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Molecular turnover time in restoration of labile organic carbon and enzyme activities due to minimal soil disturbance and increased residue retention in subtropical India: A review

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Abstract

The formation of aggregates plays a key role in shaping soil microenvironment, which in turn influences microbial community structure and organic carbon (C) dynamics in soil. Carbon in large macro-aggregates (>2 mm), small macro-aggregates (0.25–2 mm), and free organic matter (>0.053 mm) was significantly positively correlated with C, lignin, and polyphenols. Carbon in micro-aggregates and fine particles (<0.053 mm) was significantly negatively correlated with C: N ratio. The P. australis had the highest annual average activity of alkaline phosphomonoesterase, and the S. alterni flora had the highest annual average activities of β-glycosidase and invertase. However, the conventional tillage had the lowest activities of alkaline phosphomonoesterase, β-glycosidase, and invertase. Analysis also showed that the soil labile organic carbon fractions and soil enzyme activities had distinct seasonal dynamics. In addition, the soil MBC content was significantly correlated with the activities of urease and β-glucosidase. The DOC content was significantly correlated with the activities of urease, alkaline phosphomonoesterase, and invertase. The degree of soil disturbance and the use of crop residues influence the availability of organic compounds and minerals for the soil biota. This conglomerate of elements can affect population, diversity and activity of the different soil organisms. Besides, soil communities also have an impact on soil physical and chemical conditions. From macro-fauna to micro-fauna, all parts interact and therefore play a role in nutrient cycling and organic matter decomposition. The mixing of residues/surface retention into the soil increases SOM mineralisation due to greater exposure to microbial decomposers and optimal moisture and temperature regimes. Soil disturbance by tillage leads to destruction of the protective soil aggregate. This in turn exposes the labile C occluded in these aggregates to microbial breakdown.

Keywords: crop residue management, biological activity, carbon mineralization, soil aggregate

Introduction

Soil aggregates are the basic units of soil structure. Consisting of primary particles and binding agents, they contain around 90% of the soil organic matter (SOM) in the soil surface layer (Jastrow *et al*., 1998) [34]. The quantity and quality of SOM in soil aggregates both vary since aggregates of different sizes may have different textures and porosities (Cates *et al*., 2016) [10]. There are also complex interactions between aggregate stability and soil carbon (C) cycles (Graf and Frei, 2013) [22]. Inter alia, aggregates protect SOM but can also retard its mineralization (Rabbi *et al*., 2015) [54], a process that is sensitive to factors such as climate (Cheng *et al*., 2011) [11], soil management practices (He *et al*., 2015) [28], and land use. Hence, due to the importance of aggregates in both soil structure and carbon sequestration there is a growing need to understand the turnover of soil aggregate fractions, and responses of soil organic C (SOC) dynamics to changes in their turnover.

Soil characteristics such as soil total porosity, water- and air-filled pore space, organic substrates, temperature etc., are responsible for the changes in soil microbial community structure under different agricultural management practices (Kuntz *et al*., 2013) [38]. For a conservation tillage system, the reduced physical disturbance, increased soil moisture and altered distribution of organic substrates in the soil profile could cause great shifts in bacterial and fungal biomass ratios (Zhang *et al*., 2015a) [84]. When conservation tillage practice was operated, the pathway of organic C decomposition in surface soil was altered from bacteriadominated to fungi-dominated decomposition (Griffiths *et al*., 2012) [20]. Whereas, some conflicting results reported by Sun *et al*. (2016) [69] that long-term conservation tillage had potential for improving microbial abundance but might not alter their community composition, seem to be related to the effect of individual pedo-climatic conditions (Kuntz *et al*., 2013) [38]. The turnover of soil organic C is not only determined by the physical protection offered by aggregates, but also by the abundance and community of microorganisms (Miltner *et al*., 2009) [46]. Soil environmental conditions controlled by soil structure and aggregation affected the community and activity of soil microorganisms, soil enzymes and the connectivity between organic C and potential decomposers, which in turn influenced the turnover of soil organic C (Kong *et al*., 2011) [36]. The formation of macro-aggregates is driven by conservation tillage directly through decreasing physical disruption, and indirectly by enhancing organic matter inputs (Xu *et al*., 2011) [80]. Consequently, macro-aggregation, microbial community and organic C accumulation are related through dynamic feedback mechanisms which inextricably link these three primary foundations of soil functioning under conservation tillage.

Soil biological properties are critical to soil sustainability and are important indicators of soil quality (Stott *et al*., 1999) [67]. Soil microorganisms play integral roles in nutrient cycling, soil stabilization, and organic matter decomposition. As such, soil microbiological and biochemical properties must be taken into account in soil resource inventories to properly manage agricultural systems.Soil organic matter quantity and distribution are affected by soil tillage. When crop residues remain on the soil surface, the oxidation rate of organic matter is reduced and soil organic matter accumulates at the soil surface (Six *et al*., 1998) [64]. However, below the surface 5 cm, differences in soil organic C (SOC) and total N between tillage treatments diminished. Soil organic C does not always change rapidly upon conversion to a different soil management regime, especially in arid or cold climates where organic matter turnover is slow (Franzluebbers and Arshad, 1996) [15].

Straw return, as an effective practice to manage agricultural residues, has shown great carbon sequestration potentials for cropland soils (Laland Bruce, 1999) [39]. Studies have suggested that straw return can increase the SOC storage in the surface soils (0–20 cm) (Choudhury *et al*., 2014; Naresh *et al*., 2017) [12]. Bhattacharyya *et al*. (2012) [6] found that straw combined with inorganic nitrogen fertilizer significantly increased the total carbon content in the topsoil. Van Groenigen *et al*. (2011) [74] reported that straw retention under a shallow non-inversion tillage system significantly increased the soil carbon content in the 0–30 cmsoil layer. It has been suggested that the return of the strawimproves the soil aggregation and it is this that enhances the SOC stabilization (Choudhury *et al*., 2014) [12]. There are two plausiblemechanisms that could explain this phenomenon. One is that straw addition increases the carbon input and promotes fungal growth; from which, the fungal hyphae and their metabolites, such asglomalin, might entangle soil micro-aggregates and stabilize them into macro-aggregates (Wright and Anderson, 2000) [78]. The other option is that microbial mediated straw decomposition might produce adhesive organic molecules, such as aromatic components, which possibly stabilize mineral (clay-silt) particles with particulate organic matter (POM) into macro-aggregates (Kunlanit *et al*., 2014) [37]. Our objective was too aimed at evaluating microbial community and organic C accumulation in the topsoil related to soil macro-aggregation under different tillage and residue management. Consequently, we reviewed (1) how of labile organic carbon regulated soil characteristics and therefore, influenced soil organic matter and soil enzymes communities, and (2) how such changes in microbial community could be related to organic C accumulation in soil following conservation tillage.

Mbuthia *et al*. (2015) [44] revealed that the enzyme activities were significantly greater under no-till relative to till with β-glucosidase and β-glucosaminidase having approximately 14% higher activity while phosphodiesterase was approximately 10% higher [Fig.1a]. There was also an increasing trend in β-glucosaminidase activity with N-rate and a decreasing trend in the activity of phosphodiesterase. To establish linkages between shifts in the microbial community structure due to no-tillage that were associated with greater activities of key enzymes of C and N (β-glucosidase), N (β-glucosaminidase) and P cycling (phospho- diesterase) relative to till. The shift in microbial community structure, and increased enzyme activity found under no-till provides evidence that it can take several years of surface residue accumulation (Acosta-Martínez *et al*., 2008) [1]. Martinez *et al*. (2003) [43] revealed that β-glucosidase, β-glucosaminidase and alkaline phosphastase activities were increased by conservation tillage in continuous cotton under the same water management in the fine sandy loam [Fig. 1b]. In the sandy clay loam, the plot of β-glucosidase, β-glucosaminidase and arylsulfatase activities showed no differences in these enzyme activities due to tillage practices [Fig. 1b]. In the loam, the enzyme activities were generally increased by conservation tillage practices in the different cotton and sorghum or wheat rotations [Fig. 1b].

Asensio *et al*. (2015) [3] observed that In plants receiving NO_3 nutrition, elevated CO_2 both day and night decreased shoot organic N concentration [Fig. 2a]. Ambient CO_2 during the day and night increased the ρ ^{15}N (‰) of organic N in shoots [Fig. 2a]. Plants may compensate to some extent for elevated CO_2 during the day or night by increasing the proportion of NO_3 assimilated in the roots because root NO_3 assimilation is relatively insensitive to CO_2 concentration (Bloom *et al*., 2014) [9]. Zhang *et al*. (2014) [83] showed that organic amendments increased the proportion of macro-aggregate and mean weight diameter (MWD), especially in the plow layer. The macro-aggregates accounted for 43.87% and 49.96% of the total soil weight in the straw retention (SR) and manure application (MA). The distribution patterns of soil organic C (SOC) and microbial biomass C (MBC) within aggregate sizes was affected by organic treatments. In the plow layer, the SOC in MA increased by 35.5% in macro-aggregates compared with CK, and significant differences in MBC in macro-aggregates were also found among organic amendments. MWD was positively correlated with SOC, and MBC. Organic amendment, either through crop residues or manure application, enhanced soil aggregate stability through the positive effects on soil binding agents including SOC, MBC [Fig. 1c].

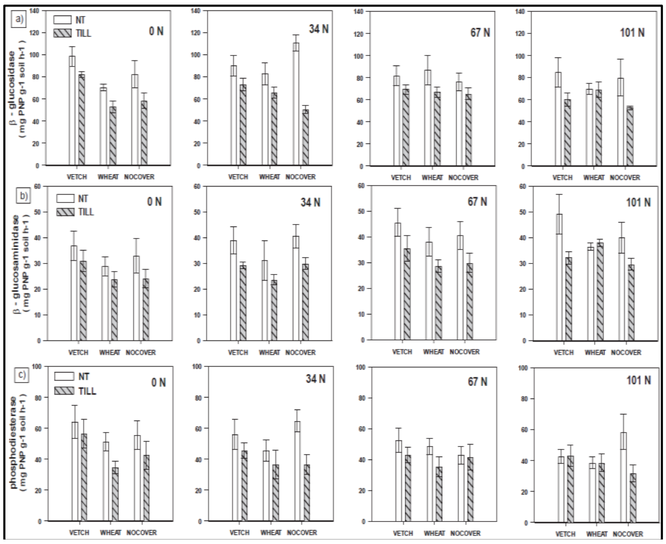

Fig 1(a): Activities of selected enzymes a) (β-glucosidase, b) β-glucosaminidase, and c) phospho- diesterase as influenced by tillage

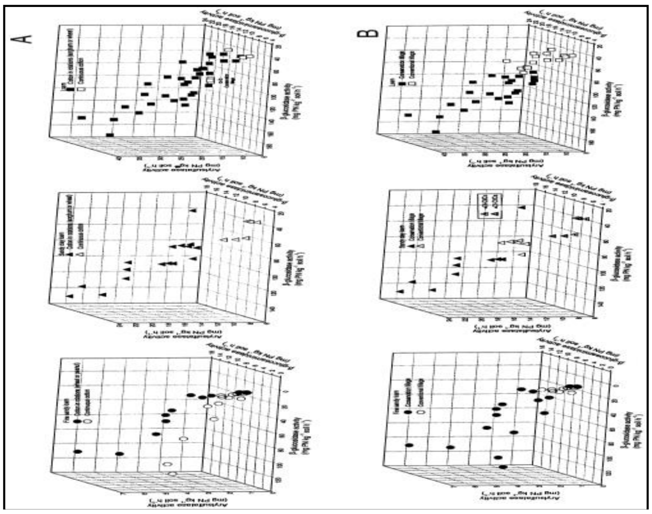

Fig 1(b): Three-dimensional plot of β-glucosidase, β-glucosaminidase and arylsulfatase activities as affected by crop rotations (A) and tillage practices (B) in the semiarid agricultural soils studied

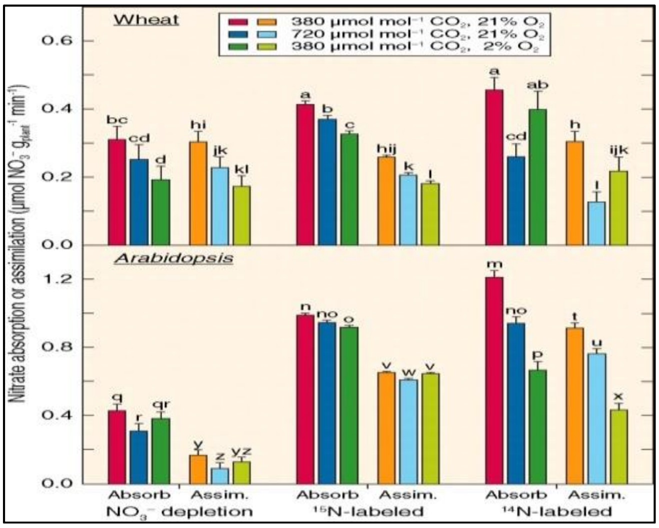

Fig 2 (a): Assessing nitrate absorption and assimilation in wheat and Arabidopsis p

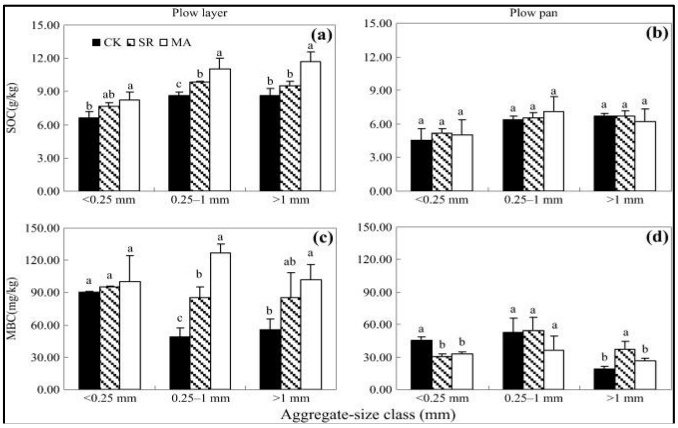

Fig 2(b): Effects organic amendments on aggregate-associated organic C, microbial biomass C

Green *et al*. (2007) [23] reported that soil enzyme activities had greater differentiation among treatments in the surface 0–5 cm depth than at lower depths. No-till management generally increased stratification of enzyme activities in the soil profile, probably because of similar vertical distribution of organic residues and microbial activity. Disk harrow and disk plow management had less stratified soil enzyme activity due to soil mixing during tillage processes [Fig. 3a and 3b]. Kandeler *et al*. (1999a) found that xylanase activity changed much more quickly than protease and phosphatase activities. It appears that some enzymes are more sensitive to changes in soil management and change more quickly than others. Climatic factors and other abiotic and biotic factors likely influence the sensitivity of soil enzymes to management practices.

Aggregate MWD of surface soils ranged from 0.75 mm for the disk plow system to 0.91 mm for the no-till system [Fig.3c]. As a comparison, MWD for the native treatment was 1.40 mm. No-till management had greater MWD than both disk harrow and disk plow management. MWD was related to many of the soil enzyme activities. High correlation of MWD with SOC and total N supports the theory that soil organic matter does play an important role in aggregation. Any increase in MWD was probably associated with macro-aggregates. Acid phosphatase enzyme activity in particular was highly correlated with MWD (r = 0.90), suggesting that the ability to convert organic P compounds may be highly related to improved soil structure. Carbon and N mineralization rates were also significantly correlated with MWD.

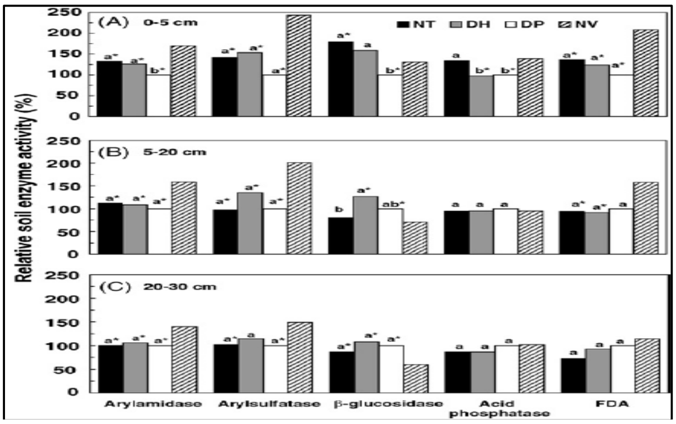

Fig 3(a): Relative soil enzyme activities from under no-till (NT), diskharrow (DH), disk plow (DP), and undisturbed plots in the 0–5, 5–20, and 20–30 cm soil layers.

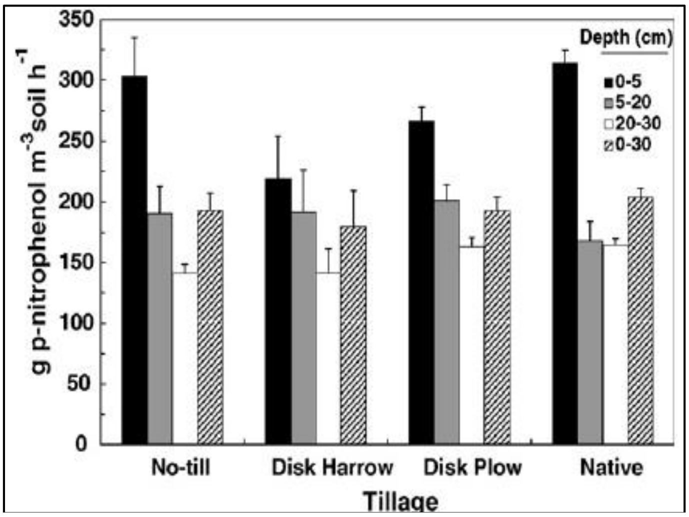

Fig 3 (b): Acid phosphatase enzyme activity under three tillage management regimes and under native vegetation at various depths

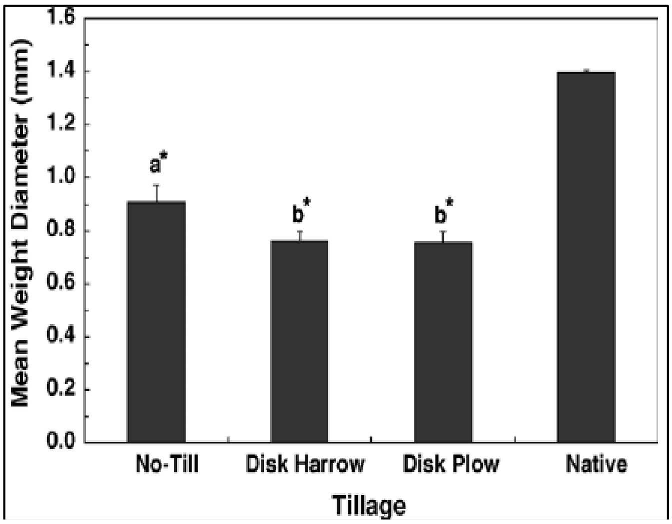

Fig 3(c): Mean weight diameter of 1–2 mm aggregates in the 0–5 cm depth for three tillage management regimes and under native vegetation

Enzyme activity highly depended on residue type and the amount of addition (generally increasing with addition level) and sampling time [Fig.4a]. Enzyme specific activity was significantly higher under root than under both leaf and stem addition at all sampling periods. With the increase of residue addition level, however, the specific activity significantly decreased compared with low residue addition. The decrease of specific enzyme activities at high residue additions can be due to the decreasing rate of enzyme production because of lower energy demands (microbial saturation by substrate) (Xiao *et al*. 2015) [79]. The increase of these activities after the intensive phase of residue decomposition confirms that microorganisms were at a nutrient limitation - or starving stage, causing (real) PE (Blagodatskaya *et al*. 2014) [7]. Mineralization of SOM significantly increased with residue addition depending on the type and amount of residue [Fig.4b]. At the doubled amount of residue addition, the cumulative SOM mineralization remained similar between low and high addition levels of leaves (up to 0.9 g C kg^{-1}) and stems (1.1 g C kg^{-1}).Relative root mineralization after intensive phase was similar at high and low addition (i.e. 29% of initial input), whereas the leaf and stem mineralization rate were up to 17 and 30% faster at high than at low additions, respectively [Fig.4b].The MB-C significantly increased (compared to the control) during the intensive decomposition phase of the residues (during the first two weeks), with an average of 42-85, 42-53 and 28-54% due to leaf, stem and root addition, respectively [Fig.4c].

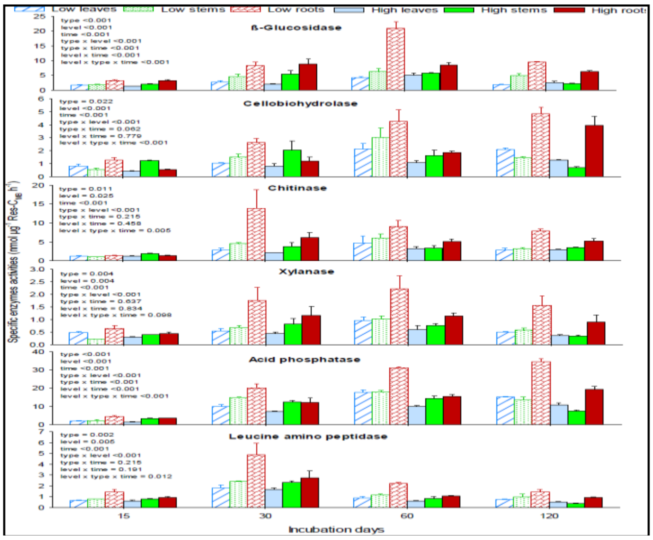

Fig 4(a): Specific enzyme activities [enzyme activities per unit of residue originated microbial biomass (Res_CMB)], depending on the residue type, addition level and time of incubation.

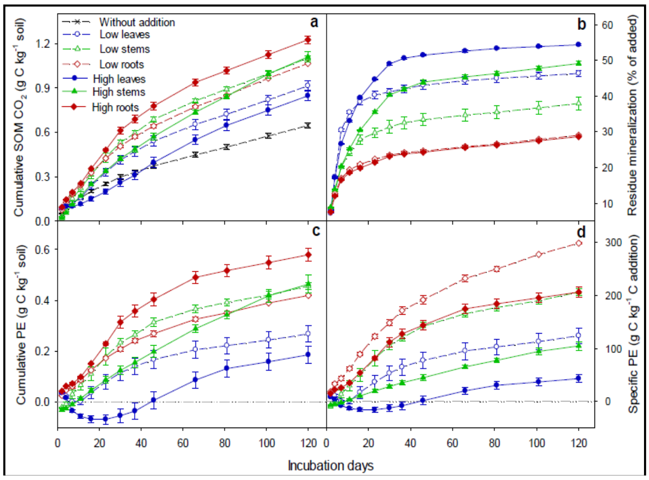

Fig 4(b): Cumulative CO₂ release originated from soil organic matter (SOM, a), crop residue decomposition (% of initial addition, b), total priming effect (PE, c), and specific PE (d) over 120 days of incubation, depending on the residue type and addition level.

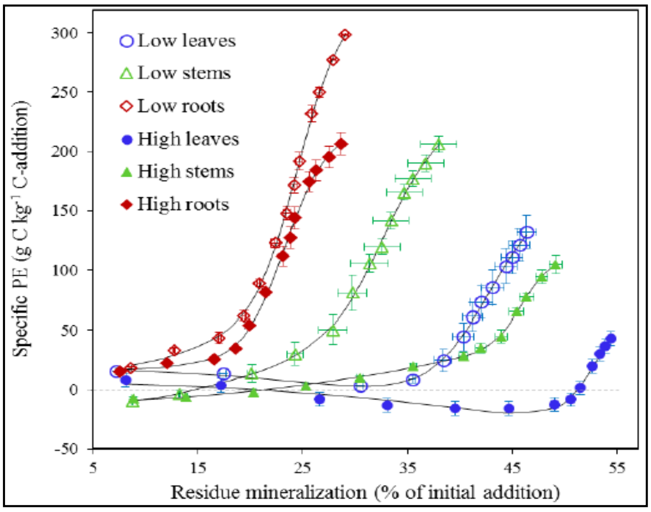

Fig 4(c): Relationship between the fractions of mineralized residue

Ye *et al*. (2017) [81] also found that there were significantly higher levels of dissolved organic C (DOC), microbial biomass C (MBC) and C accumulation in the heavy soil fraction in soil amended with fine-sized (<0.2 mm) compared with coarse-sized (5.0 mm) fragments [Fig. 5a]. The cumulative C lost by microbial respiration significantly increased with the high residue rate, while residue size did not affect the cumulative C loss. When normalized by soil C, cumulative C efflux showed a trend of convergence among the treatments with different residue addition rates. DOC increased along the residue addition rates and decreased with the residue size across the whole incubation period, leading to a significant addition rate × residue size interaction [Fig. 5b]. Higher residue addition rates resulted in higher bulk soil C, organic C in the heavy soil fraction and associated C [Fig. 5c]. The insignificant effect on C mineralization was unexpected and contrasting to the general view that reducing residue size should stimulate microbial decomposition (Angers and Recous, 1997) [2]. A reduction in tilling from conventional to no or minimal till increases macro aggregation by 21% - 42% (Liu *et al*., 2006) [40]. The chart below shows the difference in the stratification ratio, a measure of organic matter at the surface of the soil over organic matter a bit deeper [Fig. 5c]. No till systems have far more surface organic matter which helps fend off erosion and better facilitates seedling growth and root growth (Franzluebbers, 2013) [16].

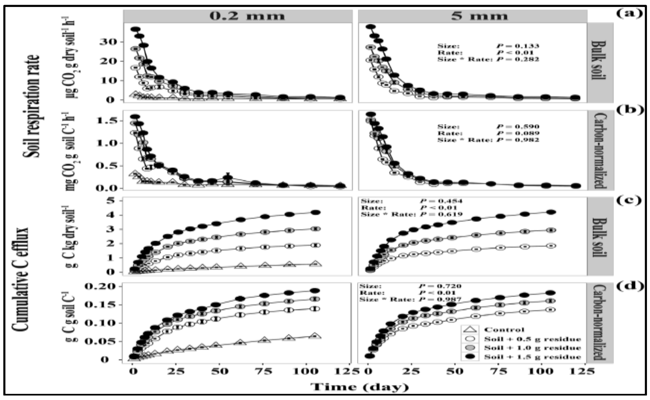

Fig 5(a): Effects of residue addition rate and size on microbial respiration rate (**a**), C-normalized respirationrate (**b**), cumulative C efflux (**c**) and C-normalized cumulative C efflux (**d**).

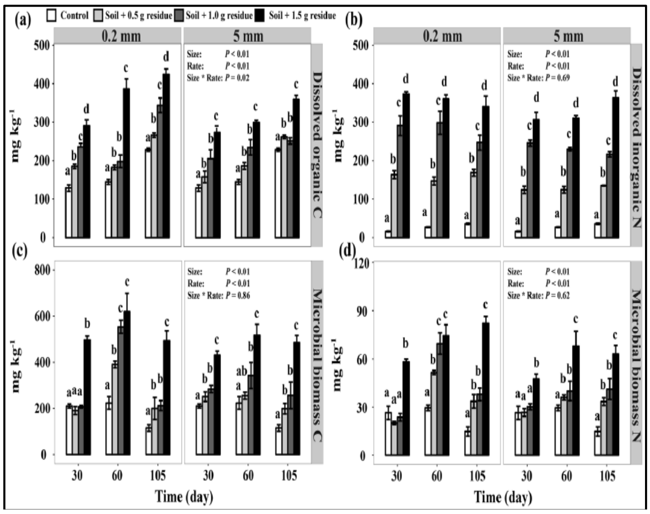

Fig 5(b): Effects of residue addition rate and size on dissolved organic C (**a**), dissolved inorganic N (**b**), microbial biomass C (**c**) and microbial biomass N (**d**).

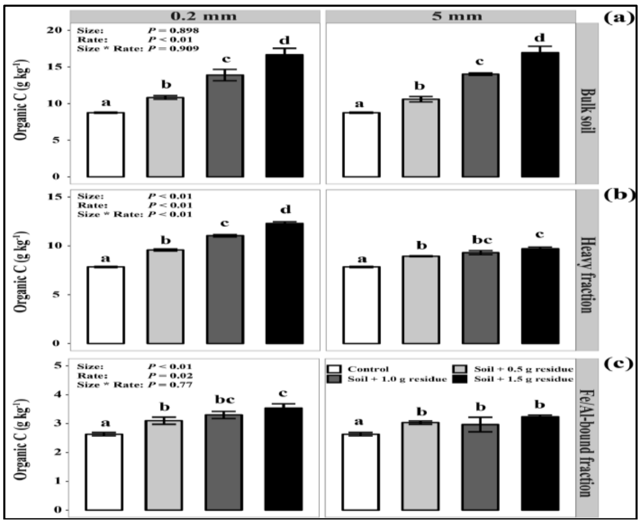

Fig 5(c): Effects of residue addition rate and size on bulk soil C (**a**), total C (**b**) and Fe/Al-bound C (**c**) in heavyfraction.

Rice–wheat systems evolved greater cumulative amounts of CO_2 from soils after 32 days of incubation than uncultivated soils and soils under maize–wheat and sugarcane agro-ecosystems

Moura *et al*. (2015) [48] reported that enhancing the soil environment for root growth in no-tillage systems and in soil covered with a residue such as mulch. This practice has been recommended because a protective layer of mulch absorbs raindrop impact and reduces evaporation from the soil surface, which may delay hard setting [Fig.6b]. In addition, the continuous application of residues improves the soil environment for root growth because it promotes the formation of unstable aggregates by increasing the free light fraction of organic matter (Duval *et al*., 2013) [14]. The priming of added residues was evident from increased mineralization of SOM which mainly depended upon the amount of addition [Fig. 6c]. Regardless of residue type, mineralization of SOM increased up to from 50 to 90% due to addition of low and high levels, respectively, whereas residue addition was increased 3.6 times. Therefore, the amount of primed CO_2 decreased per unit of applied residue. This was also reported by Guenet *et al*. (2010) [25] and Xiao *et al*. (2015) [79].

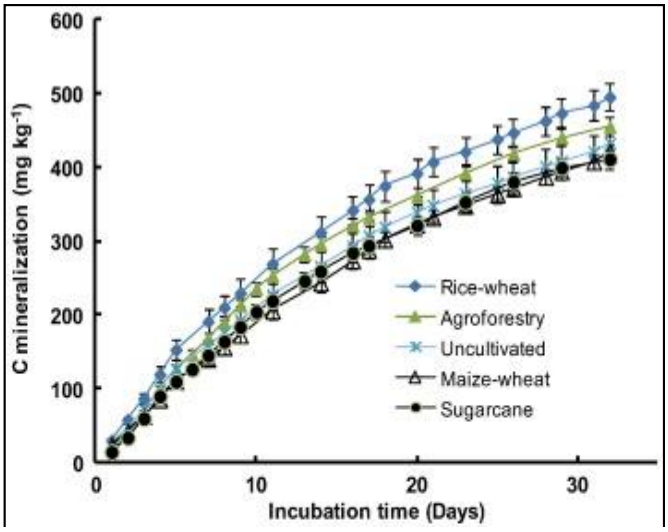

Fig 6(a): Cumulative C mineralization in 32 days of incubation at 25 °C in uncultivated soils and the soils under different agro-ecosystems

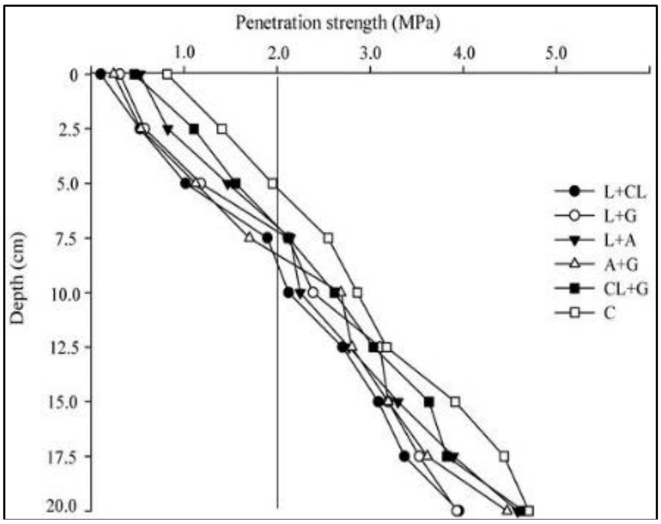

Fig 6(b): Penetration strength after four days without rain in soil covered with 10 tons/ha of different combinations of leguminous residues

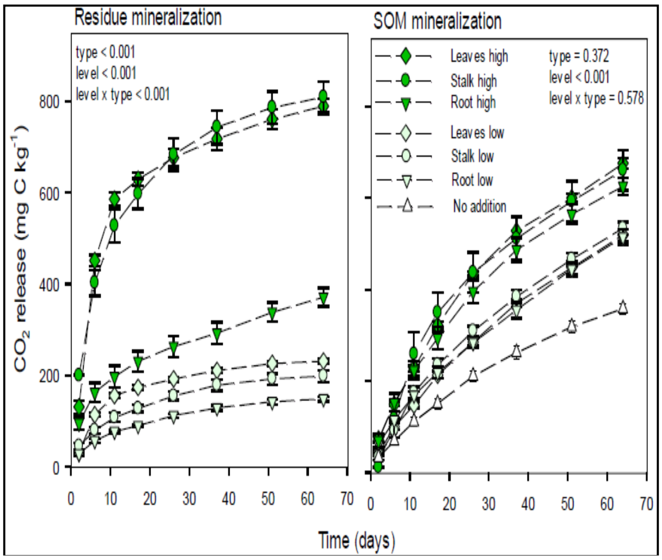

Fig 6c): Cumulative CO_2-C release during 64 days of incubation depending on type and level of crop residue additions. Left: release from crop residues; right: release from soil organic matter (SOM).

Luo *et al*. (2016) [41] revealed that the NH_4^+-N content increased and then dramatically decreased in the reed stem treatment with or without bio-char addition, but the peak time was different, at day 6 and 46 for the reed treatment, respectively [Fig.7a]. Bio-char may contain bioavailable C fractions during its production; its mineralization and release will be dependent on how recalcitrant the bio-char and soil N and C pools are, and on the soil and bio-char C: N ratio (Clough *et al*., 2013) [13]. The net N mineralization rates in the reed stem treatments (3%R and 3%R + 3%BC) were negative and much lower (−0.19 to −0.01 mg/ (kg d)) than that of the CK treatment (0.09 to 1.14 mg/ (kg d)), they increased over the incubation period [Fig.7b]. Pereira *et al*. (2015), who found that adding 3% of holm oak bio-char produced at 650 °C to a composting mixture of poultry manure and barley straw favoured N mineralization due to the improved physical properties of the mixture by preventing the formation of clumps larger than 70mmand the enhanced microbiological activity. The urea application resulted in a decreasing trend of the N mineralization rates, regardless of whether bio-char was added or not, and the rates were150–166 and 6.87–6.92 times higher than those of the CK treatment at the beginning and end of the incubation, respectively [Fig.7c]. Sigua *et al*. (2016) [61] reported that application of switch grass bio-chars produced at 250 and 500 °C caused N immobilization in 50 days of incubation because of the higher C:N ratio ranging from 129:1 to 250:1 for the bio-chars. Thiswas similar to the decay of plant litters, generally resulting inN immobilization in soils (Moreno-Cornejo *et al*., 2014) [47].

The AN content in the urea treatments with the bio-char addition [Fig.8a]. Sarkhot *et al*. (2012) [58] prepared nutrient enriched bio-char by shaking the bio-char with dairy manure effluent for 24 h, which increased the C and N content of the bio-char by 9.3% and 8.3, respectively. When the untreated bio-char and N enriched bio-char were added to a soil in eight week incubation, the reduction in availableNH_4^+-N and NO_3^--N content was observed, suggesting the possibility of N immobilization. Still, N enriched bio-char could be used as a slowrelease N fertilizer. The net N nitrification rates in the CK, 1%BC and 3% BC treatments also peaked at day 25, then dramatically decreased and stayed at a very low level (0.35–0.42mg/(kg d)) at the end of incubation [Fig.8b].

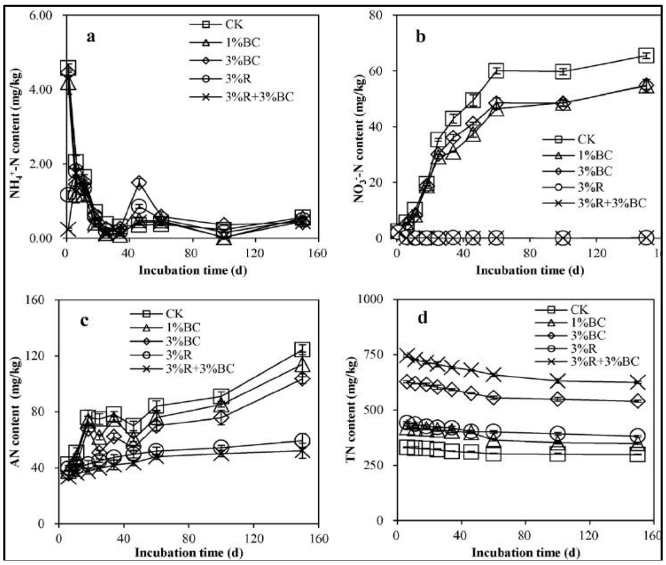

Fig 7(a): Effects of bio-char additions on soil N contents: (a) NH_4^+-N; (b) NO_3^--N; (c) available N (AN); and (d) total N (TN)

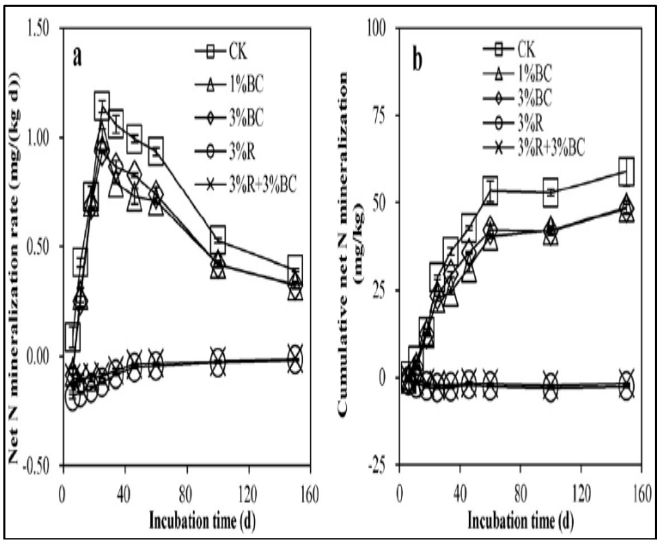

Fig. 7 (b): Effects of bio-char additions on (a) net Nmineralization rates and (b) cumulative net Nmineralization

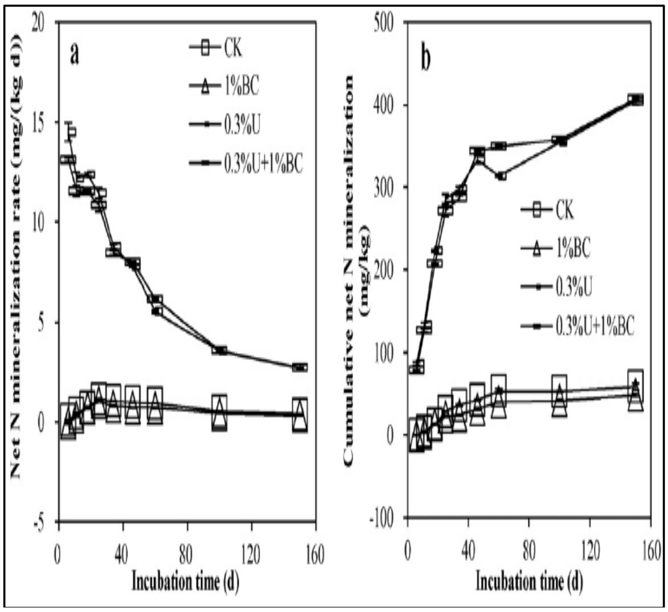

Fig 7(c): Effects of bio-char and urea additions on (a) net N mineralization rates and (b) cumulative net N mineralization

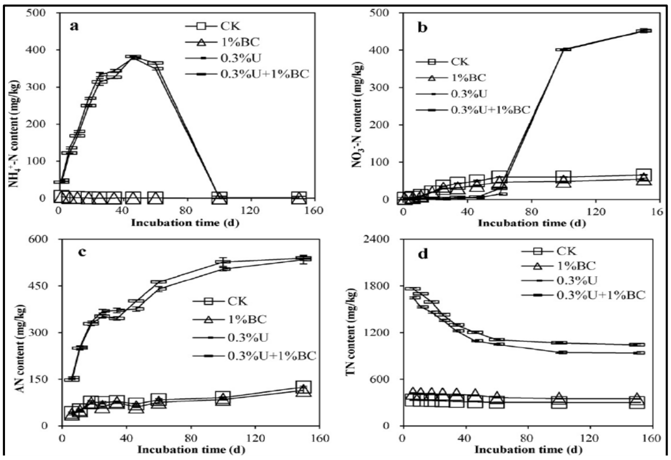

Fig 8(a): Effects of bio-char and urea additions on soil N contents: (a) NH_4^+-N; (b) NO_3^--N; (c) available N (AN); and (d) total N (TN

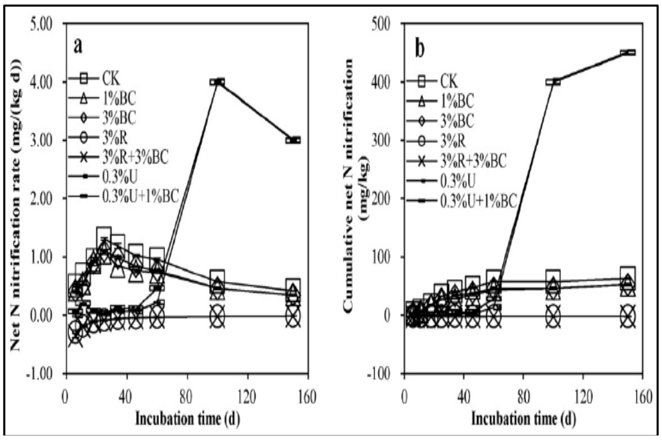

Fig 8(b): Effects of bio-char additions on (a) net N nitrification rates and (b) cumulative net N nitrification

Bertrand *et al*. (2007) [5] showed that net N mineralization occurred in all control soils, but was not statistically different between soils [Fig. 9a]. Ammonium-N did not accumulate, so the nitrification rate was almost equal to the mineralization rate. In residue-amended soils, soil mineral N concentration decreased rapidly during the first 20 days, then slowly up to day 35 when maximum N immobilization occurred. The maximum N immobilized varied between 2.8 and 3.9 mmol kg^{-1} soils, that is, 39.3and 54.6 mg N kg^{-1}. They assumed that, as the NH_4^+ ions are preferentially taken up by microbes, no nitrification would have occurred during the period of strong immobilization (0–35 days).

Zhu *et al*. (2015) [86] revealed that the soil total organic C (TOC) and labile organic C fraction contents were higher under the straw return treatments compared to the no straw return treatment (0%S) at a 0–21 soil depth. The 50% annual straw return rate (50%S) had significantly higher soil TOC, dissolved organic C (DOC), easily oxidizable C (EOC), and microbial biomass C (MBC) contents than the 0%S treatment at a 0–21 cm depth. All of the straw return treatments had a significantly higher DOC content than the 0%S treatment at a 0–21 cm depth, except for the 100% only rice straw return treatment (100%RS) [Fig. 9b]. A plausible explanation might be that the changes in TOC are generally insensitive to recent management practices, as these changes occur slowly and are relatively small compared to the vast background of SOC (Gong *et al*., 2009) [31]. While under 50%S treatment, the conditions for microorganism's growth are more favourable for the efficient decomposition of straw, thus stimulating the increase of TOC.

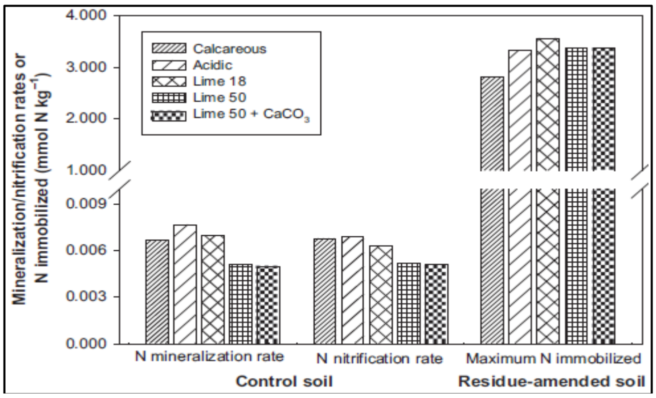

Fig 9(a): Nitrogen mineralization and nitrification rates in control soils and maximum N immobilized in plant residue-amended soils after 35 days

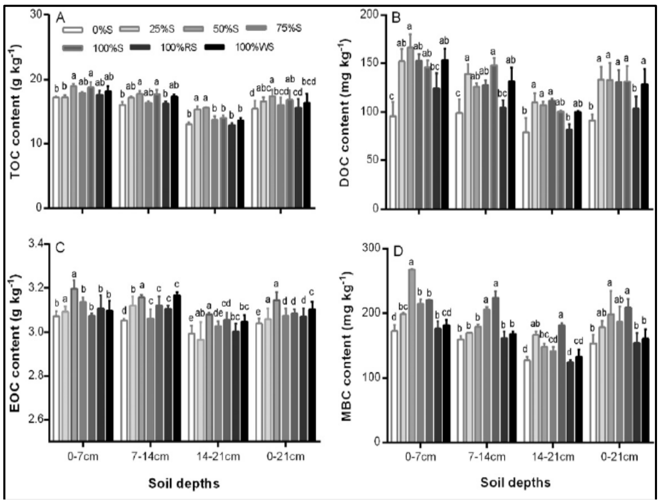

Fig 9(b): Effects of different annual straw return rates on soil TOC (A), DOC (B), EOC (C) and MBC (D) contents at the three soil depths

Wang *et al*. (2015) [77] also found that in the early paddy field, the average values of the total SOC, LFOC, DOC and MBC concentration in the top 40 cm soil were significantly higher in the straw application plots than in the controls, by 7.2%, 8.8%, 15.6%, and 128.6%, respectively [Fig. 10a]. However, there were no significant differences in the mean values of LOC in the top 40 cm soil between the straw application and control plots. In the late paddy field, the average values of the total SOC, LFOC, DOC, MBC and LOC concentration in the top 40 cm soil were significantly higher in the straw application plots than in the controls by 2.0%, 14.1%, 23.2%, 9.1%, and 10.3%, respectively [Fig.10b].Straw incorporation significantly increased soil water content both in the early and late paddy fields, which could be attributed to the ability of straw in absorbing water, thereby keeping the soil wet. Also, the addition of straw could reduce soil temperature and hence evaporation of soil water, which help retaining water in the soil (Siczek and Fra c, 2012) [62]. The increase in total SOC in response to straw application could also be related to changes in soil water content. The addition of straw increased soil water retention and promoted the development of anaerobic conditions in paddy soils, thereby reducing C release through respiration and increasing soil C sequestration (Nomura *et al*., 2013; Wang *et al*., 2014a) [49, 76]. The proportion of protected residue-derived C was smaller at high addition level for all types of residue [Fig.10c]. Thus, increasing addition level promotes macro-aggregate formation. However, the low proportion of physically protected residues at high addition levels leads a decreasing C-stabilization rate within SOM. Micro-aggregates may be more effective in stabilising C (von Lützow *et al*., 2008) [75] because sorption instead of physical occlusion may be the prevailing process (Lehmann *et al*., 2007). At high addition level of roots, we found not only a lower proportion of mineralisation but also a higher association of root C with micro-aggregates and the < 53 μm fraction.

Zhang *et al*. (2018) [85] revealed that the regression analysis showed that soil organic C content, C: N ratio and the volumetric soil water content measured at maturity of maize were significantly, positively and exponentially correlated with the mass proportion of macro-aggregates [Fig. 11a]. Hill *et al*. (2008) [29] declared that the microbial abundance primarily depended on the level of labile organic C rather than total organic C in soils. Therefore, the quality of organic substrates such as the C/N ratio was also of great importance to the microbial communities (Zhang *et al*., 2015a) [84]. Whereas, a significant, negative and logarithmic relationship was found between soil porosity or computed effective oxygen diffusion coefficients, and the mass proportion of macro-aggregates across the tested treatments. The regression analysis showed that the ratios of B/F and M/B were significantly and negatively correlated to the volumetric soil water content [Fig. 11b], whereas significantly and positively correlated to soil porosity or computed effective diffusion coefficients of oxygen in soils across the tested treatments. These results suggested that soil moisture, porosity and oxygen availability were primarily responsible for the changes in soil microbial community structure under conservation tillage (Macdonald *et al*., 2009) [42]. The redundancy analysis (RDA) revealed that the abundance of G+ bacterial, G− bacterial, fungal and monounsaturated PLFAs or the ratio of G+/ G- bacteria was significantly and positively, whereas the B/F or M/B ratio was significantly and negatively correlated with the organic C accumulation in 0–10 cm topsoil across the tested treatments [Fig. 11c]. Zhang *et al*. (2013b) [82] has documented that special functional groups of soil microbes such as arbuscular mycorrhizae fungi, cultivated in conservation tillage system, could conserve more C in biomass and ultimately increase C stock. On the other hand, the reduced mechanical perturbance, increased available organic substrates and improved microenvironment under conservation tillage favour the forming of hyphal fungi networks (Strickland and Rousk, 2010) [68] and thus promote the macro-aggregate formation and stabilization (Peng *et al*., 2013) [51]. Soil macro-aggregation, in turn, enhances the physical inaccessibility of organic C for decomposing microorganisms (Jagadamma *et al*., 2014) [32].

Franzluebbers, (2013) [16] reported that tillage is the practice of mixing and aerating soil by breaking it apart and turning it. Tilling practices increase oxygen availability to microbes and exposes aggregate bound organic matter to microbes. As a result, high tillage gives microbes' access to previously soil bound carbon which is released as carbon dioxide into the atmosphere [Fig.12a]. Tilling also damages soil structure, increasing erosion and removing yet more valuable organic carbon from fields. The increased attention on sustainable farming practices over the past decades has led to an increase in "no till" farming. In no till and reduced till systems levels of soil organic carbon, microbial biomass, and mineralizable nitrogen are significantly higher in the surface layer, but not necessarily deeper layers, of the soil. In fact, gains in SOC were 250kgha^{-1}yr^{-1} higher in minimal till than in conventional systems (Liu *et al*., 2006) [40]. No till systems have far more surface organic matter which helps fend off erosion and better facilitates seedling growth and root growth [Fig. 12a]. Hu *et al*. (2014) [31] showed that the harvest residue management treatments did not differ significantly in their effect on soil C and N, mineral N (NH_4^+-N plus NO_3^--N), dissolved organic C or total dissolved N concentrations, except for soil N concentrations in surface soil (0–10 cm) and soil total dissolved N concentrations, which were significantly lower where the slash was burnt than in the double residue retention treatment [Fig.12b]. Ghosh *et al*. (2016) [17] revealed that thebulk soils as well as macro- and micro-aggregates were incubated for 24 days at 25 °C and 35 °C. Cumulative SOC mineralization (Ct) in the 0–15 cm soil layer of bulk soils with NPK + FYM and NPK treated plots were similar but significantly higher than unfertilized control plots. However, both C_t and Q_{10} values in the NPK + FYM plots were higher than NPK in the 15–30 cm soil layer. In the 0–15 cm soil layer, NPK + FYM plots had ∼10 and 26% greater Q10 values of macro- and micro-aggregates than NPK [Fig.12c].

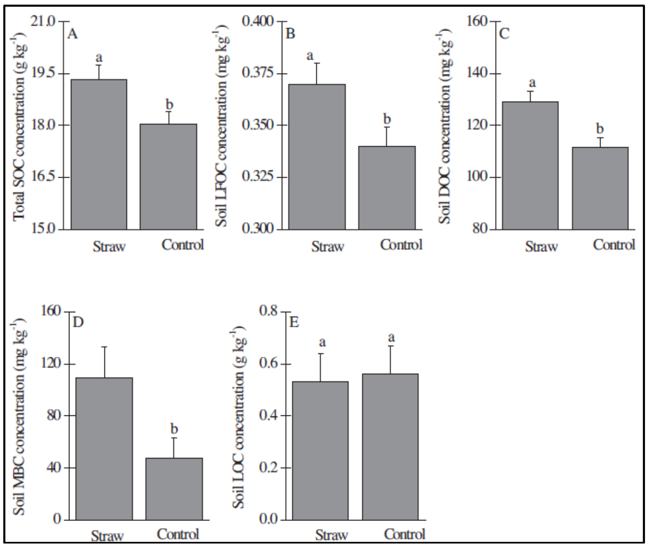

Fig 10(a): Mean concentrations of SOC (A), LFOC (B), DOC (C), MBC (D) and LOC (E) in the straw application and control plots in early paddy field

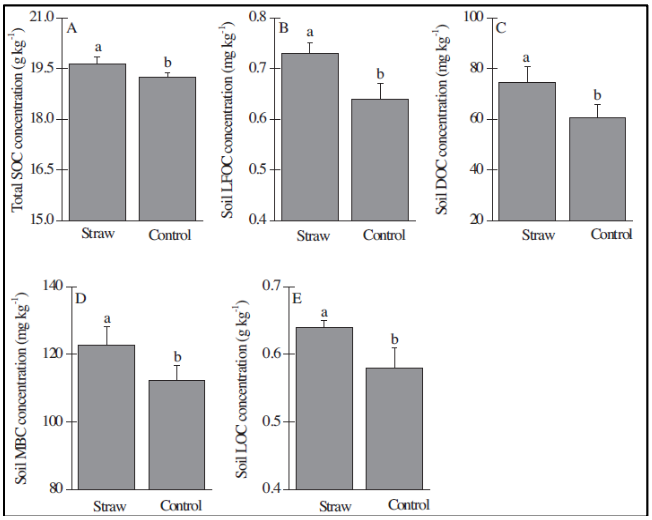

Fig 10(b): Mean concentrations of SOC (A), LFOC (B), DOC (C), MBC (D) and LOC (E) in the straw application and control plots in late paddy field.

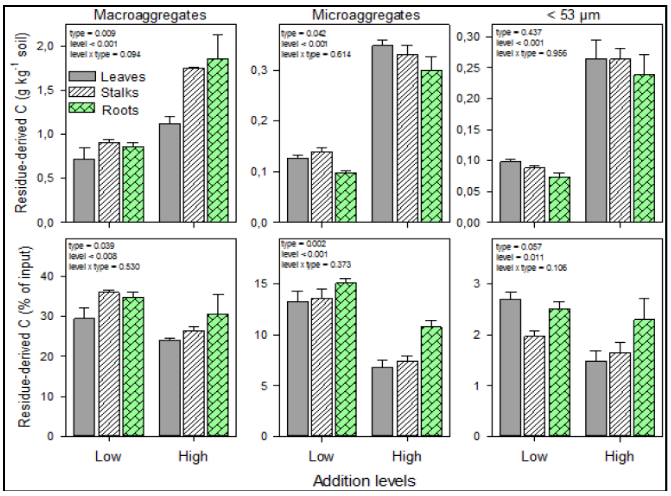

Fig 10(c): Residue-derived C in the soil aggregate size classes (Macro >250 µm, Micro 53-250 µm and silt plus clay <53 µm). Upper subfigures present total aggregate protected C in soil and lower subfigures show protected C portion of initially added residue-C

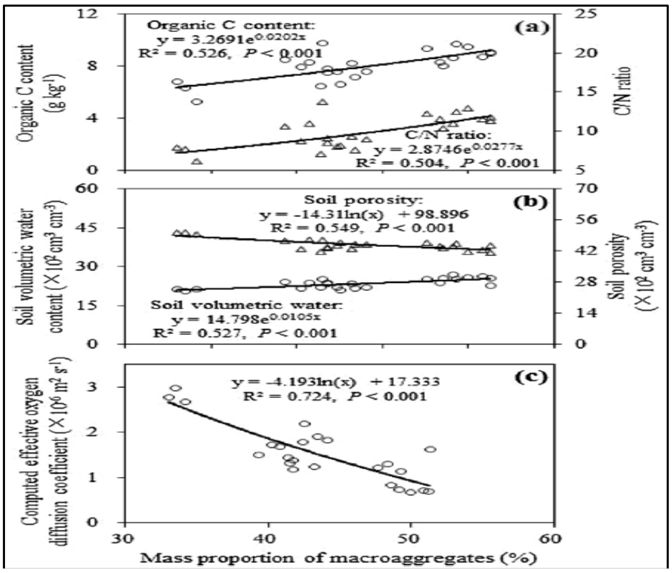

Fig 11(a): Relationships between mass proportion of macro-aggregates and organic C content, C/N ratio (a), soil porosity, volumetric soil water content (b) or computed effective oxygen diffusion coefficient (c) in soils following various tillage and residue managements

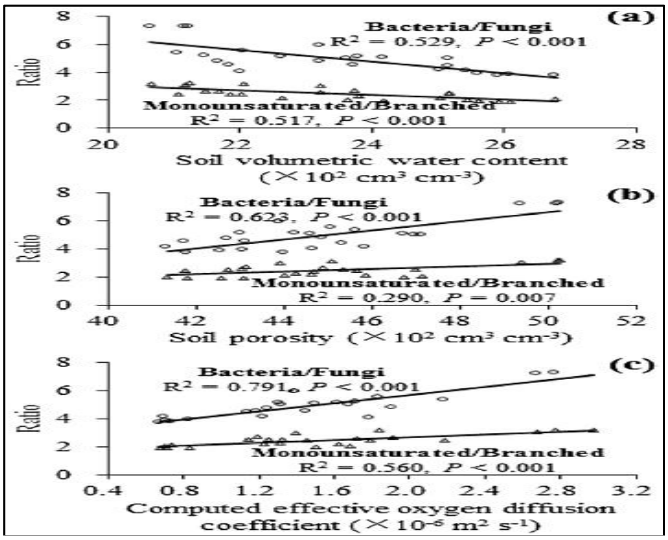

Fig 11(b): Relationships between volumetric soil water content (a), soil porosity (b) or computed effective oxygen diffusion coefficient (c) and ratios of bacteria in soils following various tillage and residue managements

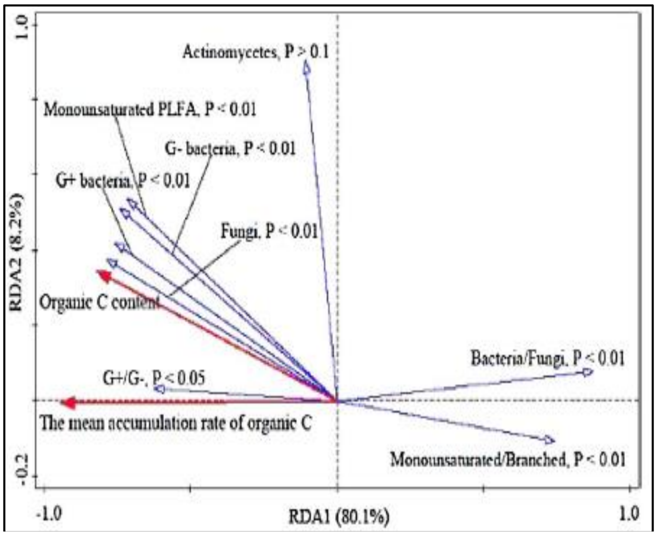

Fig 11(c): Redundancy analysis (RDA) relating organic C accumulation to microbial community composition in soils following various tillage and residue managements

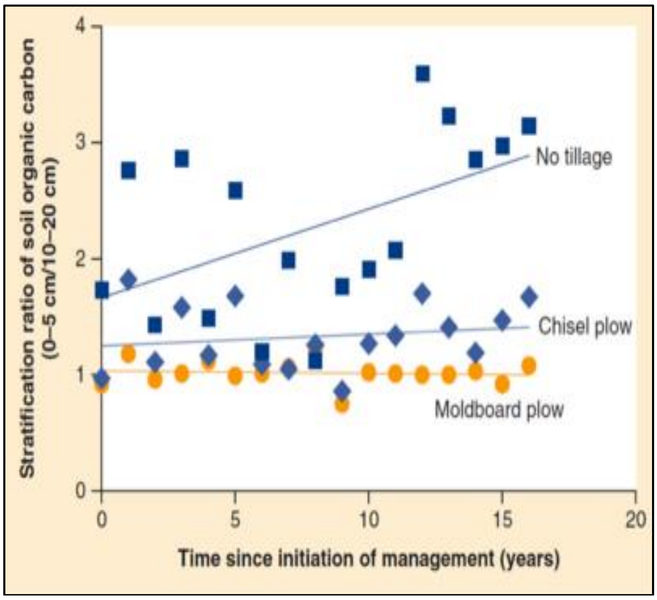

Fig 12(a): Change in stratification ratio of soil organic carbon with time under different tillage systems

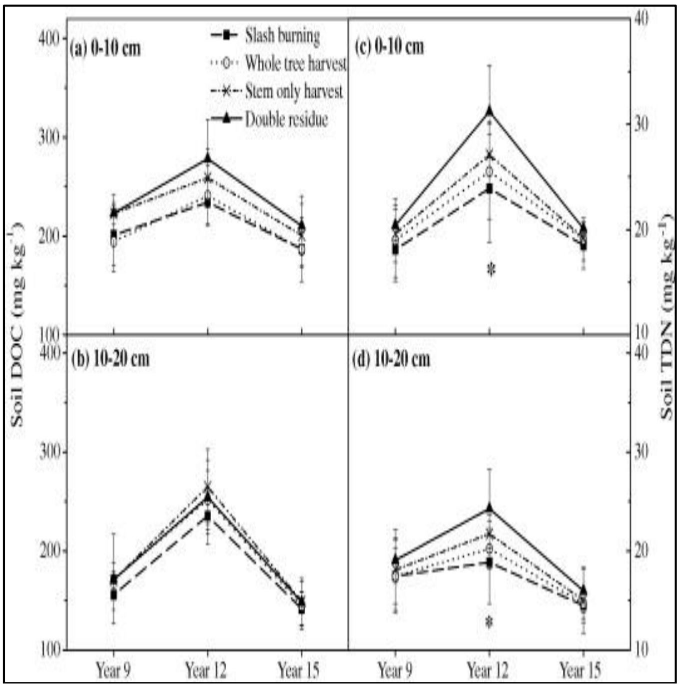

Fig 12(b): Effects of harvest residue management on soil carbon and nitrogen

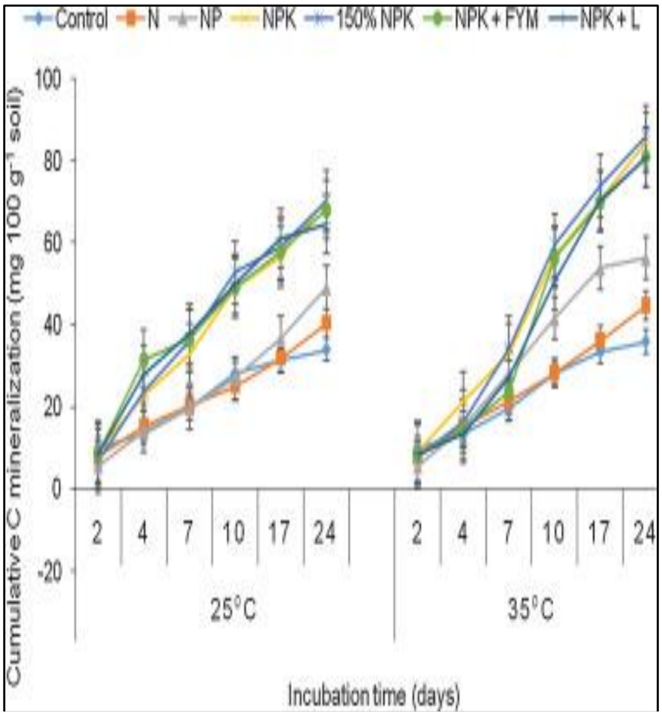

Fig 12(c): Soil organic carbon decomposition as affected by long-term fertilization

Xin *et al*. (2014) reported that the higher MWD and GMD were observed in 2TS, 4TS and NTS as compared to T. With increasing soil depth, the amount of macro-aggregates and MWD and GMD values were increased, while the proportions of micro-aggregates and the silt+clay fraction were declined [Fig.13a]. The possible reasons are that organic materials, organic binding agents and root exudates induced by residue retention play vital roles in formation of macro-aggregates by binding the relatively stable micro-aggregates and small particles (Pokharel *et al*. 2013). Additionally, by placing residues at the soil surface, the decomposition rate of organic binding agents is slowed due to reduced contact between soil microorganisms and organic matter (Roper *et al*. 2013). The OC concentrations in different aggregate fractions at all soil depths followed the order of macro-aggregates>micro-aggregates>silt+clay fraction [Fig.13b]. In the 0-5 cm soil layer, concentrations of macro-aggregate-associated OC in 2TS, 4TS and NTS were 14, 56 and 83% higher than for T, whereas T had the greatest concentration of OC associated with the silt+clay fraction in the 10-20 cm layer. Soil OC concentrations under 4TS and NTS were significantly higher than that of T in the 0-10 cm layer. Residue retention promoted formation of macro-aggregates, increased macro-aggregate-associated OC concentrations and thus increased total soil OC stock [Fig.13b].This trend demonstrated that the translocation of OC from the silt+clay fraction to macro-aggregates was likely due to the integration of fine particles into coarse fractions. Our results were consistent with previous studies in which more organic matter was associated with macro-aggregates than with micro-aggregates and the silt+clay fraction, indicating that macro-aggregates are mainly responsible for the improved soil OC stock (Du *et al*. 2013). Wright *et al*. (2007) reported that in the 0-5 cm soil depth, no-tillage increased macro-aggregate-associated OC as compared to conventional tillage. Macro-aggregates accounted for 38-64, 48-66, and 54-71% of the total soil mass in the 0-5, 5-10, and 10-20 cm soil depths, respectively. The corresponding proportions of the silt+clay fraction were 3-7, 2-6, and 1-5%, respectively. Proportions of macro-aggregates were increased with reduction of soil tillage frequency [Fig.13c]. For the 0-5 cm soil depth, treatments NT and 4T had significantly higher mass proportions of macro-aggregates (36 and 23%, respectively) than that of treatment T. With additions of crop residues, the amount of macro-aggregates increased in all tillage treatments. Because macro-aggregates are rich in labile OC (Wei *et al*. 2013), intensive tillage such as T causes rapid decomposition of labile OC fractions by breaking macro-aggregates into small aggregate-size classes.

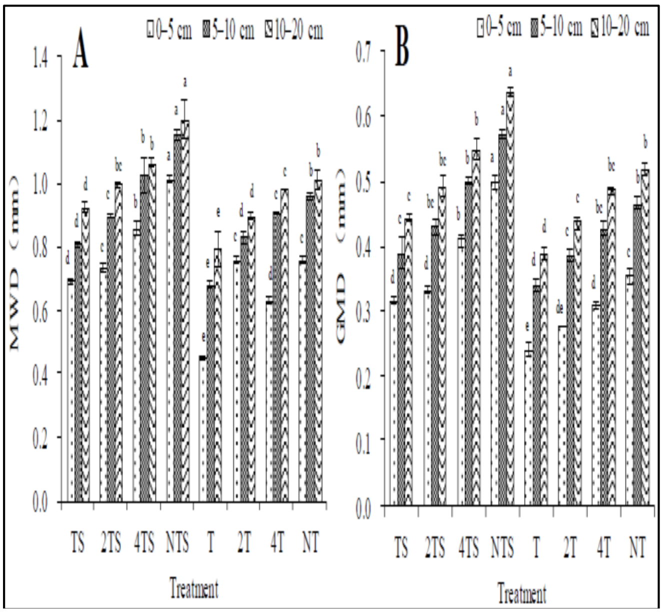

Fig 13(a): The values of MWD (A) and GMD (B) of soil aggregates in the 0-5, 5-10 and 10-20 cm soil depths under different tillage systems. T indicates plowing once every year with residue removal; 2T indicates plowing once every two years with residue removal; 4T indicates plowing once every four years with residue removal; NT indicates no plowing all years with residue removal; TS, 2TS, 4TS and NTS indicates four corresponding tillage treatments incorporated with 100% residue retention

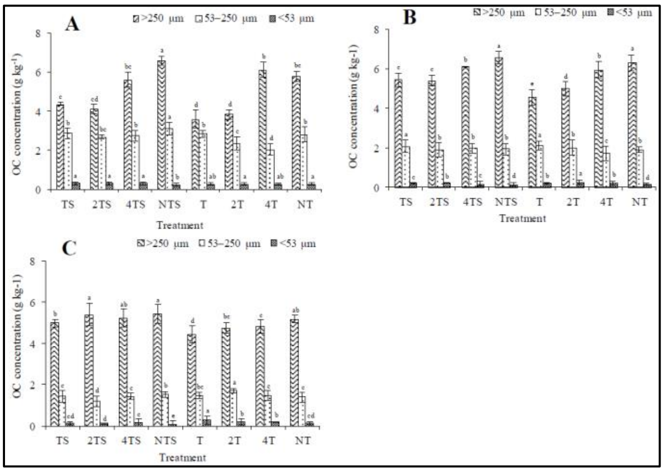

Fig 13(b): OC (organic carbon) concentrations in aggregates of 0-5 (A), 5-10 (B) and 10-20 cm (C) soil layers under different tillage systems

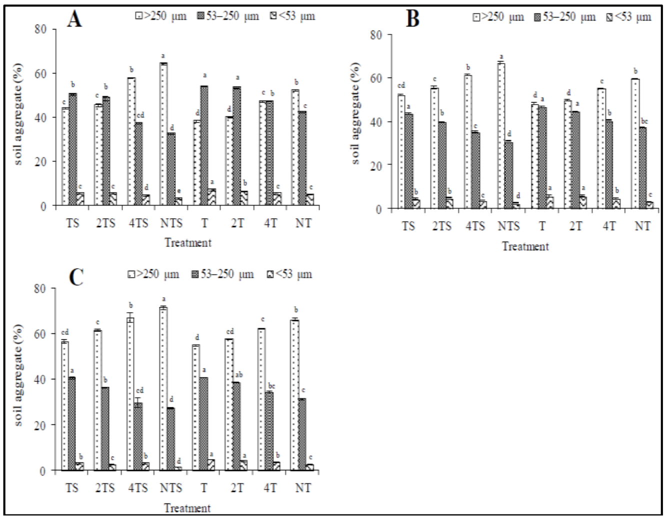

Fig 13(c): Soil aggregate distribution in the 0-5 (A), 5-10 (B) and 10-20 cm (C) depths under different tillage systems

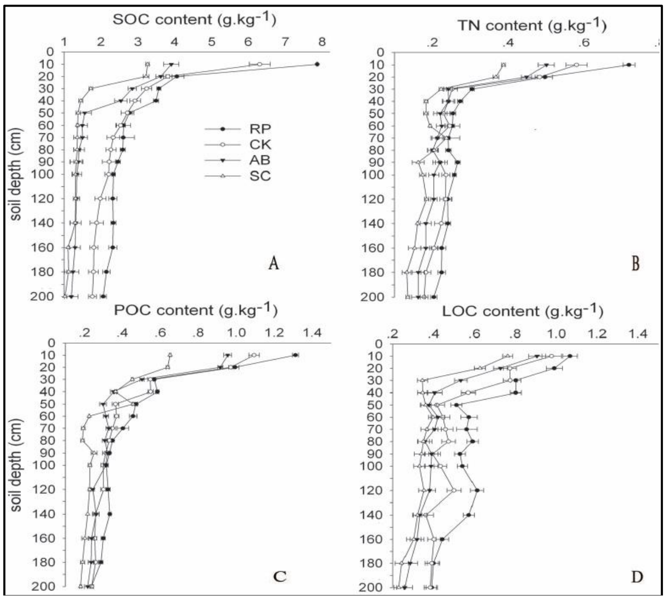

Fig 14(a): Distribution of soil organic carbon (SOC, A), total nitrogen (TN, B), particulate organic carbon (POC, C), and labile organic carbon (LOC, D) contents of different land used types in soil depth of 0–200 cm

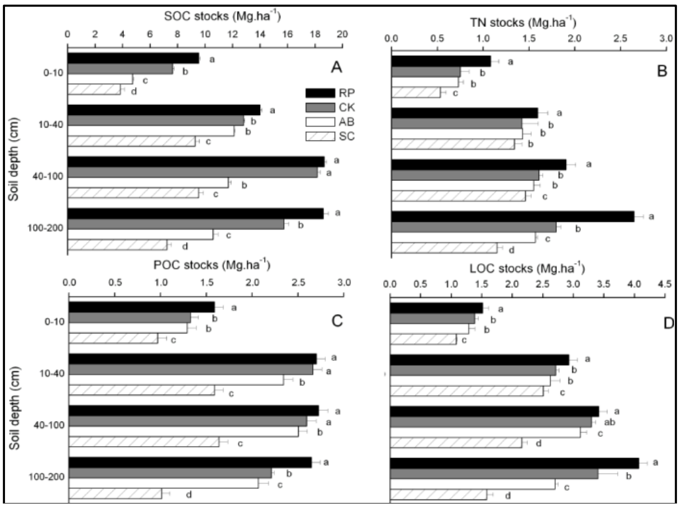

Fig 14(b): Stocks of soil organic carbon (SOC, A), total nitrogen (TN, B), particulate organic carbon (POC, C), labile organic carbon (LOC, D) of different land use types

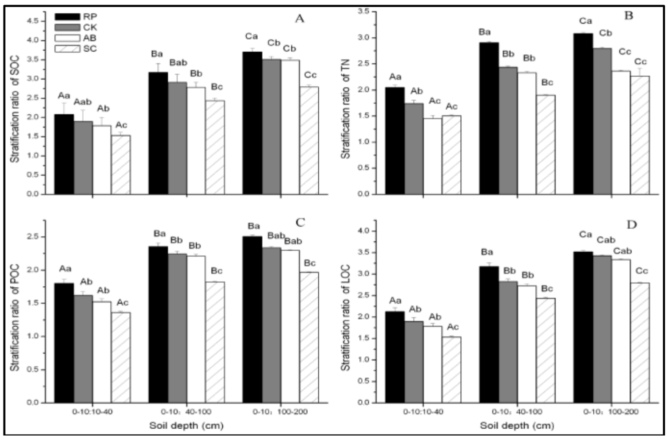

Fig 14(c): Comparison of stratification ratio of soil organic carbon (SOC, A), total nitrogen (TN, B), particulate organic carbon (POC, C), labile organic carbon (LOC, D) under different land use types

Jandl *et al*. (2007) [33] also found that the long-term balancedepends on the extent of soil disturbance. Harvesting influences soil carbon in two contrasting ways: harvest residues left on the soil surface increase the C stock of the forest floor and disturbance of the soil structure leads to soil C loss. C dynamics after harvest shows the almost immediate C loss that is followed by a slow recovery of the C pool [Fig.14a]. Continuous-cover forestry, including selective harvesting, resembles thinning with respect to its effect on the soil C pool, and is considered a possible measure to reduce soil C losses compared with clear-cut harvesting. No C changes with stand age were found in the mineral soil of the pine forest. Carbon that remains in the forest ecosystem cannot be built into wood products and cannot contribute to the substitution of fossil fuels [Fig.14b]. Halvorson *et al*. (2012) [27] revealed that the high retention openta-galloyl-glucose (PGG)observed for plots amended with alfalfa, manure or bio-solids might be associated with the comparatively high N content of these amendments, indicative of organic-N [Fig.14c]. Hydrophobic (nonpolar) organic compounds have been reported to be preferentially sorbed by soils resulting in greater improvements to soil quality and more recalcitrant soil organic matter than hydrophilic organic compounds (Spaccini *et al*., 2002) [65]. Nonpolar PGG would also be predicted to bind most effectively to soil amended with substances like manure and bio-solids because hydrophobicity is correlated with the degree of humification of the soil organic matter. Humification of organic amendments, mediated by microbial decomposition, could increase during composting or with time after application to soil (Hernández-Apaolaz *et al*., 2000) [30]. The accumulation of comparatively greater amounts of total soil-C in plots treated with manure or bio-solids.

Trivedi *et al*. (2017) [72] reported that the activity of enzymes involved in breaking down C was higher with low residue retention than full residue retention, specifically in the macro and mega aggregates [Fig. 15a]. In micro-aggregates, in majority of treatments there were no significant differences in the activity for all the four enzymes. In mega- and macro-aggregates the activity of CB, AG and BG was higher in BOW(P1)-LR, LCW(P2)-LR and BLW(P4)-LR treatments as compared with BOW(P1)-FR, LCW(P2)-FR and WWW(P3)-FR treatments. The enzymatic activities per unit C in the micro-aggregates was significantly less for all the studied enzymes as compared with mega-aggregates and macro-aggregates for most of the treatments. SEM explained higher percent of variations in both the amount of C and enzymatic activities of mega-aggregates and macro-aggregates. However, in micro-aggregates SEM explained significantly lower variations in the amount of soil C (24%) and enzymatic activities (59%) as compared with both large sized aggregates. In mega-aggregates, management practices had a direct and significant effect on the structure of microbial communities; total C and functions [Fig. 15b]. The control of management practices on these same variables was maintained in macro-aggregates however, the effect was not as strong as observed for mega-aggregates. Tiemann *et al*. (2015) [70]; Trivedi *et al*. (2015) [71] also found that the relatively labile nature of C in macro- and mega-aggregates may, at least in part, explain the high influence of agricultural management on the total soil C concentration in these aggregate.

Puttaso *et al*. (2010) [53] revealed that the C: N ratios of the microbial biomass in the residue treatments before residue incorporation were lower than in the control [Fig. 16a]. After week 16, microbial biomass C: N ratio increased in all treatments, but remained lowest in the tamarind compared to the other residue treatments. Microbial biomass C and N were positively correlated with SOC and SON after residue application. The low CO_2-C respiration loss in the tamarind treatment and confirmed by the negative correlation between increased SOC and cumulative CO_2-C [Fig. 16b].

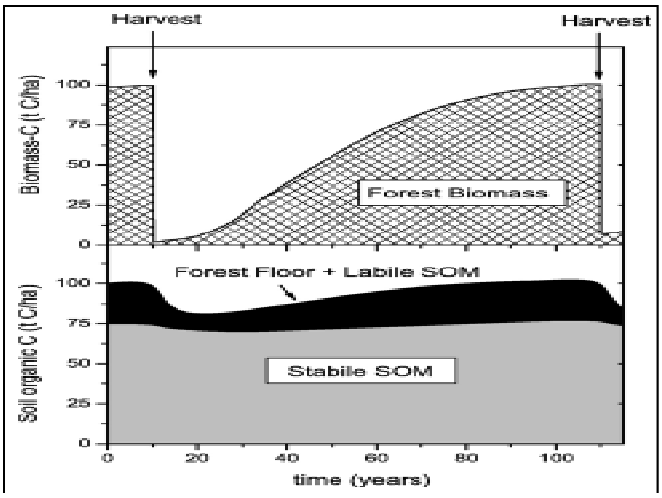

Fig 15(a): Simulation of C dynamics in the aboveground biomass and the soil after harvesting

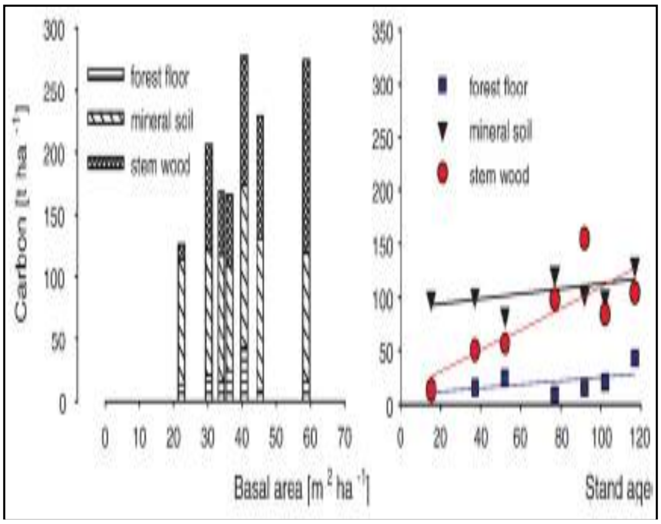

Fig 15(b): C pools versus stand basal area, and temporal trend of C pools over stand age

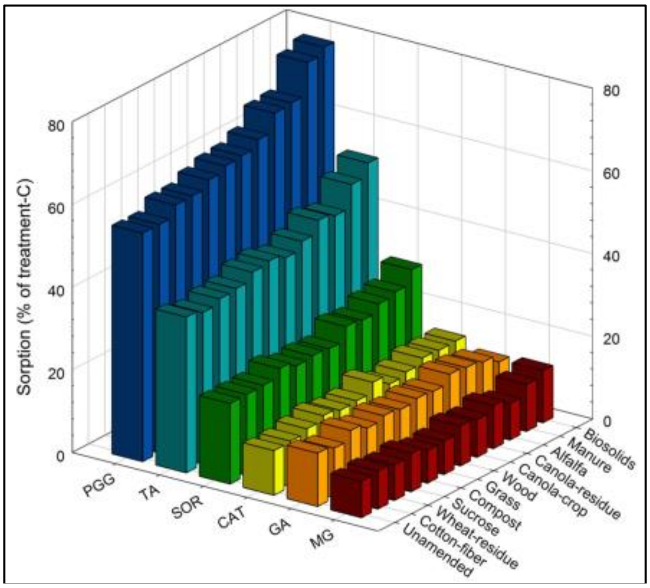

Fig 15(c): Effect of treatment by soil amendment

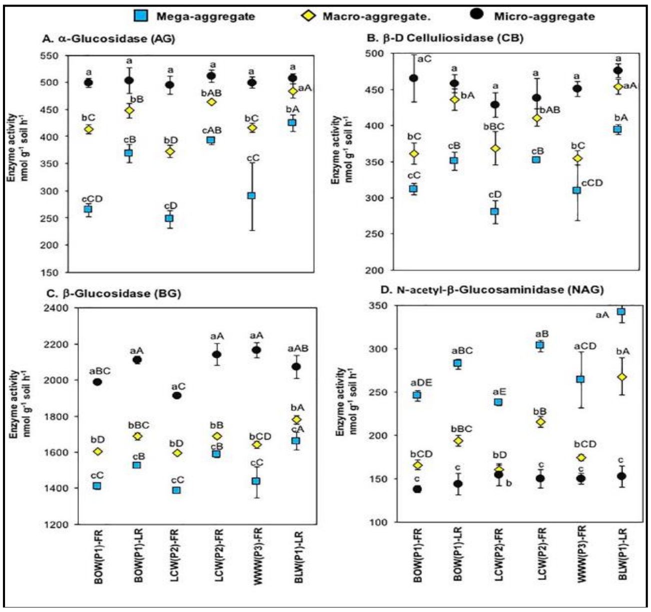

Fig 16 (a): Impacts of soil management practices on the activities of enzymes involved in C degradation among different aggregate sizes.

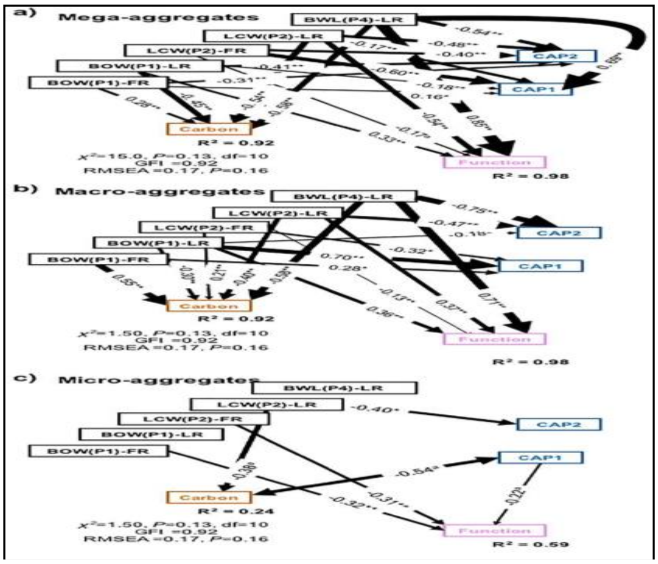

Fig 16(b): Effects of management practices, soil C, microbial community composition on the activities of enzymes involved in soil C turnover (functions) in mega-(a-1); macro-(b-1) and micro-aggregates (c-1).

Gleixner, (2013) [18] reported that the implication is that carbon storage efficiency in this system, which is rapidly accumulating soil C, is very high. The storage efficiency is much lower in comparison to aboveground plant litter addition [Fig.17a].Carbon stock changes are significantly explained by carbon input but also by an additional effect related to plant communities (Steinbeiss *et al*. 2008a) [66]. This biodiversity effect might in turn be an effect of the microbial community, which is also related to plant community (Habekost *et al*. 2008) [26]. Comparing the isotopic shift in 13C for each site enables to calculate the uptake of carbon that is related to carbon directly derived to plant carbon [Fig.17b]. More C was incorporated at high level of all residue types (2-3 times), and incorporation was highest from leaves followed by stalks and roots [Fig.17c]. Microbial biomass C derived from SOM was affected by the interaction of residue type and level. Addition with leaves and stalks decreased C contents of microbial biomass by 24 and 45 mg kg^{-1} at high compared to low addition level [Fig. 17c].

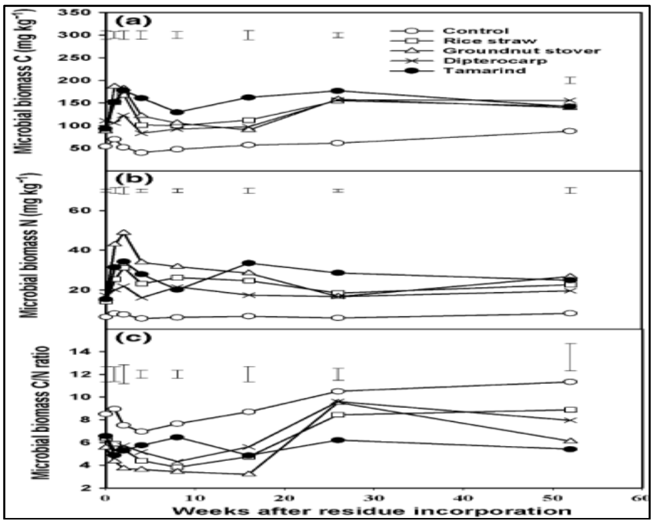

Fig 17 (a): Temporal pattern of soil microbial biomass C (a), soil microbial biomass N (b), and microbial biomass C to N ratio (c) as affected by different residue treatments

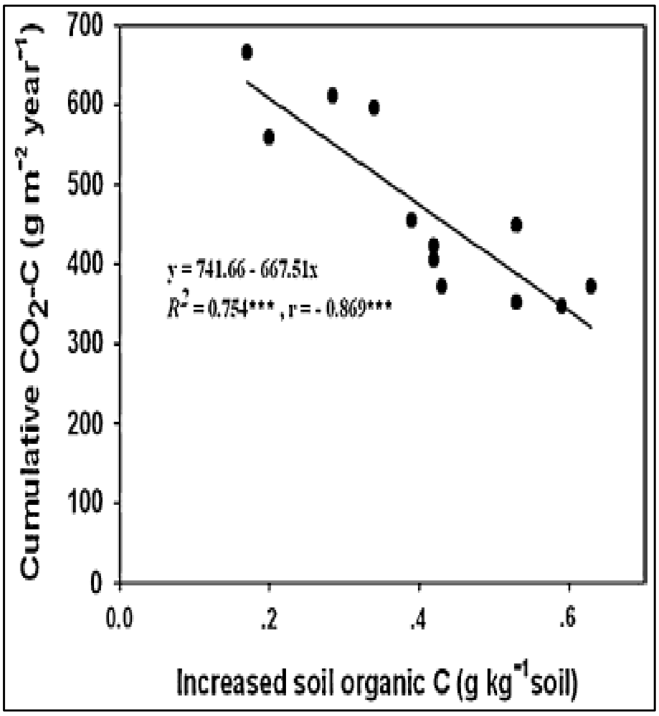

Fig 17(b): Relationship between increase of soil organic C (g kg^{-1} soil, calculated by difference of soil organic C before and after 52 weeks of residue incorporation) and cumulative CO_2-C (g m^{-2} yr^{-1})

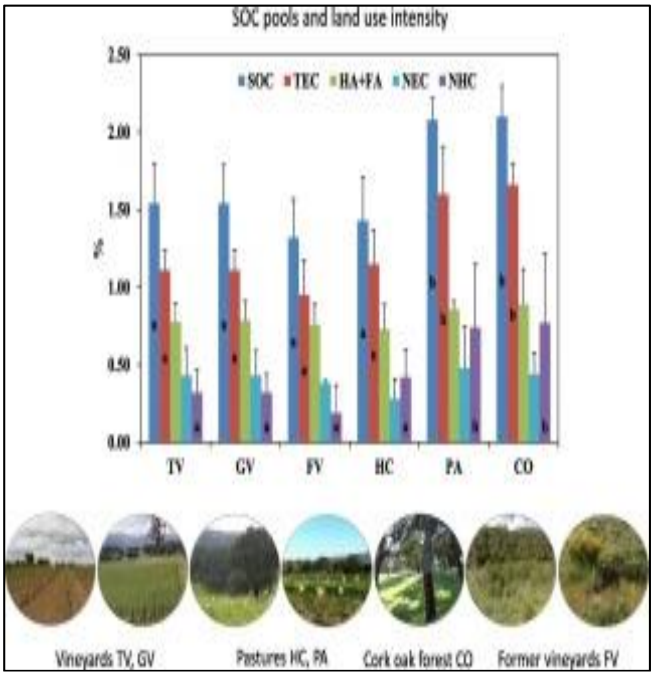

Fig 17(c): Organic carbon pools and soil biological fertility are affected by land use intensity

Md. K. Alam *et al*. (2018) [45] also found that the average WSC content in rice soil was significantly higher than that in the plots of other crops [Fig.18a]. The next highest average WSC contents were associated with jute and mustard soils. The WSC contents were significantly higher in soils treated with CTHR. The next highest values were associated with BPHR and SPHR. Significantly higher WSC contents were invariably associated with increased residue retention relative to low residue retention. Minimal disturbance of the soil and surface application of residue probably maintained a low WSC level throughout the growing seasons by regulating the microbial activities and decomposition of residues [Fig.18b]. The higher WSC values recorded under CTHR and BPHR during the growing season for all crops might also cause higher CO2-eq releases from these soils. Sainju *et al*. (2012) [55] found a positive relationship between WSC and SOM mineralization, and the methods of application and the amount of added residue also affect the WSC and C mineralization values. In total, the SPHR, SPLR, BPHR, BPLR, CTHR and CTLR treatments mineralized 4.81, 4.44, 5.37, 6.10, 7.42 and 6.99% of the TC present in the soils during the mustard and irrigated rice growing seasons. Overall, the soils containing higher C exhibited more C mineralization, except CTLR and BPLR soils, in which more C was mineralized than in CTHR and BPHR soils, respectively [Fig. 18c]. Sapkota *et al*. (2017) [56] found a three-fold increase in SOC stocks under residue retention and minimum tillage compared to no residue retention and CT practices. In Indo- Gangetic Plains, SOC storage increased at a rate of between 0.16 and 0.49 t C ha^{-1} yr^{-1} with minimum disturbance of soil and residue retention compared to CT practice (Powlson *et al*., 2016) [52].

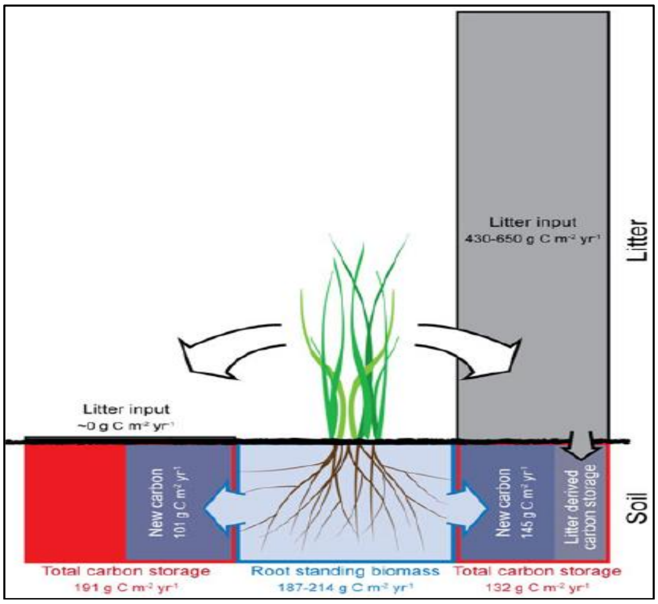

Fig 18 (a): Effect of litter addition on soil carbon storage and turnover

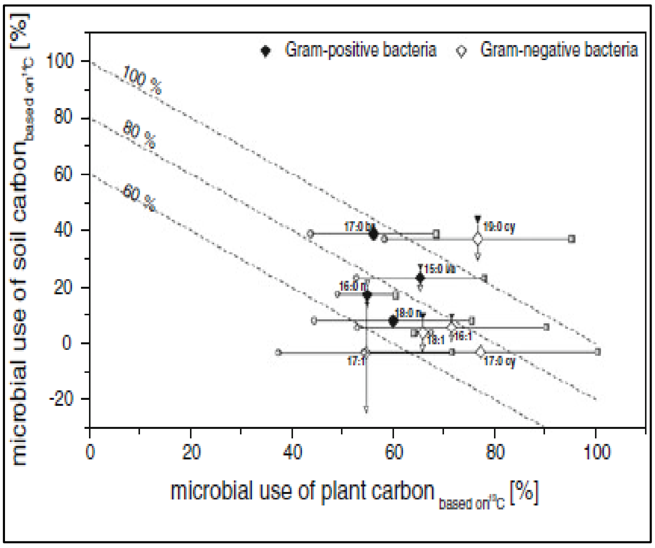

Fig 18(b): Quantification of soil- and plant-derived carbon sources of soil microbial phospholipid fatty acids

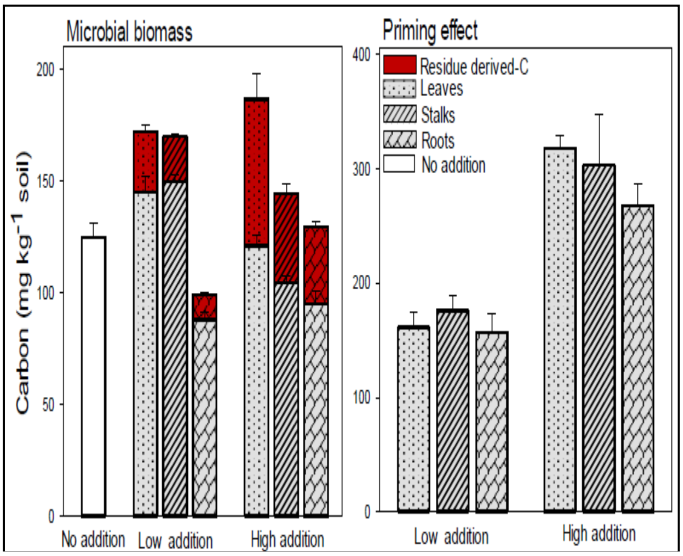

Fig 18(C): The contribution of residue derived and soil organic matter (SOM) derived C to microbial biomass (left) and the amount of primed C due to low and high level of crop residue addition (right).

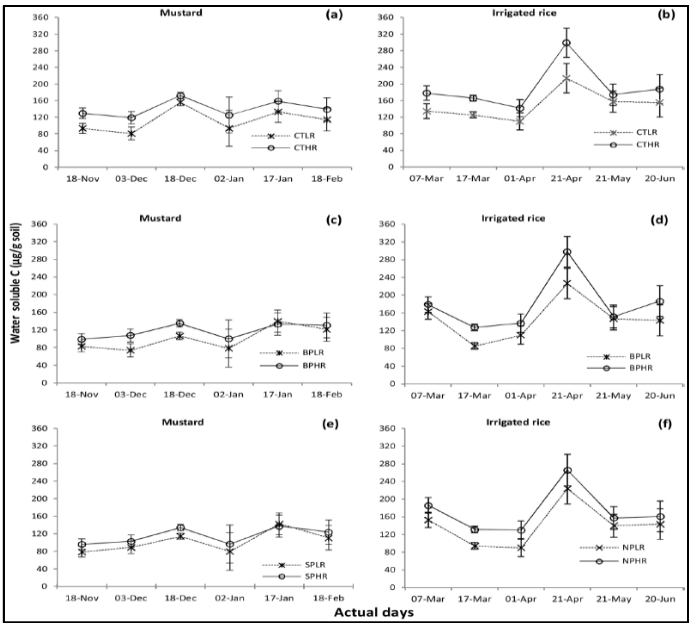

Fig 19 (a): Water soluble C in soils treated with different soil disturbance practices and residue retention

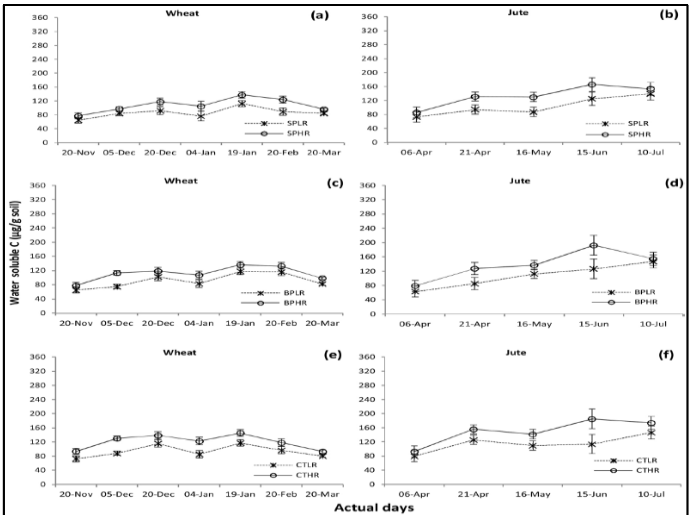

Fig 19 (b): Water soluble C in soils treated with different crop establishment practices and residue retention levels.

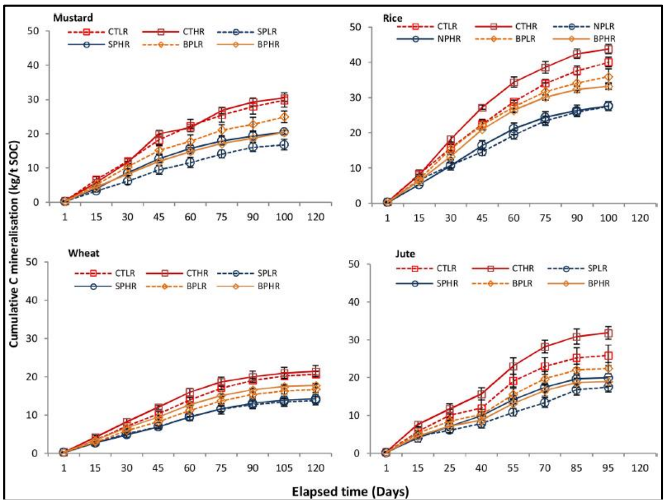

Fig 19(c): Cumulative CO_2 emissions in soils (kg respired CO_2 per tonne of SOC) treated with different soil disturbance practices and residue retention levels in two fields in two seasons.

Zhang *et al*. (2015) [84] revealed that the dehydrogenase and β-glucosidase activities were significantly increased under residue retention relative to the control.Moreover, it's suggested that residue retention may increase microbial C use efficiency and reduce some microorganisms that are capable of decomposing more recalcitrant soil C, which may help stabilization of soil organic matter in paddy soil in long term [Fig. 19a].

Okeyo *et al*. (2016) [50] indicate that RT combined with crop residue reapplication enhanced soil physical quality through increased macro-aggregate (>2000 µm) proportions and mean weight diameter. Similarly, lower respiratory quotient values indicate that soil microbes under RT have better substrate-use efficiency than those under CT. Nevertheless, soil organic carbon (C), potentially mineralisable C, microbial biomass C and mineral nitrogen contents were all higher under CT with crop residue incorporated into the soil [Fig.19b].

Gale and Cambardell, (1998) reported that the56% of the root-derived ^{14}C in the soil was evolved as $^{14}CO_2$ and 42% remained in the soil. The large (500–2000 µm) and small (53–500 µm) particulate organic matter (POM) fractions together contained 11 to 16% of the initial root-derived ^{14}C in the soil. In contrast, POM contained only 1 to 3% of the inital surface residue–derived ^{14}C. These data show clear differences in the partitioning of surface residue– and root-derived C during decomposition and imply that the beneficial effects of no-till on soil organic C accrual are primarily due to the increased retention of root-derived C in the soil [Fig. 19c].

Balota *et al*. (1996) [8] reported that increased production of crop biomass aboveground and below ground increases the food source for the microbial population in the soil. Agricultural production systems in which residues are left on the soil surface and roots left in the soil, e.g. through direct seeding and the use of cover crops, therefore stimulate the development and activity of soil micro-organisms. In one 19-year experiment in Brazil, such practices resulted in a 129-percent increase in microbial carbon biomass and a 48-percent increase in microbial N biomass [Fig.20a].Greiner *et al*. (2013) [24] also found that average carbon concentration in the 10-yeartreatment was significantly higher than the neighboring 0-year (SB) sediment and with a largeincrease in % C in between 3- and 6-cm depths [Fig.20b]. This indicated some accumulation of sedimentover time allowing for a sediment accretion and carbonaccumulation rate to be calculated as a result of the sea grass restoration. However, vertical core profiles showed low and background supported activity in the 4-year and 0-year treatments [Fig.20b]. Increases in sea-grass shoot density over time in the restored sea grass meadows influenced water flow and caused a shift from an erosional to a depositional environment. In addition, low sea grass densities such as those we observed in the 4-year treatment accelerated flow around individual shoots, created turbulence, and increased sediment suspension in amanner similar to that observed in areas without sea grass habitat. This mechanism also can explain the lack of change in organic matter and carbon content with depth in 0-and 4-year treatments.

Carbon accumulation rates increased over time following the seeding, with a rapid acceleration in accretionrates starting 5 years following the seeding as the sea grass density increased. For the 10-year treatment, the sea-grass accumulated approximate 36.68gCm^{-2} yr^{-1} [Fig.20c]. Sediment accretion rates and % C in the 10-year treatment showed a steady-state accretion rate before seeding, and the na significant increase in carbon burial rates 10 years after the seeding initiated sea grass meadow development [Fig.20c]. However, following the seeding event, there was approximatelya 5-year lag before there was a doubling in the carbon burialrate, compared to past trends. This can be attributed tochanges in seagrass density at this site, where a large increase in sea grass density took approximately 4 years, which coincided with the dramatic increase in sediment accretion rates.

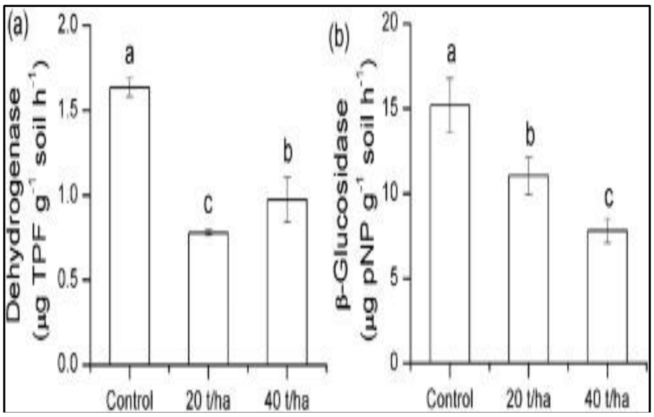

Fig 20(a): Effects of incorporation in a slightly acid rice paddy on enzymatic activities

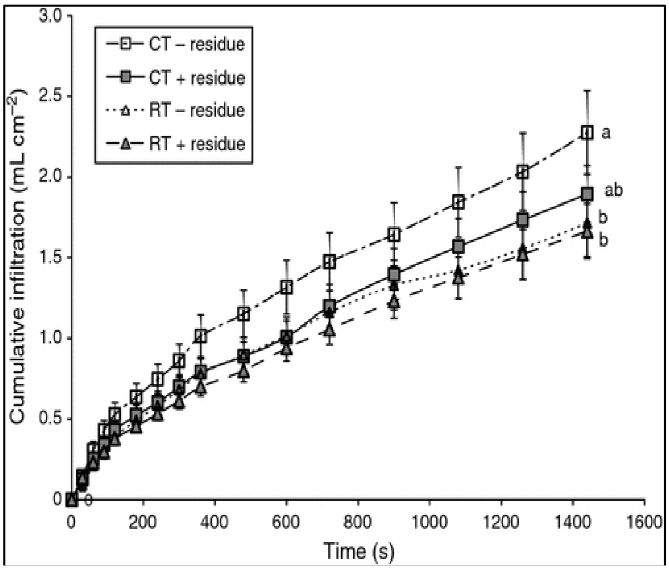

Fig 20 (b): reduced tillage and crop residue management on soil properties

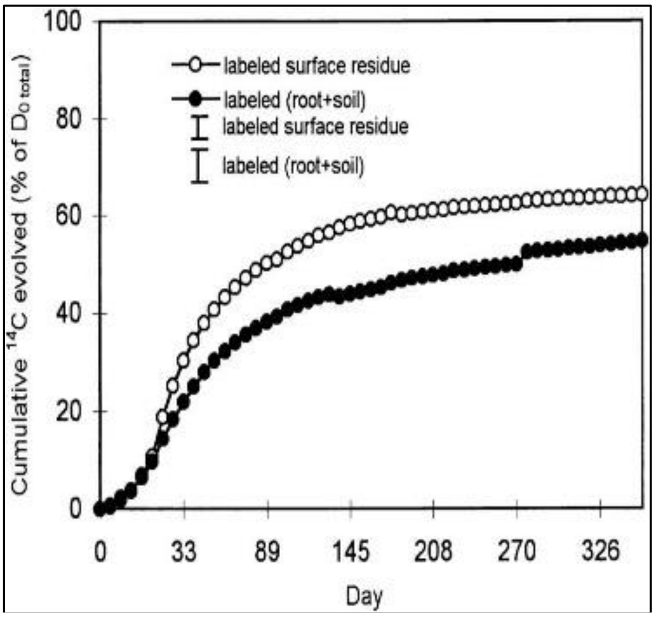

Fig 20 c): Surface Residue– and Root-derived Organic Matter under Simulated No-till

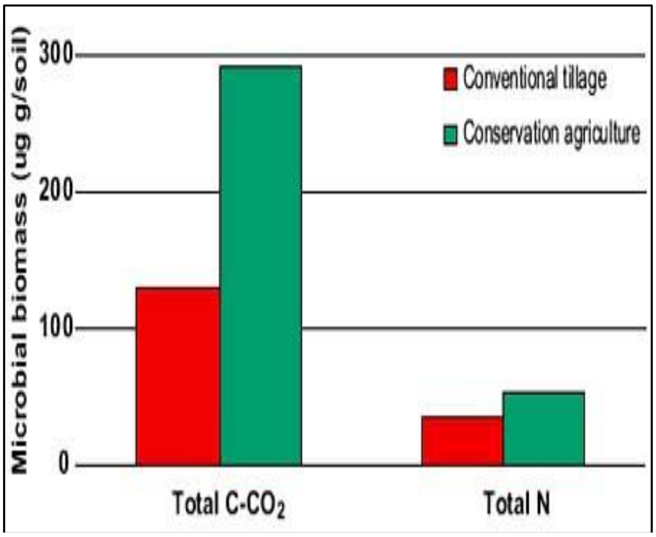

Fig 21 (a): Microbial biomass (C and N) under conventional tillage and conservation agriculture

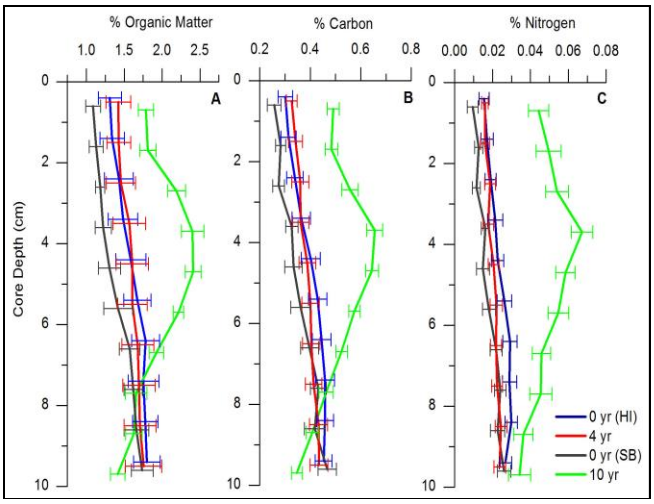

Fig 21(b): Vertical average down-core profiles of sediment characteristics in the top 10 cm

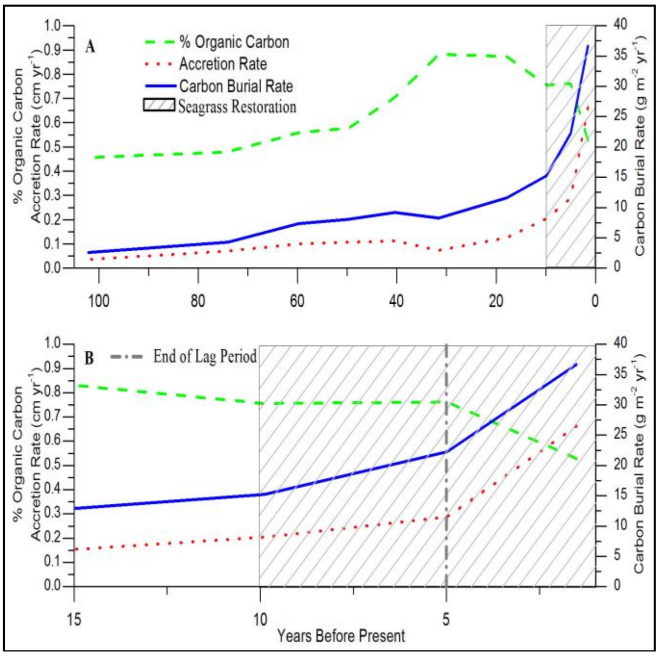

Fig 21 (c): Record of sediment accretion rate, percent organic carbon, and carbon burial rate.

Juan *et al*. (2018) reported that the LC and RC contents significantly increased after the application of OMs. Moreover, LC and RC contents were 3.2%–8.6% and 5.0%–9.4% higher in 2016 than in 2015 [Fig. 21a]. The average mass recovery rate and carbon recovery rate were 95.53% (94.51%–96.32%) and 95.87% (94.54%–96.25%), respectively after separation. Compared with CK, the LC and RC contents significantly increased after the application of OMs. Moreover, LC and RC contents were 3.2%–8.6% and 5.0%–9.4% higher in 2016 than in 2015, respectively. Compared with CK, LC contents in soil after the applications of CM and SM increased the most, and were 28.9% and 30.7%, respectively in 2016. [Fig.21a]. Wang, (2014) [76] found that LOC and POC contents after the application of straw were significantly higher in semi-arid soil than in sub-humid soil. Thus, the result illustrated that the effects of OMs on labial organic carbon might be greater in the semi-arid soil. The decomposition process of OMs could be divided into three stages, 0–90 days for a "quick decomposition period", 90–180 days for a "slow decomposition period", and 180–540 days for a "stable decomposition period" [Fig. 21b]. In 90 days, decomposition rate of OMs was over 70%. In 540 days, residual quantities of CM, SM and MS decreased to 5.69, 6.11, and 6.53 g from the initial 20 g, whereas those of MR, FG, and TL decreased to 8.05, 8.84, and 10.32 g, respectively. Moreover, the decomposition rates of CM, SM, and MS (71.55%, 68.16%, and 68.21%) were higher than those of MR, FG, and TL (58.64%, 55.28%, and 47.95%), respectively. [Fig.21b].The application of OMs, and different sources and decomposing degrees of OMs were allaffected the SOC fractions under plastic film mulch (Li *et al*., 2009). Furthermore, Vanlauwe *et al*.(2005) indicated that short-term carbon dynamics was controlled by the quality parameters of O Ms inputted, such as lignin, N, and polyphenol contents and this funding was confirmed further by Mandal *et al.* (2007) and Singh *et al.* (2009), who suggested that the quality of OMs was animportant factor on agricultural soil carbon changes besides the amount of injected carbon. The trends of quantities of carbon released from OMs were first quickly increased and then tended to stable in decomposition process [Fig.21c]. Quantity of carbon released from MS was higher than those of other OMs in each period. In 90 days, quantities of carbon released from OMs were over 65%. In 540 days, quantities of carbon released from MS, TL, MR, FG, SM, and CM were 6.38, 4.85, 4.71, 4.64, 4.37, and 3.80 g, respectively.

Stav *et al*. (2016) [59] revealed that tillage method effects on soil functions and ecosystem services depending on the combination of climatic and pedogenic settings, conventional tillage has either a positive or negative effect on the soil moisture status and its availability for crops [Fig. 22a].Impacts are separately presented for the three levels of intensity of crop residue removal, including entire removal, moderate removal, and no removal. The major soil functions and ecosystem services are graded for each of the residue removal intensities according to the scale of the following: 1 for low score, 2 for moderate score, and 3 for high score [Fig. 22a]. The combination of advantages of both of the conventional tillage and no-till methods and, particularly, the comparatively smaller competition by weeds and the lower pressures imposed by pests, together with the moderate adverse impact on soil functions, allows the increase of crop yields (Ji *et al*., 2015) [35]. Stav *et al*. (2016) [59] revealed that tillage method effects on soil functions and ecosystem services depending on the combination of climatic and pedogenic settings, conventional tillage has either a positive or negative effect on the soil moisture status and its availability for crops [Fig. 22a]. Impacts are separately presented for the three levels of intensity of crop residue removal, including entire removal, moderate removal, and no removal. The major soil functions and ecosystem services are graded for each of the residue removal intensities according to the scale of the following: 1 for low score, 2 for moderate score, and 3 for high score [Fig. 22a]. Crop residue management effects on soil functions and ecosystem services impacts are separately presented for the three levels of intensity of crop residue removal, including entire removal, moderate removal, and no removal. The major soil functions and ecosystem services are graded for each of the residue removal intensities according to the scale of the following: 1 for low score, 2 for moderate score, and 3 for high score [Fig. 22b]. The on-site, entire retention (no removal) of crop residue after harvest has been perceived as an important component of conservation agriculture. It was widely reported that this practice decreases soil-water evaporation loss, augmenting water availability for crops (van Donk *et al*. 2012) [73]. Additionally, the shading effect provided by the crop residue prevents weed germination (Sarajuoghi *et al*., 2012) [57]. The combination of advantages of both of the conventional tillage and no-till methods and, particularly, the comparatively smaller competition by weeds and the lower pressures imposed by pests, together with the moderate adverse impact on soil functions, allows the increase of crop yields (Ji *et al*., 2015) [35]. Crop residue management effects on soil functions and ecosystem services impacts are separately presented for the three levels of intensity of crop residue removal, including entire removal, moderate removal, and no removal. The major soil functions and ecosystem services are graded for each of the residue removal intensities according to the scale of the following: 1 for low score, 2 for moderate score, and 3 for high score [Fig. 22b].

Nutrient management effects on soil functions and ecosystem services impacts are separately presented for the three levels of intensity of nutrient management, including chemical, integrated, and organic. The major soil functions and ecosystem services are graded for each of the nutrient management intensities according to the scale of the following: 1 for low score, 2 for moderate score, and 3 for high score [Fig. 22c]. The on-site, entire retention (no removal) of crop residue after harvest has been perceived as an important component of conservation agriculture. It was widely reported that this practice decreases soil-water evaporation loss, augmenting water availability for crops (van Donk *et al*. 2012) [73]. Additionally, the shading effect provided by the crop residue prevents weed germination (Sarajuoghi *et al*., 2012) [57]. Nutrient management effects on soil functions and ecosystem services impacts are separately presented for the three levels of intensity of nutrient management, including chemical, integrated, and organic. The major soil functions and ecosystem services are graded for each of the nutrient management intensities according to the scale of the following: 1 for low score, 2 for moderate score, and 3 for high score [Fig. 22c].

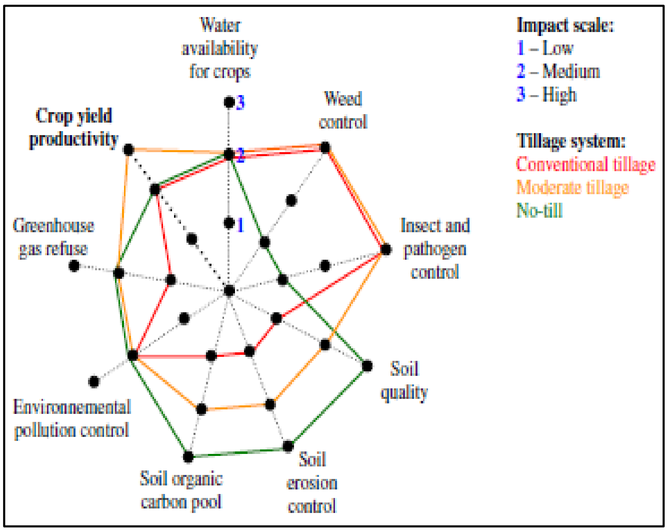

Fig 22(a): Spider chart of tillage impact on soil functions and ecosystem services

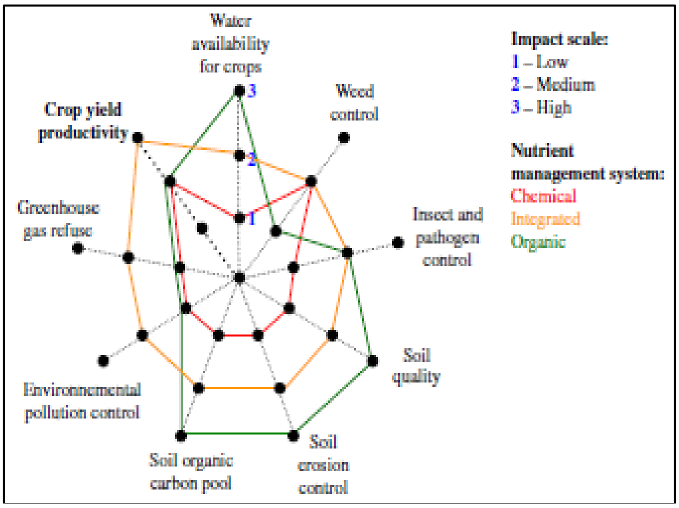

Fig 22 (b): Spider chart of crop residue management's impact on soil functions and ecosystem services

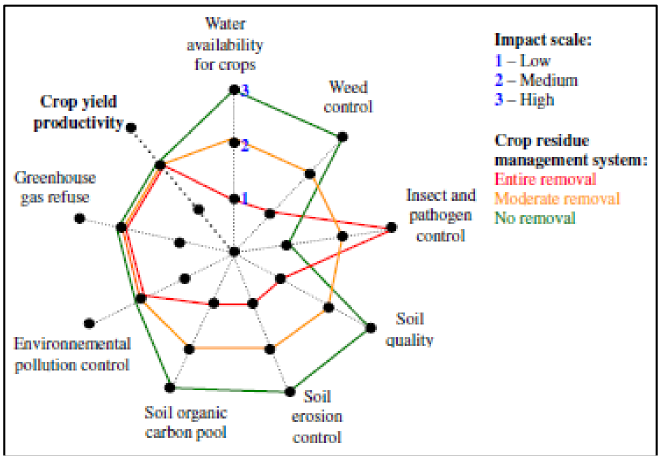

Fig 22 c): Spider chart of nutrient management's impact on soil functions and ecosystem service

Conclusions

Increased residue retention with minimal soil disturbance altered the C cycling and the decay rates of PMC and by increasing PMC and MBC. The net effect was an increase in the TOC levels in the soils of 0–10 cm depth. The rice soils had even higher PMC than any other crops studied which contributed to increase SOC under the rice-dominated rotation at western Uttar Pradesh, India. The decline in WSC values and CO_2 emissions and the increase in MBC values in soils are consistent with greater soil C sequestration under the practice. Overall, the rice-dominant rotation accumulated more SOC than rice-anchored cropping system. Crop establishment practices involving FIRB for upland crops and non-puddling for rice minimize the SOC losses relative to current crop establishment practices. The annual variation of MBC was the largest, followed by DOC and then SOC, which indicated that labile organic carbon fractions were more sensitive to environmental changes than SOC. Among the enzymes studied urease was mainly affected by microbial activities, while phosphomonoesterase, β-glycosidase, and invertase were closely correlated with plant growth. There were also significant seasonal dynamics among different enzyme activities. The excessive use of tillage affected crop productivity and decreased soil health. Tillage can alter water and oxygen flow, soil structure, temperature and aggregate formation that directly or indirectly affect soil microbiomes. Microbial communities are involved in the different biogeochemical cycles and soil formation. Alterations to this habitat may compromise the productivity of soils. A better understanding of the soil properties interactions will help to improve land management and protect our soils from further deterioration.

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