57Ac	2.72 ± 0.12Ac	18.80 ± 1.45Ab	1385 ± 88.1Aa
	*P*700	60.79 ± 1.88Aa	4.43 ± 0.22Aa	28.64 ± 1.90Aa	1480 ± 166.2Aa
Fine Sand (200–20 μm)	*P*0	9.90 ± 0.43Ac	1.01 ± 0.14Ac	4.34 ± 0.14Bb	188.0 ± 8.0Ac
	*P*50	8.45 ± 0.27Cc	0.73 ± 0.11Dd	3.66 ± 0.57Cb	309.2 ± 16.5Bb
	*P*100	16.48 ± 0.41Cb	1.57 ± 0.14Cb	7.36 ± 0.32Ca	441.1 ± 13.4Ba
	*P*300	15.16 ± 1.45Cb	1.51 ± 0.13Bb	7.03 ± 0.30Ca	445.9 ± 28.2Ba
	*P*700	19.86 ± 1.11Ca	1.81 ± 0.12Ca	7.99 ± 0.65Ba	449.9 ± 25.9Ba
Silt (20–2 μm)	*P*0	5.13 ± 0.19Bb	0.52 ± 0.14Bd	1.53 ± 0.13Db	166.7 ± 4.5Ad
	*P*50	10.73 ± 0.55Ba	1.20 ± 0.11Cb	4.50 ± 0.13Ca	296.2 ± 15.0Bc
	*P*100	10.13 ± 0.44Da	1.15 ± 0.09Cc	4.10 ± 0.26Da	287.0 ± 2.7Cc
	*P*300	11.37 ± 0.58Da	1.33 ± 0.11Ba	4.39 ± 0.29Da	392.1 ± 15.0Ba
	*P*700	10.57 ± 0.43Da	1.11 ± 0.08Dc	3.95 ± 0.69Ca	348.3 ± 10.5Cb
Clay (< 2 μm)	*P*0	9.29 ± 0.29Ac	1.17 ± 0.15Ad	2.96 ± 0.27Cc	155.6 ± 18.1Ac
	*P*50	19.80 ± 1.47Bb	2.27 ± 0.14Bc	7.99 ± 0.28Bb	284.9 ± 19.7Bb
	*P*100	22.94 ± 1.43Ba	2.70 ± 0.12Bb	9.19 ± 0.35Ba	279.4 ± 5.0Cb
	*P*300	23.45 ± 1.46Ba	2.92 ± 0.12Aa	9.36 ± 0.40Ba	324.8 ± 13.1Ca
	*P*700	24.36 ± 1.65Ba	2.73 ± 0.16Bb	9.05 ± 0.47Ba	325.7 ± 8.1Ca

bbreviation: SOC: soil organic carbon, LOC: labile organic carbon, SMBC: soil microbial biomass carbon.

Naresh *et al*. (2017) [24] reported that after 15 years, T_3 treatment resulted in significantly increased 66.1%, 50.9%, 38.3% and 32% LFOC, PON, LFON and POC, over T_7 treatment and WSC 39.6% in surface soil and 37.4% in subsurface soil. Out of the four C fractions, LFOC was the most sensitive indicator of changes in TOC induced by the soil tillage and nutrient management practices [Table 3]. LFOC were also significantly higher following the treatments including organic amendment than following applications solely of chemical fertilizers, except that the F_5, F_6 and F_7 treatments resulted in similar LFOC contents. Application solely of chemical fertilizers had no significant effects on LFOC and LFON fractions compared with unfertilized control plots. Nevertheless, application of F_5 or F_6 significantly increased contents of POC relative to F_1 (by 49.6% and 63.4%), respectively.

Table 3: Effect of 15 years of application of treatments on contents of various labile fractions of carbon in soil [Naresh *et al*., 2017] [24].

Treatments	0-5 cm layer					5-15 cm layer				
	WSC (mgkg^{-1})	POC (mgkg^{-1})	PON (mgkg^{-1})	LFOC (mgkg^{-1})	LFON (mgkg^{-1})	WSC (mgkg^{-1})	POC (mgkg^{-1})	PON (mgkg^{-1})	LFOC (mgkg^{-1})	LFON (mgkg^{-1})
Tillage crop residue practices										
T_1	23.9^{d}	638^{d}	67.2^{d}	81.3^{d}	9.1^{d}	15.7^{d}	535^{e}	54.7^{e}	65.1^{d}	7.8^{d}
T_2	25.9^{c}	898^{bc}	88.6^{cd}	107.8^{bc}	11.8^{c}	17.8^{cd}	674^{cd}	74.5^{cd}	94.1^{bc}	9.1^{c}
T_3	27.8^{ab}	1105^{ab}	106.7^{ab}	155.2^{a}	13.3^{ab}	19.6^{bc}	785^{bc}	91.8^{ab}	132.6^{a}	10.9^{ab}
T_4	22.7^{d}	779^{cd}	77.9^{d}	95.7^{c}	9.8^{d}	17.6^{cd}	609de	69.1^{de}	87.6^{c}	8.3^{cd}
T_5	26.4^{bc}	1033^{b}	97.4^{bc}	128.8^{b}	12.6^{bc}	20.3^{ab}	842^{ab}	87.3^{bc}	102.9^{b}	10.4^{b}
T_6	29.2^{a}	1357^{a}	117.5^{a}	177.8^{a}	14.2^{a}	22.6^{a}	974^{a}	106.1^{a}	141.2^{a}	11.8^{a}
T_7	17.2^{e}	620^{d}	22.5^{e}	52.7^{e}	8.2^{d}	13.2^{e}	485^{e}	18.8^{f}	49.8^{e}	6.8^{e}
Nutrient Management Practices										
F_1	21.9^{e}	631^{d}	24.7^{e}	89.2^{c}	6.8^{d}	15.1^{e}	585	17.3^{e}	47.9^{f}	5.9^{e}
F_2	29.2^{cd}	869^{c}	92.5^{c}	96.4^{c}	9.5^{c}	20.2^{cd}	789	73.5^{cd}	85.9^{d}	8.9^{c}
F_3	29.8^{c}	956^{bc}	96.8^{c}	108.1^{bc}	10.5^{bc}	21.9^{bc}	813	79.4^{c}	96.9^{cd}	9.6^{bc}
F_4	28.4^{d}	788^{cd}	72.9^{d}	91.3^{c}	7.9^{d}	18.8^{d}	728	59.4^{d}	66.7^{e}	7.2^{d}
F_5	32.5^{a}	1381^{a}	130.8^{a}	183.9^{a}	13.8^{a}	26.4^{a}	1032a	112.1^{a}	152.9^{a}	12.4^{a}
F_6	31.6^{ab}	1156^{ab}	114.2^{ab}	160.5^{a}	12.6^{ab}	23.6^{ab}	905ab	96.7^{ab}	139.7^{a}	11.9^{a}
F_7	30.9^{b}	1102^{b}	103.9^{bc}	123.5^{b}	11.5^{b}	22.7^{b}	826b	88.3^{bc}	103.2^{bc}	10.1^{b}

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

WSC = water soluble C, POC = particulate organic C, PON = particulate organic N, LFOC = light fraction organic C, and LFON = light fraction organic N.

Krishna *et al*. (2018) [17] reported that the total organic carbon (TOC) allocated into different pools in order of very labile > less labile > non labile >labile, constituting about 41.4, 20.6, 19.3 and 18.7%, respectively. In comparison with control, system receiving farmyard manure (FYM-10Mg ha^{-1}season-^{1}) alone showed greater C build up (40.5%) followed by 100% NPK+FYM (120:60:40 kg N, P, K ha^{-1}+5 Mg FYM ha^{-1}season^{-1}) (16.2%). In fact, a net depletion of carbon stock was observed with 50% NPK (-1.2 Mg ha^{-1}) and control (-1.8 Mg ha^{-1}) treatments. Only 28.9% of C applied through FYM was stabilized as SOC. A minimal input of 2.34 Mg C ha^{-1} y^{-1} is needed to maintain SOC level [Table 4]. The magnitude of carbon pools extracted under a gradient of oxidizing conditions was as follows: C_{VL}>C_{LL}> C_{NL}> C_L constituting about 41.4, 20.6, and 19.3 and 18.7%, respectively, of the TOC [Table 3]. However, the contribution of VL, L and LL pools to SOC was 51.2, 23.1 and 25.5%, respectively. While active pool (C_{VL}+C_L) constituted about60.1%, passive pool (C_{LL}+C_{NL}) represented 39.9% of the TOC. Among the treatments, 100% NPK+FYM (44.4%) maintained a proportionately higher amount of soil C in passive pools. With an increase in the dose of fertilization, on average, C allocation into passive pool was increased (33.0, 35.3, 40.7% and 39.3% of TOC under control, 50% NPK, 100% NPK and 150% NPK treatments, respectively).

Table 4: Oxidisable organic carbon fractions (very labile, labile, less labile and non-labile) in soils (g kg^{-1}) at different layers (cm) [Krishna *et al*., 2018] [17].

Treatment	Very labile C				Labile C			
	0-15	15-30	30-45	Total	0-15	15-30	30-45	Total
Control	3.6±0.5^{c}	1.4±0.3^{b}	1.3±0.2^{a}	6.3±0.4^{b}	2.4±0.3^{a}	1. 0±0.2^{a}	0.8±0.4^{a}	4.2±0.6^{a}
50% NPK	4.6±0.3^{bc}	2.1±0.7^{ab}	1.5±0.1^{a}	8.1±0.9^{a}	1.7±0.4^{ab}	0.9±0.5^{a}	0.7±0.2^{a}	3.3±0.7^{a}
100% NPK	4.4±0.3^{bc}	2.3±0.2^{a}	1.4±0.5^{a}	8.0±0.7^{a}	1.8±0.4^{ab}	0.8±0.5^{a}	0.6±0.3^{a}	3.2±0.8^{a}
150% NPK	5.0±0.2^{ab}	2.6±0.2^{a}	1.5±0.1^{a}	9.0±0.3^{a}	1.2±0.3^{b}	0.7±0.2^{a}	0.9±0.2^{a}	2.8±0.4^{a}
100% NPK+FYM	4.8±0.2^{ab}	2.0±0.2^{ab}	1.3±0.3^{a}	8.1±0.2^{a}	1.9±0.3^{ab}	0.7±0.2^{a}	0.7±0.3^{a}	3.4±0.2^{a}
FYM	5.9±1.3^{a}	2.2±0.2^{a}	1.4±0.3^{a}	9.5±1.6^{a}	2.5±0.9^{a}	0.7±0.3^{a}	0.7±0.2^{a}	3.9±0.9^{a}
Fallow	4.2±0.7^{bc}	1.5±0.5^{b}	0.7±0.3^{b}	6.3±0.8^{b}	2.2±1.0^{ab}	1.0±0.3^{a}	1.0±0.4^{a}	4.1±1.1^{a}
	Less labile C				Non labile C			
Control	1.5±0.3^{c}	0.6±0.4^{c}	0.4±0.0^{c}	2.6±0.7^{d}	1.2±0.5^{b}	1.2±0.3^{a}	0.2±0.2^{b}	2.6±0.5^{b}
50% NPK	1.8±0.1^{c}	0.4±0.1^{c}	0.5±0.2^{c}	2.7±0.1^{cd}	1.2±0.9^{b}	1.7±0.8^{a}	0.7±0.4^{ab}	3.5±1.8^{ab}
100% NPK	2.5±0.3^{ab}	0.8±0.1^{bc}	1.1±0.2^{ab}	4.4±0.1^{b}	1.3±0.6^{b}	1.5±0.6^{a}	0.5±0.2^{ab}	3.3±1.0^{ab}
150% NPK	2.6±0.2^{a}	0.9±0.1^{bc}	0.4±0.2^{c}	3.9±0.1^{b}	1.4±0.3^{b}	1.5±0.2^{a}	0.8±0.1^{a}	3.7±0.3^{ab}
100% NPK+FYM	2.7±0.6^{a}	1.5±0.2^{a}	1.4±0.1^{a}	5.6±0.7^{a}	2.0±0.8^{b}	1.3±0.1^{a}	0.3±0.3^{ab}	3.5±0.7^{ab}
FYM	1.9±0.7^{bc}	1.7±0.2^{a}	1.0±0.2^{b}	4.5±0.7^{ab}	3.7±1.3^{a}	1.0±0.2^{a}	0.5±0.5^{ab}	5.1±1.9^{a}
Fallow	1.5±0.3^{c}	1.3±0.7^{ab}	0.9±0.4^{b}	3.8±1.2^{bc}	2.1±0.2^{b}	1.4±0.7^{a}	0.4±0.2^{ab}	3.9±0.9^{ab}

*values in the same column followed by different letters are significantly different at $P<0.001$ according to Duncan's Multiple Range Test (DMRT) for separation of means, ± indicates the standard deviation values.

Six and Paustian, (2014) [35] observed that 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.6a], 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. 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.6b]. Shahbaz *et al*. (2016) also found that the 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.6c]. Moreover, the portion of root-derived C in micro-aggregates was significantly higher compared to stalk and leaves [Fig. 6c]. 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.

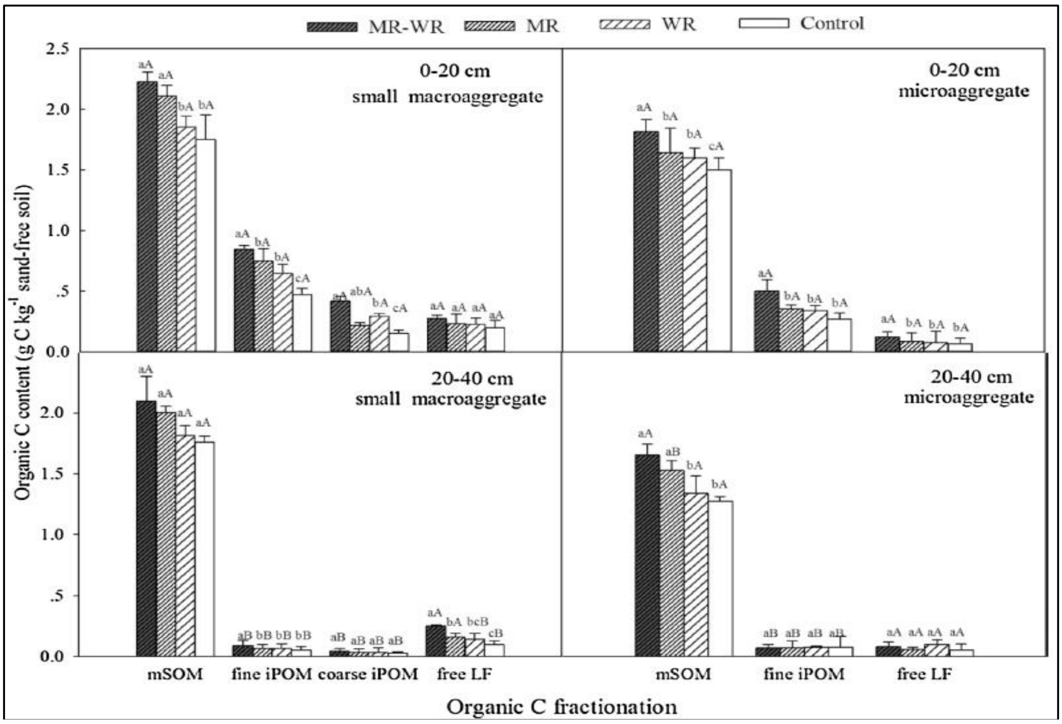


Fig 6(a): Organic C content (g kg−1 soil) of the SOC fractions: coarse iPOM, fine iPOM, mSOM, and free LF of small macro-aggregates and micro-aggregates in the 0–20 cm and 20–40 cm soil layers under MR-WR, MR, and WR

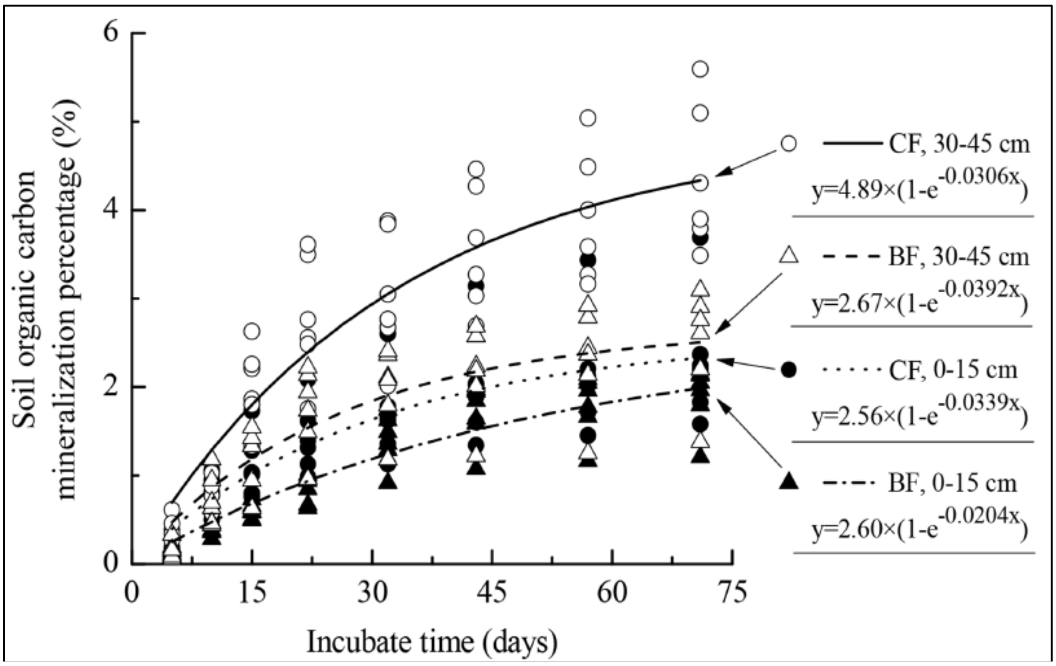


Fig 6(b): The weighted mean of soil organic carbon mineralized percentage in various aggregates vary with incubation days in two soil depths

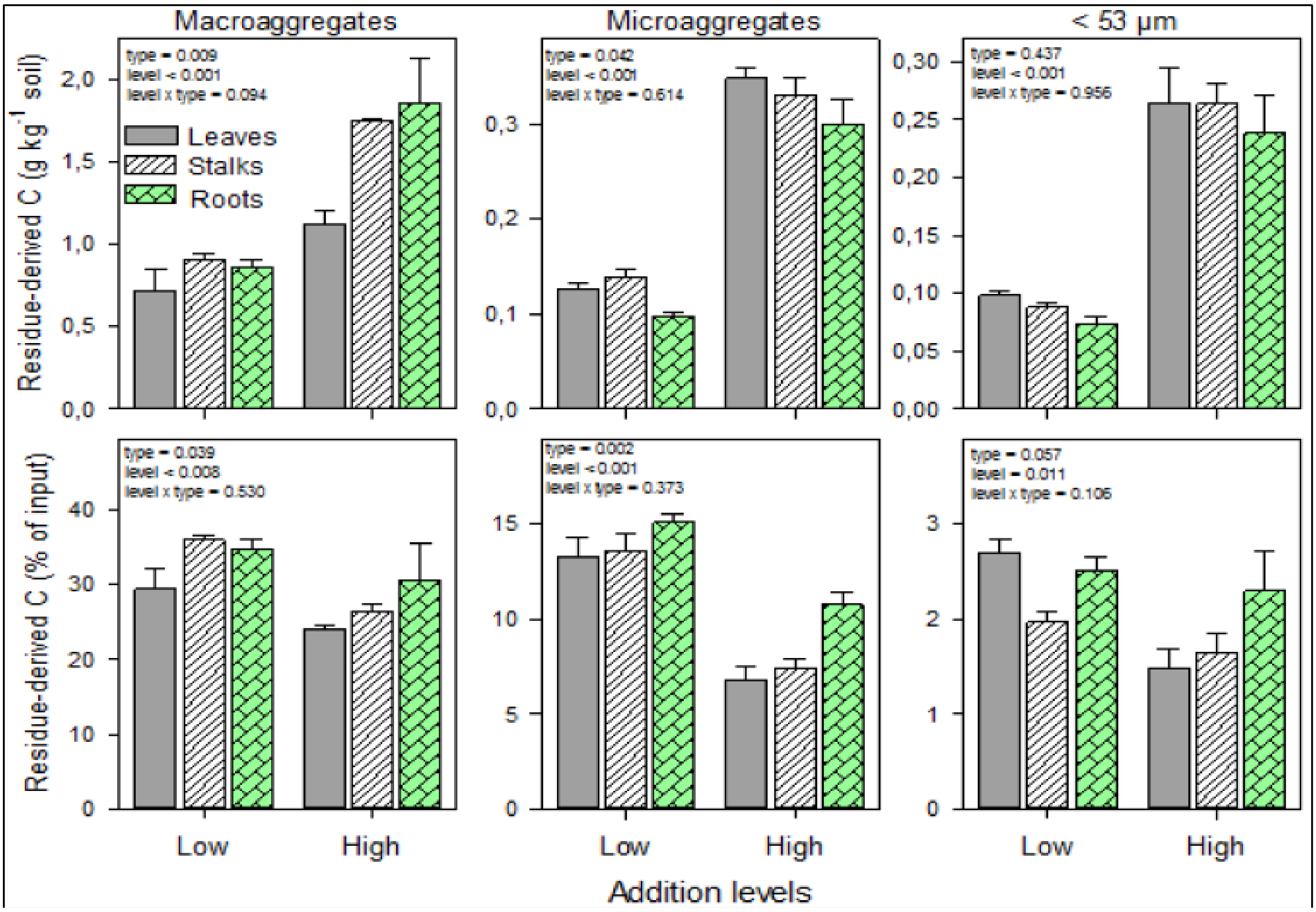


Fig 6(c): Residue-derived C in the soil aggregate size classes (Macro >250 µm, Micro 53-250 µm and silt plus clay <53 µm)

Dutta and Gokhale, (2017) [7] observed that the reduced tillage in the conservation plot resulted in higher soil moisture content, due to plant debris accumulated on the top layer of the soil. Water infiltration increased in conservation plot, which can be attributed to minimum tillage practice [Fig.7a]. Particle density or specific gravity of soil which refers to the density of the solid particles collectively was found to be higher and bulk density was significantly lower in conservation plot. The average bulk density was found to be 0.69gcm^{-3} in conservation plot while in conventional plot it was1.17gcm^{-3}. The per cent pore space or porosity was found to be higher in conservation plot in the range of 50.11+8.40%–88.87+3.59%. This is because decreased soil disturbance leads to lesser soil compaction, which increases pore-space [Fig.7a].The SOC was found to be higher in conservation plot and it ranged from 3.17+0.01kgm^{-2} to as high as 20.42+0.56 kgm^{-2} during heading stage [Fig.7b], which can be attributed to the increased accumulation of organic matter in the top soil due to minimum disturbance (minimum tillage).The reduced disturbance prevents the exposure of soil particles to microbial attack, hence reducing the loss of organic matter [Fig.7b]. A significantly higher amount of SOC was seen in heading stage, which may be because of more amount of surface water present due to heavy rainfall at that particular time [Fig.7b]. In conventional plot, less SOC was seen (2.08+0.01kgm^{-2} –7.92+0.12kgm^{-2}). Here, due to continuous tillage practices, the soil aggregates were disrupted, exposing the SOM and increasing the soils decay rate.

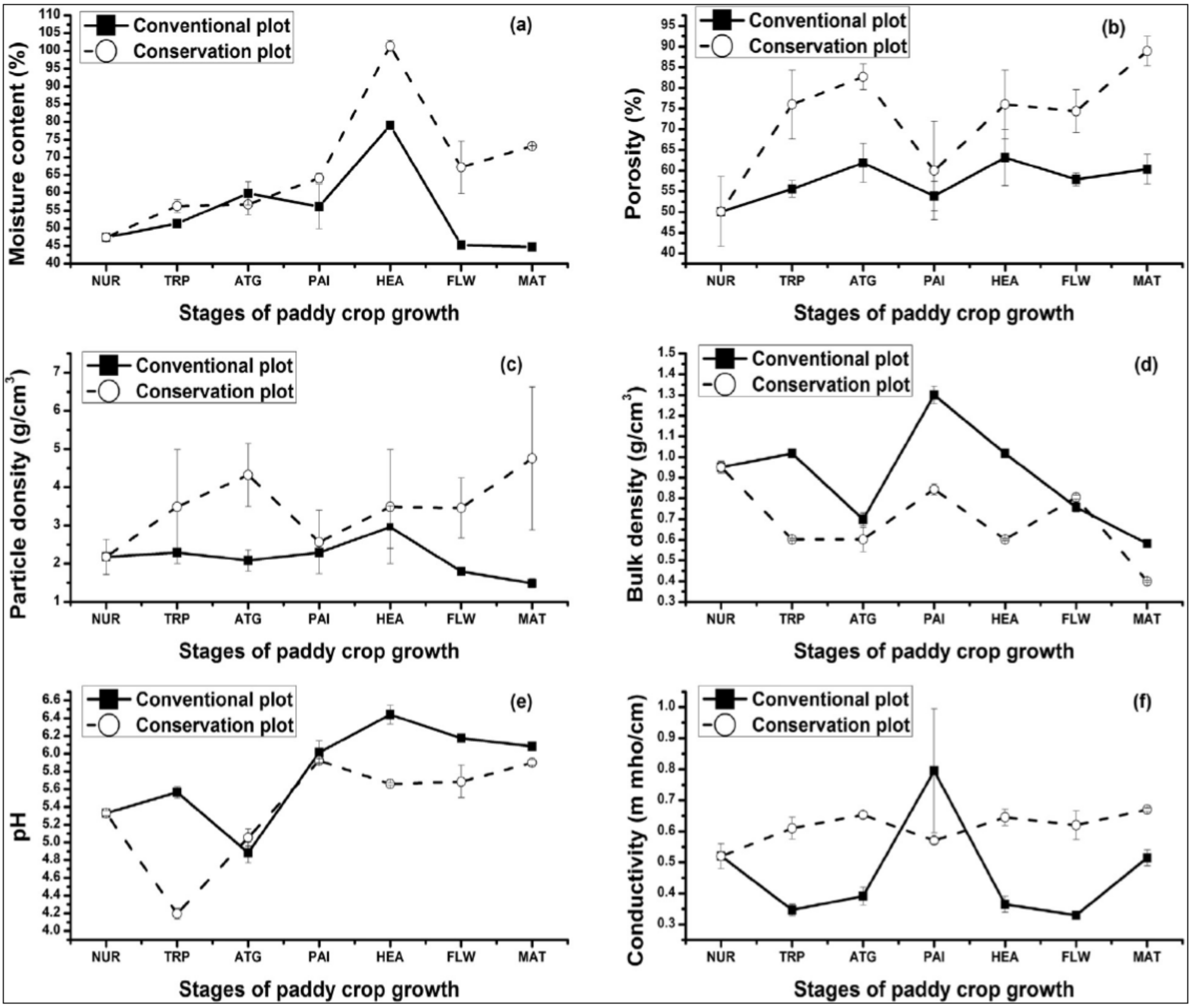


Fig 7(a): Variation of the soil parameters (a) moisture content (b) porosity (c) particle density (d) bulk density (e) pH (f) conductivity during the various stages of paddy crop growth

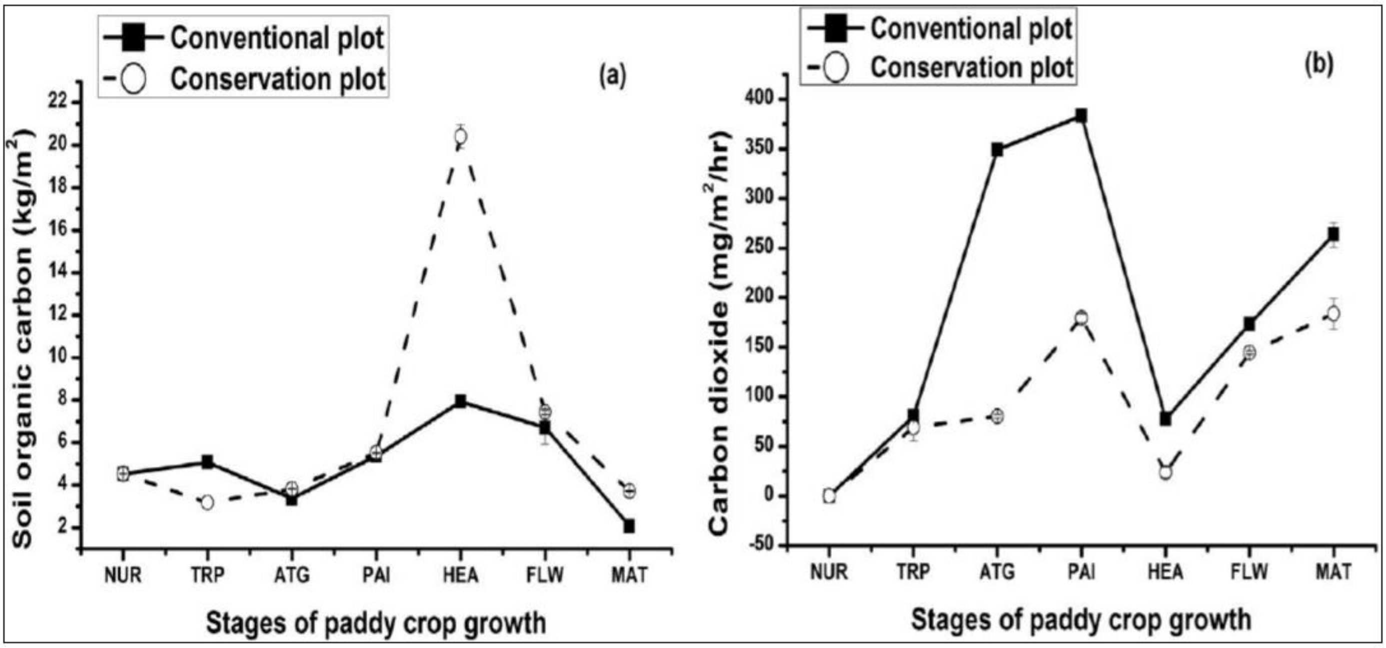


Fig 7(b): Variation of (a) soil organic carbon and (b) carbon dioxide observed in the conventional and conserved plots, during the various stages of paddy crop growth

Sheng *et al*. (2015) [32] revealed that the LFOC appeared to be more sensitive to land use changes than SOC both in top and subsoil [Fig.8a].The decrease in ROC stock through the soil depth profile. MBC stock decline was more pronounced in topsoil (49-86%) than in subsoil (21-61%) following land use change. DOC and MBC were the most sensitive indicators to land use change [Fig.8a]. POC stock cannot be used either as a sensitive indicator of SOC change because it is masked by the insensitive response of the cPOC component. Although fPOC is relatively recalcitrant and more stable than cPOC (Jolivet *et al*., 2003) [14] it consists of finer particles, and therefore, it can be easily translocate downwards by preferential flow through soil pores and cracks between aggregates. Following land use change, the reduced proportions of POC, LFOC, DOC, and MBC to SOC indicated a reduction in the proportion of readily available substrates and a lower SOC quality (Yang *et al*., 2009b) [39]. These results further imply that these four ratios can be considered as active indicators to detect alterations in SOC quality due to land use change. Furthermore, the decreased DOC to SOC ratio in subsoil following land use change showed that the main DOC loss occurred in the subsoil, highlighting the importance of DOC sorption in the subsoil. Similarly, land use and fertilization practices induced changes in the DOC to SOC ratio, which were even higher in subsoil than in topsoil (Liang *et al*., 2012). The increased ratios of POC, cPOC and fPOC to SOC in subsoil may also be largely associated with DOC leaching.

Wang, (2014) [37] found that LOC and POC contents after the application of straw were significantly higher in semi-arid soil than in sub-humid soil. Thus, the result illustrated that the effects of OMs on labial organic carbon might be greater in the semi-arid soil. The decomposition process of OMs could be divided into three stages,0–90 days for a “quick decomposition period”, 90-180days for a “slow decomposition period”, and 180-540days for a “stable decomposition period” [Fig.8b]. In 90 days, decomposition rate of OMs was over 70%. In 540 days, residual quantities of CM, SM and MS decreased to 5.69, 6.11, and 6.53 g from the initial 20g, whereas those of MR, FG, and TL decreased to 8.05, 8.84, and 10.32 g, respectively. Moreover, the decomposition rates of CM, SM, and MS (71.55%, 68.16%, and 68.21%) were higher than those of MR, FG, and TL (58.64%, 55.28%, and 47.95%), respectively [Fig.8b]. Furthermore, Vanlauwe *et al*. (2005) [36] indicated that short-term carbon dynamics was controlled by the quality parameters of OMs inputted, such as lignin, N, and polyphenol contents and this funding was confirmed further by Singh *et al*. (2009) [33] suggested that the quality of OMs was an important factor on agricultural soil carbon changes besides the amount of injected carbon. The trends of quantities of carbon released from OMs were first quickly increased and then tended to stable in decomposition process [Fig.8c]. Quantity of carbon released from MS was higher than those of other OMs in each period. In 90 days, quantities of carbon released from OMs were over 65%. In 540 days, quantities of carbon released from MS, TL, MR, FG, SM, and CM were 6.38, 4.85, 4.71, 4.64, 4.37, and 3.80 g, respectively.

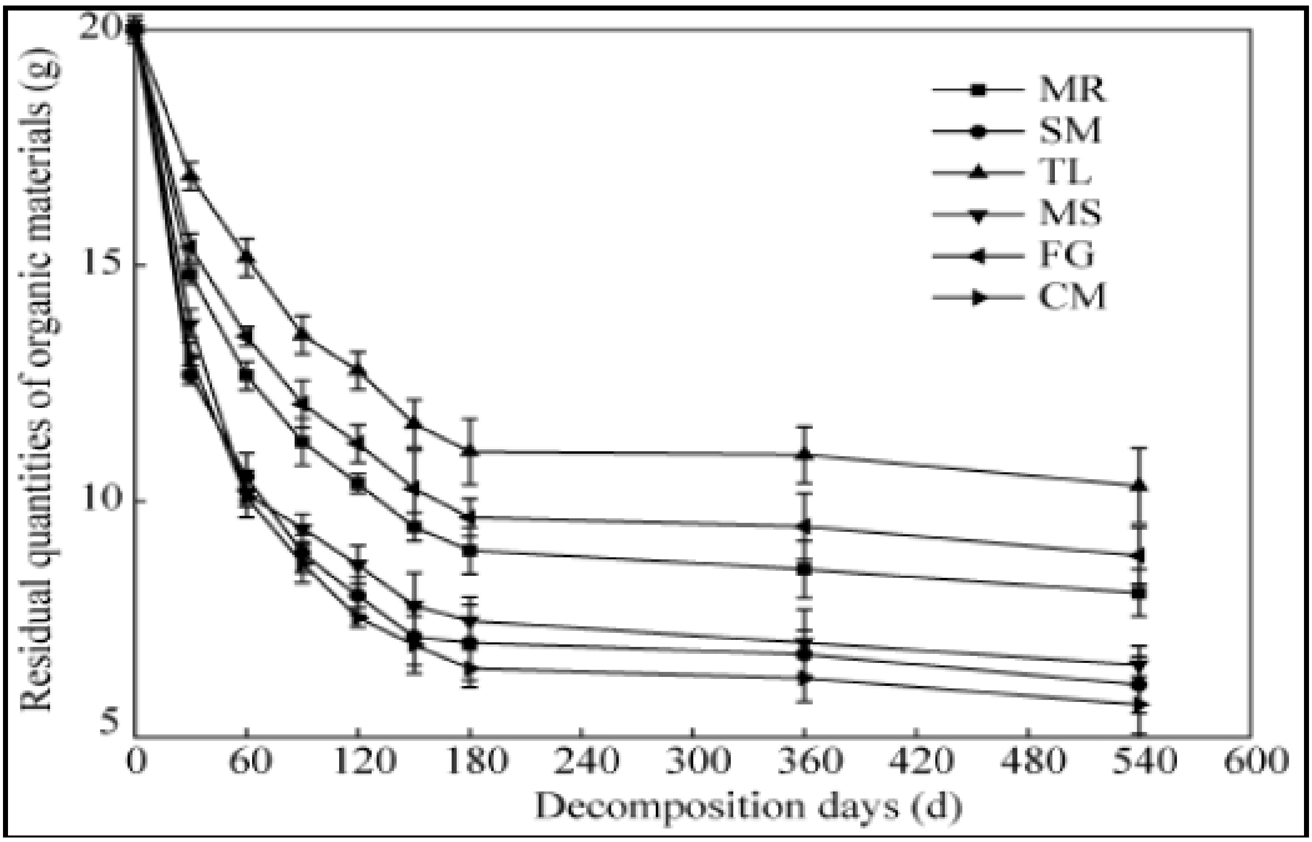


Fig 8(a): LOC fraction stocks in relation to depth and land use systems. LOC, LFOC, ROC, DOC and MBC represent labile organic C, light fraction organic C, readily oxidizable organic C, dissolved organic C and microbial biomass

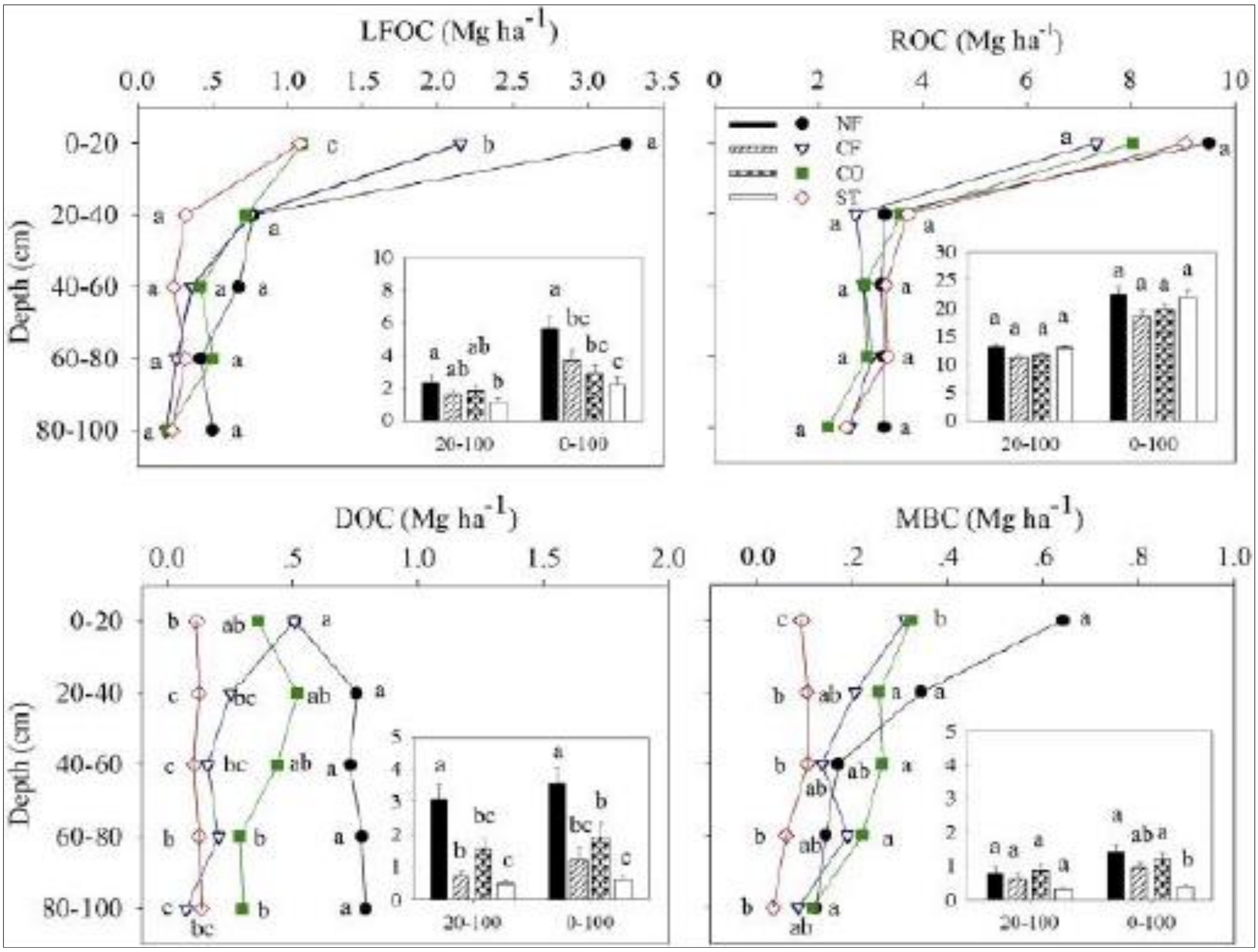


Fig 8(b): Dynamic changes of residual quantities of OMs in decomposition process under different treatments

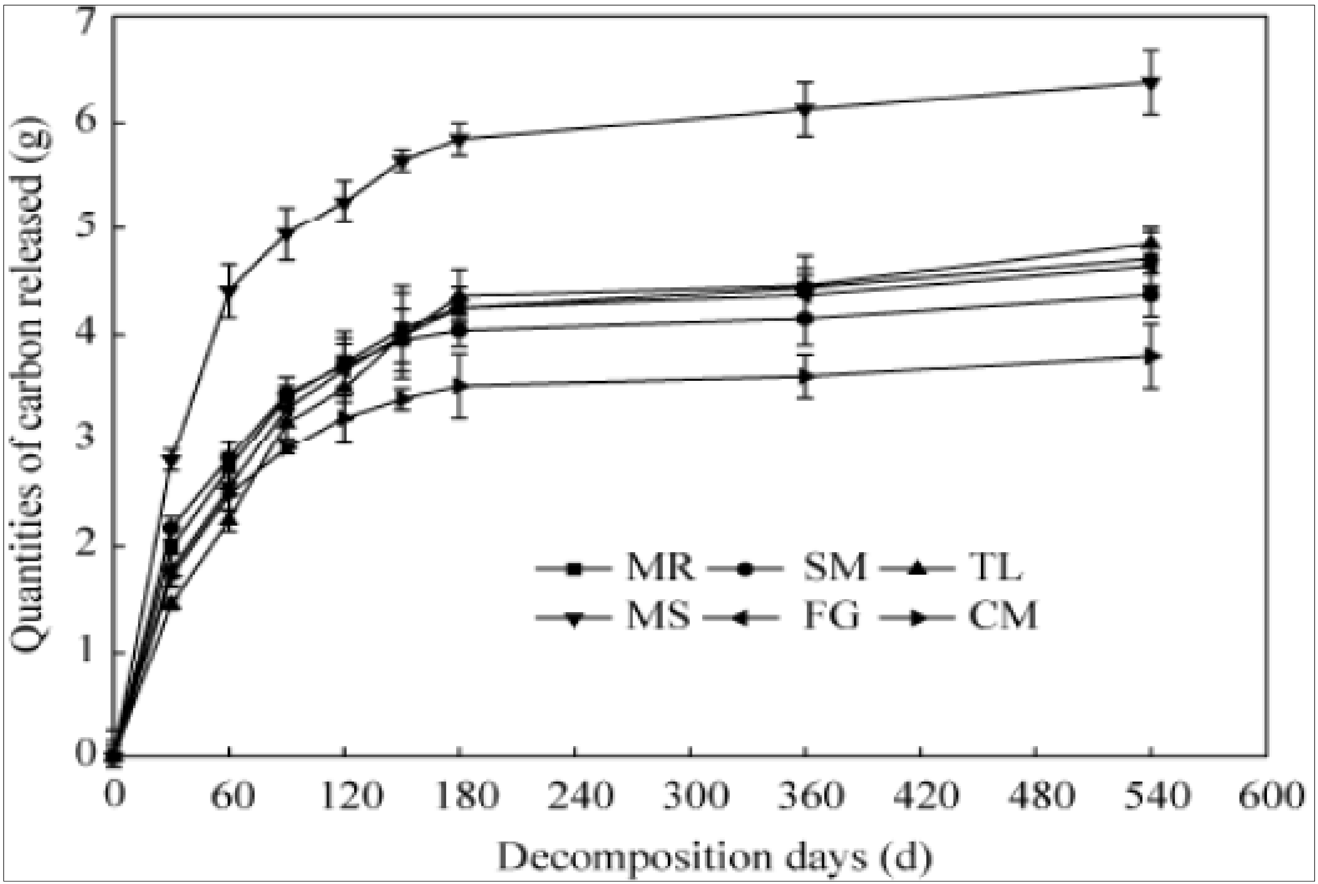


Fig 8(c): Dynamic changes of quantities of carbon released from OMs in decomposition process under different treatments

Conclusion

Zero-till direct-seeded rice and wheat provided better soil physical conditions for R–W system productivity through physical manipulation of soil as well as changes in SOC content. On the other hand, soil puddling (wet tillage) in rice showed a negative impact on soil physical status for wheat. Transplanting of rice, even without puddling, on flat or raised beds was also detrimental to soil physical productivity. Zero-till in wheat after puddled TPR did not improve soil physical properties, indicating that the positive effect of ZT in wheat was lost during rice by puddling operations. Conventional tillage (CT) significantly reduces macro-aggregates to smaller ones, thus aggregate stability was reduced by 35% compared with conservation system (CS), further indicating that tillage practices led to soil structural damage. The concentrations of SOC and other nutrients are also significantly higher under CS than CT, implying that CS may be an ideal enhancer of soil productivity in the ecosystem through improving soil structure which leads to the protection of SOM and nutrients, and the maintenance of higher nutrient content. The average concentration of particulate organic carbon (POC), dissolved organic carbon (DOC) and microbial biomass carbon (MBC) in organic manure plus inorganic fertilizer treatments (NP+S and NP+FYM) in 0–60 cm depth were increased by 64.9–91.9%, 42.5–56.9%, and 74.7–99.4%, respectively, over the CK treatment. Organic carbon concentrations in the <0.053-, 0.053- to 0.25-, 0.25- to 2.0, and >2.0-mm fractions were 14.0, 12.0, 14.4, 24.1% greater, respectively, in CA than in CF. The contents of SOC,LOC, DOC, POC and EOC by 14.73%, 16.5%, 22.5%, 41.5% and 21% in the 0-40 cm soil layer, and by 17%, 14%, 19%, and 30% in the 0-100 cm soil layer. These results suggest that over time, the MBC and MBC-derived C under the fine-sized residue treatment may constitute a significant source of stable SOC through strong physical and chemical bonding to the mineral soil matrix.

Conventional tillage in comparison with NT significantly reduced macro-aggregates with a significant redistribution of aggregates - into micro-aggregates. Aggregate protected labile C and N were significantly greater for macro-aggregates, (>2000 and 250–2000 µm) than –micro-aggregates (53–250 and 20–53 µm) and greater for M than F indicating physical protection of labile C within macro-aggregates. No -tillage and M a lone each significantly increased soil aggregation and aggregate-associated C and N; however, NT and M together further improved soil aggregation and aggregate-protected C and N. However, conservation tillage practices with integrated organic manure and mineral fertilization could be important strategies for improving SOC status and maintaining soil quality in soils in North-Western IGP. The conservation agriculture based alternative technologies seem to be promising options to sustain the rice-wheat productivity on a long-term basis.

References

1. Anonymous, Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministery of agriculture and Farmer’s welfare. Govt. of India, 2016.
2. Bhatt R, Kukal SS, Busari MA, Arora S, Yadav M. Sustainability issues on rice–wheat cropping system. Int. Bhatt R, Kukal SS, Busari MA, Arora S, Yadav M, 2016. Sustainability issues on rice–wheat cropping system. Int. Soil Water Conserv. Res. 2016; 4:64-74.
3. Causarano HJ, Franzluebbers AJ, Shaw JN, Reeves DW, Raper RL, Wood CW. Soil Organic Carbon Fractions and Aggregationin the Southern Piedmont and Coastal Plain. Soil Sci. Soc. Am. J. 2008; 72:221-230
4. Chan KY. The important role of soil organic carbon in future mixed farming systems. In: Proceedings of the 25th Annual Conference of the Grassland Society of NSW. Dubbo NSW, Australia, 2010, 24-26.
5. Chen HQ, Marhan S, Billen N, Stahr K. Soil organic carbon and total nitrogen stocks as affected by different land uses. J Plant Nutr. Soil Sci. 2009; 172:32-42.
6. Chiu CY, Chen TH, Imberger K, Tian G. Particle size fractionation of fungal and bacterial biomass in subalpine grassland and forest soils. Geoderma. 2006; 130:265-271.
7. Dutta J, Gokhale S. Field investigation of carbon dioxide (CO2) fluxes and organic carbon from a conserved paddy field of North-East India. Int. Soil Water Censer Res. 2017; 5:325-334.
8. Fang X, Zhou G, Li Y, Liu S, Chu G, Xu Z *et al*. Warming effects on biomass and composition of microbial communities and enzyme activities within soil aggregates in subtropical forest. Biol Fertil Soils. 2016; 52:353-365.
9. Gathala MK, Ladha JK, Saharawat YS, Kumar V, Vivak Kumar, Sharma PK. Effect of Tillage and Crop Establishment Methods on Physical Properties of a Medium-Textured Soil under a Seven-Year Rice−Wheat Rotation, Soil Sci. Soc. Am. J. 2011; 75:1851-1862.
10. Gu C, Liu Y, Mohamed I, Zhang R, Wang X, Nie X *et al*. Dynamic Changes of Soil Surface Organic Carbon under Different Mulching Practices in Citrus Orchards on Sloping Land. PLoS one. 2016; 11(12):e0168384. Doi: 10.1371/journal. pone.0168384
11. Jardine PM, McCarthy JF, Weber NL. Mechanisms of dissolved organic carbon adsorption on soil. Soil Sci. Soc. Am J. 1989; 53(5):1378-1385.
12. Jat ML, Gathala MK, Singh KK, Ladha JK, Singh S, Gupta RK *et al*. Experiences with permanent beds in the rice-wheat systems of the western Indo-Gangetic Plain. In: Humphreys E, Roth C H. Permanent Beds and Rice-Residue Management for Rice-Wheat Systems in the Indo-Gangetic Plain. Proceedings of a Workshop Held in Ludhiana, India, 7-9 September 2006. ACIAR Proceedings, 2008, 127:98.
13. Jat RK, Sapkota TB, Singh RG, Jat ML, Kumar M, Gupta RK. Seven years of conservation agriculture in a rice-wheat rotation of Eastern Gangetic Plains of South Asia: yield trends and economic profitability. Field Crops Res. 2014; 164:199-210.
14. Jolivet C, Arrouays D, Leveque J, Andreux F, Chenu C. Organic carbon dynamics in soil particle-size separates of sandy Spodosols when forest is cleared for maize cropping. Eur. J Soil Sci. 2003; 54:257-268.
15. Kögel-Knabner I, Guggenberger G, Kleber M, Kandeler E, Kalbitz K, Scheu S. Organo-mineral associations in temperate soils: integrating biology, mineralogy, and organic matter chemistry. J Plant Nutr. Soil Sc. 2008; 171:61-82.
16. Kölbl A, Schad P, Jahn R, Amelung W, Bannert A, Cao Z *et al*. Accelerated soil formation due to paddy management on marshlands (Zhejiang Province, China). Geoderma. 2014; 228:67-89
17. Krishna CA, Majumder SP, Padhan D, Badole S, Datta A, Mandal B *et al*. Carbon dynamics, potential and cost of carbon sequestration in double rice cropping system in semi-arid southern India. J Soil Sci. Plant Nutri. 2018; 18(2):418-434.

18. Liang C, Balser TC. Microbial production of recalcitrant organic matter in global soils: implications for productivity and climate policy. Nature Reviews Microbiol. 2010; 9:75.
19. Liu Y, Wang P, Ding Y, Lu H, Li L, Cheng K, Zheng J *et al*. Microbial activity promoted with organic carbon accumulation in macro-aggregates of paddy soils under long-term rice cultivation. Biogeosci. 2016; 13:6565-6586
20. Mandal B, Majumder B, Adhya TK, Bandyopadhyay PK, Gangopadhyay A, Sarkar D. Potential of double-cropped rice ecology to conserve organic carbon under subtropical climate. Glob Change Biol. 2008; 14:2139-2151.
21. Mondal M, Kumar S, Haris AA, Dwivedi SK, Bhatt BP, Mishra JS. Effect of different rice establishment methods on soil physical properties in drought-prone, rainfed lowlands of Bihar, India. Soil Res. 2016; 54(8):997-1006.
22. Naresh RK, Gupta RK, Kumar A, Singh B, Prakash S, Kumar S *et al*. Direct-seeding and reduced-tillage options in the rice-wheat system of the Western Indo-Gangetic Plains. Int J Agric Sci. 2011; 7(1):197-208.
23. Naresh RK, Tomar SS, Kumar D, Samsher Purushottam, Singh SP, Dwivedi A *et al*. Experiences with Rice Grown on Permanent Raised Beds: Effect of Crop Establishment Techniques on Water Use, Productivity, Profitability and Soil Physical Properties, Rice Science. 2014; 21(3):170-180.
24. Naresh RK, Timsina J, Bhaskar S, Gupta RK, Singh AK, Dhaliwal SS *et al*. Effects of Tillage, Residue and Nutrient Management on Soil Organic Carbon Dynamics and its Fractions, Soil Aggregate Stability and Soil Carbon Sequestration: A Review. EC Nutrition. 2017; (12)2:53-80.
25. Naresh RK, Tyagi S, Mahajan NC, Lali Jat, Richa Tiwari, Kumar M *et al*. Does a different tillage system after input of rice and wheat residues affect carbon dynamics through changes of allocation of soil organic matter within aggregate fractions? A review, J Pharm Phytochem. 2018; 7(3):1429-1447.
26. Qian HY, Pan JJ, Sun B. The relative impact of land use and soil properties on sizes and turnover rates of soil organic carbon pools in Subtropical China. Soil Use Manage. 2013; 29:510-518.
27. Saharawat YS, Singh B, Malik RK, Ladha JK, Gathala M, Jat ML *et al*. Evaluation of alternative tillage and crop establishment methods in a rice-wheat rotation in North Western IGP. Field Crop Res. 2010; 116:260-267.
28. Sainju UM, T Caesar-TonTh at, Jabro JL. Carbon and nitrogen fractions in dryland soil aggregates aff ected by long-term tillage and cropping sequences. Soil Sci. Soc. Am. J. 2009; 73:1488-1495.
29. Sapkota TB, Jat RK, Singh RG, Jat ML, Stirling CM, Jat, MK *et al*. Soil organic carbon changes after seven years of conservation agriculture in a rice–wheat system of the eastern Indo-Gangetic Plains. Soil Use Manage. 2017; 33:81-89.
30. Sharma PC, Jat HS, Kumar V, Gathala MK, Datta A, Yaduvanshi NPS *et al*. A Sustainable Intensification Opportunities under Current and Future Cereal Systems of North-West India. Technical Bulletin: CSSRI/ Karnal/ 2015/4. Central Soil Salinity Research Institute, Karnal, 2015, 46.
31. Shahbaz M, Kuzyakov Y, Heitkamp F. Decrease of soil organic matter stabilization with increasing inputs: Mechanisms and controls. Geoderma, 2016. http://dx. doi.org/ 10.1016/j. geoderma.2016.05.019
32. Sheng H, Zhou P, Zhang Y, Kuzyakov Y, Zhou Q, Ge T, Wang C. Loss of labile organic carbon from subsoil due to land-use changes in subtropical China. Soil Biol. Biochemist. 2015; 88:148-157.
33. Singh KP, Ghoshal N, Singh S. Soil carbon dioxide flux, carbon sequestration and crop productivity in a tropical dry land agro-ecosystem: influence of organic inputs of varying resource quality. App Soil Eco. 2009; 42(3):243-253.
34. Six J, Elliott ET, Paustian K. Aggregate and Soil Organic Matter Dynamics under Conventional and No-Tillage Systems. Soil Sci. Soc. Am J. 1998; 63(5):1350-1358.
35. Six J, Paustian K. Aggregate-associated soil organic matter as an ecosystem property and a measurement tool. Soil Biol. Biochem. 2014; 68:A4-A9.
36. Vanlauwe B, Gachengo C, Shepherd K, Barrios E, Cadisch G, Palm CA. Laboratory validation of a resource quality-based conceptual framework for organic matter management. Soil Sci Soc Am J. 2005; 69(4):1135-1145.
37. Wang R, Filley TR, Xu Z, Wang X, Li MH, Zhang Y *et al*. Coupled response of soil carbon and nitrogen pools and enzyme activities to nitrogen and water addition in a semi-arid grassland of Inner Mongolia. Plant Soil. 2014; 381(1-2):323-336.
38. Wissing L, Kölbl A, Häusler W, Schad P, Cao ZH, Kögel-Knabner I. Management-induced organic carbon accumulation in paddy soils: the role of organo-mineral associations. Soil Tillage Res. 2013; 126:60-71.
39. Yang Y, Xie J, Sheng H, Chen G, Li X, Yang Z. The impact of land use/ cover change on storage and quality of soil organic carbon in mid subtropical mountainous area of southern China. J Geographi Sci. 2009b; 19:49-57.
40. Zhao H, Shar AG, Li S, Chen Y, Shi J, Zhang X *et al*. Effect of straw return mode on soil aggregation and aggregate carbon content in an annual maize-wheat double cropping system. Soil Tillage Res. 2018; 175:178-186.