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Laser Assisted Precision Land Leveling and Organic Inputs with Cropping Systems Effects on Soil Organic Carbon Lability, Ecosystem Carbon Storage and Soil Carbon Restoration: A Review

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Abstract

Soil organic carbon plays an important role in the stability and fertility of soil and is influenced by different management practice. Soil is one of the most important terrestrial carbon (C) stores. Soil C sequestration relies of the adoption of improved management practices that increase the amount of carbon stored as soil organic matter, primarily in cropland and grazing lands. These C sequestering practices act by increasing the rate of input of plant-derived residues to soils and/or by reducing the rates of turnover of organic C stocks already in the soil. In addition to carbon dioxide removal potential, increases in soil organic matter/soil C content are highly beneficial from the standpoint of soil health and soil fertility. In agro-ecosystems, the amount of soil C in topsoil is variable under different environments and managements. Thus, to increase C input and enhance the soil organic C (SOC) content in cropping systems it is n ecessary to explore the managements practices that may achieve this, such as green manure, catch crops and animal manure in cropping systems. Poor soil fertility and soil degradation induced by persistent conventional farming with repeated tillage and removal or in situ burning of crop residue are major limitations to food security and environmental sustainability. However, degraded agricultural lands with depleted soil organic carbon (SOC) stocks are capable of soil carbon restoration through improved management practices. A significant increase in SOC levels under zero tillage (ZT) over conventional tillage (CT) was found; returning more crop residues to the soil is associated with an increase in SOC concentration that is further increased by crop diversification. Agroforestry and sugarcane systems were characterized by very labile C compared with uncultivated soils and the soils under rice–wheat and maize–wheat systems. Conversely, uncultivated soils and the soils under maize–wheat and rice–wheat held greater proportion of organic C in recalcitrant fractions. Laser assisted precision land leveling fields crop compared to unlevelled and traditional levelling increased total soil carbon (TC), total inorganic carbon (TIC), total soil organic carbon (SOC) 11.93 and 10.73 g kg^{-1} content was recorded at surface depth (0-15 cm). However, WSC, and MBC 27.8% and 35.1% in surface soil and 29.2% and 42.9% in sub surface soil content were recorded in laser levelled and unlevelled fields. Adoption of laser land levelling technology with organic inputs in cropping systems helps in reducing the farm input costs, increase SOC and enhance crop productivity.

Keywords: Precision land leveling, Soil carbon restoration, Soil carbon pools, C sequestration

Introduction

Soil organic carbon (SOC) is one part in the much larger global carbon cycle that involves the cycling of carbon through the soil, vegetation, ocean and the atmosphere. The SOC pool stores an estimated 1 500 PgC in the first meter of soil, which is more carbon than is contained in the atmosphere (roughly 800 PgC) and terrestrial vegetation (500 PgC) combined (FAO and ITPS, 2015). This phenomenal

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SOC reservoir is not static, but is constantly cycling between the different global carbon pools in various molecular forms (Kane, 2015). While CO_2 (carbon dioxide) and CH_4 (methane) are the main carbon-based atmospheric gases, autotrophic organisms (mainly plants), as well as photo- and chemo-autotrophic microbes synthesize atmospheric CO_2 into organic material. Dead organic material is incorporated into the soil-by-soil fauna, leading to carbon inputs into the soil through organic material transformation by heterotrophic microorganisms. This organic material transformation process results in a complex biogeochemical mixture of plant litter compounds and microbial decomposition products in various stages of decomposition (Paul, 2014) that can be associated with soil minerals and occluded within aggregates, enabling SOC persistence in soil for decades, centuries or even millennia (Schmidt et al., 2011). Carbon loss can also be caused by root exudates such as oxalic acid, which liberate organic compounds from protective mineral associations (Keiluweit et al., 2015). Finally, carbon is also partly exported from soils to rivers and oceans as dissolved organic carbon (DOC) or as part of erosion material. In principle, the amount of SOC stored in a given soil is dependent on the equilibrium between the amount of C entering the soil and the amount of C leaving the soil as carbon-based respiration gases resulting from microbial mineralization and, to a lesser extent, leaching from the soil as DOC. Locally, C can also be lost or gained through soil erosion or deposition, leading to the redistribution of soil C at local, landscape and regional scales. Levels of SOC storage are therefore mainly controlled by managing the amount and type of organic residues that enter the soil and minimizing the soil C losses (FAO and ITPS, 2015).

The sustainability of crop production systems based on soil quality gets affected by the nature of the farming system being implemented like prolonged cultivation of agricultural lands including tillage and inversion combined with the removal of crop residues accelerate the decomposition of soil organic matter and causes 20–67% soil C loss (Yang et al., 2019) and leads to soil degradation and diminished properties of the soil (Lal, 2014). Consequently, the depletion of carbon from soil elevates the atmospheric concentration of carbon dioxide (CO2) from 316 to 400 ppm and global temperature by 0.12°C per decade (IPCC, 2013). A loss of soil organic carbon (SOC) of 42 and 59% due to changes in land-use pattern from forest to crop and from pasture to crop respectively has been found (Guo and Gifford, 2002). In general, agricultural activities directly produce about 10–12% of the atmospheric greenhouse gases (GHGs) (Smith et al., 2007). Thus, the twin crisis of food insecurity and climate change can be addressed through the restoration of the soil carbon achieved through the implementation of recommended management practices on agricultural soils) Lal, 2004). Understanding the dynamics of SOC in relation to land use and management strategies is of foremost importance to identify pathways of C sequestration in soils. It is necessary to build up soil carbon contents by increasing carbon inputs or decreasing decomposition of organic matter in the soil for sustainable agricultural productivity and a stable environment.

Precision land levelling is a method that uses laser-equipped drag buckets to smooth the land surface (± 2 cm) from its average height, and this technique is well known for achieving higher levels of accuracy in land levelling and offers great potential for aggregate-associated SOC. Labile carbon is the SOC pool which is directly available for microbial activity and, hence, is considered to be the primary energy source for microorganisms (Haynes, 2005). Addition of organic matter as fertilizer (Gattinger et al., 2012) and precision leveled field reduced tillage will likely increase labile organic carbon (Cooper et al., 2016). In addition, these practices have the potential to enhance carbon and nitrogen cycling as well as soil aggregation, which are one of the primary mechanisms through which organic carbon is sequestered in soil (Panettieri et al., 2015). Therefore, labile carbon has potential as an indicator of soil functions, in particular: nutrient cycling, soil aggregate formation and carbon sequestration.

According to a study conducted in northern India, cultivated soils resulted in a loss of 21–36% total organic carbon as compared to uncultivated soils (Benbi et al., 2015) which is a little lesser than the values (30–60%) reported in various agro-climatic regions of India (Lal, 2004). When natural forests are converted to croplands, the soil structure gets disrupted enhancing the mineralization of organic matter by microbes subsequently leading to SOC loss (Golchin and Asgari, 2008). A wide range of SOC concentration from 0.85 to 3.56% (Bhattacharyya et al., 2008) with reported SOC stock of 20–40 Mg ha^{-1} in the top 0–30 cm soil depth (Choudhury et al., 2013) has been reported in North Eastern Himalayan Region (NEHR). In order to understand how SOC is lost or stabilized in soil, SOC stocks in soil can be classified into different functional pools depending on their varying residence.

Another SOC pool is the non-labile pool (passive pool) which is more stable and recalcitrant fraction of SOC forming organic-mineral complexes with soil mineral and gets decomposed slowly by microbial activity (Wiesenberg et al., 2010). Thus, the labile SOC pools serve a better indicator of soil quality to assess variations caused by land use changes (Vieira et al., 2007) while the non-labile SOC pools add to the total organic carbon stocks (Chan et al., 2001). In an ecosystem functioning, land use change affects SOC pools to determine whether soil act as sinks or sources of C in the global C cycle (Degryze et al., 2004). time *viz*. labile and non-labile pool. Labile pool (active pool) is the most sensitive pool available relatively in small proportion as it is easily affected by fluctuation in environmental conditions. They rapidly decompose and get oxidized easily with any changes in land use practice (Haynes, 2005).

Land use changes/ cropping systems influence the balance between the rate of input (e.g., plant litter) and output (e.g., SOC mineralization) of soil organic matter (SOM) as a result of alterations in plant community and land management practice (Poeplau and Don, 2013). Land use changes contribute 6–39% of increase in CO_2 emissions with profound impacts on SOC estimated at 1.5 PgC yr^{-1} (Brovin et al., 2004). The decrease in soil organic matter with increase in agricultural activities has been reported in numerous studies conducted worldwide (Golchi et al., 2004). Rate of carbon accumulation or loss in soil is greatly influenced by changes in soil and vegetation management practices (Post et al., 2001). SOC pool can be restored through conversion of marginal lands into restorative land uses, practice of conservation tillage with cover crops and crop residue mulch, efficient nutrient cycling with compost and manure, and other sustainable soil and water management practices (Lal, 2004). Efforts to increase SOC reservoir through carbon sequestration will nevertheless minimize global warming. Amongst different cropping systems forest plays an important role with great impact on the global biogeochemical cycles with an estimated 40% of total SOC stock stored in forest ecosystems (Dey, 2005). We hypothesized that when organic cultivation gets converted into other form of cropping systems and land uses such as agro-forestry and plantation, there will be an increase in SOC which in turn may have an impact on the active and passive SOC pools. However, studies and information on the distribution of SOC in different pools (active and passive) in different cropping systems in North West India is still limited. Therefore, the objective of this review was to quantify various SOC contents (very labile, labile, less labile and non-labile) and their relative proportions in total organic carbon (TOC) across different land cropping systems use in India.

Management Practices to Increase Soil C Storage

Organic matter additions such as compost and manures can increase soil C contents, both by virtue of the added C in the amendment itself and through improving soil physical attributes and nutrient availability, such that plant productivity and residue C inputs increase as well. Ryals et al. (2015) found substantial increases in soil C storage following modest compost additions in part attributed to improved water retention, increased productivity and hence greater residue inputs to soil. Without counting C in the compost addition, they estimated an increase in C storage of 0.5 tC/ha (1.8 tCO_{2eq}/ha) and 3.3 tC/ha (12.1 CO_{2eq}/ha) respectively, 3 years after compost addition. Ogle et al. (2012) estimated increases under NT of approximately 0.25 tC/ha/y and 0.29 tC/ha/y on sandy and non-sandy soils, respectively.

Soil Organic Carbon Lability

Sahoo et al. (2019) reported that the average distribution of total carbon (TC), soil inorganic carbon

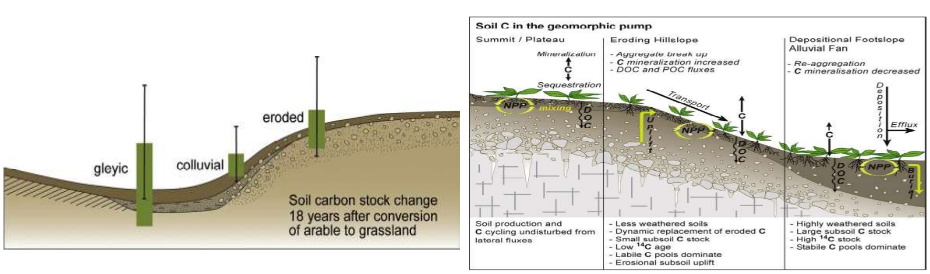
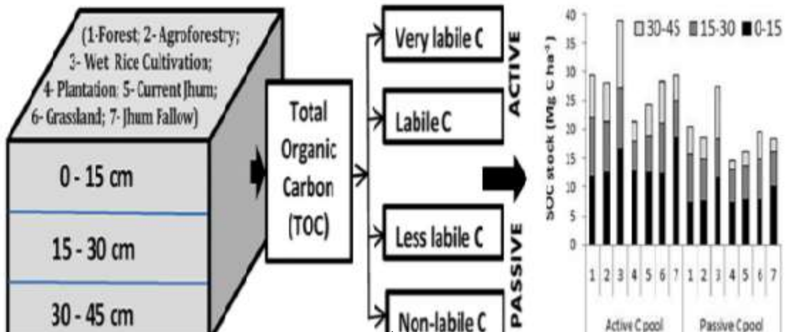
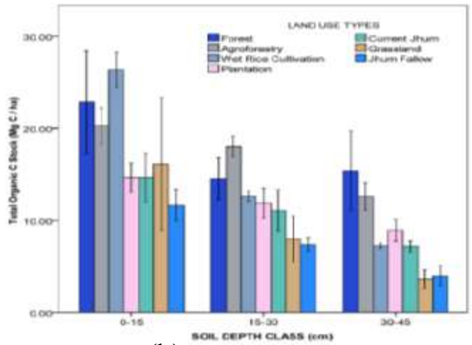


Fig. 1: Fate of soil organic carbon



(a)

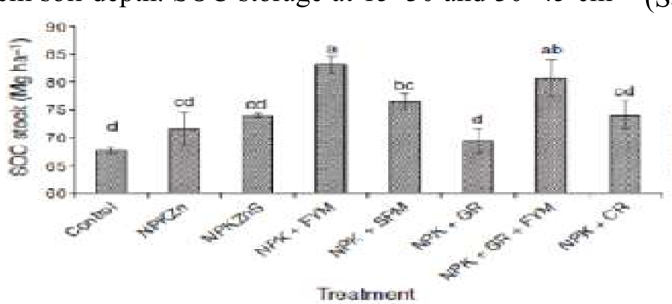


(b)

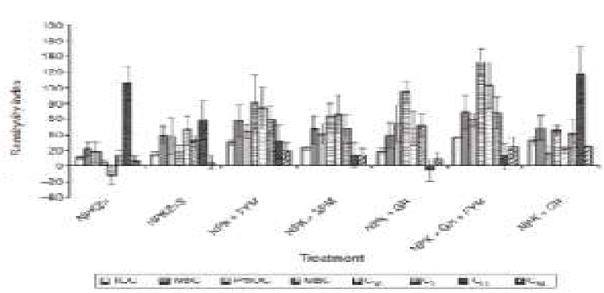
Fig. 2a: Distribution of active and passive soil carbon at three soil depths in different land use systems

Fig. 2b: Soil organic carbon stock (Mg C ha^{-1}) at different soil depth in different land use types

(SIC) and total organic carbon (TOC) in different land use types (0–45 cm) is presented in Fig. 2a. Average fine soil stock (FSS) for 15 cm soil depth was highest in agroforestry systems (10.09 Mg ha^{-1}) followed by wet rice cultivation systems (9.88 Mg ha^{-1}) and the least in current jhum systems (6.08 Mg ha^{-1}), however, no significant differences were observed between the studied land use systems. TC was highest in the forest (3.05%) followed by current jhum (2.19%) and the least in grassland (1.45%). SIC concentrations of these soils were small and averaged 0.14 to 0.31% under different land use types. Average TOC content (%) in the different land use types decreased in the following order: Forest > Current Jhum > Agroforestry > Wet Rice Cultivation > Jhum Fallow > Plantation> Grassland. However, maximum SOC stock was stored in the wet rice cultivation (26.36 Mg C ha^{-1}) at 0–15 cm soil depth. SOC storage at 15–30 and 30–45 cm soil depth classes were the maximum with 18.01 Mg C ha^{-1} and 12.59 Mg C ha^{-1} respectively in agroforestry land use type. SOC stock up to 45 cm depth soil profile was highest in forest (52.74 Mg C ha^{-1}) and the least in jhum fallow (22.92 Mg C ha^{-1}). SOC stock distribution in the different land use types was of the following order: Forest > Agroforestry > Wet Rice Cultivation > Plantation > Current Jhum > Grassland > Jhum Fallow (Fig.2b). SOC content increases with improved soil properties with the adoption of practices such as crop rotation, incorporation of plant residue and addition of composts, animal or green manure (Collins et al., 2000). Management practices such as tillage, choice of crops and cropping systems and application of fertilizers can modify the rate of SOM decomposition by affecting the soil properties like soil moisture, soil temperature, aeration and composition (Saljnikov et al., 2013).



(3a)



(3b)

Fig. 3a: Effects of long-term fertilization and manuring on soil organic carbon (SOC) stock (0–60 cm soil depth) in the rice–wheat system

Fig 3b: Comparison of treatment effects on the sensitivity index of soil organic carbon fractions. FYM, farmyard manure; SPM, sulfitation pressmud; GR, green gram residue; CR, cereal residue; TOC, total organic carbon; WBC, Walkley–Black C; PmOC, permanganate oxidizable C; MBC, microbial biomass C; C_{VL}, very labile C fraction; C_L, labile C fraction; C_{LL}, less-labile C fraction; C_{NL}, non-labile C fraction.

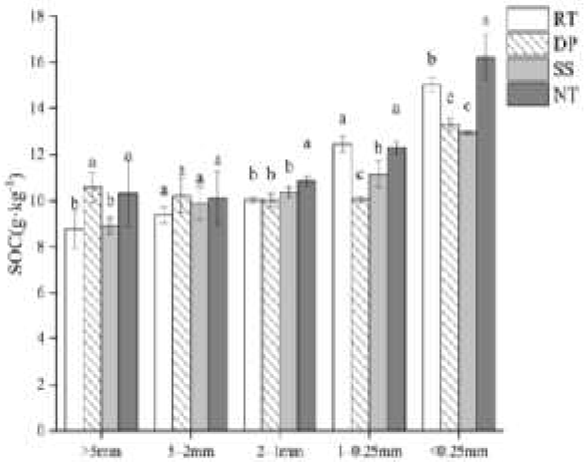
Das et al. (2016) observed that The SOC stock of the 0–60 cm profile ranged from 67.9 to 83.1Mgha^{-1} under different nutrient management options (Fig. 3a). Unfertilized control had the lowest SOC stock, which was statistically at par with sole fertilizer treatments or two IPNS treatments (NPK +GR and NPK + CR). The SOC stock under NPK+ SPM treatment was significantly greater compared with control, and increased further in the NPK +FYM and NPK +GR +FYM treatments. These results are in accordance with earlier studies showing that an increase in SOC stock is directly linked to the amount and quality of organic residues, as well as manure application and fertilization (Wang *et al*., 2012). Moreover, comparison of the sensitivity of SOC fractions with changes in nutrient management revealed that TOC and C_{NL} were least sensitive, with SI values in the range 10.7–36.5% and 4.8–24.9% respectively (Fig. 3b). Somewhat greater sensitivity was observed in the case of WBC, PmOC and C_L. The fractions most sensitive to nutrient management were MBC and C_{VL}, which exhibited similar trends in SI across treatments.

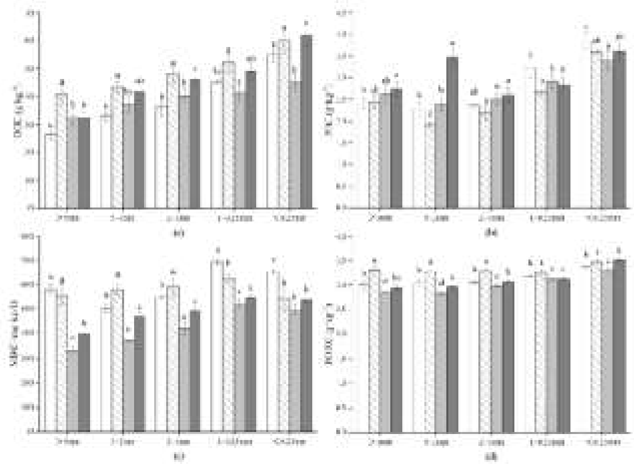
Soil carbon changes in relation to carbon input

Naresh et al. (2020) reported that an addition of stubble, root and rhizodeposition in general and alternative arable cropping systems in case of R-C-O_{PLL} and O-W-Mb_{PLL} treatments over 10 years resulted in a substantial amount of organic C input to the soil (Table 1). Despite addition of 2.98 & 3.21 Mg ha^{-1} year^{-1} C for 10 years in S-W_{PLL} and R-W_{PLL} 5.7 and 6.7 Mg ha^{-1} of initial total SOC were lost from the surface soil layer under the above treatments, respectively (Table 1). The mechanical disturbances in these plots might have promoted breaking of C-rich macro-aggregates, and accumulation of C-poor micro-aggregates (Six et al., 2000) thus resulting in oxidation of intra-aggregate SOC owing to the absence of physical protection (Jat et al., 2019; Parihar et al., 2019). In these CT plots, the moderate residue load could have been completely decomposed and used by the native microbes for the respiration process. On the other hand, precision land was levelling and alternative arable cropping system restricted SOC loss from soil, owing to improved soil structure and greater protection of SOC. The treatment R-C-O_{PLL} resulted in sequestration of 2.9 Mg SOC ha^{-1} over the period of 10 years (Table 1), whereas all other treatments had a loss of SOC during this period. In this treatment, addition of crop residue C over the years often exceeded the capability of native microbes to decompose, degrade and/or assimilate SOM to meet their cell nourishment or respiration needs (Jat et al., 2019; Parihar et al., 2019). This continuous supply of fresh organic matter encouraged formation of C-rich macro-aggregates and also entrapment as intra-aggregate SOC.

Shen et al. (2021) revealed that the content of SOC was higher in micro-aggregates than in macro-aggregates under all tillage treatments. Furthermore, there was a trend that SOC content substantially increased with the decrease in aggregate particle sizes in RT, SS, and NT treatments. However, in DP treatment there was no statistical difference in the organic carbon contents among four sizes of macro-aggregates. Compared to RT treatment, NT treatment showed significantly higher organic carbon content in >5 mm, 2–1 mm and <0.25 mm aggregates. Organic carbon content in DP treatment was higher than RT in >5 mm aggregates, while it was lower in 1–0.25 mm and <0.25 mm aggregates. Besides, SS treatment also had lower organic carbon content than RT treatment in 1–0.25 mm and <0.25 mm aggregates (Fig.4a). Tillage affected SOC by impacting the mass of aggregates and the content of aggregate associated organic carbon. According to Six et al. (2000) organic carbons in macro-aggregates is younger and more mineralizable, while organic carbon in micro-aggregates is mostly highly humified inert components. An important factor of carbon accumulation is that fresh residues gradually decompose and finally enter micro-aggregates from macro-aggregates. Tillage promotes the turnover of macro-aggregates and the organic carbon mineralization in macro-aggregates, therefore, reduces the stabilization of plants-originated SOC in micro-aggregates (Modak et al., 2020).

Moreover, DOC and POXC content increased with the decrease in aggregate particle sizes in all treatments. Compared with RT treatment, DP and NT treatments showed significantly higher DOC content in large size macro-aggregates (Fig.4b). However, significant lower DOC values were found in micro-aggregates in DP treatment. It was 1–0.25 mm macro-aggregates that showed the highest POC content in RT, DP, and SS treatments, while it was 5–2 mm in NT treatment. DP, SS, and NT treatments showed lower POC content in small size macro-aggregates and micro-aggregates. Only NT treatment showed significantly higher POC in large macro-aggregates. Compared with RT treatment, SS and NT treatments





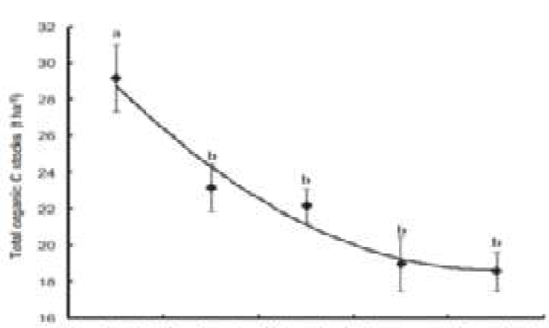
(4a) (4b)

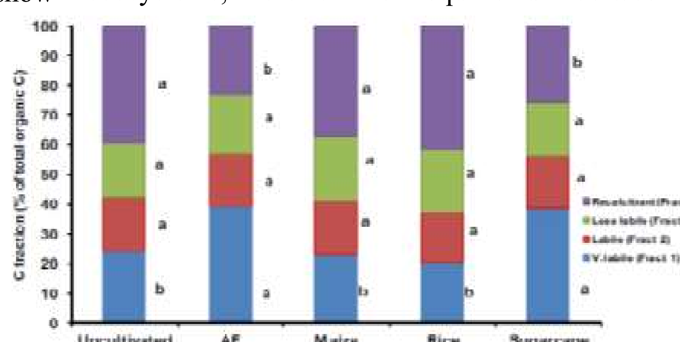
Fig 4a: Effects of tillage on SOC content in aggregates. Different filling types refer to different treatments. RT: rotary tillage, DP: deep ploughing, SS: subsoiling, NT: no tillage

Fig 4b: Effects of tillage on DOC, POC, MBC, and POXC content in aggregates (a) DOC content in aggregates; (b) POC content in aggregates; (c) MBC content in aggregates; (d) POXC content in aggregates.

contained lower MBC content in all particle sizes aggregates. In DP treatment, there were higher values of MBC content in 5–2mmand 2–1mmaggregates, while lower values of that in 1–0.25 mm and <0.25 mm aggregates than RT. Regarding POXC content, DP treatment showed significantly higher POXC content in all aggregate sizes. While the values in SS treatment were significantly lower. NT treatment showed higher POXC in macro-aggregates but lower values in micro-aggregates than RT. Xiao et al. (2019) reported that tillage disturbance increases microbial metabolic activity and increased MBC content. This may be caused by the releasing of POC in macro-aggregates. It could explain why the greatest MBC content was found under RT treatment. We conjecture that MBC content in RT treatment may decrease with the depletion of newly released POC. According to Zhong et al. (2019) however, NT treatment might show higher MBC content after long-term conservation tillage because of its minimum disturbance to microbial habitats. POXC, which comprises carbon derived from dissolved organic matter and microbial biomass, is influenced by carbon input from retained residues and the distribution of crop roots (Xue et al., 2018).

Benbi et al. (2015) also found that soils under different land uses generally did not differ in C: N ratios except that these were lower under agroforestry compared to maize–wheat and the rice–wheat cropping systems. Total organic C pool was higher (P b 0.05) in uncultivated soils than the cultivated soils, but differences among cropping systems were non-significant (Fig. 5a). Soil carbon stocks are a consequence of the balance between C inputs such as litter fall deposits, crop residues, root exudates, root biomass, and manure and through C losses such as respiration. In undisturbed ecosystems, there is a near-equilibrium between C

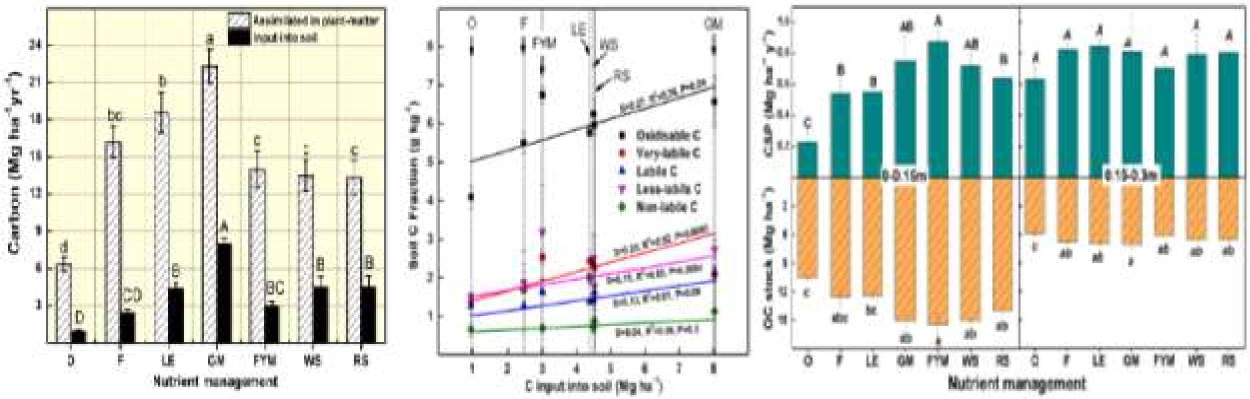




(5a) (5b)

Fig. 5a: Total organic C pool in soils under different land uses

Fig. 5b: Distribution of soil organic C fractions of different lability (as % of total organic C) in uncultivated soils and soils under agroforestry (AF), maize–wheat (maize), rice–wheat (rice) and sugarcane agro-ecosystems



(6a) (6b) (c)

Fig. 6a: Carbon (C) assimilated in the nutrient management systems and C input (*ex situ* + *in situ*) into the soil. O = no fertilizer, F = 100% inorganic fertilizers, LE = opportunity legume crop (*Vigna radiata*), GM = green manuring, FYM = farmyard manure, WS = wheat stubble, RS = rice stubble

Fig. 6b: Relationship between carbon (C) input into the soil and soil C fractions under different nutrient management. O = no fertilizer, F = 100% inorganic fertilizers, LE = opportunity legume crop (*Vigna radiata*), GM = green manuring, FYM = farmyard manure, WS = wheat stubble, RS = rice stubble

Fig. 6c: Carbon (C) sequestration potential (CSP) and soil C stock under different nutrient management

inputs and C losses through respiration by soil organisms (Raich and Schlesinger, 1992). Cultivation of undisturbed soils depletes the SOC pool. Furthermore, cultivation adversely affects the distribution and stability of soil aggregates. Soil aggregation is an essential mechanism

However, soils under sugarcane had the least amount of the less labile C (Fract 3), which was significantly lower than the uncultivated soils but not different than the other cropping systems. Soils under agroforestry, maize–wheat, and rice–wheat did not differ in less labile C pool (P b 0.05). Uncultivated soils exhibited higher (P b0.05) pool of recalcitrant C (Fract 4) compared to other land uses. The very labile C (Fract 1) constituted a higher proportion (approx. 39%) of TOC in soils under agroforestry and sugarcane than the other land uses (21–24%); (Fig. 5b). On the contrary, the agroforestry and sugarcane systems had significantly lower proportions (23–26%) of recalcitrant C than uncultivated (40%), maize–wheat (37%), and rice–wheat (42%) cropping systems. The various land uses did not differ with respect to the proportion of TOC existing as labile (Fract 2; 17–18%) and less labile C (Fract 3; 18–22%) in soils.

Bhardwaj et al. (2019) reported that budgeting total plant assimilated C and C-input into soil, revealed that the maximum C was assimilated in GM (22.3 Mg ha”1) followed by LE (18.6 Mg ha”1), F (16.2 Mg ha”1), FYM (14.0 Mg ha”1), WS (13.5 Mg ha”1), RS (13.3 Mg ha”1), and O (6.3 Mg ha”1) (Fig. 6a). Carbon input into the soil also varied in the same order. The maximum input of C into soil was in GM (8.0 Mg ha”1) followed by WS (4.5 Mg ha”1), RS (4.5 Mg ha”1), LE (4.4 Mg ha”1), FYM (3.0 Mg ha”1), F (2.5 Mg ha”1) and O (0.9 Mg ha”1). The C input into the soil as the percentage of C assimilated in the system was maximum in GM (36%) and least in O and F (15%). However, oxidizable C was the maximum in FYM followed by GM and crop residue (WS, RS) treatments in the surface 0.15 m soil. At the lower depths (0.15–0.30 m), there was no significant difference in the oxidizable C for any management. At both depths O and F accumulated least oxidizable C. VLc (very labile C) and LLc (less labile C) fractions constituted a major part of soil organic C, for all managements. All integrated nutrient management (INM) accumulated a similar amount of VLc fraction for all measured depths. GM accumulated the maximum Lc fraction at the surface 0–0.15 m. The LLc fraction was maximum in FYM which was followed by all other integrated nutrient managements. Management O had least LLc fraction in surface 0.15 m. There was no difference in NLc fraction for any of the treatments, for any measured depth. There was 46 to 65% decrease in oxidizable C, from the surface (0–0.15 m) to lower layer (0.15–0.30 m). Change in soil C content was directly related to the C input to the soil (Fig. 6b). In general, the most increases were in the VLc and the LLc fractions of soil C in all management. With an increase in C input, the most significant increase was noticed in the Lc (labile C) and the LLc (less labile C) fractions. Management FYM had maximum contributions to the LLc and the VLc fractions while GM had a maximum contribution to Lc. Non-labile (NLc) C fraction changed little with increased total C input to the soil in different treatments. Moreover, significantly higher carbon sequestration potential (CSP) was noted for FYM, GM and WS management, for shallower depths (0–0.15 m) (Fig. 6c).

Carbon buildup, stabilization and sequestration

Naresh et al. (2020) also found that higher percentage of C buildup was observed in R-CO_{PLL} treatment (43.6%) followed by R-P-O_{PLL} treatment (441.1%), which was reflected in the profile SOC concentration of respective treatments. With the exception of the precision land leveling and used of alternative arable cropping systems, the magnitude of SOC sequestration in other treatments was 5.3–9.4 Mg ha^{-1}. Higher SOC sequestration was observed with precision land leveling along with alternative arable cropping systems with O-WMb_{PLL}, R-C-O_{PLL}, R-P-O_{PLL}, O-W-Mb_{PLL} and M-PMb_{PLL}. Cultivation of rice-wheat and sorghum wheat mono-cropping caused a net depletion of SOC pool by 5.83 Mg C ha^{-1}. Though adoption of precision land leveling decreased the bulk density of the soil particularly at surface and subsurface layer due to higher SOC and increased root biomass it improves the SOC concentration significantly and ultimately increased SOC stock of the profile. SOC concentrations and stocks increased considerably with precision land leveling and alternative arable cropping systems which are possibly attributed to a larger proportion of recalcitrant organic compounds in root biomass. Use of mungbean, and onion crop can result in an increase in lignin and lignin-like products, which are major components of the resistant C pool in the soil. Crop production was also enhanced by the pulse crop inputs, which lead to higher total C inputs from rhizodeposition, root biomass and stubble return (Table 4).

Gross and Harrison, (2019) revealed that shoot-derived C is incorporated into the bulk SOC through the transport of DOC from the litter layer as well as through the mixing of particulate organic matter into superficial soil layers via soil fauna. Bioturbation can play an important role in SOC cycling in some ecosystem. However, the abundance and effect of bioturbation agents usually declines sharply with depth and their contributions to deep SOC may be negligible compared to DOC transport. Because root- and microbial-derived C are input belowground incorporation into the DOC pool and bulk SOC may be more direct. Nonetheless, most below ground C inputs undergo stages of decomposition via repeated microbial processing, protection, and release into the DOC pool (Fig.7).

Naresh et al. (2021) revealed that the SOC sequestration in other treatments reported to be in the tune of 7.6–9.8 Mg ha^{-1} while higher SOC sequestration was observed with PLL under T_5, T_3, and T_6. Further, it was revealed that rice-wheat-sugarcane based mono-cropping caused a net depletion of SOC pool by 7.6 Mg C ha^{-1}. Land productivity was also enhanced by the pulse crop intercropping or in crop diversification due to higher total C inputs from rhizodeposition, root biomass and stubble return (Table 2).

Chen et al. (2019) observed that the priming intensity increased with the proportion of recalcitrant pool and the content f recalcitrant components but decreased with physico-chemical protection by minerals and aggregates (Fig.7). The regulation of

Table 1: An estimate of total inputs to soil under different treatments over 10 years (2009-10 to 2018-19) [Naresh et al., 2020]

Crop Sequences	Stubble biomass C (Mg ha^{-1})	Root biomass C (Mg ha^{-1})	Rhizodeposition biomass C (Mg ha^{-1})	C build-up %	C build-up rate Mg C ha^{-1} y^{-1}	C Sequestrated Mg C ha^{-1}
T_1 R-W_{PLL}	3.21	8.79	14.68	27.9±0.7	1.06±0.08	6.7±0.2
T_2 R-W_{TLL}	2.15	8.16	13.76	29.8±0.06	1.28±0.007	5.6±0.8
T_3 S-W_{PLL}	2.98	7.93	13.56	25.9±1.6	0.96±0.08	5.7±0.2
T_4 S-W_{TLL}	2.18	7.35	12.82	22.4±1.2	0.89±0.06	5.3±0.5
T_5 R-P-Mb_{PLL}	3.97	8.92	15.12	39.3±1.8	1.13±0.021	6.8±0.5
T_6 R-P-Mb_{TLL}	2.85	8.25	14.68	37.5±3.1	1.02±0.006	6.3±0.8
T_7 R-P-O_{PLL}	4.45	9.15	15.53	41.0±2.2	1.63±0.09	9.3±0.2
T_8 R-P-O_{TLL}	3.36	8.76	14.93	40.7±2.4	1.82±0.006	8.7±0.8
T_9 R-C-O_{PLL}	4.89	9.65	16.25	43.6±0.09	1.88±0.001	9.6±0.7
T_{10} R-C-O_{TLL}	3.86	8.99	15.09	40.2±2.3	1.64±0.10	9.1±0.2
T_{11} O-W-Mb_{PLL}	4.87	9.45	13.68	39.3±1.8	1.96±0.09	9.4±0.8
T_{12} O-W-Mb_{TLL}	3.49	8.75	12.85	37.3±0.06	1.73±0.021	8.5±0.5
T_{13} M-W-Mb_{PLL}	3.86	8.96	15.46	34.2±1.8	1.36±0.07	8.2±0.1
T_{14} M-W-Mb_{TLL}	2.62	8.63	14.53	31.8±0.6	1.33±0.04	7.6±0.8
T_{15}-M-P-Mb_{PLL}	3.79	8.51	15.66	36.6±0.6	1.46±0.09	8.6±0.8
T_{16}- M-P-Mb_{TLL}	2.27	8.28	14.73	34.2±1.8	1.46±0.07	7.9±0.3

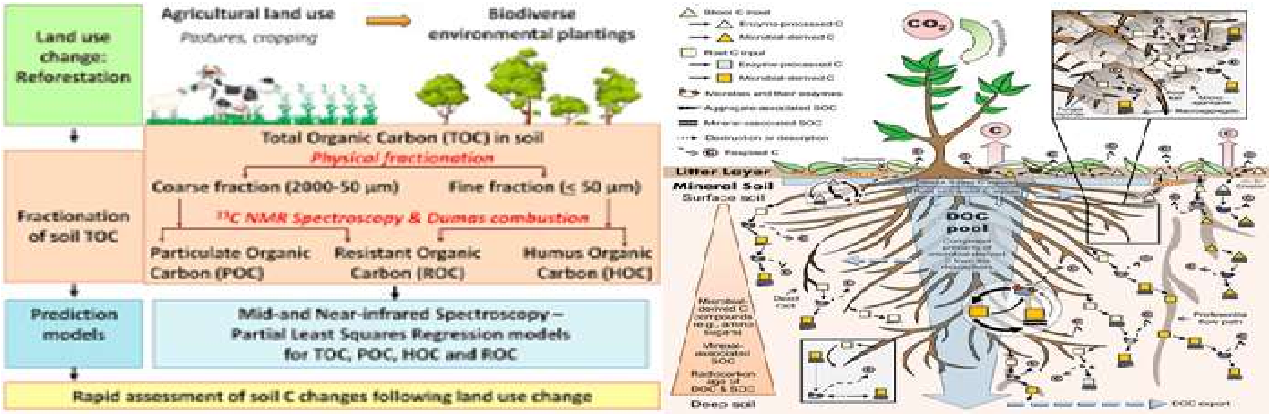


Fig.7:Soil organic carbon (SOC) cycling showing root carbon (C) inputs as the primary source of both SOC and dissolved organic C (DOC) in most ecosystems

Table 2: Soil buildup and S sequestrated under different cropping systems with levelling options from 2009–15

Crop Sequences	C build-up %	C build-up rate Mg C ha^{-1} y^{-1}	C Sequestrated Mg C ha^{-1}
T_1	36.6±0.6	1.46±0.00	0.6±0.0
T_2	33.8±1.8	1.36±0.07	7.9±0.3
T_3	41.0±2.2	1.63±0.09	9.3±0.2
T_4	40.7±2.4	1.82±0.006	8.7±0.8
T_5	43.6±0.09	1.89±0.001	9.6±0.7
T_6	40.1±2.31	1.74±0.10	9.1±0.2
T_7	39.3±1.81	1.13±0.021	6.8±0.5
T_8	37.5±3.1	1.02±0.006	6.3±0.8
T_9	39.3±1.8	1.96±0.09	9.4±0.8
T_{10}	37.3±0.06	1.73±0.021	8.5±0.5
T_{11}	34.2±1.8	1.38±0.07	8.2±0.1
T_{12}	31.8±0.6	1.33±0.04	7.6±0.8

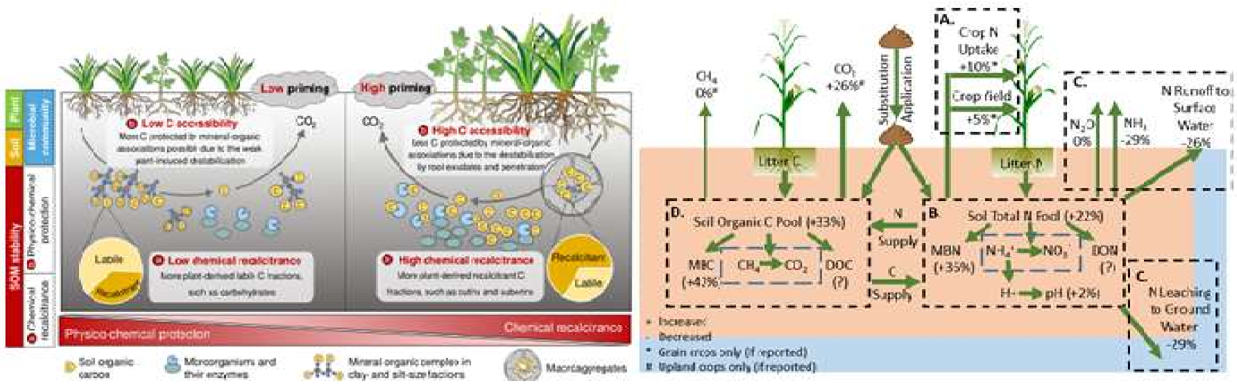


Fig. 8: Soil organic matter stability, as regulated by plant C input and community composition

SOM chemical recalcitrance on the priming effect could be attributed to its potential impacts on microbial C and N requirements.

References

Benbi DK, Brar K, Toor AS, Singh P. 2015. Total and labile pools of soil organic carbon in cultivated and undisturbed soils in northern India. Geoderma., 237–238: 149–158.

Benbi, D.K., and Senapati, N. 2010. Soil aggregation and carbon and nitrogen stabilization in relation to residue and manure application in rice–wheat systems in north-west India. Nutr. Cycl. Agroecosyst. 87: 233–247.

Bhardwaj, A.K., Rajwar, D., Mandal, U.K., Ahamad, S., et al. 2019. Impact of carbon inputs on soil carbon fractionation, sequestration and biological responses under major nutrient management practices for rice-wheat cropping systems. Sci Rep.*9:9114* https://doi.org/10.1038/s 41598-019-45534-z

Bhattacharyya T, Pal DK, Chandran P, Ray SK, Mandal C, Telpande B. 2008. Soil carbon storage capacity as a tool to prioritize areas for carbon sequestration. Curr Sci., 95: 482–494.

Brovin V, Stich S, von Bloh W, Clausen M, Bauer E, Cramer W. 2004. Role of land cover changes for atmospheric CO2 increase and climate change during the last 150 years. Glob Change Biol., 10:1253–1266.

Chan KY, Bowman A, Oates A. 2001. Oxidizable organic carbon fractions and soil quality changes in an oxicpaleustaff under different pasture lays. Soil Sci., 166: 61–67.

Choudhury BU, Mohapatra KP, Das A, Das PT, Nongkhlaw L, Fiyaz AR, et al. 2013. Spatial variability in distribution of organic carbon stocks in the soils of North East India. Curr Sci., 104: 604–614.

Collins HP, Elliot ET, Paustian K, Bundy LG, Dick WA, Huggins DR, et al. 2000. Soil carbon pools and fluxes in long term Corn Belt agro-ecosystems. Soil Biol Biochem, 32: 157–168.

Cooper J, Baranski M, Stewart G, Nobel-de Lange M, Bàrberi P, Fließbach A et al. 2016. Shallow non-inversion tillage in organic farming maintains crop yields and increases soil C stocks: a meta-analysis. Agron. Sustainable Dev., 36:22.

Das, D., Dwivedi, B.S., Singh, V.K., Datta, S.P., Meena, M.C. et al. 2016. Long-term effects of fertilizers and organic sources on soil organic carbon fractions under a rice–wheat system in the Indo-Gangetic Plains of north-west India. Soil Res., http://dx.doi.org/10.1071/SR16097

Degryze S, Six J, Paustian K, Morris SJ, Paul EA, Merckx R. 2004. Soil organic carbon pool changes following land-use conversions. Glob Change Biol., 10: 1120–1132.

Dey SK. 2005. A preliminary estimation of carbon stock sequestered through rubber (*Hevea brasiliensis*) plantation in North Eastern regional of India. Ind For., 131(11): 1429–1435.

FAO and ITPS. 2015. Status of the World's Soil Resources, Rome

Gattinger A, Muller A, Haeni M, Skinner C, Fliessbach A, Buchmann N et al. 2012. Enhanced top soil carbon stocks under organic farming. Proc Natl Acad Sci, 09:18226–18231

Golchin A., Asgari H. 2008. Land use effects on soil quality indicators in northeastern Iran. Aust J Soil Res., 46, 27–36.

Golchin A, Clarke P, Oades JM, Skjemstad JO. 1995. The effects of cultivation on the composition of organic matter and structural stability of soils. Aust J Soil Res., 33: 975–993.

Gross, C.D., and Harrison, R.B. 2019. The Case for Digging Deeper: Soil Organic Carbon Storage, Dynamics, and Controls in Our Changing World. Soil Syst. 2019,3, 28; doi:10.3390/ soilsystems3020028

Guo L B. and Gifford RM. 2002. Soil carbon stocks and land-use change: A Meta analysis. Glob Chan Biol. 8(4):345-360

Haynes RJ. 2005. Labile organic matter fractions as central components of the quality of agricultural soils. Adv Agron., 85: 221–268.

IPCC. Climate Change 2013: Executive Summary. Geneva, Switzerland: Intergovernmental Panel on Climate Change; 2014

Jat SL, Parihar CM, Dey A, Nayak HS, Ghosh A, Parihar N, Singh AK.2019. Dynamics and temperature sensitivity of soil organic carbon mineralization under medium-term conservation agriculture as affected by residue and nitrogen management options. Soil Tillage Res.,190: 175–185.

Keiluweit, M. et al. 2015. Mineral protection of soil carbon counteracted by rootexudates. Nat. Clim. Change5, 588–595.

Lal R. 2004. Soil carbon sequestration impacts on global climate change and food security. Science, 304: 1623–1627.

Lim DL, Santos SM, Scherer HW, Schneider RJ, Duarte AC, Santos EB, et al. 2009. Effects of organic and inorganic amendments on soil organic matter properties. Geoderma, 150(1):38-45.

Kane, D. 2015. Carbon Sequestration Potential on Agricultural Lands: A Rev Curr Sci Avai Pract,

Keiluweit, M., Bougoure, J. J., Nico, P. S., Pett-Ridge, J., Weber, P. K. and Kleber, M. 2015. Mineral protection of soil carbon counteracted by root exudates. Nature Clim Chan, 5: 588–595.

Lal R. 2004. Soil carbon sequestration impacts on global climate change and food security. Science. 304:1623-1627

Lal R. 2014. Societal value of soil carbon. J Soil Water Conserv. 69(6):186A-192A

Modak, K., Biswas, D.R., Ghosh, A., Pramanik, P., Das, T.K., Das, S., Kumar, S., Krishnan, P., Bhattacharyya, R. 2020. Zero Tillage and Residue Retention Impact on Soil Aggregation and Carbon Stabilization within Aggregates in Subtropical India. Soil Tillage Res., 202: 104649.

Naresh, R.K., Kumar, Y., Tomar, S. S., Kumar, M., Chandra, M.S., Rajput, P., Mohd Shah Alam, and Singh, P.K. 2020. Measuring and Monitoring the Impact of Precision Land Levelling and Arable Cropping Systems on Aggregate Associated Carbon Fractions and Soil Carbon Stock in Sub-tropical Ecosystems. IRJPAC, 21(24): 197-220.

Naresh, R.K., Bhatt, R. Tomar, S.S. et al. 2021. Precision Land Leveling Practices of Sugarcane based Cropping System Improves Soil Organic Carbon Dynamics, Reducing the Environmental Footprints for the Western Indo-Gangetic Plains. (In press).

Ogle, S. M., Swan, A., and Paustian, K. 2012. No-till management impacts on crop productivity, carbon inputs and soil carbon sequestration. *Agri. Ecosys. Environ.* 149: 37–49.

Panettieri M, Berns AE, Knicker H, Murillo JM, Madejón E. 2015. Evaluation of seasonal variability of soil biogeochemical properties in aggregate-size fractioned soil under different tillage. Soil Tillage Res. 151: 39–49.

Parihar CM, Singh AK, Jat SL, Ghosh A, Dey A, Nayak HS et al. 2019. Dependence of temperature sensitivity of soil organic carbon decomposition on nutrient management options under conservation agriculture in a subtropical Inceptisol. Soil Tillage Res., 190: 50–60.

Paul, E. 2014. Soil microbiology, ecology and biochemistry. Academic Press. pp. 598.

Poeplau C, Don A. 2013. Sensitivity of soil organic carbon stocks and fractions to different land-use changes across Europe. Geoderma, 192: 189–201

Post WM, Izaurralde RC, Mann LK, Bliss N. 2001. Monitoring and verifying changes of organic carbon in soil. Climate Change, 51: 73–99.

Raich, J.W., and Schlesinger, W.H. 1992. The global carbon dioxide flux in soil respiration and its relationship to climate. Tellus 44B: 81–99.

Ryals, R., Hartman, M. D., Parton, W. J., DeLonge, M. S., and Silver, W. L. 2015. Long-term climate change mitigation potential with organic matter management on grasslands. *Ecol. Appl.* 25: 531–545.

Sahoo UK, Singh SL, Gogoi A, Kenye A, Sahoo SS. 2019. Active and passive soil organic carbon pools as affected by different land use types in Mizoram, North-east India. PLoS ONE 14(7): e0219969

Saljnikov E, Cakmak D, Rahimgalieva S. 2013. Soil Organic Matter Stability as Affected by Land Management in Steppe Ecosystems. In: Dr. Maria C. Hernandez Soriano (Ed.). Soil Processes and Current Trends in Quality Assessment, pp 269–310.

Schmidt, M. W. I., Torn, M. S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I. A., Kleber, M., et al. 2011. Persistence of soil organic matter as an ecosystem property. Nature, 478: 49–56

Shen, X., Wang, L., Yang, Q., Xiu, W., Li, G., Zhao, J., Zhang, G. 2021. Dynamics of Soil Organic Carbon and Labile Carbon Fractions in Soil Aggregates Affected by Different Tillage Managements. Sustainability, 13: 1541. https://doi.org/10.3390/su13031541

Six, J., Paustian, K., Elliott, E.T., Comb rink, C. 2000. Soil Structure and Organic Matter: I. Distribution of Aggregate-Size Classes and Aggregate-Associated Carbon. Soil Sci. Soc. Am. J. 64: 681–689.

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, et al. Agriculture. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA, editors. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2007

Vieira FCB, Bayer C, Zanatta JA, Dieckow J, Mielniczuk J, He ZL. 2007. Carbon management index based on physical fractionation of soil organic matter in an Acrisol under long-term no-till cropping systems. Soil Tillage Res., 96: 195–204.

Wang S, Liang X, Luo Q, Fan F, Chen Y, Li Z, Sun H, Dai T, Wan J, Li X. 2012. Fertilization increases paddy soil organic carbon density. *J Zhejiang Univ Sci B* 13: 274–282.

Wiesenberg GLB, Dorodnikov M, Kuzyakov Y. 2010. Source determination of lipids in bulk soil and soil density fractions after four years of wheat cropping. Geodarma, 156: 267–277.

· Xiao, D., Ye, Y.Y., Xiao, S.S., Zhang, W., He, X.Y., Liu, N., Xu, Z.H., Wang, K.L. 2019.Tillage Frequency Affects Microbial Metabolic Activity and Short-Term Changes in CO_2 Fluxes within 1 Week in Karst Ecosystems. *J. Soils Sediments*, *19*: 3453–3462.

Xue, J.F., Pu, C., Zhao, X., Wei, Y.H., Zhai, Y.L., Zhang, X.Q., Lal, R., Zhang, H.L. 2018. Changes in Soil Organic Carbon Fractions in Response to Different Tillage Practices under a Wheat-Maize Double Cropping System. *Land Degrad. Dev. 29*: 1555–1564.

Yang Y, Tilman D, Furey G, Lehman C. 2019. Soil carbon sequestration acceleration by the restoration of grassland biodiversity. Natural Commu., 10(1):1-7.

Zhong, S., and Zeng, H.C. 2019. Influence of Long-Term Tillage and Residue Management on