Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2018; 7(4): 583-602
Received: 24-05-2018
Accepted: 29-06-2018

Impact of long-term agricultural management practices on stability of soil organic matter and soil organic carbon stocks under rice-wheat cropping system: A review

RK Naresh, RK Gupta, Vivek, Sandeep Chaudhary and SS Tomar

RK Naresh
Department of Agronomy, Krishi Vigyan Kendra Baghpat Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, Utter Pradesh, India

RK Gupta
Borlaug Institute for South Asia (BISA), New Delhi, India

Vivek
Department of Agronomy, Krishi Vigyan Kendra Baghpat Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, Utter Pradesh, India

Sandeep Chaudhary
Krishi Vigyan Kendra Baghpat Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, Utter Pradesh, India

SS Tomar
Rajamata VijayarajeScindia Krishi Vishwavidyalaya, ZARA-A B. Road Morena, Madhya Pradesh, India

Correspondence
RK Naresh
Department of Agronomy, Krishi Vigyan Kendra Baghpat Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, Utter Pradesh, India

Abstract

Stability of soil organic matter and soil organic carbon stock plays the crucial role in maintaining soil quality. The impact carbon and nitrogen dynamics and rate of SOC sequestration in long term tillage agricultural management practices are still in investigation in this environment. As tillage intensity increased there was a redistribution of SOC in the profile, but it occurred only between ZT and PRB since under CT, SOC stock decreased even below the plow layer. Average SOC concentration of the control treatment was 0.54%, which increased to 0.65% in the RDF treatment and 0.82% in the RDF+FYM treatment. Compared to F_1 control treatment the RDF+FYM treatment sequestered 0.33 Mg C ha^{-1} yr^{-1} whereas the NPK treatment sequestered 0.16 Mg C ha^{-1} yr^{-1}. Increasing the quantity of C input could enhance soil C sequestration or reduce the rate of soil C loss, depending largely on the local soil and climate conditions. SOC can be best preserved by crop rotations with conservation tillage practices such as no or reduced tillage, and with additions of residues, chemical fertilizers and manure SOC change was significantly influenced by the crop residue retention rate and the edaphic variable of initial SOC content.

Soil organic carbon change is a balance between C input from crops and manures and C output through decomposition. Agricultural management practices for increasing SOC in the context of local environmental conditions, enabling farmers to contribute to climate change mitigation and sustaining agricultural production. However, agricultural management practices indicate that SOM is a ready source of plant available nutrients, and tillage and stubble retention generally enhanced SOM mineralisation and nutrient release, which varied with soil type. However, it should be noted that the increased SOC sequestration rate that is contributed to by the increased C input can be limited at longer periods, as the SOC would eventually reach a relatively stable threshold.

Keywords: soil organic carbon, total carbon stocks, soil quality

Introduction

Rice-wheat is the major production system covering an area of 13.5 million hectares across the Indo-Gangetic Plains (IGP) of south Asia and feeds about 1/5th of world population (Saharawat *et al*., 2010) [39]. But after impressive gain in production due to various inputs used and adoption of improved agronomic practices during green revolution, now the sustainability of the system is questionable. Conventionally grown rice and wheat are highly money, water and energy intensive. Conventional rice requires puddling and seed bed preparation, which needs more water and labour; and in turn breaks soil aggregates exposing the soil for oxidation of organic carbon (Mondal *et al*., 2016) [32]. Kumar *et al*. (2008) reported 8% 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) [42]. Declining soil health, decreasing water use efficiency and environmental pollution are major sustainability issues of RWCS (Bhatt *et al*., 2016) [3]. 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) [28]. Pragmatic solution of the aforesaid concerns is conservation Agriculture (CA), which includes practices like reduced tillage (or no tillage), residue incorporation and crop rotation. These practices are needed to be adopted by integrating into a set of appropriate management condition for reversing loss of soil organic carbon (SOC).

The interaction between climate change and the global carbon cycle is an important aspect of the global environmental changes (IPCC, 2007) [13]. Soil is the largest pool of terrestrial organic carbon in biosphere, storing more Carbon (C) (Jobbagy and Jackson, 2000) [16]. Therefore, the Soil Organic Carbon (SOC) stock has an irreplaceable function in mitigating climate change as a key component of the biosphere carbon cycle. Meaning that changes in SOC content significantly influence climate change and a slight change in the SOC stocks can have a considerable effects on atmospheric carbon dioxide concentration, contributing to climate warming (Davidson and Janssens, 2006) [10]. Changes of the climate, particularly the temperature and rainfall have more pronounced effects on the resident period of the SOC by accelerating SOC decomposition offsetting a portion of the SOC losses. However, many researches relating the climate change to SOC are biased towards revealing the trends and future projection changes in the SOC and its effects on the environment, ignoring the current climatic scenarios. The climate change is manifested by changes in temperature, precipitation and length of the season (Smith *et al.*, 2008) [46]. Precipitations that are punctuated by prolonged mid-season dry spells are now a common phenomenon in many parts of the world and could result to detrimental effects on soil microbial action on SOC hence soil losses through erosion. The climatic factors affect the soil microbial activities on the Soil Organic Matter (SOM) thereby influencing the SOM resident period (Cox *et al*., 2000) [9].

The SOC is one of the key factors influencing soil erodibility. This is due to the positive feedback of the SOC on soil quality as influenced by the Organic Matter (OM) (Cerda, 2000) [6]. The OM is the source of all SOC and the rate of OM decomposition in the soil has a direct effect on the amount of SOC present at any given time. Whilst any OM source can be used to enhance soil aggregation and stability, a major drawback is on ensuring selection of OM with clear and prolonged soil stabilizing effects. Different OM may have different effects on soil erodibility and organic carbon resident time depending on properties of the soil in question. Therefore, to maximize the benefits of OM in soil conservation, there is need to explore effects of various OM sources in stabilizing soils of different properties.

The patterns and controls of SOC storage are critical for our understanding of the biosphere, given the importance of SOC in the soil and the feedback to the atmosphere and the rate of climate change. The capacity to predict and ameliorate the consequences of climate change depends on a clear description of SOC content and controlling of SOC inputs and outputs (Jobbagy and Jackson, 2000) [16]. One aspect of the organic carbon pool that remains poorly understood is its mineralization in different soils varying in moisture. What are the general patterns of SOC in different soils? Do the major determinants of SOC content differ with litter quality and soil moisture regime? How much SOC is stabilized in different soils especially under continuously wet and alternating wet dry soil moisture conditions and what is the effect of litter quality on the SOC?

Assmanna *et al*. (2014) [2] reported that the changes in soil C stocks and particulate organic C with NG treatment. Soil C additions ranged from 0.54 to 8.68 Mg ha^{-1}from NG to the other grazing treatments. The G10 led to a soil N loss of 1.17 Mg ha^{-1}dueto soil organic matter degradation [Fig.1 & 1b]. Nicoloso *et al*. (2008) [34] found values of approximately 4.5 Mg ha^{-1}yr^{-1}in an ICL system under no-tillage conditions. Such amounts of continuous dry matter addition are important to support POM-C, as well as MAC. Greater POM-C guarantees a positive C flux to the soil, there by maintaining or increasing soil biological activity and quality (Salton *et al*., 2005) [40]. Carbon stocks in the 0 to 40 cm soil layer followed the same general pattern as for the 0 to 20 cm layer, with greater POM-C in NF, followed by no (NG), low, and moderate grazing intensities(G20, G30, G40), and finally high grazing intensity (G10). The TOC stocks in this layer (110.6 Mg ha^{-1}) in the native forest followed the same patter as POM-C. The G10 was 25% lower than native forest and, on average, 15% lower than the other grazing intensity treatments and the non-grazed area.

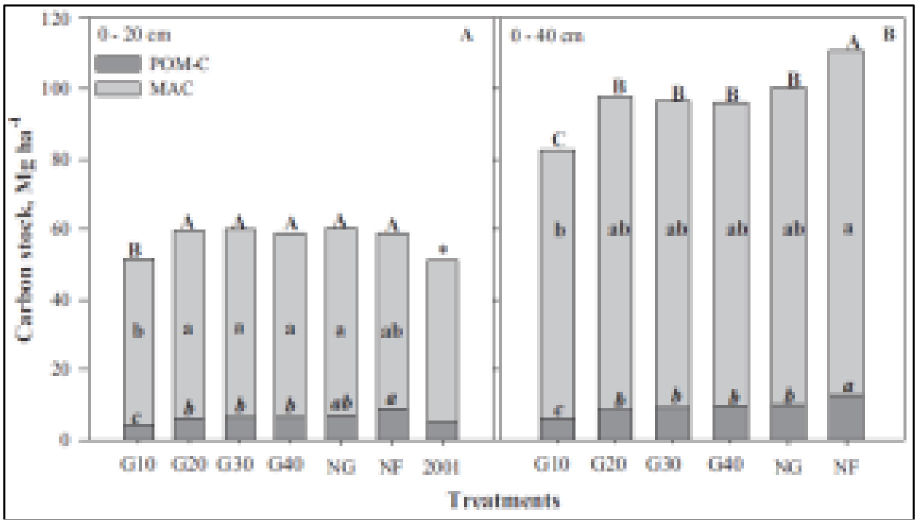

Fig 1(a): Total carbon, particulate organic matter carbon (POM-C) and mineral associated carbon (MAC) in the 0 to 20cm (A) and 0 to 40cm (B) layer under integrated crop–livestock system in no-tillage with different grazing intensities.

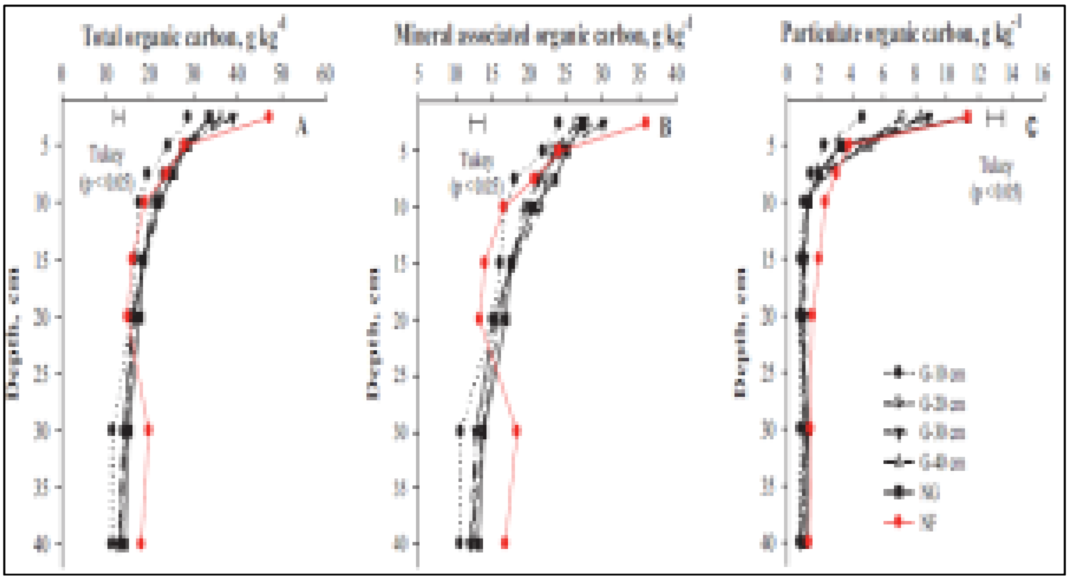

Fig 1(b): Soil organic carbon contents in soil profile under integrated crop–livestock system under no-tillage with different grazing intensities: total organic carbon (A), mineral associated organic carbon (B) and particulate organic carbon (C).

Sheng et al. (2015) Soil labile organic C fractions, including particulate organic carbon (POC) and its components [coarse POC and fine POC], light fraction organic carbon (LFOC), readily oxidizable organic carbon, dissolved organic carbon (DOC) and microbial biomass down to 100 cm soil depth from four typical land use systems in subtropical China. Decrease in fine root biomass was more pronounced below 20 cm than in the overlying topsoil (70% vs. 56% for plantation and 62% vs. 37% for orchard. respectively) driving a reduction in subsoil labile organic C stocks. Land use changes from natural forest to Chinese fir plantation, Chinese chestnut orchard, or sloping tillage reduced soil organic C stocks and that of its labile fractions both in top and subsoil (20-100 cm). POC reduction was mainly driven by a decrease in fine POC in topsoil, while DOC was mainly reduced in subsoil. Fine POC, LFOC and microbial biomass can be useful early indicators of changes in topsoil organic C. In contrast, LFOC and DOC are useful indicators for subsoil. Reduced proportions of fine POC, LFOC, DOC and microbial biomass to soil organic C reflected the decline in soil organic C quality caused by land use changes. SOC stock below 20 cm depth was also significantly reduced by 23% with the conversion to plantation, 29% to orchard, and 40% to sloping tillage. In total, after conversion, SOC stock in 0-100 cm soil decreased by 26% (plantation), 30% (orchard), and 35% (sloping tillage) [Fig. 2a]. The decrease in ROC stock through the soil depth profile following land use change was smaller than that of LFOC [Fig. 2b]. ROC stocks did not differ significantly between natural forest and sloping tillage areas, suggesting that ROC stock was relatively insensitive to land use change. The DOC stock in the topsoil decreased by 29% and 78% following the conversion of natural forest to plantation and orchard, respectively, and subsoil DOC stocks decreased even more dramatically following land use change [Fig. 2b]. Moreover, the stocks associated with the different LOC fractions in topsoil and subsoil responded differently to land use changes. POC decreased by 15%, 38%, and 33% at 0-20 cm depth, and by 10%, 12%, and 18% at 20e100 cm depth following natural forest conversion to plantation, orchard, and sloping tillage [Fig. 2c].

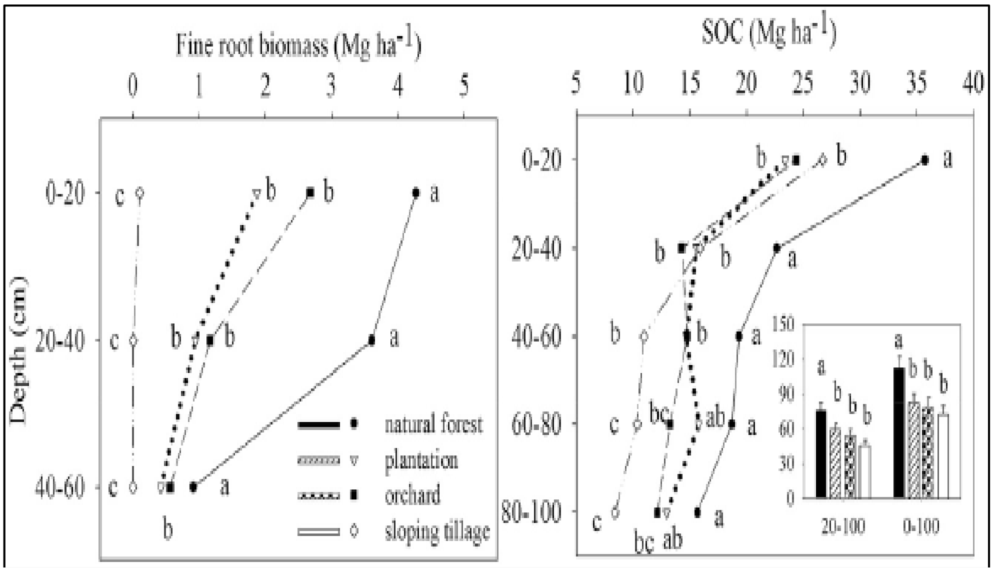

Fig 2(a): Fine root biomass (left) and soil organic C stocks (right) in relation to depth and land use systems

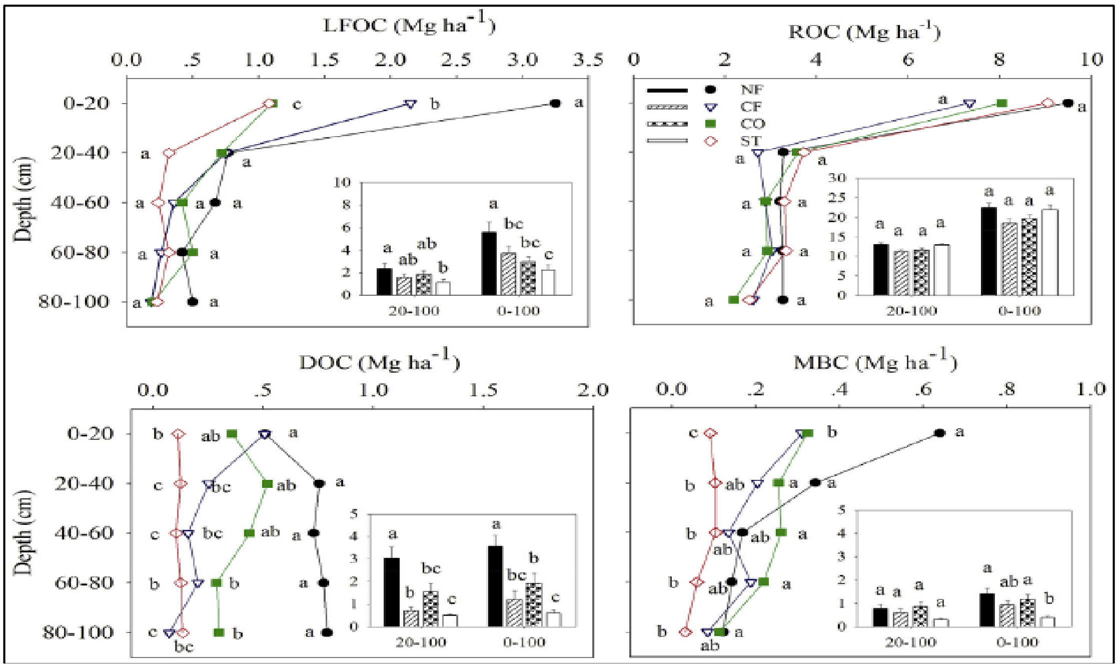

Fig 2(b): LOC fraction stocks in relation to depth and land use systems

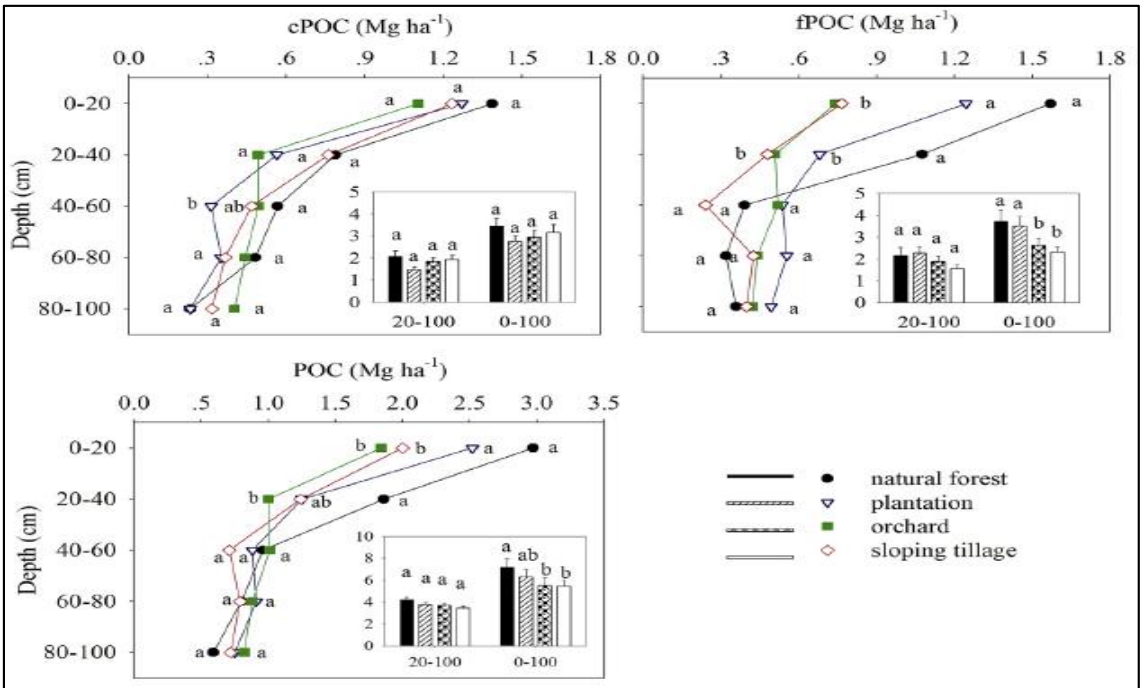

Fig 2(c): POC stocks and those of its components (cPOC, fPOC) in relation to depth and land use systems

Joao *et al*. (2014) [17] reported that the physical fractions >53 mm (i.e., LOC and POC), averaged across all soil depths, accounted for 45%, 40%, 46% and 43% of the total soil mass under CT, MT, NT_{ch} and CNT, respectively. As expected, clay + silt sized (<53 µm) SOC complexes comprised of the largest C concentrations. The MAOC concentration decreased slightly with depth, regardless of tillage treatments, and ranged from 23.1 to 14.9 g C kg^{-1} of bulk soil in 0–5 and 20–40 cm depths, respectively. Although not significant, the LOC concentrations appeared in the order MT < CT < NT_{ch} < CNT in 0–2.5 cm depth. By contrast, significant differences in POC and MAOC concentrations among tillage treatments were observed in soil surface layer [Fig.3]. Both POC and MAOC in 0–2.5 cm depth decreased from 12.2 and 24.9 g C kg^{-1} under CNT to 5.9 and 19.5 g C kg^{-1} under CT, representing a decline of 52% and 22% in POC and MAOC, respectively.

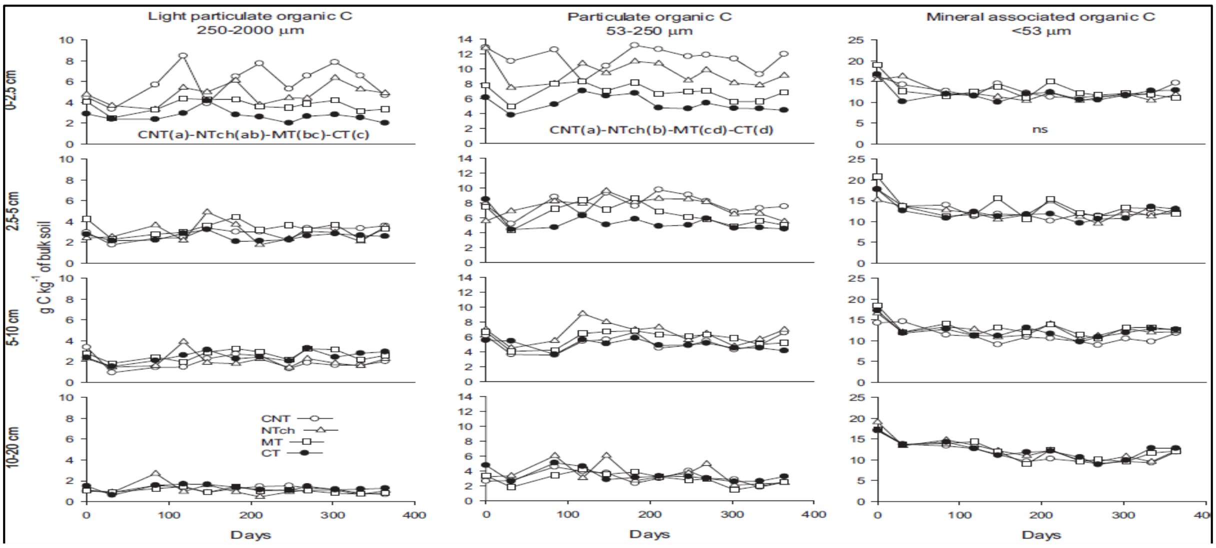

Fig 3: Monthly changes in particle size fractions (i.e., 250–2000 µm: light particulate organic C; 53–250 µm: particulate organic C; <53 µm: mineral associated organic C) to 20 cm depth under conventional tillage (CT =●), minimum tillage (MT = □), no-till chisel (NT_{ch} = Δ), and continuous no-till (CNT = ○)

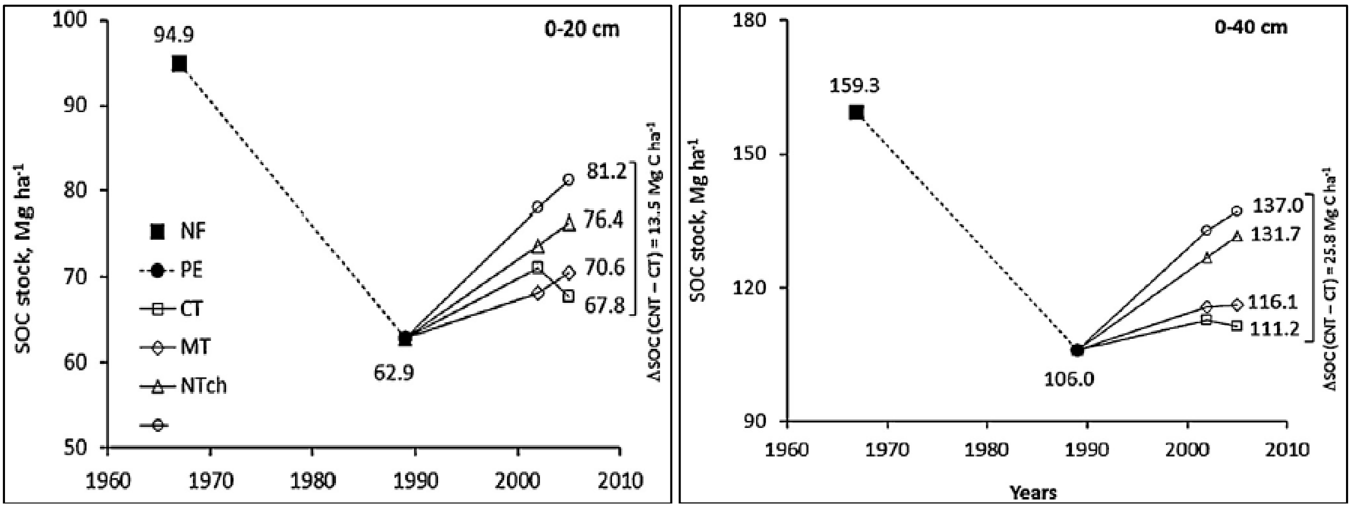

Fig 4(a): Changes in soil organic C stocks (Mg C ha^{-1}) to 0–20 and 0–40 cm depths under native vegetation (NV), (PE), conventional tillage (CT), minimum tillage (MT), no-till chisel (NTch), and continuous no-till (CNT).DSOC = CNT -CT, refers to the difference between the SOC stock of CNT and CT

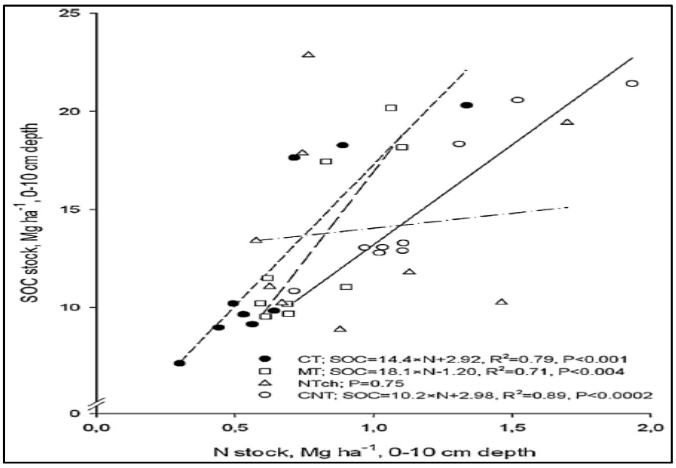

Fig 4(b): Relationship between SOC and N stocks (Mg ha^{-1}) in 0–10 cm depth

Joao Carlos *et al.* (2014) [17] reported that the average SOC stock in 0–20 cm depth decreased from 94.9 Mg ha^{-1} under NV to 62.9 Mg ha^{-1} for CT in 1989 which attained the value of 67.8 Mg ha^{-1} in 2005, a loss of ~29% over 38 years since the conversion of NV into cultivated field with the use of CT [Fig. 4a]. The decline of SOC under CT represents a depletion rate of ~0.60 and ~1.07 Mg C ha^{-1} yr^{-1} in 0–20 and 0–40 cm depths, respectively. Although soil erosion was not measured, the visual observation of these plots, sited on about 1–2% slope, showed a minimal erosion impact. Thus, the depletion in SOC is primarily related to a higher oxidation rate of SOC under plowing (Reicosky *et al.*, 1995) [37]. Sa *et al.* (2001) [38] reported for a Brazilian Oxisol of the same region that SOC loss due to the conversion of NV during the first 20 years was 1.09 Mg ha^{-1} yr^{-1} in 0–40 cm depth. A strong correlation between SOC and total N [Fig. 4b] is observed; emphasizing that SOC sequestration is closely related to N accumulation. Most of the increase in SOC stock observed in the soil under CNT, as compared with that in the CT, was in the 0–5 cm (38%) and the 20–40 cm (48%) layers. Based on SOC and N stocks, the C: N ratio increased in the order of CNT (12.9) < NTch (14.0) < MT (15.4) < CT (19.1) in 0–5 cm depth. Other researches (Martins *et al.*, 2011; Tivet *et al.*, 2013b) [29, 47] have reported that the humification degree of SOC in soil under CT can be higher than those under NT in 0–5 cm depth, indicating a release of labile SOC under CT as a result of the continuous and strong disruption of aggregates.

Van-Camp *et al.* (2004) [48] found that organic amendments influence soil characteristics by the interdependent modification of biological, chemical and physical properties (Fig. 5). Also, fertility improvement through an effective management of these properties has the capability of optimizing crop production. Habteselassie *et al.* (2006a) [12] found that, over a 5-year period, the C pool was enhanced by 115% in dairy-waste compost treated soil. Moreover, the dairy-waste compost increased organic carbon by 143 and 54% as compared with ammonium sulfate and liquid dairy-waste treatments, respectively, applied at the same available N level (200 kg Nha^{-1}). This C stored in the soil organic matter accounts for approximately 11% of the total amount of C applied. Under 7–36-year fertility experiments in five different rice based cropping systems, the application of organic amendments at 5–10 t ha^{-1}yr^{-1}, through farmyard manure or compost combined with balanced mineral NPK, increased organic carbon by 10.7% (Mandal *et al.*, 2007) [27]. In a rice–wheat system, farmyard manure application at 20 t ha^{-1} showed, after a period of 32 years, higher organic carbon concentration of 17% compared with NPK fertilizers in the 0–15 cm soil layer (Kukal *et al.*, 2009) [20].

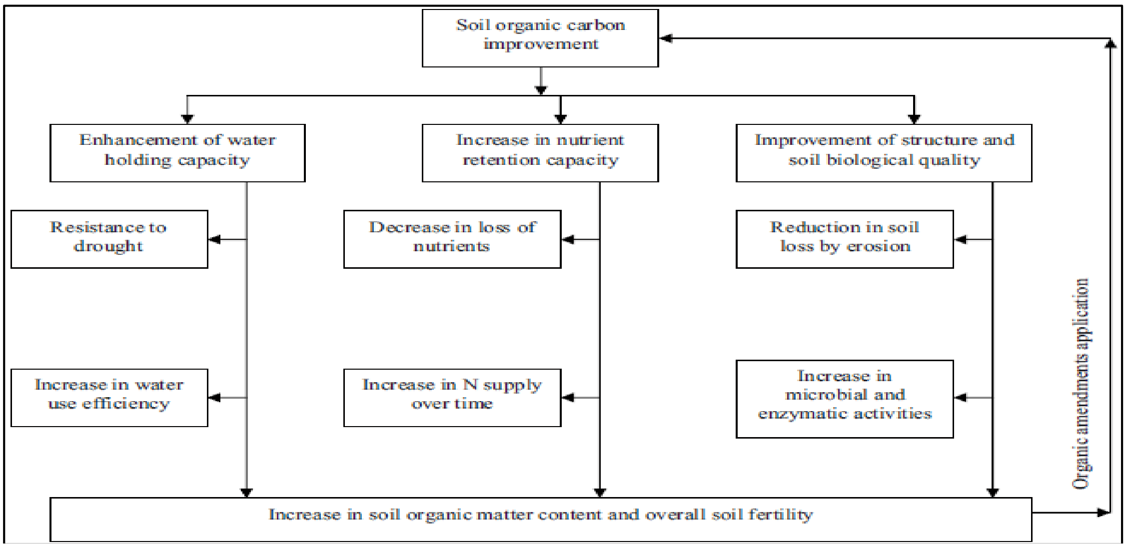

Fig 5: Effects of increasing soil organic matter content and overall soil fertility by soil organic carbon improvement (adapted from Lal, 2006) [21]

Poeplau *et al.* (2017) [35] reported that the average increase in SOC stock in the 0–30cm soil layer was 3.1Mgha^{-1} or 6.8%, with no difference between N fertilization rates. Retention coefficients of residues did not exceed 4% and decreasedsignificantly with increasing Nrate (R^2=0.49). The effect of RI was higher after 20 years (4.6Mgha^{-1}) than after 40 years, indicating that a new equilibrium has been reached and no further gains in SOC can be expected. Most (92%) of the total SOC was stored in the silt and clay fraction and 93% of the accumulated carbon was also found in this fraction, showing the importance of fine mineral particles for SOC storage, stabilization and sequestration in arable soils [Fig. 6a, 6b, 6c and 6d]. Lehtinen *et al.* (2014) [22] found an SOC increase of 7%, averaged over several studies. Liu *et al.* (2014) [23] revealed that an overall, there were significant differences in the SOC stocks measured in the RR and RI treatments, but these were only apparent when the results were aggregated over all N levels. This indicates that the treatment effect was lower than the minimum detectable difference with four replicates (*Knebl et al.* 2015) [19]. Bol *et al.*(2009) [4] found 67% and 23% of SOC stored in the clay and silt fraction, respectively, while Christensen (2001) [8] reported that 50–75% and 20–40% SOC is usually attached to clay and silt particles, respectively, in temperate soils. Flessa *et al.* (2008) [11] found 88% of SOC in the silt and clay fraction of two German arable soils and suggested that the main stabilization mechanism is the formation of oreganos mineral complexes. Apart from the well-established negative effect of tillage on soil aggregation Wiesmeier *et al.* (2014) suggested that tillage might promote the formation of such oreganos-mineral complexes due to mixing of fresh organic material with unsaturated mineral surfaces.

Wang *et al.* (2017) revealed that, on a global average, the cropland SOC density increased at annual rates of 0.22, 0.45 and 0.69MgCha^{-1} yr^{-1} under crop residue retention rates of 30, 60 and 90%, respectively. Increasing the quantity of C input could enhance soil C sequestration or reduce the rate of soil Carbon lose, depending largely on the local soil and climate conditions. In general, the annual rates of change in SOC were 0.22MgCha^{-1}yr^{-1} under R$_{30}$, 0.45MgCha^{-1}yr^{-1} under R$_{60}$, and 0.69MgCha^{-1}yr^{-1} under R$_{90}$ [Fig.7a]. the regions with higher annual C input rates (e.g., Europe and North America) experienced higher SOC increases than the areas with relatively lower C input rates (e.g., Oceania and Africa) across all three crop residue retention scenarios [Fig 7b]. The quantified SOC changes were regulated by soil, climate and management practices. The initial SOC was significantly but negatively correlated (ρ =−0.20) with SOC change, while the soil clay fraction showed a negligible correlation [ρ =−0.17, Fig7b]. The selected climatic variables displayed a negligible correlation (temperature, ρ =−0.18), and a significant but negative correlation (precipitation, ρ = −0.22) with SOC change [Fig. 7b]. The crop residue retention rate showed a strong and positive correlation (ρ =0.34) with the SOC change [Fig. 7b]. [Fig. 7c] presents the impacts of crop residue retention, initial SOC content and precipitation on SOC change. In general, crop residue retention seemed to be linearly and positively correlated with SOC change [Fig. 7ca], whereas the initial SOC content [Fig. 7cb] and precipitation [Fig.7cc] had negative linear effects on SOC change. Wang *et al.* (2014) [50, 55] found positive effects of temperature and precipitation on SOC accumulation. This is because, in temperature and water deficient areas increased temperature and precipitation promote crop production and hence increases the C input to soils, which favors SOC sequestration.

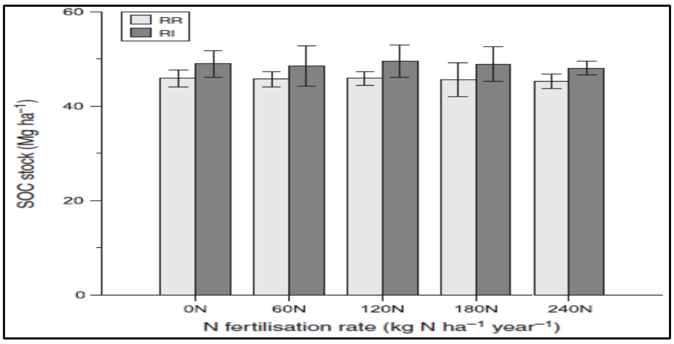

Fig 6(a): Soil organic carbon (SOC) stocks in the residue removed (RR) and residue incorporated (RI) treatments under five different N fertilizer rates

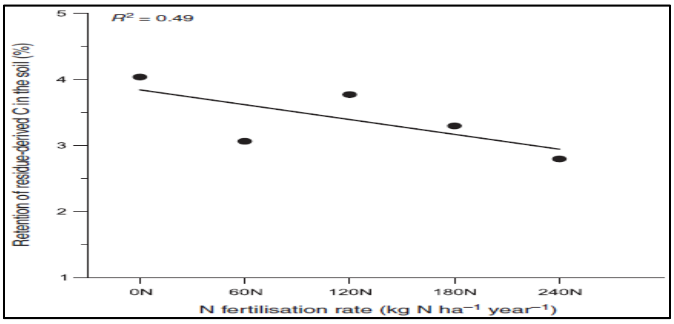

Fig. 6(b): Retention of residue-derived carbon (C) in the soil (%) at different nitrogen (N) fertilizations rates, with regression line and coefficient of variation (R^2).

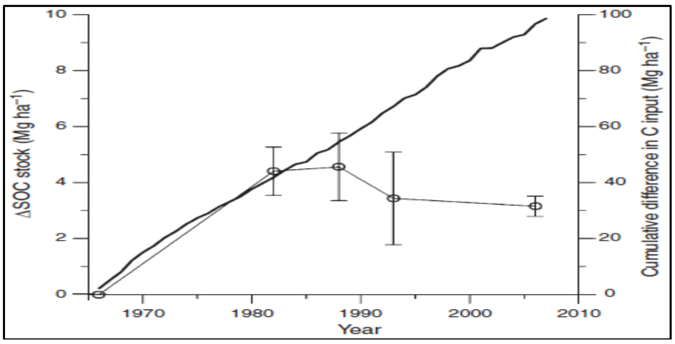

Fig 6(c): Average difference in soil organic carbon stock (ΔSOC stock) over time (1966–2006) between treatments of residues incorporated (RI) and residues removed (RR)

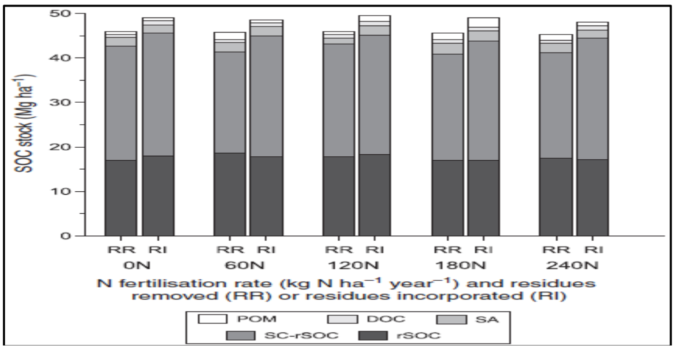

Fig 6(d): Soil organic carbon (SOC) stock in different fractions for residues removed (RR) and residues incorporated (RI) treatments at different nitrogen (N) fertilization rates after 40 years of residue incorporation

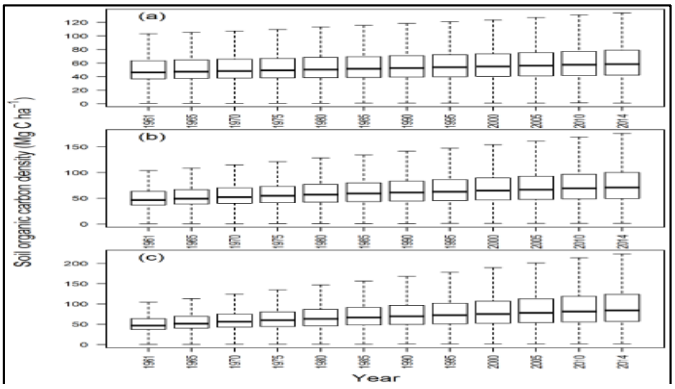

Fig 7(a): Temporal changes in the soil organic carbon ($MgCha^{-1}$) of the main global cereal cropping regions under different aboveground crop residue retention rates of 30% (a), 60% (b) and 90% (c).

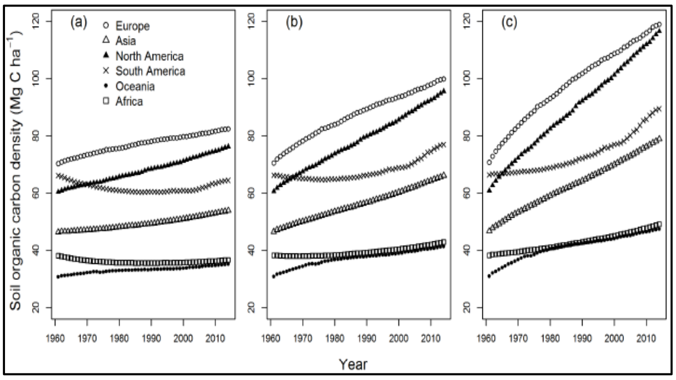

Fig 7(b): SOC evolution of five continents in the main global cereal cropping regions under different above-ground crop residue retention rates of 30%(a), 60%(b)and 90%(c).

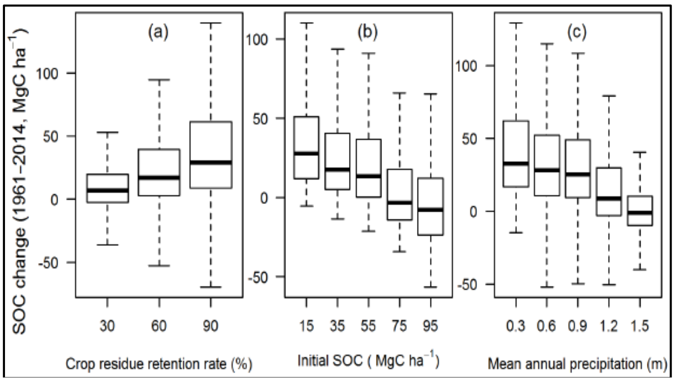

Fig 7(c): Response of SOC change (1961–2014, $MgCha^{-1}$) to the three most influential variables of crop residue retention rate (a), initial SOC (b), and mean annual precipitation (c).

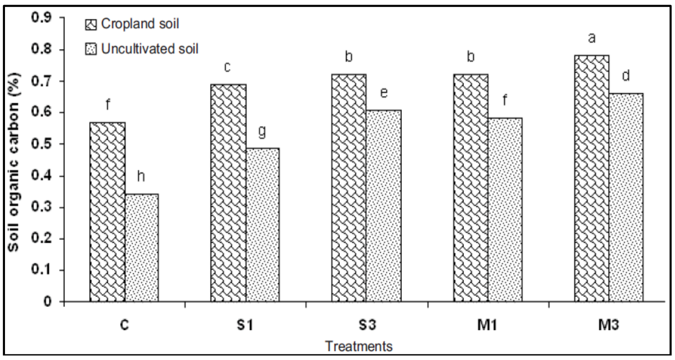

Fig 8(a): Comparison between the soil organic carbon contents in cropland and uncultivated soils affected by the type and application rate of organic matters. C – Control, S1 – 1% wheat straw residue, S3 – 3% wheat straw residue, M1 – 1% FYM, M3 – 3% FYM.

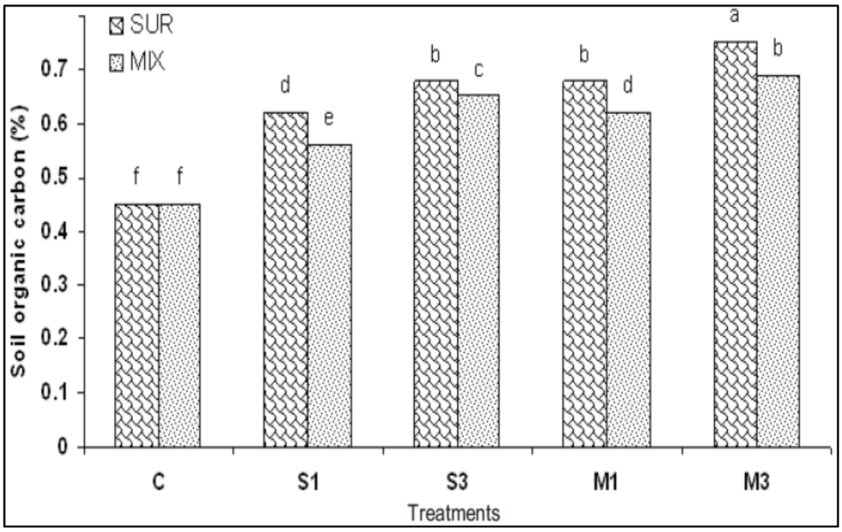

Fig 8(b): Comparison between the soil organic carbon content affected by the different methods of organic matter application. SUR – mixed with the soil surface layer of 0-7 cm, MIX – homogeneously mixed with the 0-20 cm soil layer, S1 – 1% wheat straw residue, S3 – 3% wheat straw residue, M1 – 1% FYM, M3 – 3% FYM

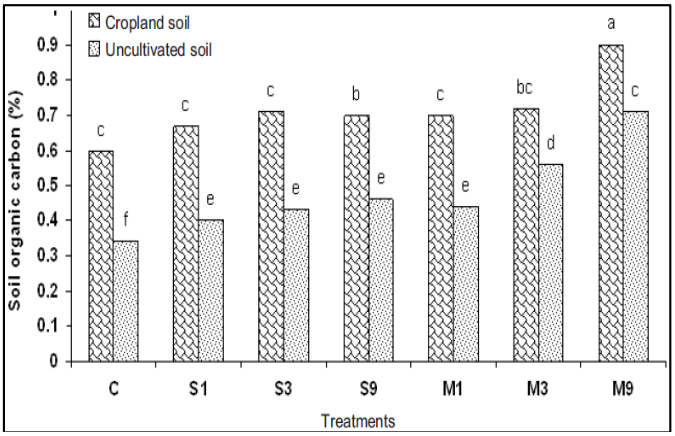

Fig 8(c): Comparison between the soil organic carbon content in the 0-7 cm soil layer at the different rates of organic matter. C–control, S1–1%wheatstrawresidue,S3–3%wheatstrawresidue,S9– 9% wheat straw residue, M1 – 1% FYM, M3 – 3% FYM, M9 – 9% FYM

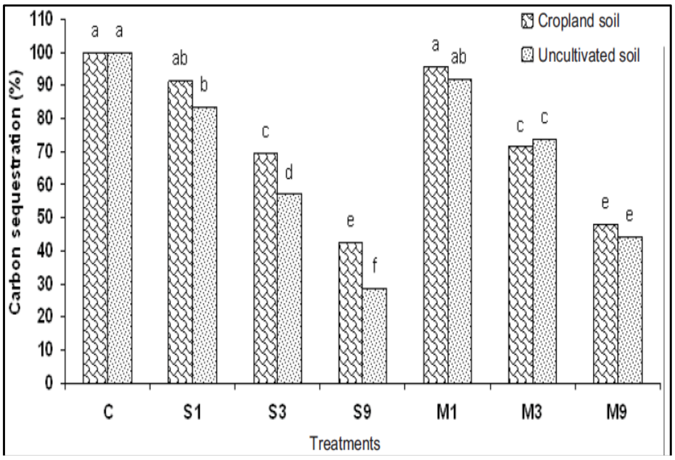

Fig 8(d): Comparison of the means of carbon sequestration potentials affected by the different rates of organic matter added to the surface layer (0-7 cm) of the soils. C – control, S1 – 1% wheat straw residue, S3 – 3% wheat straw residue, S9 – 9% wheat straw residue, M1 – 1% FYM, M3 – 3% FYM, M9 – 9% FYM

Mahmoodabadi and Heydarpour, (2014) [26] showed that the application of organic matter, especially the farmyard manure incorporation led to a significant increase in the final soil organic carbon content. Higher amounts of soil organic carbon were stored in the cropland soil than in the uncultivated soil. On average, the soil surface layer treatment caused a higher sequestration of soil organic carbon compared to the whole soil depth treatment. If higher rates of organic matter were added to the soils, lower carbon sequestration was observed and vice versa [Fig.8a, 8b, 8c and 8d]. Rasse *et al.* (2005) [36] found that organic substances originating from crop roots were more resistant to decomposition than those of aboveground shoot residues. In general, the accumulation of SOC after inputs of organic matter is likely to be influenced by their biochemical composition and decomposition rates. Wu *et al.* (2008) [51], who found an increase in the final SOC content after application of organic matter. It is obvious that the content of SOC increased with the increasing rate of organic matter. However, the differences observed in the SOC content were insignificant in some cases. The application of FYM, compared to straw residue, led to a sharper increase in the SOC content, particularly at the higher rates. Besides, the cropland soil exhibited higher values of the SOC content than the uncultivated soil.

Ingram and Fernandes, (2001) [14] reported that, on average a loss between 25 and 30% of SOC with most of the loss occurring in the first 2–5 years. The main C sequestration strategy should, therefore, be directed towards minimising losses (i.e., promoting SOC protecting measures; [Fig. 9a]. Soils naturally higher in clay content generally retain more organic matter than sandy soils. Memon *et al.* (2018) [30] reported that the average SOM content in 2016–2017 significantly increased ($p < 0.05$) by 3.08% to 17.07% under all residue-incorporated treatments. Plots without straw incorporation showed a decreased SOM content (1.69–3.97%) compared with pre-treatment values under reduced and conventional tillage methods. However, the SOM content was higher (25.12, 24.06, 23.83, 23.80, 22.41, and 22.12 g/kg) in the RTsi$_{60}$, RTsi$_{100}$, CTsi$_{100}$, CTsi$_{60}$, RTsi30, and CTsi$_{30}$ treatments, respectively, compared to RTns (21.10 g/kg) and CTns (20.61 g/kg). The SOM difference between CTsi$_{60}$ and CTsi$_{100}$ was non- significant in the 0–30 cm soil profile depth. Moreover, SOM in the topsoil (0–10 cm) was higher in RTsi$_{60}$ (26.31 g/kg) and CTsi$_{60}$ (24.51 g/kg) under RT and CT, respectively [Fig.9b]. Yadav *et al.* (2017) [54] and Mi *et al.* (2016) [31] concluded that SOM significantly improved with the incorporation of straw into the soil profile at depths of 0–40 cm under RWR system.

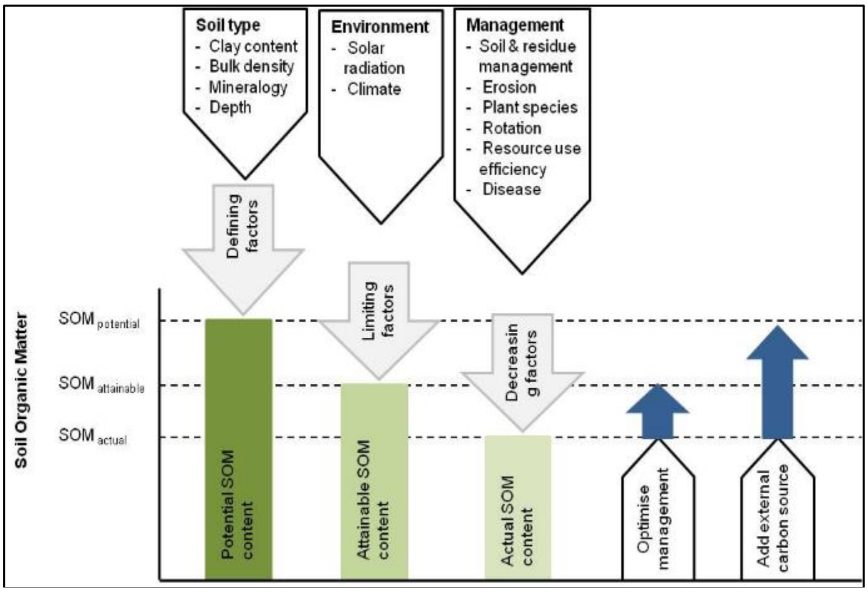

Fig 9(a): The influence of soil type, climate and management factors on the retention of soil organic matter in soils (Ingram and Fernandes, 2001) [14]

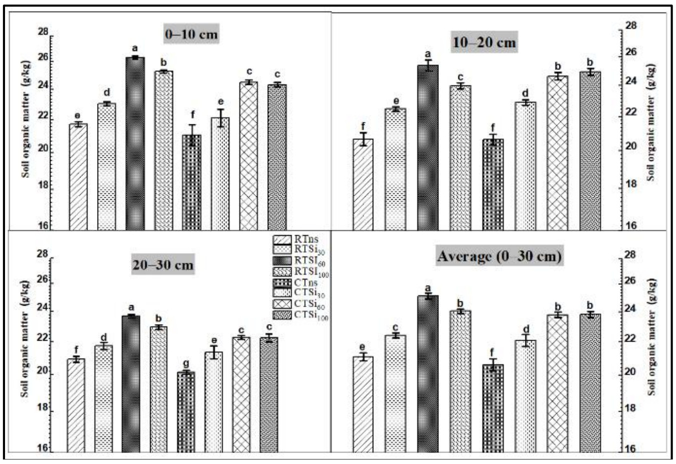

Fig 9(b): Depth-wise distribution of mean soil organic matter (SOM) under each treatment. Note: RTns: RT without straw incorporation, RTsi$_{30}$: RT with straw incorporation (SI) at 30%, RTsi$_{60}$: RT with SI at 60%, RTsi$_{100}$: RT with SI at 100%, CTns: CT without straw incorporation, CTsi$_{30}$: CT with SI at 30%, CTsi$_{60}$: CT with SI at 60%, and CTsi$_{100}$: CT with SI at 100%

Bhattacharyya *et al.* (2015) reported that plots under MBR+ DSR-ZTW + RR-ZTMB had 14% higher total SOC concentration than TPR-CTW plots in that soil layer. Both DSR-ZTW and DSR-ZTW + RR plots had similar total SOC concentrations and the values were similar to TPR-ZTW and TPR-CTW plots in that soil layer [Fig. 10a]. The results thus explicitly indicated that DSR-ZTW or DSR-ZTW + RR managements regimes were incapable of increasing total SOC by an appreciable amount after three years and some additional residues (in the form of brown manuring/mungbean residues in this experiment) were required. Again, three years of MBR+ DSR-ZTW + RR-ZTMB management practice did not significantly increase total SOC concentrations in the 5–15cm soil layer [Fig.10b].

Adoum *et al.* (2017) [1] revealed that SOC and soil inorganic carbon (SIC) stocks show a spatial variability between polders. SOC stocks were t0 200 ±0.8; t_{60} 183 ± 34; and t_{65} 189 ± 1.1 MgCha^{-1}, whereas the SIC stocks were negligible. These results show the highest stocks of soil carbon observed for this climatic region. The SOC stocks were also calculated for the equivalent soil mass at a defined depth (0–0.3 m); the corrected calculation of SOC stocks (S_{corr}) for 2450 Mgha^{-1} of equivalent soil mass is t0 64 ±1.9, t_{60} 59 ± 9.8, and t_{65} 53 ± 2.2 MgCha^{-1}; the stocks decrease by -7.8% and -17.2% from t0 to t_{60} and t_{65} [Fig.11a and 11b]. Cheverry *et al.* (1972) [7] showed that the youngest organic sedimentation produced clayey–peaty horizons. Organic matter, based on the study of thin sections, was inherited from the sedimentation of vegetal residues provided by lacustrine floating vegetation, as observed in the central part of the lake. Zhang *et al.* (2015) [44, 56] revealed that the average retention of maize-derived carbon plus manure-derived carbon during the early period of the trial (up to 11 years) was relatively high (10%) compared to the later period (22 to 27 years, 5.1–6.3%). About 11% of maize-derived carbon was converted to soil organic carbon, which was double the retention of manure-derived carbon (4.4–5.1%) [Fig. 12 a to 12d]. This implies that adequate mineral fertilizer application is necessary to stabilize and maintain soil organic carbon levels in intensive maize cropping systems.

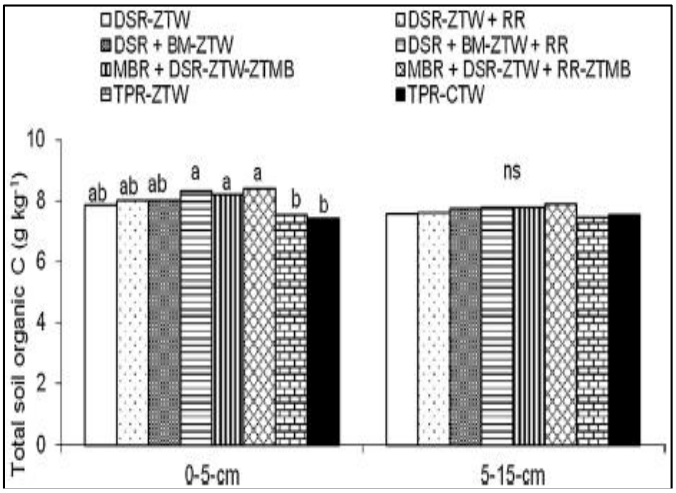

Fig 10(a): Impacts of resource conservation technologies on total soil organic carbon concentration after three years of rice–wheat cropping. TPR- CTW: puddle-transplanted rice-conventionally tilled wheat; DSR-ZTW: direct-seeded rice (DSR)-zero-till wheat (ZTW); BM= brown manuring; MBR = mung-bean (green-gram residue); RR = rice residue; ZTMB= zero-tilled mung-bean (green gram)

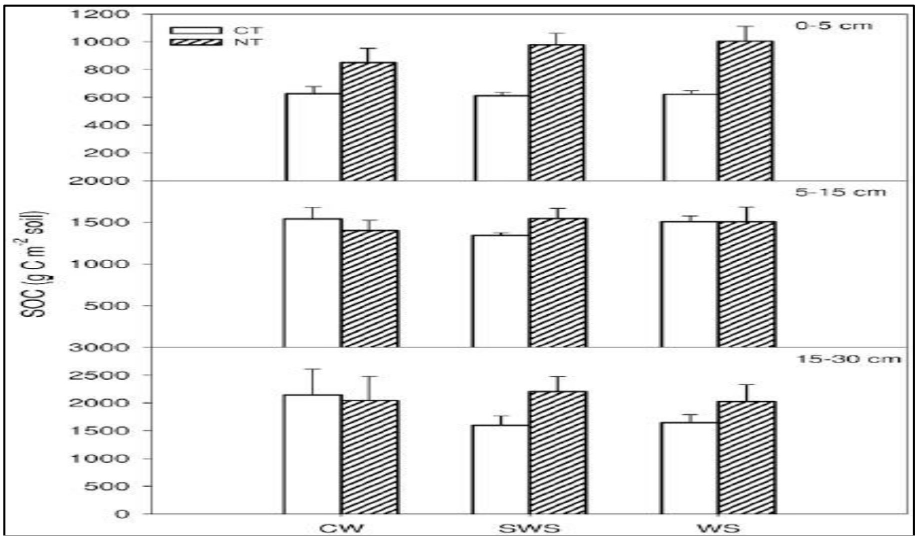

Fig 10(b): Soil organic C (SOC) as affected by cropping sequence and tillage at 0- to 5-, 5- to 15-, and 15- to 30-cm depths (CT, conventional tillage; NT, no-till; CW, continuous wheat; SWS, sorghum–wheat– soybean; WS, wheat–soybean)

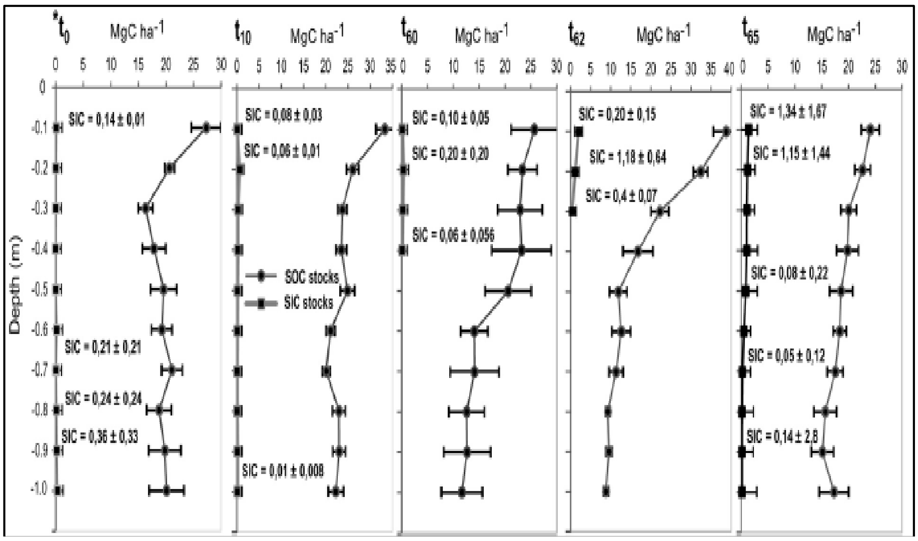

Fig 11(a): Average soil organic carbon (SOC) and soil inorganic carbon (SIC) stocks followed by the standard error in soil profiles (0–1 m)

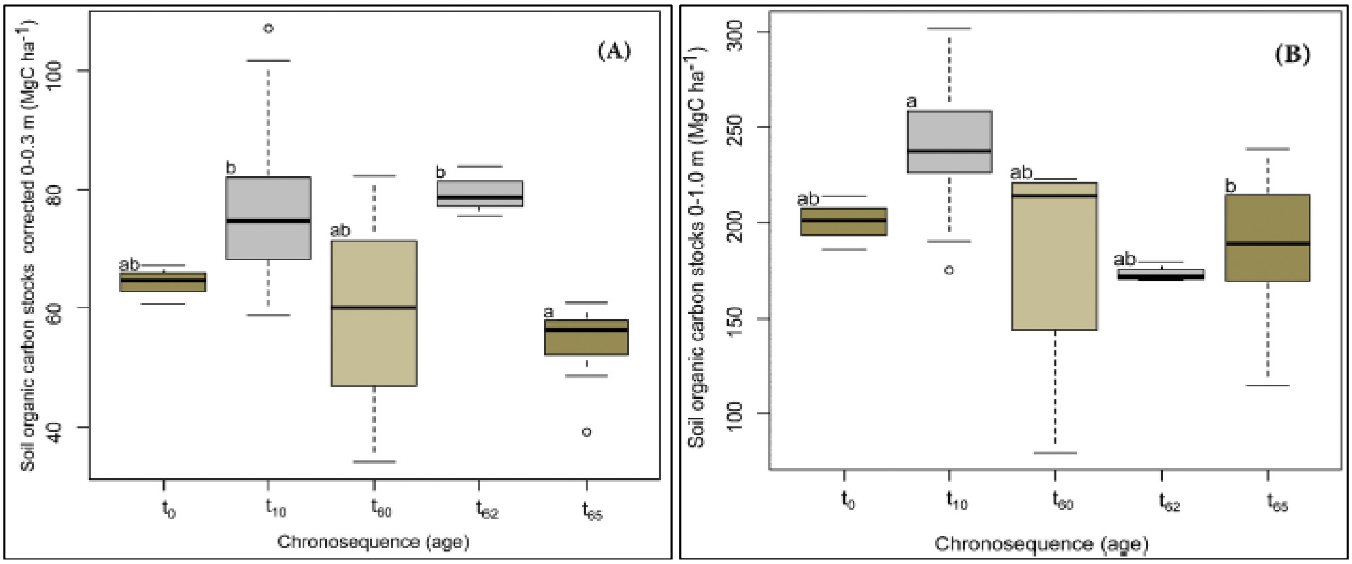

Fig 11(b): oil organic carbon (SOC) stock layers 0–0.3 m (A) and 0–1 m (B) in the polders according to the chronosequence

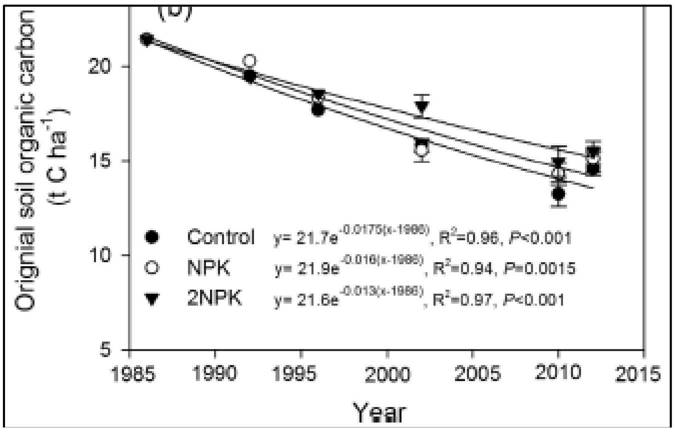

Fig 12(a): Original SOC stock under the control and chemical fertilizer (NPK and 2NPK) treatments in a maize double-cropping system

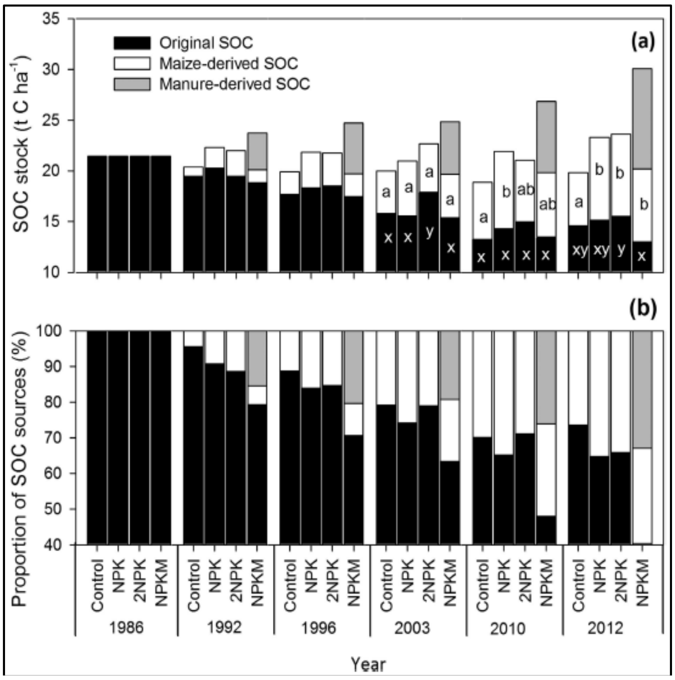

Fig 12(b): Changes in stock of original, maize-derived, and manure-derived soil organic carbon (SOC) (tCha^{-1}) **(a)** and their proportions (**b**) from 1986 to 2012 in the long-term fertilization experiment

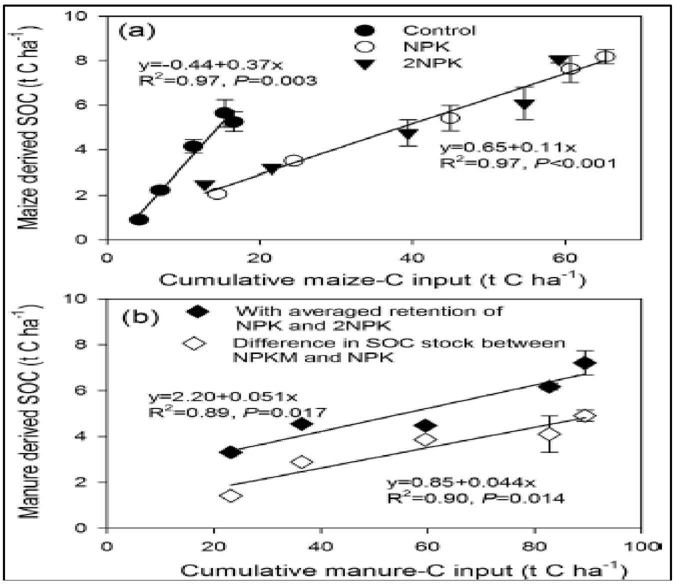

Fig 12(c): Relationship between maize-derived soil organic carbon (SOC) and cumulative maize carbon input

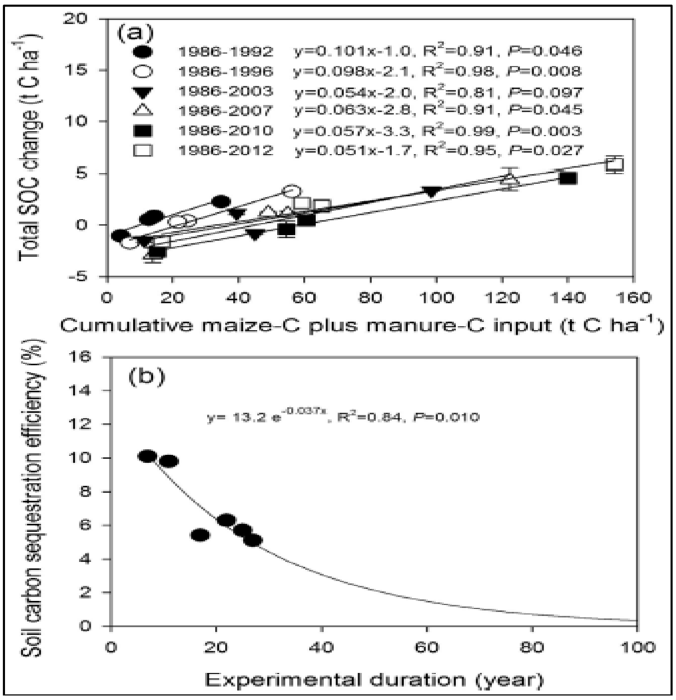

Fig 12(d): Relationships between total soil organic carbon (SOC) and cumulative maize-derived C plus manure-derived C input

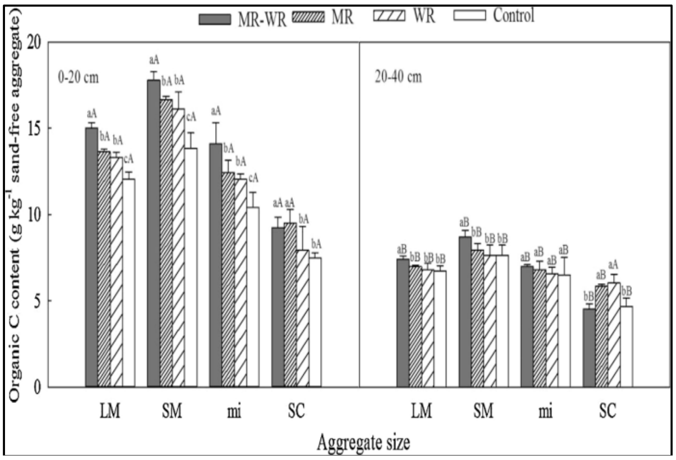

Fig 13(a): Organic C content (g kg^{-1} aggregate) of aggregates: LM, SM, mi, and SC in the 0–20 cm and 20–40 cm soil layers under MR-WR, MR, WR, and Control

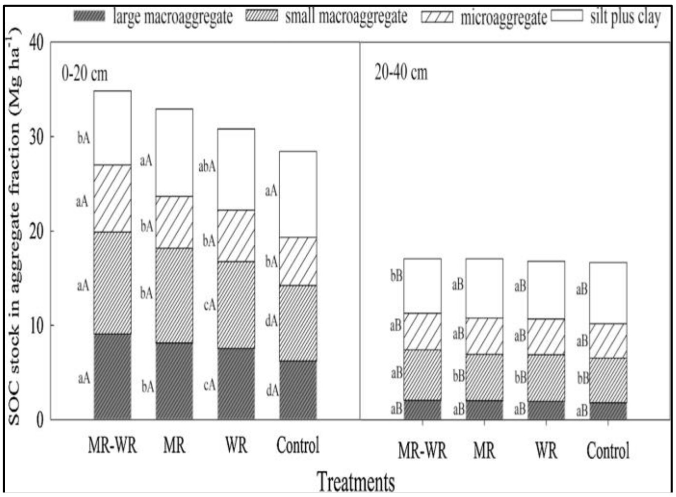

Fig 13(b): SOC stock of aggregate fractions (Mg ha^{-1}): large macro-aggregates, small macro-aggregates, micro-aggregates, and silt plus clay in the 0–20 cm and 20–40 cm soil layers under MR-WR, MR, WR, and Control.

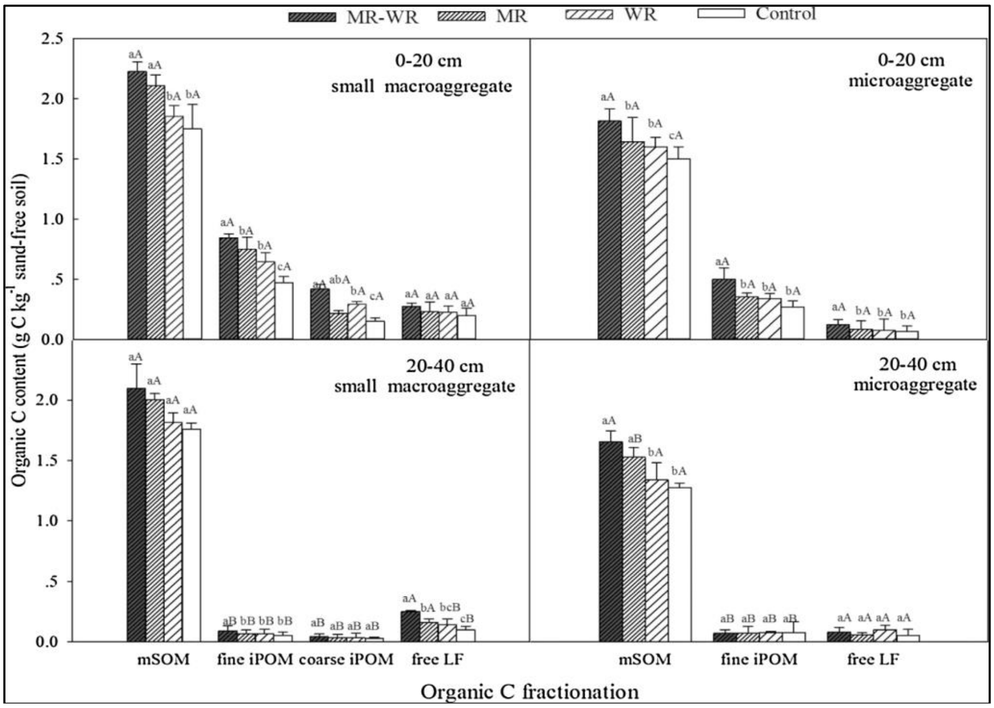

Fig 13(c): Organic C content (g kg^{-1} soil) of the SOC fractions: coarse iPOM, fine iPOM, mSOM, and free LF of small macro-aggregates and micro-aggregates in the 0–20 cm and 20–40 cm soil layers under MR-WR, MR, and WR

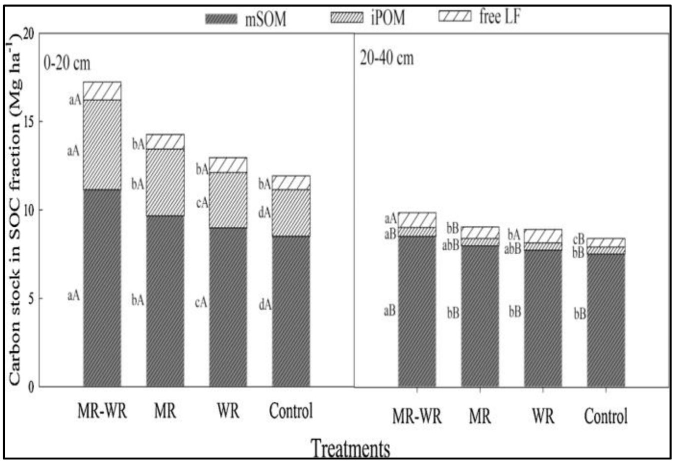

Fig 13(d): Carbon stock of mSOM, iPOM, and free LF (small macro-aggregates and micro-aggregates) in the 0–20 and 20–40 cm soil layers under MR-WR, MR, WR, and Control

Zhao *et al*. (2018) [57] reported that straw returns 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. The SOC content of each aggregate class in the 0–20 cm layer was significantly higher than that in the 20–40 cm layer [Fig. 13a]. Increases in the SOC content of aggregate fractions were highest in MRWR, followed by MR, and finally WR [Fig. 13a]. 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. 13b]. 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. 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. 13c]. The carbon content of iPOM was much lower at 20–40 cm than at 0–20 cm [Fig. 13c]. Continuous straw return, particularly MR-WR, also greatly increased the proportions of mSOM-C, iPOM-C and free LF-C [Fig. 13d]. In both the 0–20 and 20–40 cm layers, mSOM-C contributed to the majority (67.0–71.9% and 86.3–89.6%) of the total SOC stock within small macro-aggregates and micro-aggregates [Fig. 13d]. In the 0–20 cm layer, mSOM-C was 31%, 13.6% and 5% higher in MR-WR, MR, and WR relative to the control, respectively [Fig. 13d]; in the 20–40 cm depth, the corresponding values were 13.2%, 6.1% and 2.8%. In the 0–20 cm layer, iPOM-C was 75.9%, 36.7%, and 33.3% higher in MR-WR, MR and WR relative to the control, respectively; in the 20–40 cm layer, the corresponding values were 30.7%, 7.1%, and 8.9%. Free LF-C was 30.8%, 5.1%, and 3.8% higher in MR-WR, MR, and WR relative to the control, respectively; in the 20–40 cm layer, the corresponding values were 74.5%, 35%, and 56.4%. Therefore, straw return had much greater impact on the proportions of mSOM and iPOM compared with that of free LF, and the iPOM fraction was the most sensitive to different straw return modes and soil depth. Samahadthai *et al*. (2010) [41] reported that lower quality residues enhanced the free LF pool, whereas higher quality residues promote heavy SOM fractions. Fine particulate OC of small macro-aggregates tended to increase with increasing straw input in the 0–20 cm layer 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].

Shahid *et al.* (2017) revealed that as compared to the initial (13.7 Mg ha^{-1}), the SOC stock in 0–15 cm depth increased under all the fertilized treatments during 41 year period in the order: NPK + FYM > N + FYM > NPK > FYM > N > control [Fig. 14a]. Thus the rate of increase in SOC stock due to fertilizer application alone varied between 57 and 89 kg ha^{-1} yr^{-1}, while for FYM addition the rate of increase was 61 to

138 kg ha^{-1} yr^{-1}, highest being in NPK + FYM [Fig.14a]. Campbell *et al.* (2005) [5] reported that fertilization of continuous wheat after a decade has increased the rates of carbon sequestration (570 kg ha^{-1}) in sub-humid tropics. Xiao *et al.* (2018) [52, 53] reported that compared with the SR treatments, the greatest SOC sequestration rates were recorded in NEC (0.57, 0.41–0.77Mg Cha^{-1} yr^{-1}), followed by SC (0.36, 0.30– 0.43MgCha^{-1} yr^{-1}), NC (0.33, 0.25–0.40MgCha^{-1} yr^{-1}) and NWC (0.19, 0.14–0.25Mg Cha^{-1} yr^{-1}) [Fig. 14b]. The annual SOC sequestration rates were significantly ($P <0.05$) greater in the shortest time interval (3–10years) after SI began (0.53, 0.44–0.63Mg Cha^{-1} yr^{-1}), compared with the medium term (10–20 years; 0.29, 0.23–0.37Mg Cha^{-1} yr^{-1}) or long term (>20 years; 0.17, 0.13–0.21Mg Cha^{-1} yr^{-1}) [Fig. 14c]. The effect of SI on SOC sequestration varied between different crop frequencies in the order: triple (0.51, 0.37–0.67Mg Cha^{-1} yr^{-1})> single (0.41, 0.31–0.53Mg Cha^{-1} yr^{-1}) > double (0.28, 0.24–0.32Mg Cha^{-1} yr^{-1}).

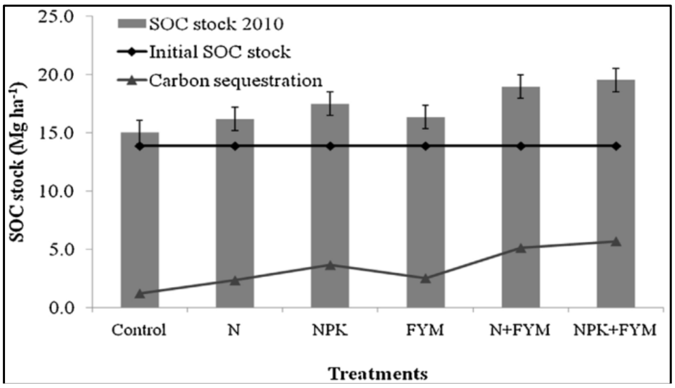

Fig 14(a): Soil organic carbon stocks and carbon sequestration (0–15 cm soil depth) after 41 years of chemical and organic fertilization in a sub-humid tropical rice-rice system. Control: no application of fertilizers and FYM; NPK: application of N, P and K fertilizers; FYM: application of farm yard manure; N + FYM: application of both N and FYM; NPK+ FYM: application of both NPK and FYM.

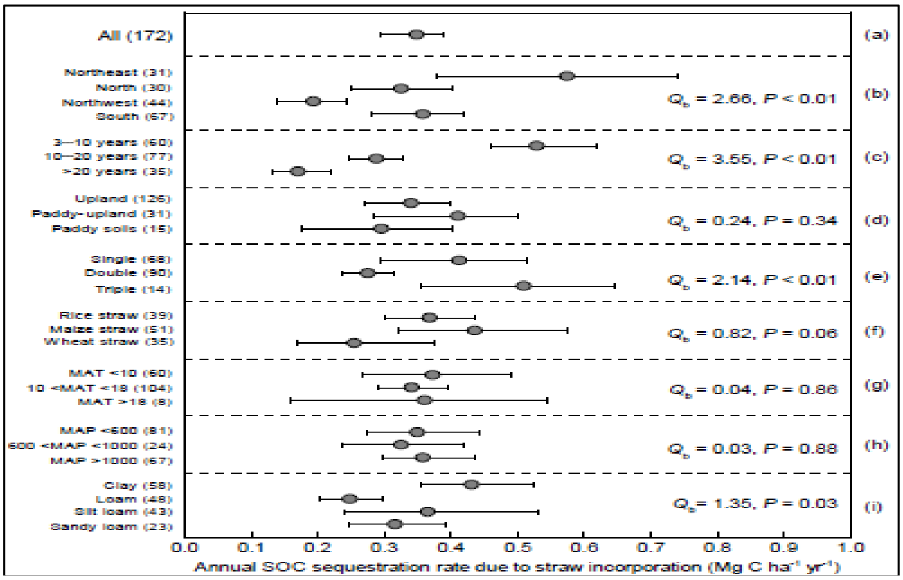

Fig 14(b): Responses of soil organic carbon (SOC) to SI compared with SR (a) categorized into (b) region, (c) experiment duration, (d) land use, (e) crop frequency (seasonyr^{-1}), (f) straw type, (g) mean annual temperature (MAT), (h) mean annual precipitation (MAP) and (i) soil texture

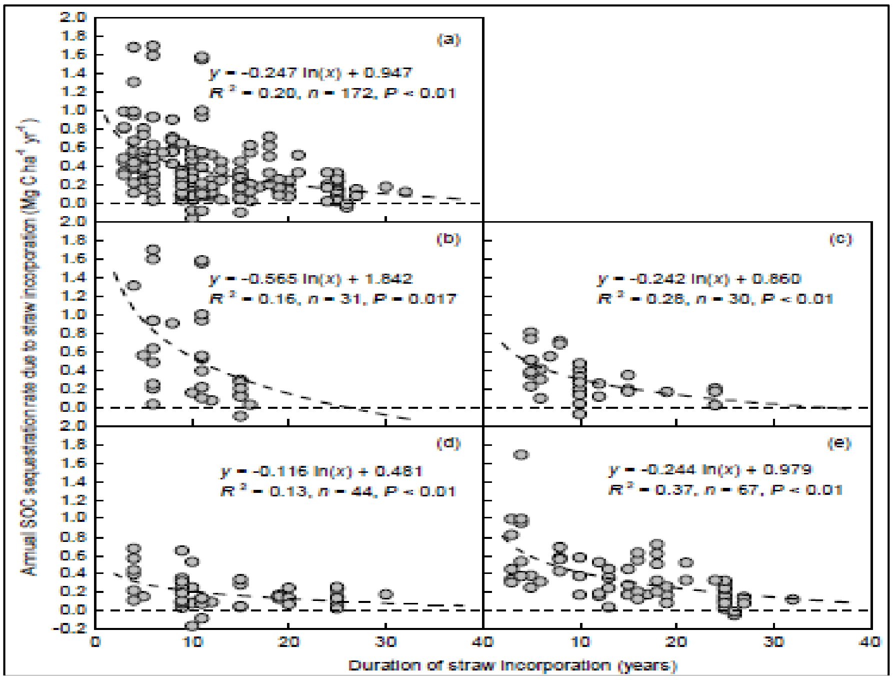

Fig 14(c): Relationships between annual soil organic carbon (SOC) sequestration rate and straw carbon input

Zhang *et al*. (2017) [55] found that application of inorganic fertilizer, straw, straw with inorganic fertilizer, manure, and manure with inorganic fertilizer increased soil microbial biomass carbon (C_{mic}) concentration, while nitrogen-only (N) and nitrogen plus manure (NM) decreased soil microbial biomass nitrogen (N_{mic}) concentration compared with control (no fertilizer application). Many inorganic fertilization treatments (NPK, NP, and PK), NPKS and all manure fertilization treatments (NPKM, NPM, NKM, NM, and M) had significantly positive effect on C_{mic}, other fertilization treatments had either significantly positive or insignificant effect on C_{mic} [Fig. 15a]. The greatest MD in N_{mic} occurred under NPKS and NPKM treatments, both with increases in N_{mic} of 1.41 mg kg^{-1}, while the lowest significant MD was obtained under NPK treatment, with an increase of 0.29 mg kg^{-1} compared with that of the control treatment. The N_{mic} values for NPKS and NPKM treatments were significantly higher than that of NPK treatment [Fig. 15b]. The differences in means (Cmic or Nmic concentration) among different fertilization treatments decreased with experimental duration, and Nmic concentration decreased with increase in N rate [Fig.15 c & 15d].

Jian *et al*. (2016) [15] also found that N acquisition enzymes (N-$_{acq}$) were significantly reduced when the N rate was more than 150 kg ha^{-1} yr^{-1}. Likewise, Kallenbach and Grandy (2011) reported that the highest N rate (more than 200 kg ha^{-1} yr^{-1}) led to the greatest C_{mic} and moderate N application (100–200 kg ha^{-1} yr^{-1}) resulted in the highest increase in N_{mic} through meta-analysis [Fig.16 a & 16b]. Lupwayi *et al.* (2012) [25] also reported that Nmic decreased when N exceeds the recommended values (50–80 kg N ha^{-1}). Therefore, N fertilizer applied at the agronomically recommended rate probably would not have negative effects on SMB [Fig.16c & 16d]. Xu *et al*. (2018) [53] reported that the SOC, SMBC, SMBN contents, and the SMQ in the paddy field were highest in the LOM and HOM treatments, followed by the RF treatment, at the main growth stages of early and late rice [Fig.17 a, 17b & 17 c]. However, in early and late rice, the SMBC content in the paddy field at late growth stages was higher than at early growth stages. The highest SMBC content in the paddy field with five fertilization treatments was at the heading stage, and it then decreased at the mature stage of early and late rice. At the heading stage, in comparison with the CK treatment, the SMBC content in the paddy field increased by 144.34, 190.61, 330.84, and 365.90 g kg^{-1} under the MF, RF, LOM, and HOM treatments, respectively, in early rice. It increased by 145.36, 191.60, 331.86, and 359.93 g kg^{-}1 under the MF, RF, LOM, and HOM treatments, respectively, in late rice [Fig.167]. Liu *et al*., 2014) [23] observed that incorporation of organic matter into paddy soils increases the supply of valuable soil nutrients, SOC, and soil microbial biomass contents. Lu *et al.* (2018) [47] also found that throughout the rice growth period, the SMBC and SMBN contents increased along with the advance in rice growth stages. The SMBC and SMBN contents were higher under the MF, RF, LOM, and HOM treatments at the heading stage of rice. This could be due to organic matter decomposing and providing a large amount of available substrates for soil microbial growth. Compared with early growth stages, the SMBC and SMBN contents were lower at the mature stage of rice; the reason may be that plant root exudation decreased along with the soil drainage practiced at mature rice stages. Moreover, in early and late rice, the SMBN content in the paddy field under five fertilization treatments was higher at the heading stage than at the other stages [Fig.17c]. Liu *et al.* (2017) [24] reported that combined application of chemical fertilizer and organic matter is the best way to increase SOC, SMBC, and SMBN contents, soil quality of rice.

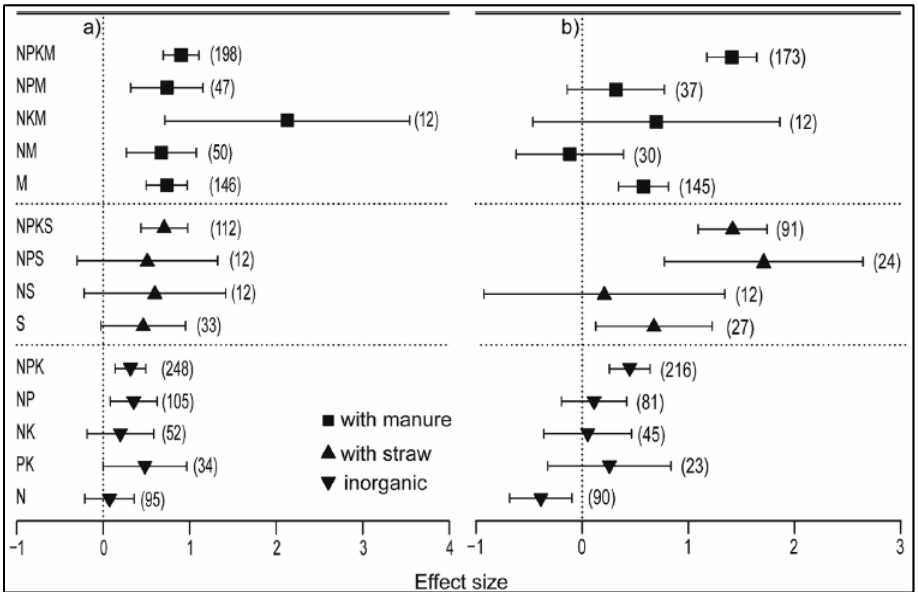

Fig 15(a): Mean differences in soil microbial biomass (a) carbon (C_{mic}) and (b) nitrogen (N_{mic}) for different fertilization treatments. The fertilizers considered were N, mineral nitrogen fertilizer only; NP, mineral nitrogen and phosphorus fertilizers; NK, mineral nitrogen and potassium fertilizers; NPK, mineral nitrogen, phosphorus and potassium fertilizers; S, straw return only; NS, mineral nitrogen plus straw return; NPS, mineral nitrogen and phosphorus plus straw return; NPKS, mineral nitrogen, phosphorus, and potassium plus straw return; M, manure only; NM, mineral nitrogen plus manure; NPM, mineral nitrogen and phosphorus plus manure; NKM, mineral nitrogen and potassium plus manure; NPKM, mineral nitrogen, phosphorus, and potassium plus manure.

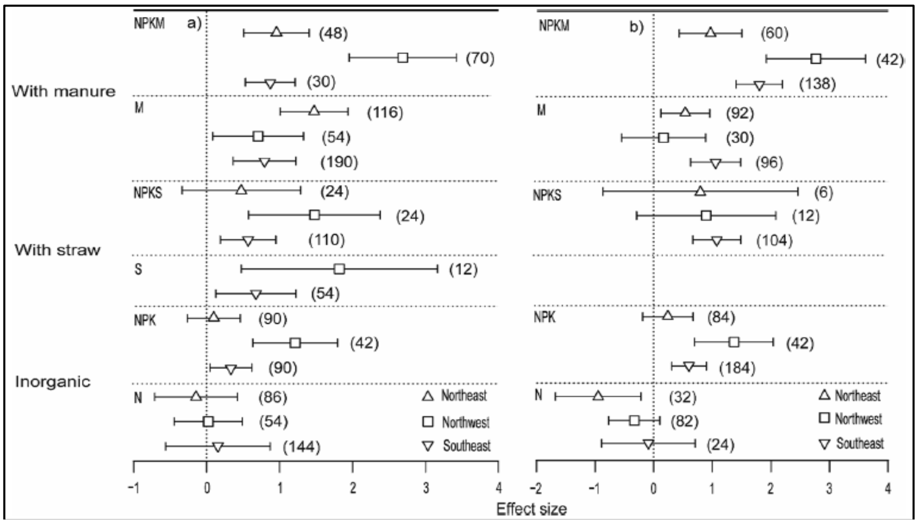

Fig 15(b): Mean differences in soil microbial biomass (a) carbon (C_{mic}) and (b) nitrogen (N_{mic}) change for different cropland regions

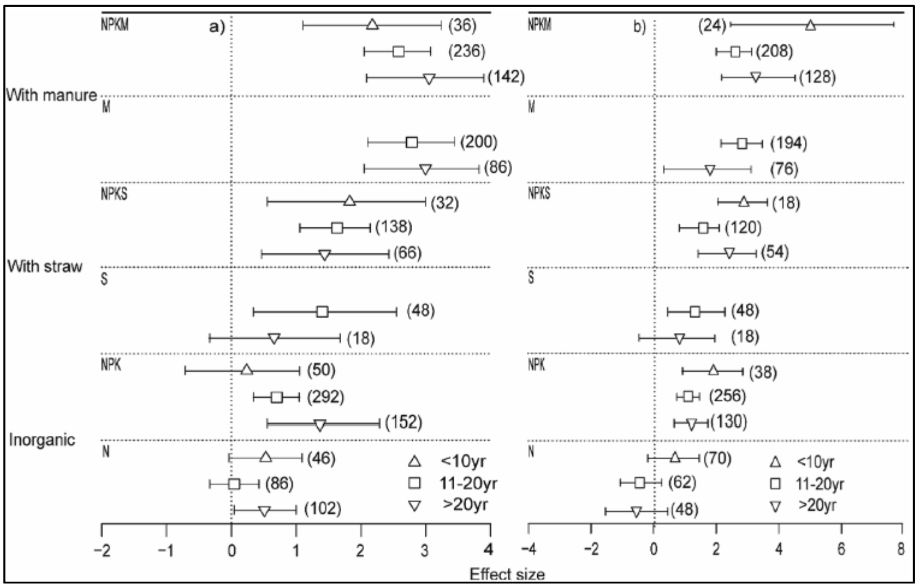

Fig 15(c): Mean differences in soil microbial biomass (a) carbon (C_{mic}) and (b) nitrogen (N_{mic}) for different experimental duration

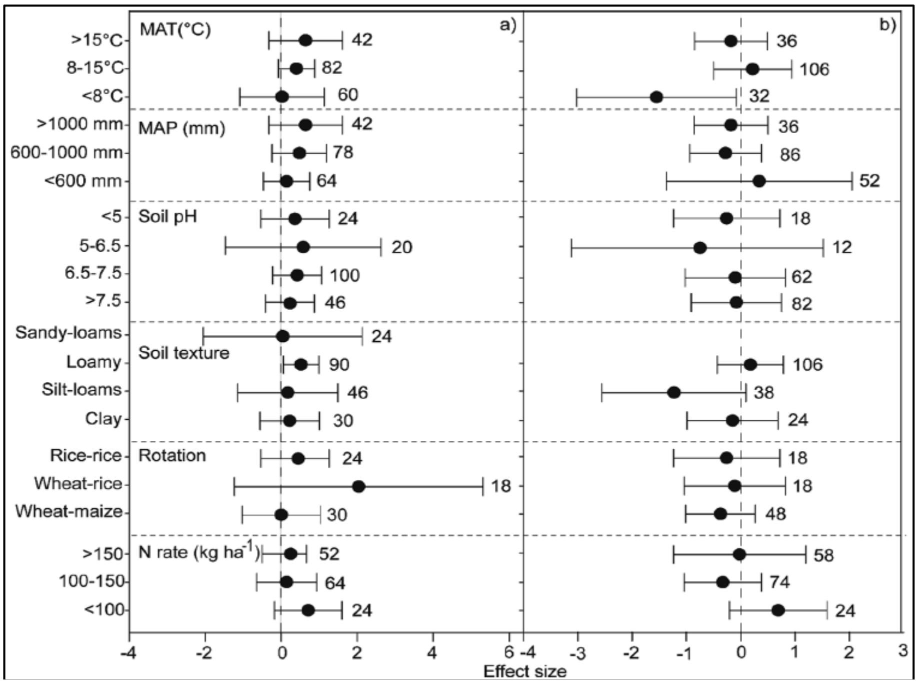

Fig 15(d): Climatic, edaphic and experimental conditions effects on soil microbial biomass (a) carbon (C_{mic}) and (b) nitrogen (N_{mic}) under N fertilization.

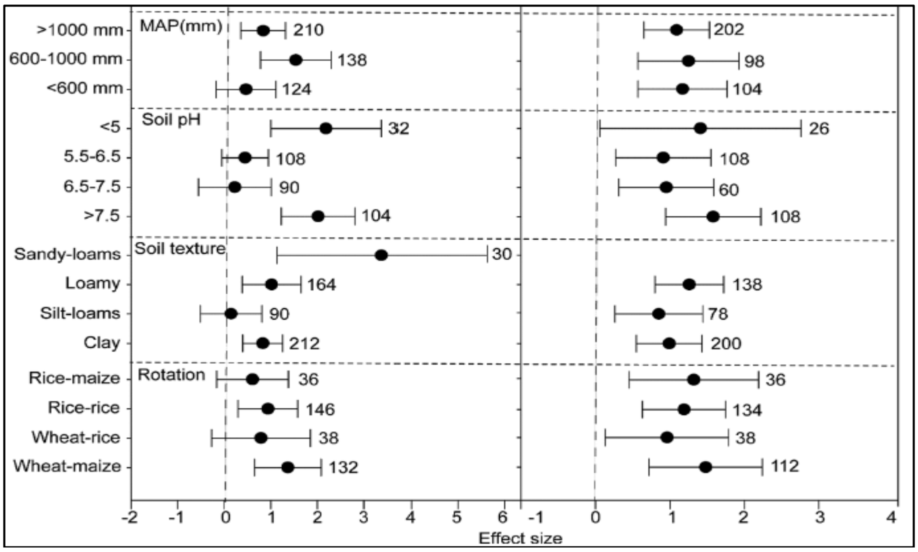

Fig 16(a): Climatic, edaphic, and experimental conditions effects on soil microbial biomass (a) carbon (C_{mic}) and (b) nitrogen (N_{mic}) changes under NPK fertilization

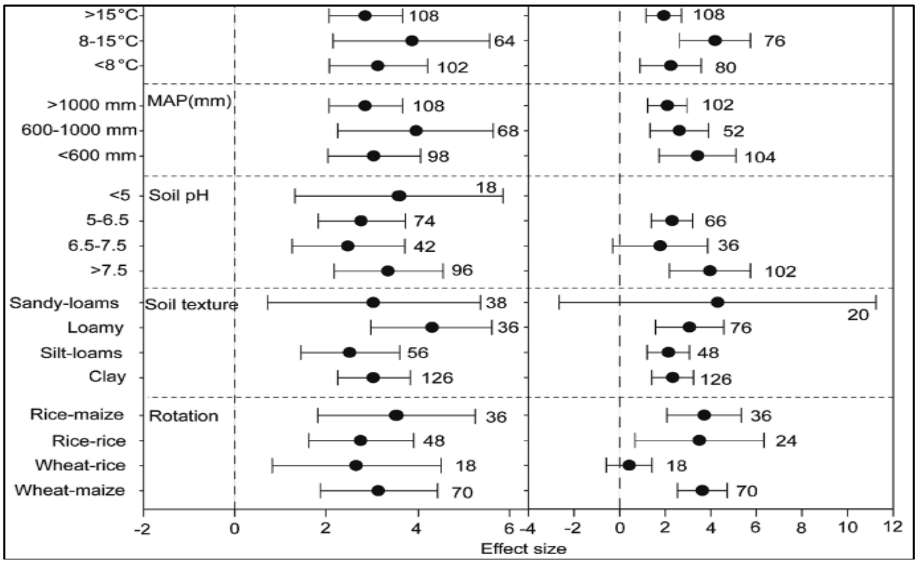

Fig 16(b): Climatic, edaphic, and experimental conditions effects on soil microbial biomass (a) carbon (C_{mic}), and (b) nitrogen (N_{mic}) changes under manure fertilization

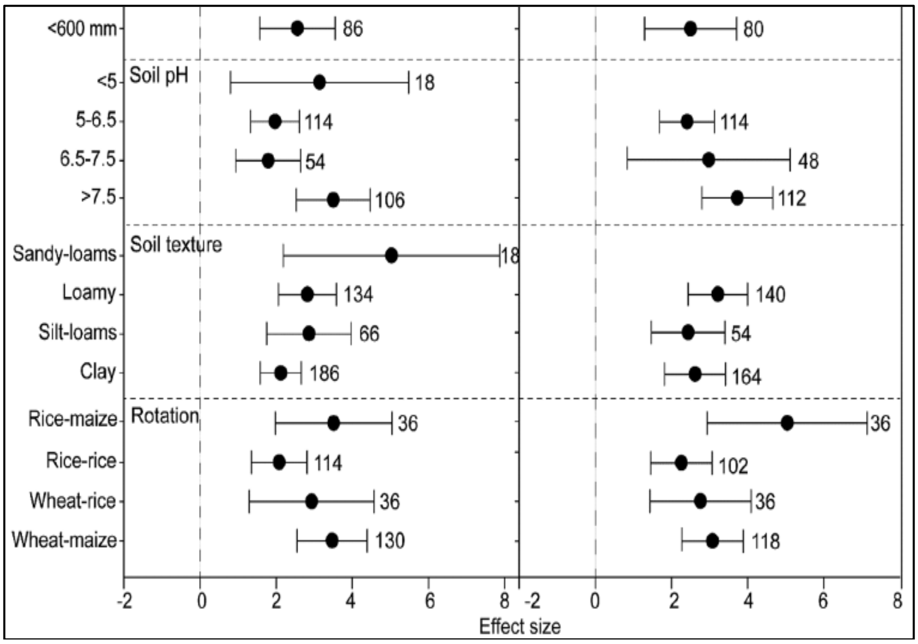

Fig 16(c): Climatic, edaphic, and experimental conditions effects on a soil microbial biomass (a) carbon (C_{mic}) and (b) nitrogen (N_{mic}) changes under NPKM fertilization

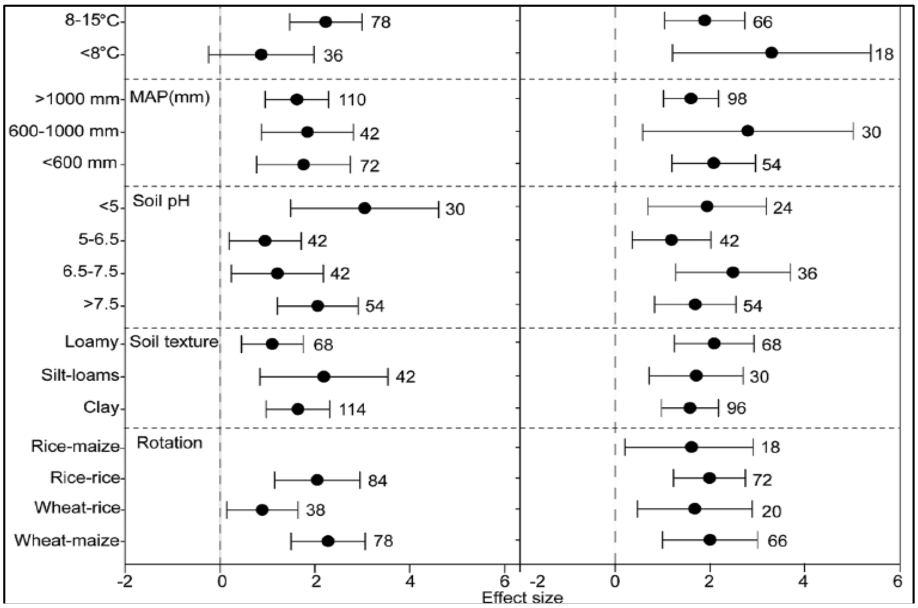

Fig 16(d): Climatic, edaphic, and experimental conditions effects on soil microbial biomass (a) carbon (C_{mic}), and (b) nitrogen (N_{mic}) changes under NPKS fertilization

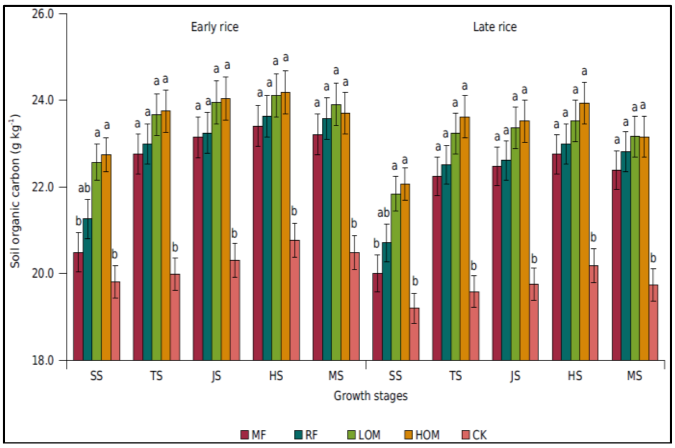

Fig 17(a): Effects of different long-term fertilization treatments on soil organic carbon content in a paddy field at main rice growth stages. MF = mineral fertilizer alone; RF = rice straw residues and mineral fertilizer; LOM = 30 % organic matter and 70 % mineral fertilizer; HOM = 60 % organic matter and 40 % mineral fertilizer; CK = without fertilizer input; SS = seedling stage; TS = tillering stage; JS = jointing stage; HS = heading stage; MS = mature stage.

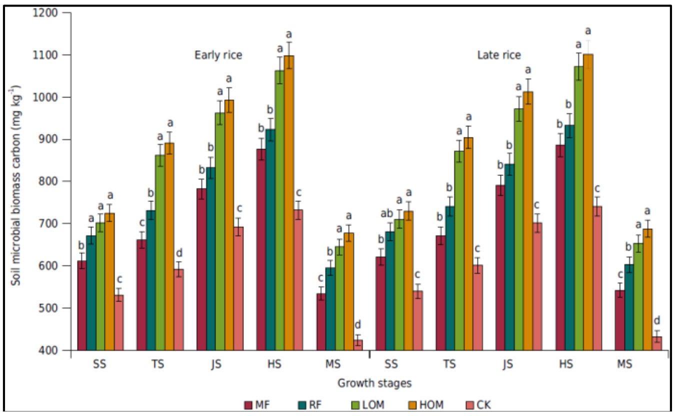

Fig 17(b): Effects of different long-term fertilization treatments on soil microbial biomass carbon in a paddy field at main rice growth stages. MF = mineral fertilizer alone; RF = rice straw residues and mineral fertilizer; LOM = 30 % organic matter and 70 % mineral fertilizer; HOM = 60 % organic matter and 40 % mineral fertilizer; CK = without fertilizer input; SS = seedling stage; TS = tillering stage; JS = jointing stage; HS = heading stage; MS = mature stage.

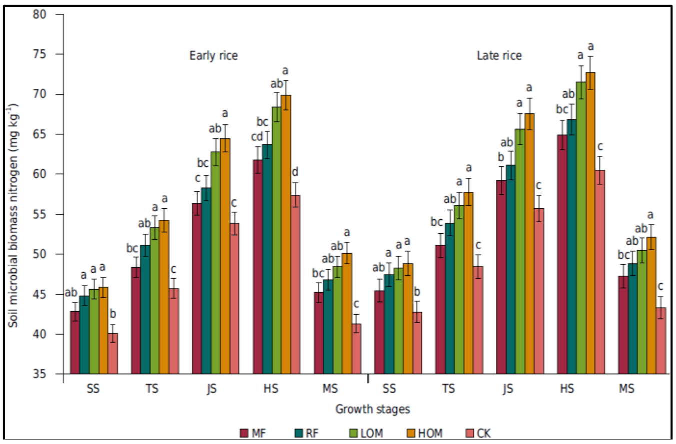

Fig 17(c): Effects of different long-term fertilization treatments on soil microbial biomass nitrogen in a paddy field at main rice growth stages. MF = mineral fertilizer alone; RF = rice straw residues and mineral fertilizer; LOM = 30 % organic matter and 70 % mineral fertilizer; HOM = 60 % organic matter and 40 % mineral fertilizer; CK = without fertilizer input; SS = seedling stage; TS = tillering stage; JS = jointing stage; HS = heading stage; MS = mature stage.

Naresh *et al*. (2018) [33] showed that, soil organic carbon buildup was affected significantly by tillage and residue level in upper depth of 0-15 cm but not in lower depth of 15-30 cm. Higher SOC content of 19.44 g kg^{-1} of soil was found in zero tilled residue retained plots followed by 18.53 g kg^{-1} in permanently raised bed with residue retained plots. Whereas, the lowest level of SOC content of 15.86 g kg^{-1} of soil were found in puddled transplanted rice followed by wheat planted under conventionally tilled plots. Zero tilled residue retained plots sequestrated 0.91gkg^{-1}yr^{-1} SOC in the year 2015-16 which was 22.63% higher over the conventionally tilled residue removed plots after seven seasons of experimentation (Table 1). Resck *et al*. (1999) revealed that the loss of organic carbon under CT might be the breakdown of soil structure and of macro aggregates by relatively frequent and deep plowing of the soil. It is of prime importance to increase or preserve the soil organic matter content for the physical, chemical and biological qualities of the soil.

Table 1: Concentrations of different soil organic matter carbon fractions fPOM and cPOM at different soil depths as

affected by tillage and nutrient management to the continuous RW cropping system [Naresh *et al.*, 2018] [33].

** Different letters within columns are significantly different at P=0.05 according to Duncan Multiple Range Test (DMRT) for separation of means. WSC = water soluble carbon, MBC = microbial biomass carbon, LFC = labile fraction carbon, cPOM = coarse particulate organic carbon, fPOM = fine particulate organic carbon

Conclusion

Stability of soil organic matter and soil organic carbon stock in the rice-wheat cropping system increased by combined application of organic matter with inorganic fertilizer. It is noteworthy that application of organic matter to maintain soil fertility and yield achieved by combined application of organic matter and mineral fertilizer. That is, combined application of organic matter with mineral fertilizer is a benefit in sustaining or increasing SOC in a rice-wheat cropping system. Furthermore, the long term application of rice straw residues is another important way to increase stability of soil organic matter and soil organic carbon stock in the rice-wheat system field; therefore, the significance of the practice of returning rice straw residues to the wheat field should be emphasized. The increase of SOC was attributed to the amendments of crop residues and organic manure, the augment of synthetic fertilizer application and the optimal combination of nutrients, and the development of no-tillage and reduced-tillage practice. Results have very significant implications for soil C sequestration potential in semiarid agro-ecosystems of western Uttar Pradesh of India. SOC concentration in surface soil (0–15 cm) and SOC storage of the profile (0–30 cm) were slightly increased by the long term fertilizer treatments, but they were sharply increased by the manure and straw amendment (VC, 50%RDF+ VC @ 5tha^{-1} and 100% RDF+ VC @ 5tha^{-1}). Results were additive with higher rates of organic manure resulting in further beneficial effects. The effect of SOC stock is primarily attributed to its ability to act as a source of nutrients for crops, increase in plant available water capacity, improved soil biological activities enhancing plant nutrition, and to favorable soil structure and other physical properties. Thus, there could be a trade-off between enhancing SOM mineralization and nutrient release *via* tillage, to support plant growth, *versus* increasing their storage in less disturbed systems, which could further vary with soil types and climatic conditions.

References

1. Adoum AA, Moulin P, Brossard M. Pioneering assessment of carbon stocks in polder soils developed in inter-dune landscapes in a semiarid climate, Lake Chad. C. R. Geoscience. 2017; 349:22-31.
2. Assmann BM, Ibanor Anghinonia, Amanda Posselt Martins, Sérgio Ely Valadão Gigante de Andrade Costa, Diego Cecagno, Filipe Selau Carlos, Paulo Cesar de Faccio Carvalhob. Soil carbon and nitrogen stocks and fractions in a long-term integrated crop–livestock system under no-tillage in southern Brazil. Agri, Ecosyst Environ. 2014; 190:52-59.
3. Bhatt R, Kukal SS, Busari MA, Arora S, Yadav M. Sustainability issues on rice–wheat cropping system. Int. Soil Water Conserv. Res. 2016; 4:64-74.
4. Bol R, Poirier N, Balesdent J, Gleixner G. Molecular turnover time of soil organic matter in particle-size fractions of an arable soil. Rapid Communications in Mass Spectrometry. 2009; 23:2551-2558.
5. Campbell CA, Janzen HH, Paustian K, Gregorich EG, Sherrod L, Liang BC, Zentner RP, Carbon storage in soils of the North American Great Plains. Agron. J. 2005; 97:349.
6. Cerda A. Aggregate stability against water forces under different climates on agriculture land and scrubland in southern Bolivia. Soil Tillage Res. 2000; 57:159-166.
7. Cheverry C, Fromaget M, Bocquier G. Quelques aspects micromorphologiques de la pe´dogene` se des sols de polders conquis sur le lac Tchad. Cah. ORSTOM Ser. Pe´dologie. 1972; 10:373-387.
8. Christensen BT. Physical fractionation of soil and structural and functional complexity in organic matter turnover. Eur J Soil Sci. 2001; 52:345-353.
9. Cox PM, Betts RA, Jones CD, Spall SA, Totterdell IJ. Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. Nature. 2000; 408:184-187.
10. Davidson EA, Janssens IA. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature. 2006; 440:165-173.
11. Flessa H, Amelung W, Helfrich M, Wiesenberg GL, Gleixner G, Brodowski S, Rethemeyer J, Kramer C, Grootes PM. Storage and stability of organic matter and fossil carbon in a Luvisol and Phaeozem with continuous maize cropping: a synthesis. J. Plant Nutri Soil Sci. 2008; 171:36-51.
12. Habteselassie MY, Miller BE, Thacker SG, Stark JM, Norton JM. Soil nitrogen and nutrient dynamics after repeated application of treated dairy-waste, Soil Sci. Soc. Am. J. 2006a; 70:1328-1337.
13. IPCC. Climate change 2007. The physical science basis, coupling between changes in the climate systems and biogeochemistry. Contribution of working group 1 to the fourth assessment report of the intergovernmental panel on climate change. Cambridge university press: Cambridge, UK and NY, USA, 2007.
14. Ingram JSI, Fernandes ECM. Managing carbon sequestration in soils: concepts and terminology. Agric Ecosyst Environ. 2001; 87:111-117.
15. Jian S, Li J, Chen J, Wang GS, Mayes MA, Dzantot KE, Hui DF, Luo YQ. Soil extracellular enzyme activities, soil carbon and nitrogen storage under nitrogen fertilization: A meta-analysis. Soil Biol. Biochem. 2016; 101:32-43.
16. Jobbagy EG, Jackson RB. The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecol Applications. 2000; 10:423-436.
17. Joao Carlos de Moraes Sa, Florent Tivet, Lal R, Briedis C, Daiani Cruz Hartman, Juliane Zuffo dos Santos, Josiane Burkner dos Santos. Long-term tillage systems impacts on soil C dynamics, soil resilience and agronomic productivity of a Brazilian Oxisol. Soil Tillage Res. 2014; 136:38-50.
18. Kallenbach C, Grandy AS. Controls over soil microbial biomass responses to carbon amendments in agricultural systems: A meta-analysis. Agric. Ecosyst. Environ. 2011; 144:241-252.
19. Knebl L, Leithold G, Brock C. Improving minimum detectable differences in the assessment of soil organic matter change in short term field experiments. J Plant Nutri Soil Sci. 2015; 178:35-42.
20. Kukal SS, Rehana-Rasool, Benbi DK. Soil organic carbon sequestration in relation to organic and inorganic

fertilization in rice– wheat and maize–wheat systems, Soil Tillage Res. 2009; 102:87-92.

21. Lal R. Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural lands, Land Degrad. Dev. 2006; 17:197-209.
22. Lehtinen T, Schlatter N, Baumgarten A, Bechini L, Krüger J, Grignani C, Zavattaro L, Costamagna C, Spiegel H. Effect of crop residue incorporation on soil organic carbon and greenhouse gas emissions in European agricultural soils. Soil Use Manag. 2014; 30:524-538.
23. Liu S, Huang D, Chen A, Wei W, Brookes PC, Li Y, Wu J. Differential responses of crop yields and soil organic carbon stock to fertilization and rice straw incorporation in three cropping systems in the subtropics. Agri, Ecosys Environ. 2014; 184:51-58.
24. Liu Z, Rong Q, Zhou W, Liang G. Effects of inorganic and organic amendment on soil chemical properties, enzyme activities, microbial community and soil quality in yellow clayey soil. PLoS One, 2017, 12:e0172767. https://doi.org/10.1371/journal.pone.0172767
25. Lupwayi NZ, Lafond GP, Ziadi N, Grant CA. Soil microbial response to nitrogen fertilizer and tillage in barley and corn. Soil Tillage Res. 2012; 118:139-146.
26. Mahmoodabadi M, Heydarpour E. Sequestration of organic carbon influenced by the application of straw residue and farmyard manure in two different soils. Int. Agrophys. 2014; 28:169-176.
27. Mandal B, Majumder B, Bandyopadhyay PK, Hazra GC, Gangopadhyay A, Samantaray RN, Mishra AK, Chaudhury J, Saha MN, Kundu S. The potential of cropping systems and soil amendments for carbon sequestration in soils under long-term experiments in subtropical India, Global Change Biol. 2007; 13:357-369.
28. Mandal B, Majumder B, Adhya TK, Bandyopadhyay PK, Gangopadhyay A, Sarkar D, Kundu MC, Choudhury SG, Hazra GC, Kundu S, Samantaray RN, Misra AK. Potential of double-cropped rice ecology to conserve organic carbon under subtropical climate. Glob. Change Biol. 2008; 14:2139-2151.
29. Martins T, Saab SC, Milori D, Brinatti AM, Rosa JA, Cassaro FAM, Pires LF. Soil organic matter humification under different tillage managements evaluated by Laser Induced Fluorescence (LIF) and C: N ratio. Soil Tillage Res. 2011; 111:231-235.
30. Memon MS, Jun Guo, Tagar AA, Nazia Perveen, Changying Ji, Memon SA, Memon N. The Effects of Tillage and Straw Incorporation on Soil Organic Carbon Status, Rice Crop Productivity, and Sustainability in the Rice-Wheat Cropping System of Eastern China. Sustainability. 2018; 10(4):961. DOI:10.3390/su10040961
31. Mi W, Wu L, Brookes PC, Liu Y, Zhang X, Yang X. Changes in soil organic carbon fractions under integrated management systems in a low-productivity paddy soil given different organic amendments and chemical fertilizers. Soil Tillage Res. 2016; 163:64-70.
32. 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, rain-fed lowlands of Bihar, India. Soil Res. 2016; 54(8):997-1006.
33. Naresh RK, Gupta Raj K, Kumar V, Rathore RS, Purushottam Kumar V, Kumar S, Singh SP, Tyagi Saurabh Mahajan NC, Singh V. Carbon, Nitrogen Dynamics and Soil Organic Carbon Retention Potential after 16 years by different land uses and Nitrogen Management in Typic Ustochrept Soil. Paddy Water Environ, (In press), 2018.
34. Nicoloso RS, Lovato T, Amado TJC, Bayer C, Lanzanova ME. Balanc¸ o decarbono orgânico no solo sob integrac¸ ão lavoura-pecuária no sul do Brasil. Rev. Bras. Cienc. Solo. 2008; 32:2425-2433.
35. Poeplau C, Lisa Reiter L, Berti A, Thomas Kätterer. Qualitative and quantitative response of soil organic carbon to 40 years of crop residue incorporation under contrasting nitrogen fertilisation regimes. Soil Res. 2017; 55:1-9.
36. Rasse DP, Rumpel C, Dignac MF. Is soil carbon mostly rooting carbon? Mechanisms for a specific stabilization. Plant Soil. 2005; 269:341-356.
37. Reicosky DC, Kemper WD, Langdale GW, Douglas Jr, CL, Rasmussen PE. Soil organic matter changes resulting from tillage and biomass production. J Soil Water Conser. 1995; 50:253-261.
38. Sa JCM, Cerri CC, Dick WA, Lal R, Venske SP, Piccolo MC, Feigl BE. Organic matter dynamics and carbon sequestration rates for a tillage chronosequence in a Brazilian Oxisol. Soil Sci Soc Am J. 2001; 65:1486-1499.
39. Saharawat YS, Singh B, Malik RK, Ladha JK, Gathala M, Jat ML, Kumar V. Evaluation of alternative tillage and crop establishment methods in a rice–wheat rotation in North Western IGP? Field Crops Res. 2010; 116:260-267.
40. Salton JC, Mielniczuk J, Bayer C, Fabricio AC, Macedo MCM, Broch DL, Boeni M, Conceic ão, PC. Matéria Orgânica do Solo na Interac¸ ão Lavoura-Pecuária em Mato Grosso do Sul. Embrapa Agropecuária Oeste, Dourados, 2005.
41. Samahadthai P, Vityakon P, Saenjan P. Effects of different quality plant residues on soil carbon accumulation and aggregate formation in a tropical sandy soil in northeast thailand as revealed by a 10-year field experiment. Land Degrad. Dev. 2010; 21:463-473.
42. Sapkota TB, Jat RK, Singh RG, Jat ML, Stirling CM, Jat MK, Bijarniya D, Kumar M, Singh Y, Saharawat YS, Gupta RK. 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; l 33:81-89.
43. Shahid M, Nayak AK, Chandrika Puree, Rahul Tripathi, R, Banwari Lal, Priyanka Gautam, Bhattacharyya P, Mohanty S, Kumar A, Panda BB, Kumar U, Shukla AK. Carbon and nitrogen fractions and stocks under 41 years of chemical and organic fertilization in a sub-humid tropical rice soil. Soil Tillage Res. 2017; 170:136-146.
44. Sheng H, Zhou P, Zhang Y, Kuzyakov Y, Qing Zhou, Ge T, Wang C. Loss of labile organic carbon from subsoil due to land-use changes in subtropical China. Soil Bio Biochem. 2015; 88:148-157.
45. Six J, Paustian K. Aggregate-associated soil organic matter as an ecosystem property and a measurement tool. Soil Biol. Biochem. 2014; 68:A4-A9.
46. Smith P, Fang C, Dawson JJC, Moncrieff JB. Impact of global warming on soil organic carbon. Adv Agron. 2008; 97:1-43.
47. Tivet F, Sa JCM, Lal R, Milori DBM, Briedis C, Letourmy P, Pinheiro LA, Borszowskei PR, Hartman DDC. Assessing humification and organic C fractions by laser-induced fluorescence and FTIR spectroscopies in

conventional and no-till methods in Brazil's sub-tropical and tropical agro-ecoregions. Geoderma. 2013b; 207-2018:71-81.

48. Van-Camp L, Bujarrabal B, Gentile AR, Jones RJA, Montanarella L, Olazabal C, Selvaradjou SK. Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection, EUR 21319 EN/3, 2004, 872.
49. Wang GC, Li TT, Zhang W, Yu YQ. Impacts of agricultural management and climate change on future soil organic carbon dynamics in North China Plain, *PLoS ONE*, 9, e94827, 2014, https://doi.org/10.1371/journal.pone.0094827.
50. Wang GZ, Wen Sun W, Li T, Pengfei Han. Modelling soil organic carbon dynamics and their driving factors in the main global cereal cropping systems. Atmos. Chem. Phys. 2017; 17:11849-11859.
51. Wu L, Wood Y, Jiang P, Li L, Pan G, Lu J, Chang A, Enloe H. Carbon sequestration and dynamics of two irrigated agricultural soils in California. Soil Sci. Soc. Am. J. 2008; 72:808-814.
52. Xiao Han, Cong X, Jennifer AJ, Dung ait, Roland Bol, Xiaojie Wang, Wenliang Wu, Fanqiao Meng. Straw incorporation increases crop yield and soil organic carbon sequestration but varies under different natural conditions and farming practices in China: a system analysis Bio-geo-sci. 2018; 15:1933-1946.
53. Xu Y, Tang H, Xiao X, Li W, Li C, Sun G, Cheng K. Effects of long-term fertilization management practices on soil microbial carbon and microbial biomass in paddy soil at various stages of rice growth. Rev Bras Cienc Solo. 2018; 42:e0170111.
54. Yadav GS, Lal R, Meena RS, Babu S, Das A, Bhowmik SN, Datta M, Layak J, Saha P. Conservation tillage and nutrient management effects on productivity and soil carbon sequestration under double cropping of rice in north eastern region of India. Ecol. Indic, 2017.
55. Zhang Q, Miao F, Wang Z, Shen Y, Wang G. Effects of Long-Term Fertilization Management Practices on Soil Microbial Biomass in China's Cropland: A Meta-Analysis. Agron. J. 2017; 109(4):1183-1195.
56. Zhang W, Liu K, Wang J, Shao X, Xu M, Li J, Wang X, Murphy DV. Relative contribution of maize and external manure amendment to soil carbon sequestration in a long term intensive maize cropping system. Scientific Reports. 2015; 5:10791.
    DOI: 10.1038/ srep10791
57. Zhao H, Shar AG, Li Shuo, Chen Y, Shi J, Zhang X, Tian X. 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.