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Soil Organic Carbon Fractions, Soil Microbial Biomass Carbon, and Enzyme Activities Impacted by Crop Rotational Diversity and Conservation Tillage in North West IGP: A Review

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A B S T R A C T

Soil organic carbon (SOC) and its fractions (labile and non-labile) including particulate organic carbon (POC) and its components [coarse POC and fine POC], light fraction organic carbon (LFOC), readily oxidizable organic carbon, dissolved organic carbon (DOC) are important for sustainability of any agricultural production system as they govern most of the soil properties, and hence soil quality and health. Being a food source for soil microorganisms, they also affect microbial activity, diversity and enzymes activities. The content of OC within WSA followed the sequence: medium-aggregates (1.0–0.25 mm and 1.0–2.0 mm)> macro-aggregates (4.76–2.0 mm)> micro-aggregates (0.25–0.053 mm) >large aggregates (4.76 mm) >silt+ clay fractions (<0.053 mm). The highest levels of MBC were associated with the 1.0–2.0 mm aggregate size class. The C_{mic}/C_{org} was greatest for the large macro-aggregates regardless of tillage regimes. The tillage treatments significantly influenced soil aggregate stability and OC distribution. Higher MWD and GMD were observed in plowing every 2 years (2TS), plowing every 4 years (4TS) and no plowing (NTS) as compared to plowing every year without residue (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. The OC concentrations in different aggregate fractions at all soil depths followed the order of macro-aggregates>micro-aggregates>silt+ clay fraction. 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. Tillage regimes that contribute to greater aggregation also improved soil microbial activity. Soil OC and MBC were at their highest levels for 1.0–2.0 mm aggregates, suggesting a higher biological activity at this aggregate size for the ecosystem. Compared with CT treatments, NT treatments increased MBC by11.2%, 11.5%, and 20%, and dissolved organic carbon (DOC) concentration by 15.5% 29.5%, and 14.1% of bulk soil, >0.25 mm aggregate, and <0.25 mm aggregate in the 0−5 cm soil layer, respectively. The portion of 0.25–2 mm aggregates, mean weight diameter (MWD) and geometric mean diameter (GMD) of aggregates from ST and NT treatments were larger than from CT at both 0–15- and 15–30-cm soil depths. Positive significant correlations were observed between SOC, labile organic C fractions, MWD, GMD, and macro-aggregate (0.25–2 mm) C within the upper 15 cm. The arylsulfatase, β-glucosaminidase and α-glucosidase activities showed a significant increase in the enzyme activities due to crop rotations in comparison to continuous mono-cropping. The activities of chitinase, leucine amino-peptidase and tyrosine aminopeptidase) in the topsoil layer were higher under conservation agriculture (CA).Moreover, compared with CT, the ZT and FIRB treatments significantly increased nitrifying [Gn] and denitrifying bacteria [D] by 77%, 229%, and 3.03%, 2.37%, respectively. The activity of phosphatase tended to be higher in the FIRB treatment compared to the ZT and CT treatments. In conclusion, soil organic carbon fractions (SOC), microbial biomasses and enzyme activities in the macro-aggregates are more sensitive to conservation tillage (CT) than in the micro-aggregates. Soil aggregation regulates the distributions of SOC and microbial parameters under CT in North West IGP.

Introduction

Soil contains the largest carbon (C) pool of the global terrestrial ecosystem. The total soil organic carbon (SOC) pool is approximately 1 500 Pg C, which is three times that of the atmospheric carbon pool (Song *et al.,* 2014). Soil organic matter (SOM) not only plays a vital role in global carbon cycling, but also contributes considerably to improvements in soil quality, crop production, and terrestrial ecosystem health (Lu *et al.,* 2009; Naresh *et al.,* 2018). However, increasing SOM has become a major global problem (Keesstra *et al.,* 2016). SOC dynamics are strongly influenced by agricultural management practices, such as fertilization, crop residue return, and tillage (Dou *et al.,* 2016; Naresh *et al.,* 2017). Many studies indicate that various tillage systems have a strong effect on labile SOC, soil aggregation, and SOC distributions in aggregates size fractions. Such effects varied depending on regional climate, soil type, residue management practice, and crop rotation (Puget and Lal, 2005). Research on soil C sequestration for specific soil/climate/cropping system is therefore necessary.

Soil microbial biomasses influence the conversion of SOM, and are critical for the cycle of nutrients and energy in the ecosystem (Merino, Pérez-Batallón, and Macías 2004). Soil MBC and MBN refers to the C and N in the microorganisms in soil, which are the most active and labile (Powlson, Prookes, and Christensen 1987). Although MBC and MBN are less in quantity, they are significant source and sink for soil available nutrients (Powlson, Prookes, and Christensen 1987). Therefore, studying MBC and MBN is of great significance to explicit soil nutrient flow, soil C cycle, and the balance of soil C pools. Powlson, Prookes, and Christensen (1987) pointed out that the MBC and MBC/SOC ratio can provide an early effective warning of the deterioration of soil quality. Especially, the ratio of MBC/MBN could reliably indicate the tendency of SOC variation.

Soil aggregation and stability can change dramatically with tillage. In tropical regions, no-till practices have been shown to increase the water stable aggregate fraction and maintain aggregates of a larger size than in conventionally tilled soils (Beare *et al.,* 1994). No-till practices allow continued aggregation over a long period of time, whereas conventional tillage disrupts the aggregation process annually. Soil biological properties are critical to soil sustainability and are important indicators of soil quality (Stott *et al.,* 1999).

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. The objectives of this review paper areimpact of different tillage practices and crop rotation diversity on soil organic carbon fractions, soil microbial biomass carbon, and enzyme activities of sub-tropical climatic conditions in north west IGP.

Soil Organic Carbon Fractions

Soil Organic Matter

Soil organic matter in its broadest sense, encompasses all of the organic materials found in soils irrespective of its origin or state of decomposition. Included are living organic matter (plants, microbial biomass and faunal biomass), dissolved organic matter, particulate organic matter, humus and inert or highly carbonised organic matter (charcoal and charred organic materials). The functional definition of soil organic matter excludes organic materials larger than 2 mm in size. (Baldock and Skjemstad 1999)

Soil Organic Carbon

Soil organic matter is made up of significant quantities of C, H, O, N, P and S. For practical reasons, most analytical methods used to determine the levels of soil organic matter actually determine the content of soil organic carbon in the soil. Conversion factors can be applied to the level of soil organic carbon to provide an estimate of the level of soil organic matter based on the content of carbon in the soil organic matter. The general conversion factor is 1.72, so the level of soil organic matter is ≈ 1.72 x the soil organic carbon.

However this conversion factor does vary depending on the origin and nature of the soil organic matter from 1.72 to 2.0. The general convention now is to report results as soil organic carbon rather than as soil organic matter. (Baldock and Skjemstad 1999)

Inorganic Soil Carbon

Significant amounts of inorganic carbon can occur in soils especially in more arid areas and in association with more mafic parent materials (lime stones, basalts).Calcium carbonate as concretions, nodules or as diffuse carbonate can be very common in some soils. Carbon can also occur as dolomite or magnesium carbonate. Carbonates can be formed in the soil (pedogenic) or have a lithogenic origin (be derived from the parent material). The inorganic carbon is not included in the soil organic carbon content and measures are required to ensure it is not included in any determination of the soil organic carbon levels. Inorganic carbon does not contribute to the soil organic matter (Drees and Hallmark 2002).

Poffenbarger *et al.,* (2017) reported that the N fertilizer inputs, SOC in the surface 15 cm declined by 0.15 Mg C ha^{-1} yr^{-1} in the continuous maize system [Fig.1a] and by 0.07 Mg C ha^{-1} yr^{-1} in the maize-soybean system [Fig.1a].

There was a significant positive relationship between SOC change over time and mean annual residue C input for both cropping systems for continuous maize, for maize-soybean; [Fig.1b]. The SOC change was estimated to be -0.22 Mg C ha^{-1} yr^{-1} with zero residues C input for both systems (no cropping system effect on y-intercept. However, the slope of the relationship between SOC change and residue C input was 58% greater for the continuous maize system than for the maize-soybean system. This cropping system effect on the slope persisted when we performed the regression using a truncated range of residue C input values for the continuous maize system, which allowed us to use equal ranges of residue C inputs across the two cropping systems [Fig.1b]. The residue C input level required to maintain SOC (i.e., the x-intercept) was 3.2 Mg C ha^{-1} yr^{-1} for the continuous maize system and 4.2 Mg C ha^{-1} yr^{-1} for the maize-soybean system.

N inputs are below the AONR, added N stimulates crop growth, increasing crop residue inputs to the soil, thereby increasing the rate of SOC storage. When N inputs are above the AONR, added N imparts no change in crop residue production but increases residual inorganic N, enhancing SOC mineralization, thereby decreasing the rate of SOC storage [Fig.1c]. Residual soil inorganic N may enhance SOC mineralization by eliminating N limitation on microbial growth (Mulvaney *et al.,* 2009) or by decreasing soil aggregation (Chivenge *et al.,* 2011), making previously protected SOM more susceptible to decay.

Dutta and Gokhale, (2017) revealed that the soil moisture content in conservation plot was from 47.47+1.15% to as high as 101.37+1.63%. The reduced tillage in the conservation plot resulted in higher soil moisture content, due to plant debris accumulated on the top layer of the soil. Water infiltration increased in conservation plot, which can be attributed to minimum tillage practice [Fig.2a]. Vignozzi, and Pellegrini (2004) also reported that minimum tillage improves the soil pore system and increased soil water content leads to an increase in availability of this water to the plants. The average bulk density was found to be 0.69 g cm^{-3} in conservation plot while in conventional plot it was 1.17 g cm^{-3}. The per cent pore space or porosity was found to be higher in conservation plot in the range of 50.11+ 8.40%–88.87+ 3.59%. This is because de-creased soil disturbance leads to lesser soil compaction, which increases pore space. Causarano *et al.,* (2014) also found that the pastures contained significantly greater SOC than cropland at 0- to 5-cm depth (1.9 times greater than CsT and 3.1 times greater than CvT), but there were no differences among management systems at lower depths (5–20 cm). A similar management effect was observed for POC [Fig.2b]. Pastures and CsT had less soil disturbance, which allowed SOC fractions to accumulate at the surface. Aboveground residues decompose more slowly than incorporated residues because reduced contact with the soil increases drying and rewetting and reduces interactions with soil faunaand microbes [Fig.2b]. Causarano *et al.,* (2014) observed that there was a significant impact of management on water-stable MWD and ASD, however, following the order: pasture > CsT > CvT [Fig.2c]. Comparing dry to wet ASD, differences occurred mainly among large macro-aggregates (1000–4750 μm). Pasture soils withstood disruptive forces during wet sieving better than CsT soils, which were more stable than CvT soils. Large macro-aggregates under pasture were 24% of the whole soil with dry and wet sieving, while large macro-aggregates under CsT were 24% of the whole soil with dry sieving and 17% with wet sieving; in CvT, the same aggregate-size class was 22% with dry sieving and 10% with wet sieving. Disruption of macro-aggregates with wet sieving increased the <53-μm aggregate-size class, i.e., silt- and clay-size micro-aggregates. In pasture soils, disruption occurred in the 53- to 250-μm aggregate-size class, resulting in an increase in the <53-μm aggregate-size class [Fig.2c].Total organic C explained minimal variation in the MWD of dry aggregates and 21% of the variation in the MWD of wet aggregates. These data indicated that clay-sized particles played a major role in holding dry aggregates together, but that total SOC was more important in wet aggregates.

Mamta Kumari *et al.,* (2014) showed that the tillage induced changes in the intra-aggregate POM-C content was distinguishable at 0- to 5-cm depth only [Fig.3a]. On average, the iPOM C content in soil was higher at wheat than at rice harvest, and accumulated in greater portion as fine (0.053– 0.25 mm) than the coarse (0.25–2 mm) fraction. A significantly higher particulate-C fraction was recorded in the zero-till systems (T_5 and T_6), and was associated more with the fine fractions (20–30% higher than under conventional-tillage T_1 and T_2) [Fig.3a].

Quintero and Comerford, (2013) indicated that reduced tillage in potato-based crop rotations increased the soil C concentration and average C content in the whole profile (≈117 cm depth) by 50 and 33% (1636 t Cha^{-1} vs.1224 t Cha^{-1}), respectively, as compared to conventional farming practices. Carbon content increased 177% in the subsoil (A2 horizon, 78 - 117 cm depth, from 215 to 596 tha^{-1}), although most of the soil C was in the A1 horizon (between 0 - 78 cm average thickness, 1097 tha^{-1}). These increases show that reduced tillage enhances C stores in Andisols which are already high in organic matter. In addition, C in aggregates represented more than 80% of the total organic matter and it was positively affected by conservation practices. The C increase was preferential in the smaller macro-aggregates (<2 mm). The aggregate dispersion energy curves further suggested that C increase was occurring in micro-aggregates within the smaller macro-aggregate fraction [Fig.3b & 3c].

Franzluebbers, (2002) observed that the increasing cropping intensity would be expected to supply greater quantities of crop residues to soil, which should improve soil organic matter in the long term. Under CT, the stratification ratio of soil organic C, total soil N, and soil microbial biomass C tended to increase with increasing cropping intensity, but was not significant [Fig.4a]. However, the stratification ratio of the more biologically active pools of potential C and N mineralization did increase with increasing cropping intensity. Under NT, stratification ratios of soil C and N pools also tended to increase with increasing cropping intensity. The greater stratification ratios with increasing cropping intensity were probably due to greater C inputs with more intensive cropping and reduced soil water available for decomposition by soil microorganisms because of greater crop water uptake [Fig.4a].Stratification ratios of soil C and N pools were also lowest under CT compared with other tillage types and increased along a gradient with less soil disturbance [Fig.4b].

Paraplowing loosened soil in the autumn followed by NT planting. Shallow cultivation controlled weeds in the summer following NT planting. In-row chisel loosened the soil zone immediately below the seed only. Paraplowing likely incorporated some surface residues and, therefore, is a more disruptive soil management operation than in-row chiselling [Fig.4b]. The stratification ratio of water-stable aggregation and potential N mineralization indicated that coarse textured soils responded to NT management more than fine-textured soils [Fig.4c]. This soil textural interaction with tillage management occurred, perhaps because coarse-textured soils are generally lower in the degree of aggregation and organic matter, and therefore, had a greater potential to respond to non-disturbance effects from transient and temporary binding agents (Franzluebbers and Arshad, 1996c).The stratification ratio of these two properties was significantly greater under NT than under CT in the loam (18% clay, 4.3 kg soil organic C m^{-2}) and the silt loam (28% clay, 5.1 kg soil organic C m^{-2}), but not in the clay loam (37% clay, 6.8 kg soil organic C m^{-2}) and the clay (63% clay, 8.2 kg soil organic C m^{-2}) [Fig.4c].

Simansky *et al.*, (2017) reported that the soil-management practices significantly influenced the soil organic carbon in water-stable aggregates (SOC in WSA). The content of SOC in WSA ma increased on average in the following order: T<G< G+NPK_1<G+NPK_3< T+FYM. Intensive soil cultivation in the T treatment resulted in a statistically significant build-up of SOC in WSA ma at an average rate of 1.33, 1.18, 0.97, 1.22 and 0.76 $gkg^{-1}yr^{-1}$ across the size fractions > 5 mm, 5–3 mm, 2–1 mm, 1–0.5 mm and 0.5–0.25 mm, respectively [Fig.5].

Naresh *et al.*, (2017) revealed that significantly increased 66.1%, 50.9%, 38.3%, 37.3% and 32% LFOC, PON, LFON, DOC and POC, over T_7 treatment and WSC 39.6% in surface soil and 37.4% in subsurface soil [Table 1]. The proportion of MBC ranged from 16.1% to 21.2% under ZT and PRB without residue retention and 27.8% to 31.6% of TOC under ZT and PRB system with residue retention, which showed gradual increase with the application of residue retention treatments and was maximum in 6 tha^{-1} residue retention treatment under both tillage systems [Table 1].

Sheng *et al.,* (2015) observed that the stocks associated with the different LOC fractions in topsoil and subsoil responded differently to land use changes. POC decreased by 15%, 38%, and 33% at 0-20 cm depth, and by 10%, 12%, and 18% at 20e100 cm depth following natural forest conversion to plantation, orchard, and sloping tillage, respectively [Fig.6a]. POC stock in topsoil was more sensitive to land use change than that in subsoil [Fig.6a]. Regarding the different POC components, only fPOC stock in 0-20 cm topsoil decreased by 21%, 53%, and 51% after natural forest conversion to plantation, orchard, and sloping tillage, respectively [Fig. 6a]. Significant loss of LFOC occurred not only in topsoil, but also in subsoil below 20 cm following land use change [Fig.6b]. The decrease in ROC stock through the soil depth profile following land use change was smaller than that of LFOC [Fig.6b]. ROC stocks did not differ significantly between natural forest and sloping tillage areas, suggesting that ROC stock was relatively insensitive to land use change. The DOC stock in the topsoil decreased by 29% and 78% following the conversion of natural forest to plantation and orchard, respectively, and subsoil DOC stocks decreased even more dramatically following land use change [Fig.6b].

The proportion of the different LOC pools in relation to SOC can be used to detect changes in SOC quality. In the topsoil, the ratios fPOC, LFOC, and MBC to SOC decreased, while those of ROC and cPOC increased following land use change [Fig.6c].

In subsoil, only the ratio of DOC to SOC decreased, the ratios POC, fPOC and ROC to SOC increased, and those of LFOC and MBC remained constant following land use change. In the topsoil, ratios fPOC, LFOC, DOC and MBC to SOC were more sensitive to conversion from natural forest to sloping tillage than SOC [Fig.6c].

Soil Microbial biomass carbon (C_{mic})

SMB is defined as the small (0-4 %) living component of soil organic matter excluding macro-fauna and plant roots (Dalal, 1998).Soil microbial biomass carbon (C_{mic}) have been used as indicators of changes in soil organic matter status that will occur in response to alterations in land use, cropping system, tillage practice and soil pollution (Sparling *et al.,* 1992).

Ma *et al.,* (2016) reported that the proportion of SMBC to TOC ranged from 1.02 to 4.49, indicating that TOC is relatively low, or due to sampling for the summer after spring harvest, when soil temperature is high, the microbial activity is relatively strong. The SMBC at all depths (0–90 cm) with a sharp decline in depth increased perhaps due to a higher microbial biomass and organic matter content. SMBC was significantly higher in PRB in the surface soil layer (0–10 cm) than in TT and FB, which showed that no-till and accumulation of crop residues enriches the topsoil with microbial biomass. Microbial biomass concentrations are controlled by the level of SOM and oxygen status. Tripathi *et al.,* (2014) observed that the significant positive correlations were observed between TOC and organic C fractions (POC and SMBC), illustrating a close relationship between TOC and POC and TOC and SMBC and that SOC is a major determinant of POC and SMBC. The microbial biomass carbon includes living microbial bodies (bacteria, fungi, soil fauna and algae) (Divya *et al.,* 2014); it is more sensitive to soil disturbance than TOC. The proportion of SMBC to TOC is evaluation of carbon availability indexes for agriculture soil, which is usually 0.5–4.6% (Marumoto and Domsch, 1982). Liu *et al.,* (2012) showed that SMBC may provide a more sensitive appraisal and an indication of the effects of tillage and residue management practices on TOC concentrations.

Liu *et al.,* (2016) also found that the averaged across soil depths (0–25 cm depth), MBC of the grassland (1624.1 mg kg^{-1}) and forestland (839.1 mg kg^{-1}) were 6.9 and 3.6 times more, respectively than those for arable land use (245.9 and 226.2 mg kg^{-1} for no tillage (NT) and plow tillage (PT), respectively. Similarly, the MBN concentration was 4.1 and 2.5 times more in grassland (78.0 mg kg^{-1}) and forest (50.0 mg kg^{-1}) than in arable land (20.0 and 18.0 mg kg^{-1} for NT and PT, respectively, in the 0–25 cm soil layer. The higher MBC and MBN concentrations under NT than that of PT could be attributed to several factors including higher moisture content, more soil aggregation, higher SOC and TN concentration, and minimum disturbance, which provide a steady source of SOC and TN to support microbial community near the soil surface.

Bolat *et al.,* (2016) showed higher values for mean soil microbial biomass C (afforestation: 311.97 μg g^{-1}; control: 149.68 μg g^{-1}) and N (afforestation: 43.07 μg g^{-1}; control: 19.21 μg g^{-1}) and basal respiration (afforestation: 0.303 μg CO_2-C g^{-1} h^{-1}; control: 0.167 μg CO_2-C g^{-1} h^{-1}) [Fig.7]. However, the mean metabolic quotient (qCO_2) assessed at the control sites was higher (1.47 mg CO_2-C $g^{-1}C_{mic}$ h^{-1}) than that observed the afforestation sites (0.96 mg CO_2-C g^{-1} C_{mic} h^{-1}), likely due to difficulties in the utilization of organic substrates by the microbial community [Fig.8a].Soil organic C and total N are important factors that contribute to improve the physical properties of soil, and then its productivity. The largest soil organic C and total N amount were detected in the soils sampled at the afforestation sites. Such evidence is reasonably related to their higher clay content (Campbell *et al.,* 1996), the presence and diversity of tree species (Kara & Bolat 2008), the higher input of root exudates and plant residues (García-Orenes *et al.,* 2010), and the chemical composition of litter.

Jiang *et al.,* (2011) observed that the highest levels of MBC were associated with the 1.0–2.0 mm aggregate size class (1025 and 805 mg C kg^{-1} for RNT and CT, respectively) which may imply that RNT was the ideal enhancer of soil productivity for this subtropical rice ecosystem. However, the lowest in the <0.053 mm fraction (390 and 251 mg C kg^{-1} for RNT and CT respectively). It is interesting to note the sudden decrease of MBC values in 1–0.25 mm aggregates (511 and 353 mg C kg^{-1} for RNT and CT, respectively) [Fig.8b].The highest values corresponded to the largest aggregates, N4.76 mm, (6.8 and 5.4% for RNT and CT, respectively) and the lowest to the aggregate size of 1.0–0.25 mm (1.6 and 1.7 for RNT and CT, respectively) [Fig.8c].

Maharjan *et al.,* (2017) also found that thetotal soil organic C was highest in organic farming (24 mg C g^{-1} soil) followed by conventional farming (15 mg C g^{-1} soil) and forest (9 mg C g^{-1} soil) in the topsoil layer (0–10 cm depth). Total C content declined with increasing soil depth, remaining highest in the organic farming soil al all depths tested. A similar trend was found for total N content in all three land uses [Fig.9a], with organic farming soil possessing the highest total N content in both top and subsoil. Similarly, microbial C and N were also highest under organic farming, especially in the topsoil layer (350 and 46 mgg^{-1} soil, respectively), [Fig.9a]. However, conventional farming and forest soils had similar microbial biomass content. Microbial biomass C and N in topsoil followed the order: organic farming > conventional farming = forest soil which contradicts hypothesis (ii). Higher soil C and N in organic farming is mainly due to the regular application of farmyard manure and vermin-composting [Fig.9b]. Farmyard manure supplies readily available N, resulting higher plant biomass. As a result, more crop residues are incorporated through tillage, which maintains higher OM (C and N) levels in surface layers (Roldán *et* *al.,* 2005). Li *et al.,* (2018) observed that compared with CK, NPSM and NPS treatments caused greater measures of G+ and G- biomarkers by 107±160% and 106±110%, and greater measures of actinomycetes by 66±86%. The NPSM and NPS treatments were also greater in abundances of fungal communities, the saprophytic fungi were greater by 123±135% and AMF was greater by 88±96%. The G+/G- ratio was higher under NPSM treatment compared to other treatments, indicating that NPSM fertilization had changed soil microbial communities. However, there were no obvious differences of F/B ratios across all treatments [Fig.9c]. Lazcano *et al.,* (2013) described that bacteria were the most sensitive microbial groups to the different fertilizers because bacteria have a much shorter turnover time than fungi and can react faster to the environmental changes in soil.

In gentle slope landscapes, both SOC and MBC contents increased downslope in a roughly consecutive increment [Fig.10a]. SOC contents averaged 12.99 and 12.42 g kg^{-1} at lower slope positions of the 7%- and 4%-slopes with an increase of 44% and 31%, respectively, compared with those at respective upper slope positions [Fig.10a] From the upper to lower slope positions, MBC contents changed from 182.13 to 217.80 mg kg^{-1} with an increase of 20% on the 7%-slope, and from 168.78 to 221.13 mg kg^{-1} with an increase of 31% on the 4%-slope [Fig.10a].The MBC distribution pattern was in agreement with soil redistribution in gentle slope landscapes but independent of soil redistribution in steep slope landscapes. This is attributed to impacts of water-induced soil redistribution on SOC and MBC in gentle slope landscapes, and impacts of tillage-induced soil redistribution in steep slope landscapes. The difference in the relationship between MBC and SOC under the disturbances of water and tillage erosion differed from the studies Vineela *et al.,* (2008).

Ma *et al.,* (2016) reported that the differences in SMBC were limited to the surface layers (0–5 and 5–10 cm) in the PRB treatment [Fig.10b]. There was a significant reduction in SMBC content with depth in all treatments. SMBC in the PRB treatment increased by 19.8%, 26.2%, 10.3%, 27.7%, 10% and 9% at 0–5, 5–10, 10–20, 20–40, 40–60 and 60–90 cm depths, respectively, when compared with the TT treatment. The mean SMBC of the PRB treatment was 14% higher than that in the TT treatment. There were no significant differences in SMBC content between the three treatments from 10 to 90 cm depth [Fig.10b].

Malviya, (2014) inferred that significant difference were observed among soybean+ pigeon pea, soybean – wheat and soybean + cotton (2:1) cropping system compared to soybean fallow system. Whereas, SMBC value were at par in soybean-fallow R and maize gram cropping system, among surface and subsurface soil [Fig.10c]. Malviya, (2014) also indicated that irrespective of soil depth the SMBC contents were significantly higher under RT over CT. This was attributed to residue addition increases microbial biomass due to increase in carbon substrate under RT [Fig.10c].Spedding *et al.,* (2004) found that residue management had more influence than tillage system on microbial characteristics, and higher SMB-C and N levels were found in plots with residue retention than with residue removal, although the differences were significant only in the 0-10 cm layer.

Nath *et al.,* (2012) also showed that in North-east India, in rice-rape seed rotation for two years soil enzyme activities were highest when fertilizers, composts and bio-fertilizers were added together [Table 2]. In the context of the debate of chemical versus organic fertilization, it is important to keep in mind that addition of animal manures to build up carbon in passive fractions like humus is essential for sustaining the environmental soil quality functions like buffering. At the same time building up carbon in sand size fractions like particulate organic matter (POM) is equally important for improving biological soil quality functions like ability to break down added organic materials and transformation of nutrients and sustaining plant productivity. Building up POM and microbial biomass would demand addition of crop residues and addition of more chemical fertilizers (and not less) in a balanced form and also to achieve intermediate C: N ratios since what is being built up through biological mechanisms is after all a reservoir of chemical nutrients in slow and intermediate pools of organic matter.

Franzluebbers, (2002) also found that the time of soil sampling could influence estimates of biologically active soil C and N pools because fresh roots and their decomposition products would accumulate during the growing season. Stratification ratios of potential C and N mineralization tended to be greater at wheat flowering in March than at planting in November, irrespective of tillage system [Fig.11a].However, the significantly higher stratification ratio of soil microbial biomass and potential C and N mineralization under NT than under CT was maintained, independent of sampling time. Seasonal variability in the stratification ratio of soil microbial biomass C was small (3–6%) compared with seasonal variation in absolute estimates of soil microbial biomass C (8–13%) [Fig.11a].The type and frequency of tillage would be expected to alter the depth distribution of soil properties because of differences in the amount of soil disturbance. Stratification ratios of soil C and N pools were lowest with yearly CT and increased with decreasing frequency of paraplow tillage [Fig.11b].Stratification ratios of soil microbial biomass C were lower than of particulate organic C and N, but the lower random variability in the stratification ratio of soil microbial biomass C was more sensitive to differences among tillage variables. Stratification ratio of soil C pools also tended to increase with increasing aggregate size [Fig.11c]. Although the tillage effect was variable or not significant, the stratification ratios of soil microbial biomass C and potential C mineralization were more strongly related to aggregate size fraction, independent of tillage system, than was the stratification ratio of soil organic C. The high stratification ratios with large water-stable aggregates under both CT and NT suggests that soil quality improvements are likely to be preferentially expressed in labile soil organic matter associated with transient aggregation processes.

Liu *et al.*, (2016) revealed that the both MBC and MBN concentrations were significantly higher in the 0–5 cm soil layer than 5–15 and 15–25 cm layers under grassland, forestland and NT treatments [Fig.12a & 12b]. These distribution patterns may be attributed to decrease in labile C and N pools with increase in soil depth. Similar patterns of decreased in microbiological parameters with soil depth had been reported for forestland (Agnelli *et al.*, 2004), grassland (Fierer *et al.*, 2003) and arable land (Taylor *et al.*, 2002). At the top 0–5 cm depth, the MBC: MBN ratio was highest under grassland and lowest under PT [Fig.12c]. The MBC concentration accounted for 6.79%, 3.90%, 2.84%, and 2.24% of the SOC concentration, while MBN concentration accounted for 3.13%, 3.09%, 2.29%, and 1.55% of TN concentration under grassland, forest, PT and NT, respectively. At the 5–15 cm depth, the MBC: MBN ratio was higher under grassland and forestland than NT and PT [Fig. 2c]. At the 15–25 cm depth, the MBC: MBN ratios were generally lower under PT and NT than grassland and forestland

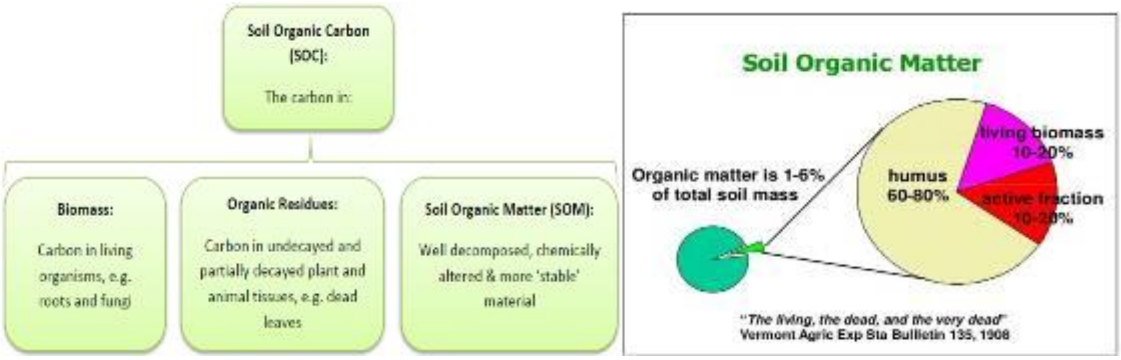
[Fig.12c].The MBC concentration accounted for 4.94%, 3.20%, 2.45%, and 1.50% of SOC concentration, while MBN concentration accounted for 2.44%, 1.75%, 1.74%, and 1.78% of TN concentration under grassland, forestland, PT, and NT, respectively. The MBC: MBN ratios were generally not affected by soil depth for grassland, forestland and PT [Fig. 2c]. For NT however, the MBC: MBN ratios significantly decreased with increase in soil depth. These further implied that grassland and forestland would effectively promote soil C forming MBC and avoid more soil C decomposing. Correspondingly, arable land had relatively weak function on SOC sequestration by forming MBC. Among arable land, in the top layer the soil of NT was better than PT on forming MBC to C sequestration.

Enzyme activities

Soil enzymes play a key role in the energy transfer through decomposition of soil organic matter and nutrient cycling, and hence play an important role in agriculture. These enzymes catalyze many vital reactions necessary for the life processes of soil microorganisms and also help in stabilization of soil structure. Although microorganisms are the primary source of soil enzymes, plants and animals also contribute to the soil enzyme pool. Soil enzymes respond rapidly to any changes in soil management practices and environmental conditions. Their activities are closely related to physio-chemical and bio-logical properties of the soil. Hence, soil enzymes are used as sensors for soil microbial status, for soil physio-chemical conditions, and for the influence of soil treatments or climatic factors on soil fertility.

Maharjan *et al.,* (2017) observed that the activity of β-glucosidase was higher in organic farming (199nmol g^{-1}soil h^{-1}) followed by conventional farming (130 nmol g^{-1} soil h^{-1}) and forest soil (19 nmol g^{-1} soil h^{-1}) in the topsoil layer. The activity of cellobiohydrolase was higher in organic farming compared to forest soil, but was similar in organic and conventional farming soil. In contrast, xylanase activity was higher under conventional farming (27nmol g^{-1}soil h^{-1}) followed by organic farming (17nmol g^{-1} soil h^{-1}) and forest soil (12nmol g^{-1} soil h^{-1}) [Fig.13a]. The activities of N-cycle enzymes (chitinase, leucine amino-peptidase and tyrosine aminopeptidase) in the topsoil layer were higher under organic farming (138, 276 and 255 nmol g^{-1} soil h^{-1}, respectively) compared with other land-use systems [Fig.13b]. The activities of tyrosine aminopeptidase and chitinase were also higher in subsoil under organic farming [Fig.13b]. Acid phosphatase (P-cycle) activity in topsoil was affected by land use [Fig. 13c]. In contrast to C- (except xylanase) and N-cycle enzymes, the activity of acid phosphatase in the topsoil layer was higher under conventional farming (936 nmol g^{-1}soil h^{-1}) followed by forest (672 nmol g^{-1} soil h^{-1}) and organic farming soil (118 nmol g^{-1} soil h^{-1}).

Aschi *et al.*, (2017) revealed that among the four tested enzymes, two were involved in nitrogen cycle (arylamidase and urease) and the two others were involved in carbon cycle (cellulase and β glucosidase). All these enzymes did not respond in a similar way to the presence of faba bean in the rotation [Fig.14a]. Arylamidase activity was significantly 2.2 times higher in Leg+ rotation than in the control rotation. The activity of β-glucosidase and cellulase also responded differently to the presence of faba bean in crop rotation. The β-glucosidase activity seemed to be more sensitive to the presence of faba bean and was 1.3 times higher in Leg+ rotation than in Leg− rotation, whereas, the analysis of cellulase activity revealed no significant difference [Fig.14a].Dodor and Tabatabai, (2002) also found that crops diversification induces a greater C addition and increases both C-cycle and N-cycle enzyme activities.



Pools of organic carbon in soils according to Essington (2004)

Table.1 Soil Organic Matter Pools and Related Fractions [Source: Michelle Wander, 2015]

Organic Matter Pools, Theorized Kinetics and Function	Procedurally Defined Fractions of Organic Matter[a]
Labile or Active SOM	
Half-life days to a few years Equated with material of recent origin or embodied living components of SOM Material of high nutrient or energy value Physical status (not physically protected) makes soil incorporated matter likely to participate in biologically or chemically based reactions Physical role of materials located at the soil surface and of compounds that promote macroaggregation is transient	**Microbial biomass** Chloroform-labile SOM (B) Microwave-irradiation-labile SOM (B) Amino compounds (B, P) Phospholipids (B) **Labile substrates** Mineralizable C or N, estimated by incubation (B) Substrate-induced activity (B) Soluble, extractable by hot water or dilute salts (C, B) Easily oxidized by permanganate or other oxidants (C, B) **Residues for which chemical formula can be described, inherited from living organisms** Litter, vegetative fragments or residues (B,P) Nonaggregate protected POM (B, P) Polysaccharides, carbohydrates (C, P)
Slow or Intermediate SOM	
Half-life of a few years to decades Physical protection, physical status, or location help separate this fraction from the other two fractions	**Partially decomposed residues and decay products** Amino compounds, glycolproteins (B, P) Aggregate protected POM (B, P) **Some humic materials** Acid/base hydrolyzable (B, C) Mobile humic acids (B, C)
Recalcitrant, Passive, Stable, and Inert SOM	
Half-life of decades to centuries Recalcitrance because of biochemical characteristics and/or mineral association	**Refractory compounds of known origin** Aliphatic macromolecules (lipids, cutans, algaenans, suberans) (C) Charcoal (C) Sporopollenins (C) Lignins (C) **Some humic substances** High molecular weight, condensed SOM (C, P) Humin (C) Nonhydrolyzable SOM (C) Fine-silt, coarse-clay associated SOM (C, P)

[a] Letters in parentheses that follow fraction labels identify measures commonly used to study biologically active matter (B) associated with nutrient supply or microbial growth, physically active or sequestered matter (P) associated with matter accessibility and soil structure, and chemically active or inactive matter (C) that explains or influences material persistence and its chemical reactivity, including exchange and sorption–desorption properties.

Table.2 Effect of 15 years of application of treatments on contents of various labile fractions of carbon in soil [Naresh *et al.*, 2017]

Treatments	0-5 cm layer					5-15 cm layer				
	WSC ($mgkg^{-1}$)	POC ($mgkg^{-1}$)	PON ($mgkg^{-1}$)	LFOC ($mgkg^{-1}$)	LFON ($mgkg^{-1}$)	WSC ($mgkg^{-1}$)	POC ($mgkg^{-1}$)	PON ($mgkg^{-1}$)	LFOC ($mgkg^{-1}$)	LFON ($mgkg^{-1}$)
Tillage crop residue practices										
T_1	23.9^{d}	638^{d}	67.2^{d}	81.3^{d}	9.1^{d}	15.7^{d}	535^{e}	54.7^{e}	65.1^{d}	7.8^{d}
T_2	25.9^{c}	898^{bc}	88.6^{cd}	107.8^{bc}	11.8^{c}	17.8^{cd}	674^{cd}	74.5^{cd}	94.1^{bc}	9.1^{c}
T_3	27.8^{ab}	1105^{ab}	106.7^{ab}	155.2^{a}	13.3^{ab}	19.6^{bc}	785^{bc}	91.8^{ab}	132.6^{a}	10.9^{ab}
T_4	22.7^{d}	779^{cd}	77.9^{d}	95.7^{c}	9.8^{d}	17.6^{cd}	609^{de}	69.1^{de}	87.6^{c}	8.3^{cd}
T_5	26.4^{bc}	1033^{b}	97.4^{bc}	128.8^{b}	12.6^{bc}	20.3^{ab}	842^{ab}	87.3^{bc}	102.9^{b}	10.4^{b}
T_6	29.2^{a}	1357^{a}	117.5^{a}	177.8^{a}	14.2^{a}	22.6^{a}	974^{a}	106.1^{a}	141.2^{a}	11.8^{a}
T_7	17.2^{e}	620^{d}	22.5^{e}	52.7^{e}	8.2^{d}	13.2^{e}	485^{e}	18.8^{f}	49.8^{e}	6.8^{e}

Table.3 Activities of soil enzymes and microbial biomass carbon under INM in rice-rapeseed sequence after two years [Source: Nath *et al*., 2012]

Treatments	Fluorescein di-acetate hydrolase (µg fluoresce in g^{-1}soil h^{-1})	Phospho-monoesterase (µg p-nitrophenol g^{-1} soil h^{-1})	DHA (µgTPFg^{-1} Soil $24h^{-1}$)	SMBC (µgg^{-1} soil)
Absolute control	7.81	229.4	136.6	90.3
NPK	9.39	319.7	198.0	124.0
50% NP + RDK* + BF**	9.71	337.8	197.2	139.8
50% NP + RDK + BF+compost @ 1 t ha^{-1}**	9.54	337.2	209.0	157.1
25% NP + RDK + BF+ compost @ 2 t ha^{-1}**	10.36	370.1	257.3	222.8
50% NP + RDK + BF +enriched compost @ 1 t ha^{-1}**	10.39	364.8	287.6	215.3
25% NP + RDK + BF +enriched compost @ 2 t ha^{-1}**	10.75	393.5	247.0	194.2
Biofertilizers +compost @ 1 t ha^{-1}	9.61	293.4	171.4	132.3
CD (P=0.05)	**0.89**	**48.8**	**57.3**	**15.0**

*a & b Means of pooled analysis after the four crops under the sequence *RDK – Recommended dose of potassium, ** BF + Biofertilisers*

Table.4 Change in nitrifying and denitrifying bacteria and phosphatase enzyme activity in soil profile as affected by tillage crop residue practices [Source: Naresh *et al*., 2018]

Treatments	Nitrifying bacteria (×10^3/g)			Denitrifying bacteria (×10^4/g)			Phosphatase(µg PNP g^{-1} h^{-1})		
	Jointing stage	Booting stage	Milky stage	Jointing stage	Booting stage	Milky stage	Jointing stage	Booting Stage	Milky stage
Tillage crop residue practices									
T_1	2.0 ± 0.4^c	4.2 ± 6.5^a	35.4 ± 4.1^c	35.6 ± 10.3^{cd}	42.0 ± 8.5 ^{c}	59.7 ± 5.3^{bc}	20.5± 4.1^c	34.8± 4.3^{cd}	16.1± 4.1^c
T_2	5.9 ± 1.0^b	7.2 ± 0.6^c	48.6 ± 9.2^{bc}	41.2 ± 8.8^{bc}	63.8 ± 10.7^{bc}	95.1 ± 20.6^b	24.9± 5.7^{cd}	46.3± 9.3^a	17.3± 8.5 ^{c}
T_3	6.5 ± 0.7^b	13.9 ± 1.3^b	64.3 ± 6.2^b	69.3 ± 6.6^a	110.8 ±10.7^b	137.1± 9.9^a	25.8± 6.6^a	49.1±10.7^b	17.9± 8.8^{bc}
T_4	3.9 ± 1.4^{bc}	11.6 ± 0.8^{bc}	48.2 ± 8.2^{bc}	23.8 ± 0.9^d	32.8 ± 2.4^d	57.3 ± 20.1^a	24.5± 5.7^{cd}	38.3± 8.4^a	21.3± 7.1^a
T_5	9.9 ± 0.7^a	19.6 ± 1.0^b	107.8 ± 4.1^a	34.5 ± 5.7^{cd}	54.3 ± 4.3^{cd}	82.2± 11.6^a	29.8± 8.8^{bc}	50.8± 9.9^a	27.1± 6.6^a
T_6	10.1 ± 1.7^a	19.9 ± 0.8^b	119.3 ± 8.4^a	60.9 ± 3.9^{ab}	82.5 ± 11.8^b	114.5 ± 9.3^a	31.2± 9.2^{bc}	52.3± 11.8^b	29.1± 10.3^{cd}
T_7	1.80± 0.6^c	3.9 ± 0.7^c	29.8± 3.4^c	17.6 ± 2.4^c	23.8 ± 3.9^c	28.7 ± 4.1^c	17.9± 3.9^{ab}	26.2± 3.4^c	15.7± 2.4^c

****** Different letters within columns are significantly different at P=0.05 according to Duncan Multiple Range Test (DMRT) for separation of means.

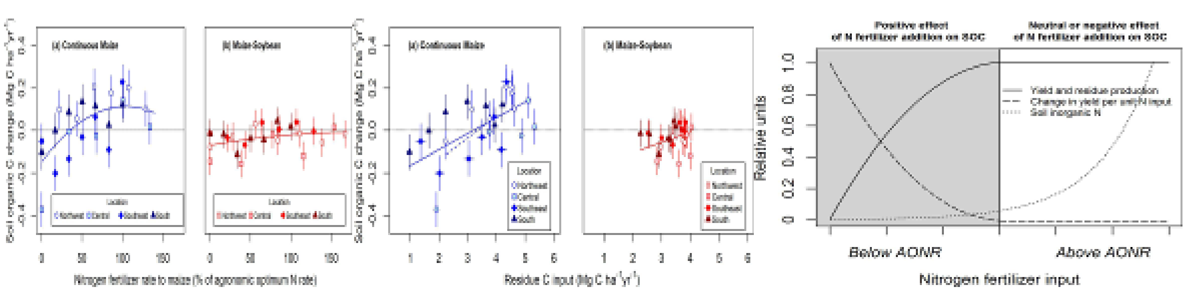
Table.5 Effect of tillage crop residue practices on the soil enzymatic activities [Source: Naresh *et al.*, 2018]

Treatments	β-glucosidase(μg PNP $g^{-1}h^{-1}$)			Urease (μg NH_3 $g^{-1}h^{-1}$)			Dehydrogenase(μg INTF $g^{-1}h^{-1}$)		
	Jointing stage	**Booting stage**	**Milky stage**	**Jointing stage**	**Booting stage**	**Milky stage**	**Jointing stage**	**Booting stage**	**Milky stage**
Tillage crop residue practices									
T_1	4.58 ± 0.14	4.23 ± 0.66	0.46 ± 0.04	14.08 ±1.84	19.97 ±0.94	16.82± 2.42	4.21 ± 0.28	4.83 ± 0.34	3.55 ± 0.17
T_2	4.94 ± 0.58	4.75 ± 0.84	0.60 ± 0.05	15.36 ±1.29	22.02 ±2.70	18.90 ± 1.33	5.91 ± 0.13	5.40 ± 0.12	4.83 ± 0.07
T_3	5.15 ± 0.21	4.96± 0.56	2.88± 0.19	18.57± 1.79	24.48±3 .84	19.36 ± 1.01	7.36 ± 0.22	6.46 ± 0.27	5.06 ± 0.54
T_4	4.48 ± 0.43	4.38 ± 0.05	0.23 ± 0.03	14.02 ±2.72	20.10 ±1.17	17.41 ±0.85	4.55 ± 0.14	4.91 ± 0.51	4.74 ± 0.17
T_5	4.98 ± 0.59	4.85 ± 0.59	0.84 ± 0.26	16.54 ±2.18	23.39 ±1.01	19.19 ± 1.22	6.77 ± 0.15	6.56 ± 0.03	4.96 ± 0.18
T_6	5.75 ± 0.41	5.14 ± 0.46	3.25 ± 0.09	20.13 ±1.80	26.23 ±4.59	20.79 ± 2.71	8.92 ± 0.38	7.71 ± 0.37	6.41 ± 0.15
T_7	3.28 ± 0.15	2.31 ± 0.68	0.19±0 .09	12.05 ±1.78	17.74 ±3.24	14.38 ± 1.54	3.06± 0.21	2.86± 0.23	1.97± 0.28

Fig.1 (a) Cropping system and N fertilizer rate effects on soil organic C storage. Mean (± SE) annual change in surface (0±15 cm) soil organic C (SOC) in response to N fertilizer rate applied to maize in continuous maize (a) and maize-soybean (b) systems [Source: Poffenbarger *et al.*, 2017]

Fig.1 (b) Relationship between soil organic C storage and residue C inputs [Source: Poffenbarger *et al.*, 2017]

Fig.1 (c) Conceptual relationships between N fertilizer input and maize yield, residue production, and residual soil inorganic N [Source: Poffenbarger *et al.*, 2017]

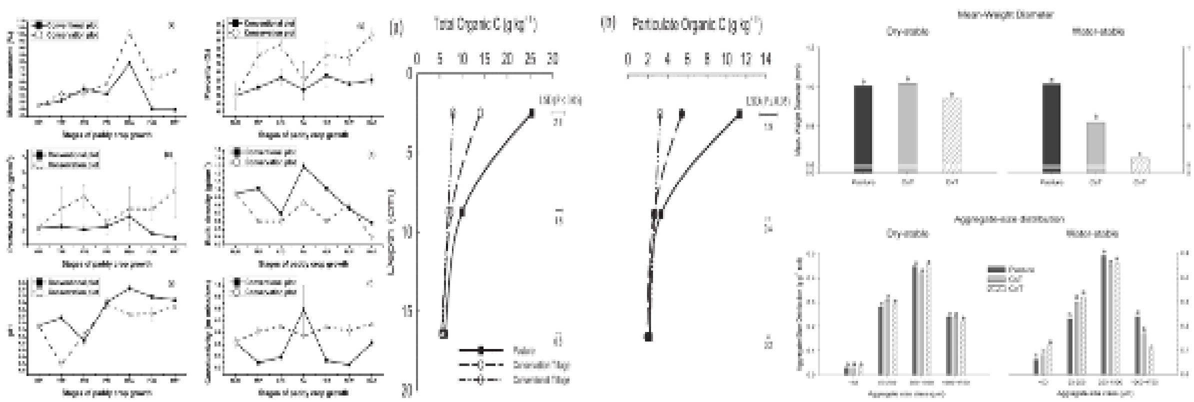


(a) **(b)** **(c)**

Fig.2 (a) Variation of the soil parameters (a) moisture content (b) porosity (c) particle density (d) bulk density (e) pH (f) conductivity observed in the two experimental plots, during the various stages of paddy crop growth (NUR: Nursery stage, TRP: Transplantation, ATG: Active tillering, PAI: Panicle initiation, HEA: Heading, FLW: Flowering, MAT: Maturation) [Source: Dutta and Gokhale, 2017]

Fig.2 (b) Depth distribution of (a) total soil organic C, (b) particulate organic C [Source: Causarano *et al.*, 2014]

Fig.2 (c) Dry-stable and water-stable mean-weight diameter and aggregate-size distribution (0–5 cm) under pasture, conservation tillage (CsT), and conventional tillage (CvT) systems [Source: Causarano *et al.*, 2014]

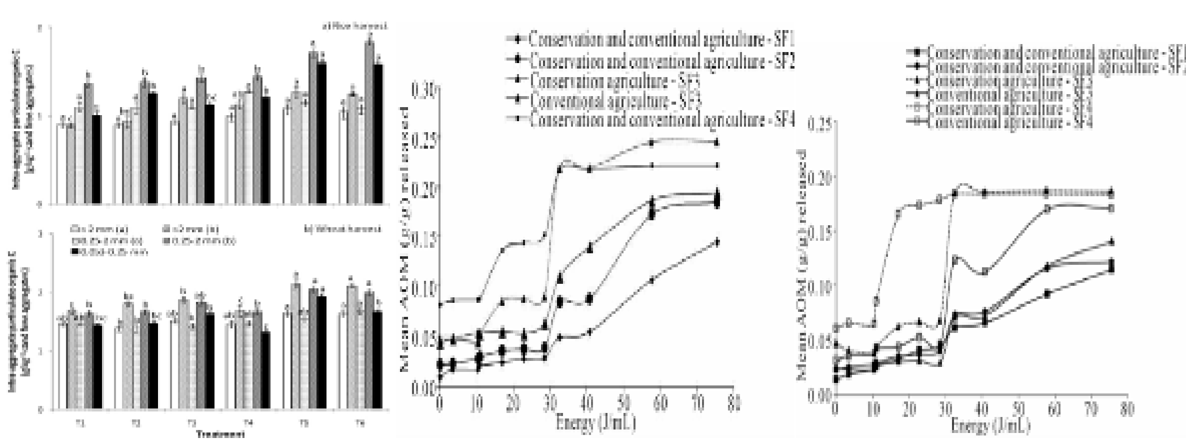


(a) **(b)** **(c)**

Fig.3 (a) Intra-aggregate particulate organic matter (iPOM) C (g kg^{-1} of sand-free aggregates) in aggregate-size fractions at the 0- to 5-cm soil depth at (i) rice and (ii) wheat harvest. '(a)' and '(b)' in legend refer to coarse (0.25–2 mm) and fi ne (0.053–0.25 mm) iPOM in the respective size of aggregates [Source: Mamta Kumari *et al.*, 2014]

Fig.3 (b) Aggregated organic matter of all aggregates size classes from horizon A1 (top horizon), released with different energy inputs [Source: Quintero and Comerford, 2013]

Fig.3 (c) Aggregated organic matter of all size class aggregates for horizon A2 released with different energy inputs from the soil [Source: Quintero and Comerford, 2013]

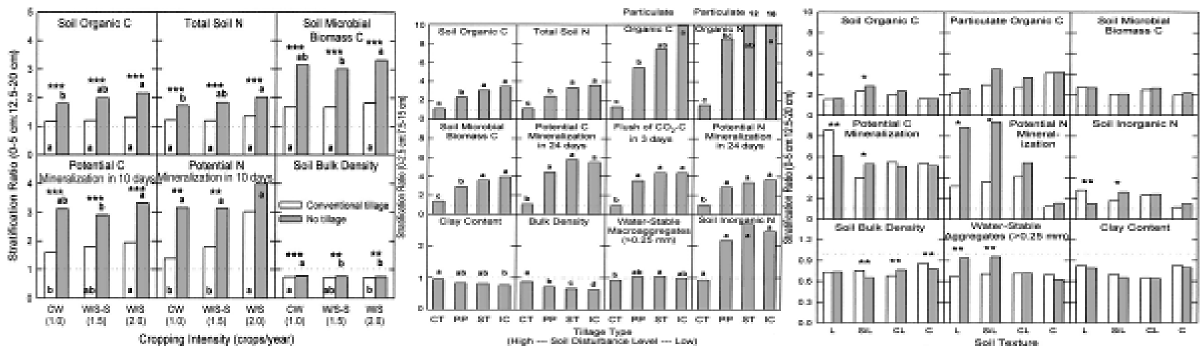


(a) **(b)** **(c)**

Fig.4 (a) Stratification ratio of soil properties under conventional and NT as affected by cropping intensity [Source: Franzluebbers, 2002]

Fig.4 (b) Stratification ratio of soil properties in Georgia as affected by tillage type [Source: Franzluebbers, 2002]

Fig.4 (c) Stratification ratio of soil properties under conventional and NT as affected by soil texture [Source: Franzluebbers, 2002]



(a) **(b)** **(c)**

Fig.5 Water-stable aggregates contents under different soil-management practices [Source: Simansky *et al.*, 2017]

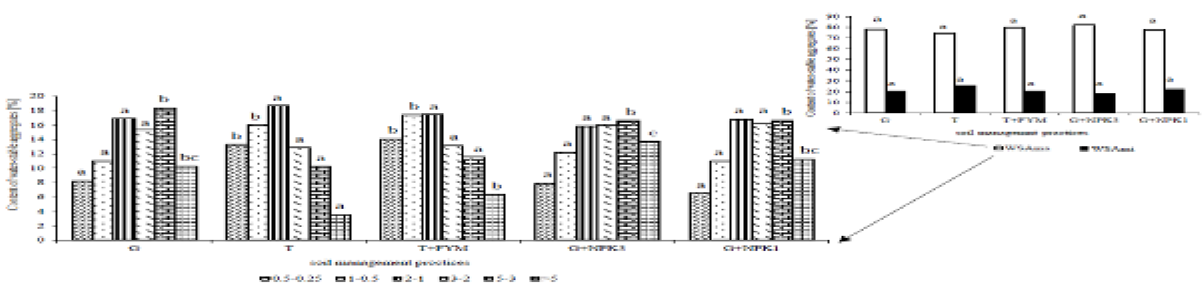
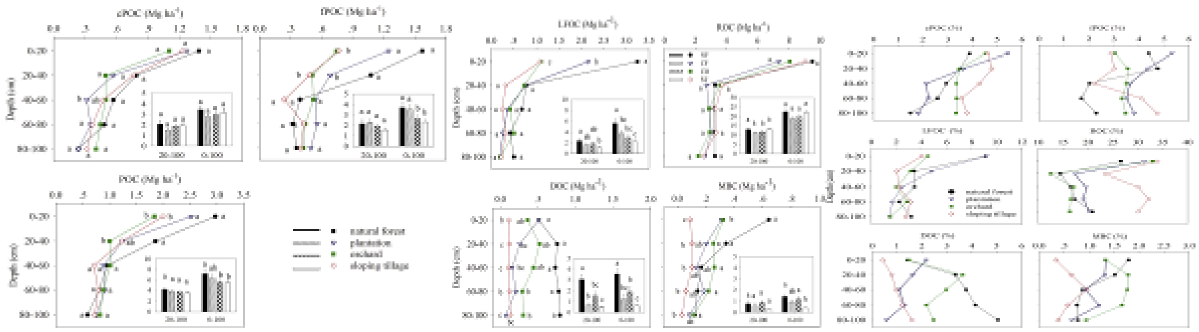


Fig.6 (a) POC stocks and those of its components (cPOC, fPOC) in relation to depth and land use systems in subtropical condition [Source: Sheng *et al.*, 2015]

Fig.6 (b) LOC fraction stocks in relation to depth and land use systems in subtropical condition [Source: Sheng *et al.*, 2015]

Fig.6 (c) Proportions of labile organic C fractions to soil organic C in relation to depth and land use systems in subtropical conditions [Source: Sheng *et al.*, 2015]



(a) **(b)** **(c)**

Fig.7 Changes in mean soil microbial biomass C (a), soil microbial biomass N (b) and soil basal respiration (c) in the soil at the control and afforestation [Source: Bolat *et al.*, 2016]

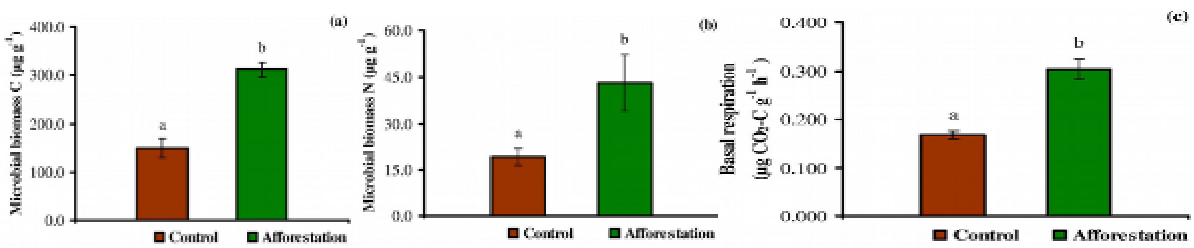
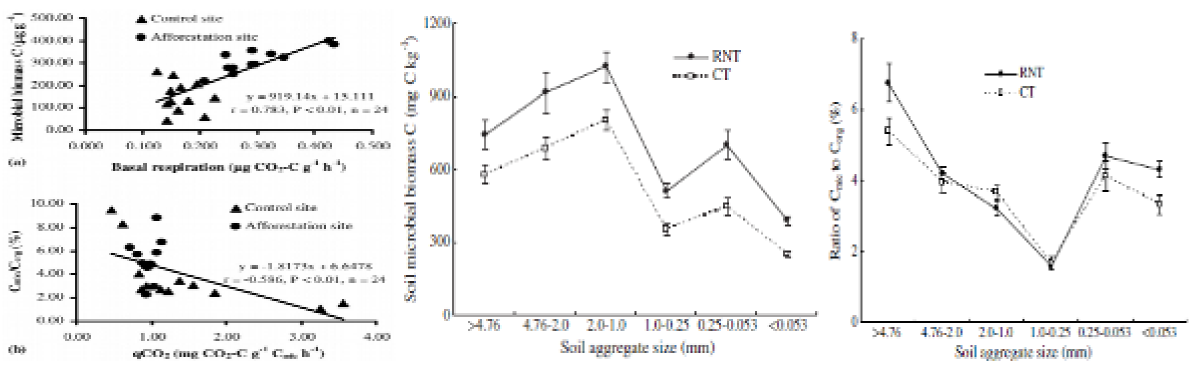


Fig.8 (a) The relation between the microbial biomass C and basal respiration (a), C_{mic}/C_{org} and qCO_2 (b) [Source: Bolat *et al.*, 2016]

Fig.8 (b) Soil microbial biomass C associated with different sizes of aggregate under RNT and CT (RNT, combines ridge with no-tillage; CT, conventional tillage) [Source: Jiang *et al.*, 2011]

Fig.8 (c) Ratio of soil microbial C to total organic C associated with different sizes of aggregate under RNT and CT [Source: Jiang *et al.*, 2011]

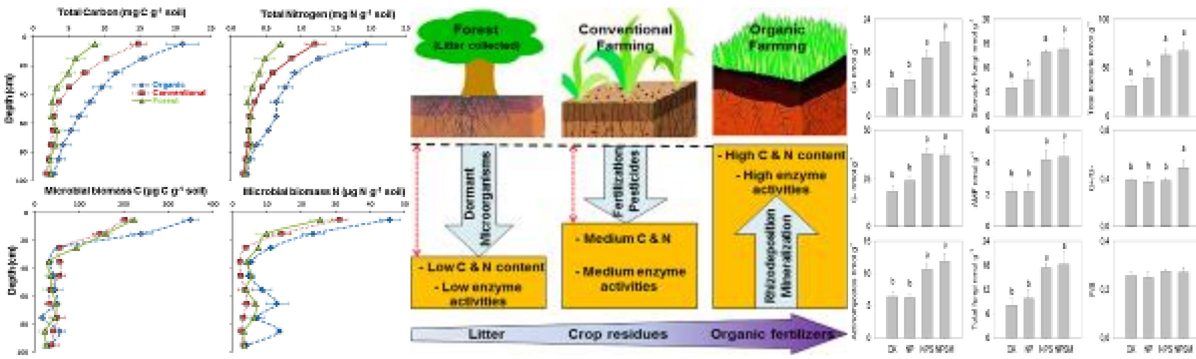


(a) **(b)** **(c)**

Fig.9 (a) Total C, N, and microbial biomass C and N depending on land use and depth [Source: Maharjan *et al.*, 2017]

Fig.9 (b) Conceptual diagram representing the effect of land use on carbon and nitrogen content in soil along with enzyme activities [Source: Maharjan *et al.*, 2017]

Fig.9 (c) Abundance of microbial biomarker groups under different fertilization regimes [Source:Li *et al.*, 2018]

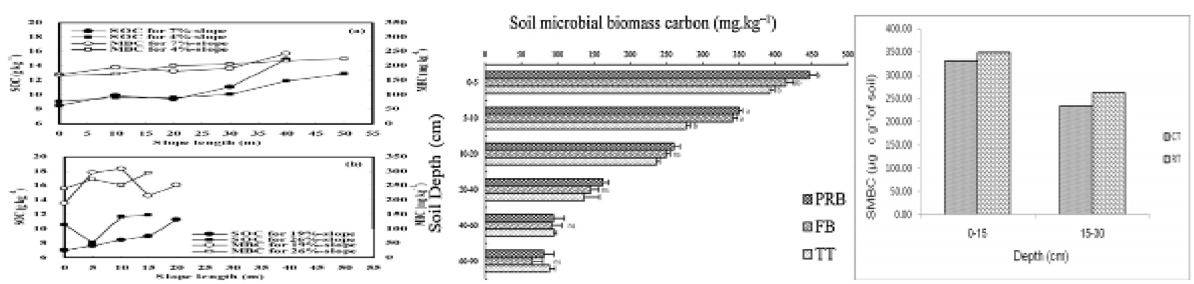


(a) (b) (c)

Fig.10 (a) Distribution of SOC and MBC contents over eroded slopes. (a) Gentle slope landscape; (b) steep slope landscape [Source: Xiaojun *et al.*, 2013]

Fig.10 (b) Microbial biomass carbon content with depth under traditional tillage (TT), flat raised bed with controlled traffic and zero tillage (FB) and permanent raised bed (PRB) [Source: Ma *et al.*, 2016]

Fig.10 (c) Effect of soil microbial biomass carbon (µg c g^{-1} of soil) under different tillage systems [Source: Malviya, 2014]

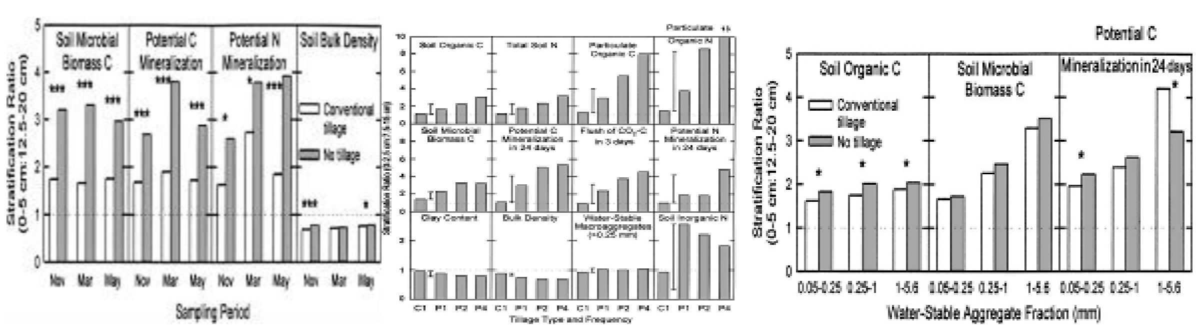


(a) (b) (c)

Fig.11 (a) Stratification ratio of soil properties under conventional and NT as affected by sampling period [Source: Franzluebbers, 2002]

Fig.11 (b) Stratification ratio of soil properties in response to tillage type and frequency [Source: Franzluebbers, 2002]

Fig.11 (c) Stratification ratio of soil properties from water-stable aggregate fractions under conventional and NT [Source: Franzluebbers, 2002]



(a) (b) (c)

Fig.12 Microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) concentrations (gkg^{-1}), and ratios of microbial biomass carbon to microbial biomass nitrogen (MBC/MBN) in the 0–5 cm, 5–15 cm, and 15–25 cm layers expressed as a, b, and c for three land uses (forestland, grassland and arable land) and two tillage systems (NT: no-tillage, PT: plow tillage) [Source: Liu *et al.*, 2016]

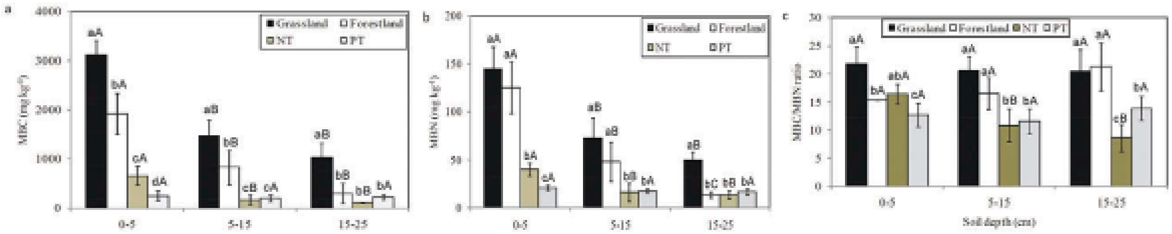
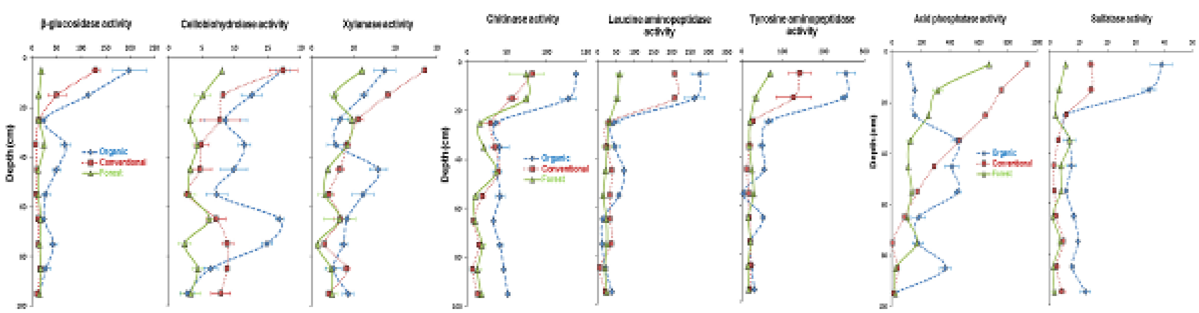
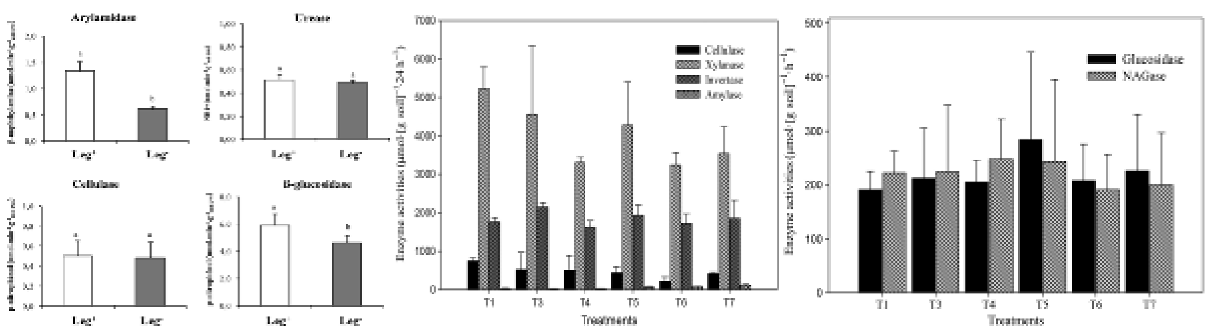


Fig.13 (a) Activities of C-cycle enzymes: β-glucosidase, cellobiohydrolase and xylanase depending on land use and depth [Source: Maharjan *et al.*, 2017]:
Fig.13 (b) Activities of N-cycle enzymes: chitinase, leucine aminopeptidase and tyrosine aminopepti-dase depending on land use and depth [Source: Maharjan *et al.*, 2017]
Fig.13 (c) Activities of P and S-cycle enzymes: acid phosphatase and sulfatase depending on land use and depth [Source: Maharjan *et al.*, 2017]



(a) **(b)** **(c)**

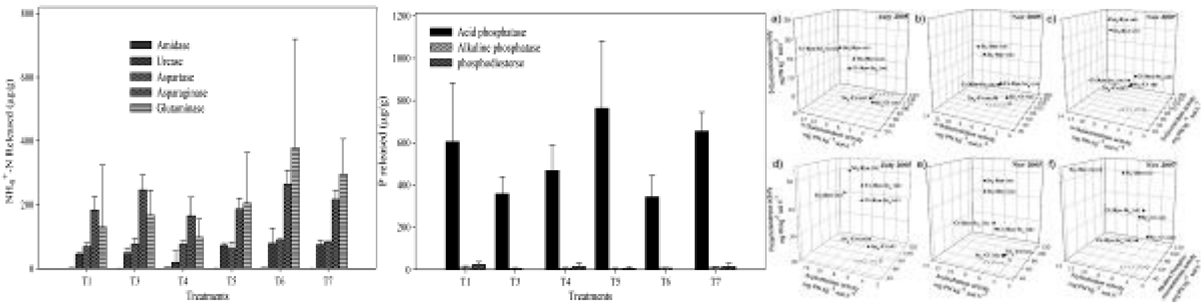
Fig.14 (a) Enzyme activities in the Leg+ and Leg− treatments. [Source: Aschi *et al.*, 2017]
Fig.14 (b) Impact of treatment type on enzyme activities [Source: Owiti *et al.*, 2017]
Fig.14 (c) Impact of treatment type on enzyme activities [Source: Owiti *et al.*, 2017]



(a) **(b)** **(c)**

Fig.15 (a) Treatment effect on nitrogen enzyme activities [Source: Owiti *et al.*, 2017]
Fig.15 (b) Effect of treatment on phosphatase activity [Source: Owiti *et al.*, 2017]
Fig.15 (c) Three-dimensional plot of α-glucosidase, ρ-glucosaminidase and arylsulfatase activities as affected by crop rotations (A) and tillage practices (B) in the semiarid agricultural

soils[Source: Acosta-Martínez *et al.*, 2003]

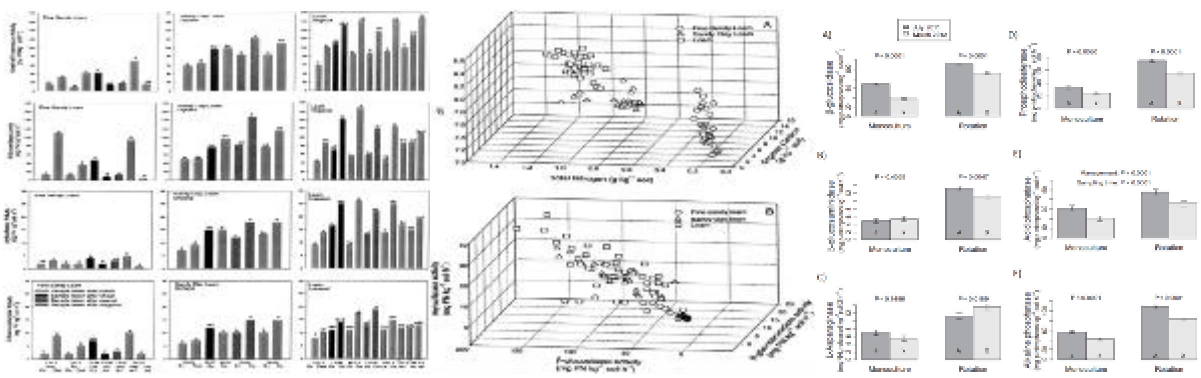


(a) **(b)** **(c)**

Fig.16 (a) Enzyme activities in the semiarid agricultural soils [Source: Acosta-Martínez *et al.*, 2003]

Fig.16 (b) Three-dimensional plot of the soil pH, organic C, and total N contents (A); and of the β glucosidase, β-glucosaminidase and arylsulfatase activities (B) in the three semiarid agricultural soils [Source: Acosta-Martínez *et al.*, 2003]

Fig.16 (c) Enzyme activities which showed a significant difference due to management history (monoculture and rotation) [Source: Acosta-Martinez *et al.*, 2014]

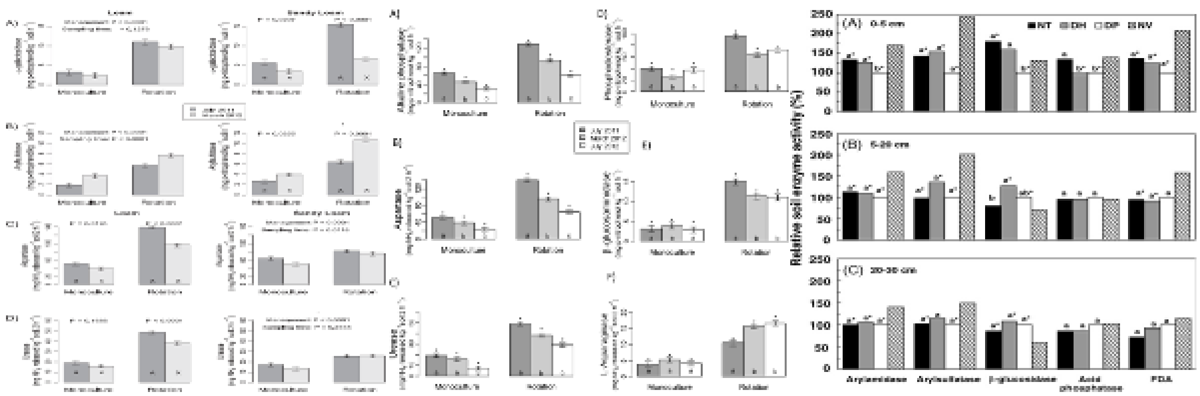


(a) **(b)** **(c)**

Fig.17 (a) Enzyme activities that were affected by a three-way interaction (P < 0.05) of management history (monoculture and rotation), soil type (loam and sandy loam), and sampling time (July 2011 and March 2012) [Source: Acosta-Martinez *et al.*, 2014]

Fig.17 (b) Enzyme activities in the loam soil as affected by management history (monoculture and rotation) and sampling date (July 2011, March 2012 and July 2012) [Source: Acosta-Martinez *et al.*, 2014]

Fig.17 (c) Relative soil enzyme activities from under no-till (NT), disk harrow (DH), and disk plow (DP), and undisturbed (NV) in the 0–5, 5–20, and 20–30 cm soil layers [Source: Green *et al.*, 2007]



(a) **(b)** **(c)**

Furthermore, the higher POXC content and carbon mineralization rate can be associated to the higher β-glucosidase activity which is involved in catalyzing the hydrolysis and biodegradation of plant debris. Owiti *et al.*, (2017) showed that irrespective of treatment, xylanase activity was the highest (3244±327–5223± 567 µmol/g 24h^{-1}), whereas amylase activity was the lowest (12.57± 8.9–116± 42.8 µmol/g 24h^{-1}; [Fig.14b]. Invertase is an enzyme that cleaves sucrose, one of the most abundant soluble sugars in plants, releasing glucose and fructose (Deng and Popova 2011). Its activity was determined to range from 1633 to 2150 µmol/g soil 24 h^{-1} [Fig.14b]. Increased temperature during and after burn treatment application may have stimulated invertase synthesis by microorganisms and the subsequent increased activity. □-glucosidase activity was stimulated by burn and thin treatments and ranged from 190 to 284 µmol/g soil h^{-1}, with the least activity in T_1 and the highest activity in T_5 [Fig.14c]. Hedo *et al.*, (2015) reported a decrease in □-glucosidase activity in burned treatment with low moisture content. Barreiro *et al.*, (2016) reported that □-glucosidase activity reduced immediately after burn application, but recovered after 10 yr of fire application, although the addition of a fire retardant to the bunt soil significantly decreased the □-glucosidase activity. N-acetyl-ρ-glucosaminidase (NAGase) is one of the enzymes involved in the breakdown of chitin, a cell wall component of both fungi and arthropods (Boerner *et al.*, 2006). Its activity was highest in treatment T_4 and T_5 treatments and least in T_6 treatment [Fig.14c].

Naresh *et al.*, (2028) revealed that in the turning jointing stage, compared with CT, the ZT and FIRB treatments significantly increased nitrifying bacteria [Gn] by 77% and 229%, respectively. At the booting stage, the Gn rates in ZT and FIRB soils were 2.16 and 3.37 times greater than that in CT soil, respectively. At the milking stage, the Gn rates in ZT and FIRB soils were 1.96 and 3.08 times greater than that in CT soil, respectively. Similarly, Table 3 shows the denitrifying bacteria [D] rates of the different treatments. In the jointing stage, the D rates in ZT and FIRB soils were 2.77 and 2.26 times greater than that in CT soil [Table 3]. At the booting stage, compared with CT, the ZT and FIRB treatments significantly increased D by 3.03% and 2.37%, respectively. At the milking stage, the ZT and FIRB treatments increased D by 3.39% and 2.95%, respectively. The Gn rates of the different treatments were T_6>T_3> T_4>T_7. The D rates were T_3>T_6> T_2 ≥ T_4 [Table 3].Moreover, FIRB system with residue retention showed statistically significant differences in the phosphatase enzyme activity in the soil comparing with ZT with residue removal and CT. The activity of phosphatase tended to be higher in the FIRB treatment compared to the

ZT and CT treatments [Table 3]. Naresh *et al.,* (2017) reported the positive effects of CA practices on soil enzyme activities. The generally higher enzyme activities in FIRB mainly resulted from the larger water availability in the plots rather than the better soil fertilities.

Acosta-Martínez *et al.,* (2003) concluded that the high enzyme activities in treatment T_6 relative to other treatments may be due to substrate amount and quality that remains in the soil after burning. With heavy thin, more organic N compounds are released and available for mineralization after burn, especially if the fire intensity is not high enough to destroy and degrade the substrate [Fig.15a]. Heterogeneity of enzyme response to treatment can be attributed to the fact that enzymes have different functions and not all resources they utilize will likely change in the same way following treatment application (Geng *et al.,* 2012).Altered substrate availability may favour the growth of certain microbial groups over others due to different nutrient demands and growth characteristics of specific microbial groups, thereby causing microbial community shifts. Acid phosphatase is more dominant in acid soils, whereas alkaline phosphatase is predominant in alkaline soils. Because the pH of this soils was acidic in nature, acid phosphatase activity was the highest compared to alkaline and phosphodiesterase activities [Fig.15b]. Acosta-Martínez *et al.,* (2003) also found that a plot of arylsulfatase, ρ-glucosaminidase and β-glucosidase activities showed a significant increase in the enzyme activities due to crop rotations in comparison to continuous cotton in the three soils [Fig.15c]. These results are due to the little residue cover during the winter and spring periods in soils under continuous cotton, which makes the soil more susceptible to wind and water erosion, and reduces the soil organic matter content. Generally, under crop rotation each residue provides C, N, and other elements in different amounts and available forms. In comparison to monoculture, the amounts and type of residue left in soils by different crops affect differently soil organic matter content and the microbial populations and, thus the amounts of enzymes produced and stabilized in soils. In the loam, the enzyme activities were generally increased by conservation tillage practices in the different cotton and sorghum or wheat rotations studied [Fig.15c]. Ekenler and Tabatabai (2002) reported that the specific activity values could be used as indexes of organic C quality. In general, there were significantly higher specific activities under the combination of crop rotations and conservation tillage practices in comparison to continuous cotton and conventional tillage. There were also significant increases in the specific activities in systems that still were not showing significant differences in the organic C content in comparison to continuous cotton and conventional tillage. Therefore, the enzyme activities reflected the differences in soil organic matter quality and quantity developed under alternative systems to continuous cotton and conventional tillage.

Acosta-Martínez *et al.,* (2003) observed that the alkaline phosphatase and β-glucosidase activities were higher than arylsulfatase and ρ-glucosaminidase activities in the semiarid soils [Fig.16a]. Even though enzyme activities are affected by soil properties, the predominance and ecological role among enzymes do not change in different soils and vegetation. The impact of crop rotations on the enzyme activities investigated differed among the fine sandy loam, sandy clay loam, and loam soils and with the type of enzyme studied [Fig.16a]. The enzyme activities were not impacted by the cotton-peanut rotation in comparison to continuous cotton in the fine sandy loam [Fig.16a]. There was generally a significant increase in the enzyme activities in cotton rotated with wheat or sorghum compared to continuous cotton in the sandy clay loam and loam [Fig.16a]. The differences in the enzyme activities could be attributed to the combination of irrigation and conservation tillage practices, and the impacts of tillage on the soil organic matter. A plot of the activities of β-glucosidase, ρ-glucosaminidase, and arylsulfatase activities showed there were greater activities in the loam and sandy clay loam than in the fine sandy loam reflecting the differences in the chemical properties among the soils [Fig.16b]. It is known that a particular enzyme has many different sources (i.e., microorganisms, plant roots, animals) and states (i.e., active microbial biomass, enzyme stabilized in soil surfaces and cell fragments) (Skujins 1976), and that soil organic matter affects enzyme activities (Tabatabai 1994).Acosta-Martinez *et al.*, (2014) reported that the enzymes involved in C (β-glucosidase, ρ-glucosaminidase) and P cycling (phosphodiesterase, acid and alkaline phosphatases) were significantly higher(19–79%) in July 2011 than in March 2012 [Fig.16c].

Naresh *et al.*, (2018) reported that the tillage systems also showed significant effect on urease activity. A significant increase in the activity of urease was realized with ZT and FIRB treatments, and with residue retention of 4 and 6 tha^{-1} [Table 4]. Raiesi and Kabiri (2016) reported higher urease activity in a barley crop under reduced tillage practices comprising of chisel and disk plough as compared with CT practices comprising of rotary and mouldboard plough in a 6 year study in semi-arid calcareous soil in central Iran. Zhang *et al.*, (2016) observed that activity of the enzymes (urease and sucrase) increased with the amount of straw applied. Incorporation of maize straw was more effective to increase enzyme activities as compared with wheat straw incorporation because of narrow C: N ratio of maize straw than wheat straw which facilitates faster decomposition of maize straw.

Acosta-Martinez *et al.*, (2014) observed that the response of the other four EAs (α-galactosidase, arylsulfatase, aspartase and urease) was not always consistent in both soils, as indicated by a significant three-way interaction between sampling time, soil type, and management history [Fig.17a].Prolonged warming alone (5–6 years) resulted in increases (10–38%) in urease and α-glucosidase activities (Sardans *et al.*, 2008a). Alkaline phosphatase and aspartase showed a continual decrease over time in both management histories, with urease showing the same decrease for the rotation [Fig.17b]. Although phosphodiesterase and β-glucosaminidase activities were generally highest in July 2011, these EAs did not continue to decline over all three sample times [Fig.17b].The higher EAs during the peak drought/heat wave period of 2011 may be explained by a change in enzyme pool distribution (Schimel *et al.*, 2007) toward increased extracellular pools as a result of a combination of different mechanisms. Green *et al.*, (2007) revealed thatthe 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.17c]. α-Glucosidase, arylamidase, and acid phosphatase enzyme activities were significantly influenced by tillage management in the 0–5 cm depth [Fig.17c]. α-Glucosidase activity was significantly greater under no-till and disk harrows (100 and 88 g ρ-nitrophenol m^{-3} soil h^{-1}, respectively) than under disk plow (55 g ρ-nitrophenol m^{-3} soil h^{-1}). Acid phosphatase activity was greater under no-till than under disk harrow and disk plow (304, 219, and 226 g ρ-nitrophenol m^{-3} soil h^{-1}, respectively), while arylamidase activity was greater under no-till and disk harrow than under disk plow (8.7, 8.2, and 6.5 g ρ-nitrophenol m^{-3} soil h^{-1}, respectively).

Across the management practices evaluated in the review paper, tillage had the greatest effect on SOC and its various fractions and in the surface (0–15 cm) soil of tillage implementation, with positive results observed with conservation tillage practices compared with conventional tillage. SOC stocks and those of the labile fractions decreased in topsoil and subsoil below 20 cm following land conversion. The LOC fractions to SOC ratios also decreased, indicating a reduction in C quality as a consequence of land use change. Reduced LOC fraction stocks in subsoil could partially be explained by the decrease in fine root biomass in subsoil, with consequences for SOC stock. However, not all labile fractions could be useful early indicators of SOC alterations due to land use change. In fact, only fPOC, LFOC, and MBC in topsoil, and LFOC and DOC in subsoil were highly sensitive to land use change in subtropical climatic conditions of North West IGP. There was a significant reduction in SMBC content with depth in all treatments. SMBC in the PRB treatment increased by 19.8%, 26.2%, 10.3%, 27.7%, 10% and 9% at 0–5, 5–10, 10–20, 20–40, 40–60 and 60–90 cm depths, respectively, when compared with the TT treatment. The mean SMBC of the PRB treatment was 14% higher than that in the TT treatment.

Conventional tillage in comparison with NT significantly reduced macro-aggregates with a significant redistribution of aggregates - into micro-aggregates. Aggregate protected labile C and N were significantly greater for macro-aggregates, (>2000 and 250–2000 µm) than – micro-aggregates (53–250 and 20–53 µm) and greater for M than F indicating physical protection of labile C within macro-aggregates. No -tillage and M a lone each significantly increased soil aggregation and aggregate-associated C and N; however, NT and M together further improved soil aggregation and aggregate-protected C and N. Moreover, compared with CT, the ZT and FIRB treatments significantly increased nitrifying [Gn] and denitrifying bacteria [D] by 77%, 229%, and 3.03%, 2.37%, respectively. The activity of phosphatase tended to be higher in the FIRB treatment compared to the ZT and CT treatments.

The distribution pattern of soil microbial biomass associated with aggregates was likely governed by the size of aggregates, whereas the tillage effect was not significant at the aggregate-size scale. Tillage regimes that contribute to greater soil aggregation also will improve soil microbial activity to aid in crop production. Heterogeneous distribution of OC and microbial biomass may lead to “hot-spots” of aggregation, and suggests that microorganisms associated with 1.0–2.0 mm aggregates are the most biologically active in the ecosystem. Conventional tillage (CT) significantly reduces macro-aggregates to smaller ones, thus aggregate stability was reduced by 35% compared with conservation system (CS), further indicating that tillage practices led to soil structural damage. The concentrations of SOC and other nutrients are also significantly higher under CS than CT, implying that CS may be an ideal enhancer of soil productivity in this sub-tropical ecosystem through improving soil structure which leads to the protection of SOM and nutrients, and the maintenance of higher nutrient content. The average concentration of particulate organic carbon (POC), dissolved organic carbon (DOC) and microbial biomass carbon (MBC) in organic manure plus inorganic fertilizer treatments (NP+S and NP+FYM) in 0–60 cm depth were increased by 64.9–91.9%, 42.5–56.9%, and 74.7–99.4%, respectively, over the CK treatment. Conservation tillage stimulated the -glucosidase and chitinase activities in the macro-aggregates but not in the micro-aggregates. In conclusion, SOC, microbial biomasses and enzyme activities in the macro-aggregates are more sensitive to manure amendment than in the micro-aggregates. Conservation tillage benefited soil structure, increased microbial activities, and most likely enzyme activity especially soil fertility.

References

Acosta-Martinez, V., Zobeck, T.M., · T. E. Gill, T.E., and Kennedy, C. 2003. Enzyme activities and microbial community structure in semiarid agricultural soils. *Biol Fertil Soils* 38:216–227.

Acosta-Martineza, V., Moore-Kucera, J., Cotton, J., Gardner, T., and Wester, D. 2014.Soil enzyme activities during the 2011 Texas record drought/heat wave and implications to biogeochemical cycling and organic matter dynamics. *Appl Soil Ecol* 75: 43– 51.

Agnelli, A., Ascher, j., Corti, G., Ceccherini, M.T., Nannipieri, P., and Pietramellara, G. 2004. Distribution of microbial communities in a forest soil profile investigated by microbial biomass, soil respiration and DGGE of total and extracellular DNA. *Soil Bio Biochem*. 36:859−868.

Aschi, A., Aubert, M., Riah-Anglet, W., Nélieuc, S., Dubois, C., Akpa-Vinceslas, M., Trinsoutrot-Gattin, I. 2017. Introduction of Faba bean in crop rotation: Impacts on soil chemical and biological characteristics. *Appl Soil Ecol* 120:219–228.

Baldock, J.A., and Skjemstad, J.O. 1999. Soil organic carbon /Soil organic matter. In Peverill, KI, Sparrow, LA and Reuter, DJ (eds). Soil Analysis-an interpretation manual. CSIRO Publishing Collingwood Australia.

Barreiro, A., Martin, A., Carballas, T., and Diaz-Ravina, M. 2016. Long-term response of soil microbial communities to fire and fire-fighting chemicals. *Biol Ferti Soils* 52:963–975.

Beare, M.H., Hendrix, P.F., and Coleman, D.C. 1994. Water-stable aggregates and organic matter fractions in conventional- and no-tillage. *Soil Sci. Soc. Am. J*. 58: 777–786.

Boerner, R.E.J., Waldrop, T.A., and Shelburne, B.V. 2006. Wildfire mitigation strategies affect soil enzyme activity and soil organic carbon in loblolly pine (*Pinus taeda*) forests. *Canadian J Forest Res*. 36:3148–3154.

Bolat, I., Kara, Ö, Sensoy, H., and Yüksel, K. 2016. Influences of Black Locust (*Robinia pseudoacacia* L.) afforestation on soil microbial biomass and activity. *Forest* 9: 171-177.

Campbell, C.A., McConkey, B.G., Zentner, R.P., Selles, F., and Curtin, D. 1996. Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in south western Saskatchewan. *Canadian J Soil Sci*. 76: 395-401.

Causarano, H.J., Franzluebbers, A. J., Shaw, J.N., Reeves, D.W., Raper, R.L., and Wood, C.W. 2014. Soil Organic Carbon Fractions and Aggregation in the Southern Piedmont and Coastal Plain. *Soil Sci Soc Am J*.72:221-230.

Chivenge, P., Vanlauwe, B., Gentile, R., and Six, J. 2011. Comparison of organic versus mineral resource effects on short-term aggregate carbon and nitrogen dynamics in a sandy soil versus a fine textured soil. *Agric Ecosyst Environ*. 140:361-71.

Dalal, R.C. 1998. Soil microbial biomass- What do the numbers really mean? *Aust J Exp Agri*. 38:645-665.

Divya, P., Madhoolika, A., and Jitendra, S.B. 2014. Effects of conventional tillage and no tillage permutations on extracellular soil enzyme activities and microbial biomass under rice cultivation. *Soil Tillage Res*. 136: 51–60.

Dodor, D., and Tabatabai, M. 2002. Effects of cropping systems and microbial biomass on arylamidase activity in soils. *Biol. Fertil. Soils* 35: 253–261.

Dou, X., He, P., Zhu, P., and Zhou, W. 2016. Soil organic carbon dynamics under long-term fertilization in a black soil of China: Evidence from stable C isotopes. *Sci Rep*, 6: 21488.

Drees, L.R., and Hallmark, C.T.2002. Inorganic carbon analysis.In Rattan Lal (ed). *Encyclopedia of Soil Science*. Marcel Dekker. New York

Dutta, J., and Gokhale, S. 2017. Field investigation of carbon di oxide (CO_2) fluxes and organic carbon from a conserved paddy field of North–East India. *Int. Soil Water Conser. Res*. 5:325–334

Dutta, J., and Gokhale, S. 2017. Field investigation of carbon dioxide (CO_2) fluxes and organic carbon from a conserved paddy field of North–East India.*Int Soil Water Conser Res*. 5:325–334.

Ekenler, M., and Tabatabai, M.A. 2002. □-Glucosaminidase activity of soils: effect of cropping systems and its relationship to nitrogen mineralization. *Biol Fertil Soils* 36:367–376.

Essington, M. E. 2004. Soil and water chemistry: an integrative approach. CRC Press LCC, Boca Raton, Florida, USA.

Fierer, N., Schimel, J.P., and Holden, P.A. 2003. Variations in microbial community composition through two soil depth profiles. *Soil Bio. Biochem*. 35:167−176.

Franzluebbers, A.J. 2002. Soil organic matter stratification ratio as an indicator of soil quality.*Soil Tillage Res*. 66:95–106.

Franzluebbers, A.J., and Arshad, M.A. 1996c. Water-stable aggregation and organic matter in four soils under conventional and zero tillage. *Can. J. Soil Sci*. 76: 387–393.

García-Orenes, F., Guerrero, C., Roldán, A., Mataix-Solera J., Cerdà, A., Campoy, M., Zornoza, R., Bárcenas, G., and Caravaca, F. 2010. Soil microbial biomass and activity under different agricultural management systems in a semiarid Mediterranean agro-ecosystem. *Soil Tillage Res*.109 (2): 110-115.

Geng, Y., Dighton, J., and Gray, D. 2012. The effects of thinning and soil disturbance on enzyme activities under pitch pine soil in New Jersey Pinelands. *Appl Soil Ecol* 62:1–7.

Green, V.S., Stott, D.E., Cruz, J.C., and Curi, N. 2007.Tillage impacts on soil biological activity and aggregation in a Brazilian Cerrado Oxisol. *Soil Tillage Res*. 92: 114–121.

Hedo, J., Lucas-rja, M.E., Wic, C., Anes-Abellan, M., and de Las Heras, J. 2015. Soil micro-biological properties and enzymatic activities of long-term post-fire recovery in dry and semiarid Aleppo pine (*Pinus halepensis* M.) forest stands. *Solid Earth* 6:243–252.

Jiang, X., Wright, A.L., Wang, J., and Li, Z. 2011. Long-term tillage effects on the distribution patterns of microbial biomass and activities within soil aggregates. *Catena* 87:276–280.

Kara, O., and Bolat, I. 2008. Soil microbial biomass C and N changes in relation to forest conversion in the north-western

Turkey. *Land Degrad Dev*. 19 (4): 421-428

Keesstra, S.D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., Montanarella, L., Quinton, J. N., Pachepsky, Y., Van der Putten, W. H., Bardgett, R. D., Moolenaar, S., Mol, G., Jansen, B., and Fresco, L.O. 2016. The significance of soilsand soil science towards realization of the United Nations Sustainable Development Goals. *Soil*, 2: 111–128.

Lazcano, C., GoÂmez-BrandoÂn, M., Revilla, P., and DomõÂnguez, J.2013. Short-term effects of organic and inorganic fertilizers on soil microbial community structure and function. *Biol Fertil Soils*. 49: 723-733.

Li, J., Wu, X., Gebremikael, M.T., Wu, H., Cai, D., Wang, B., *et al.,* 2018. Response of soil organic carbon fractions, microbial community composition and carbon mineralization to high- input fertilizer practices under an intensive agricultural system. *PLoS ON*E 13(4): e0195144.

Liu, M., David A. N. Ussiri, and Lal, R. 2016.Soil Organic Carbon and Nitrogen Fractions under Different Land Uses and Tillage Practices. *Comm Soil Sci Plant Anal* 47(12):1528-1541.

Liu, Z.P., Shao, M.A., and Wang, Y.Q. 2012. Estimating soil organic carbon across a large scale region: a state-space modeling approach. *Soil Sci.* 177: 607–618.

Lu, F., Wang, X., Han, B., Ouyang, Z., Duan, X., Zheng, H., and Miao, H. 2009. Soil carbon sequestrations by nitrogen fertilizer application, straw return and no-tillage in China’s cropland. *Glob Change Biol*, 15: 281–305.

Ma, Z., Chen, J., Lyu, X., Liu, Li-li., and Siddique, K.H.M. 2016. Distribution of soil carbon and grain yield of spring wheat under a permanent raised bed planting system in an arid area of northwest China. *Soil Tillage Res*. 163: 274–281.

Maharjana, M., Sanaullaha, M., Razavid, B.S., and Kuzyakov, Y. 2017. Effect of land use and management practices on microbial biomass and enzyme activities in subtropical top-and sub-soils. *Appl Soil Ecol*. 113: 22–28.

Malviya, S.R. 2014. Effect of conservation agricultural practices on selected soil physical properties and carbon pools in black soils of central India. M.Sc. Thesis, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, M. P.

Mamta, Kumari., Chakraborty, D., Gathala, Mahesh, K., Pathak, H.,Dwivedi, B.S., Tomar, R.K., Garg, R.N., Singh, R., and Ladha, J.K. 2014. Soil Aggregation and Associated Organic Carbon Fractions as Affected by Tillage in a Rice–Wheat Rotation in North India. *Soil Sci. Soc. Am. J.* 75:560–567.

Marumoto, T.J., and Domsch, K.H. 1982. Mineralization of nutrients from soil microbial biomass. *Soil Biol. Biochem*. 14: 469–475.

Merino, A., Pérez-Batallón, P., and Macías, F. 2004. Responses of soil organic matter and green-house gas fluxes to soil management and land use changes in a humid temperate region of southern Europe. *Soil Biol Biochem*. 36:917−925.

Michelle Wander. 2015. Soil Organic Matter Fractions and Their Relevance to Soil Function. https://www.researchgate.net/publication/242450025

Mulvaney, R.L., Khan, S.A., and Ellsworth, T.R.2009. Synthetic nitrogen fertilizers deplete soil nitrogen: A global dilemma for sustainable cereal production. *J Environ Qual*.38:2295-314.

Naresh, R.K., Arvind Kumar, Bhaskar, S., Dhaliwal, S.S., Vivek, Satendra Kumar, Sunil Kumar and Gupta, R.K. 2017.

Organic matter fractions and soil carbon sequestration after 15- years of integrated nutrient management and tillage systems in an annual double cropping system in northern India. *J.Pharmacognosy Phytochem*. 6(6): 670-683

Naresh, R.K., Gupta, Raj. K., Kumar, V., Rathore, R.S., Purushottam, Kumar, V., Kumar, S., Singh, S.P., Saurabh Tyagi, Mahajan, N.C., and Singh, V. 2017. Carbon, Nitrogen Dynamics and Soil Organic Carbon Retention Potential after 16 years by different land uses and Nitrogen Management in Typic Ustochrept Soil. Paddy Water Environ, (In press)

Nath D.J. *et al.,* 2012. Soil enzymes and microbial biomass carbon under rice-toria sequence as influenced by nutrient management. *J. Indian Soc Soil Sci*, 60: 20-24.

Owiti, D.A., Tazisong, I.A., and, Senwo, Z. N. 2017.Microbial and organic matter patterns in a prescribed burned and thinned managed forest ecosystem. *ECOSPHERE* 8(12): Article e01962

Poffenbarger, H.J., Barker, D.W., Helmers, M.J., Miguez, F.E., Olk, D.C., Sawyer, J.E., *et al.*, 2017.Maximum soil organic carbon storage in Midwest U.S. cropping systems when crops are optimally nitrogen-fertilized. *PLoS ONE* 12(3): e0172293.doi:10.1371/journal.pone.0172293

Powlson, D. S., Prookes, P.C., and Christensen, B.T. 1987. Measurement of soil microbial biomass provides an early indication in total soil organic matter due to straw incorporation. *Soil Biol Biochem* 19:159−164.

Quintero, M., and Comerford, N.B. 2013. Effects of Conservation Tillage on Total and Aggregated Soil Organic Carbon in the Andes. *Open J Soil Sci*, 3: 361-373.

Roldán, A., Salinas-García, J.R., Alguacil, M.M., Díaz, E., and Caravaca, F. 2005. Soil enzyme activities suggest advantages of conservation tillage practices in sorghum cultivation under subtropical conditions. Geoderma 129:178–185.

Sardans, J., Penuelas, J., and Ogaya, R. 2008a. Changes in soil enzymes related to C and N cycle and in soil C and N content under prolonged warming and drought in a Mediterranean shrubland. *Appl. Soil Ecol*. 39: 223–235.

Schimel, J., Balser, T.C., and Walleinstein, M.D. 2007. Microbial stress–response physiology and its implications for ecosystem function. *Ecol* 88: 1386–1394.

Sheng, H., Zhou, P., Zhang, Y., Kuzyakov, Y., Zhou, Q., Ge, T., and Wang, C. 2015. Loss of labile organic carbon from subsoil due to land-use changes in subtropical China.*Soil Biol Biochem.* 88: 148-157

Simansky, V., Horak, J., Clothier, B., Buchkina, N., and Igaz, D. 2017.Soil organic-matter in water-stable aggregates under different soil-management practices. *Agric*. 63 (4):151–162.

Skujins, J. 1976. Extracellular enzymes in soil. CRC *Crit Rev Microbiol* 4:383–421.

Song, Z. W., Zhu, P., Gao, H. J., Peng, C., Deng, A. X., Zheng, C.Y., Mannaf, M. A., Islam, M. N., and Zhang, W. J. 2014. Effects of long-term fertilization on soil organic carbon content and aggregate composition under continuous maize cropping in Northeast China. *J. Agric Sci*, 153: 236–244.

Sparling, G.P. 1992. Ratio of microbial biomass to soil organic carbon as a sensitive indicator of changes in soil organic matter. *Aust J Soil Res* 30: 195–207.

Spedding, T.A., Hamel, C., Mehuys, G.R. and Madramootoo, C.A. 2004.Soil microbial dynamics in maize-growing soil under different tillage and residue management systems. *Soil Biol. Biochem.*, 36:499-512.

Stott, D.E., Kennedy, A.C., and Cambardella, C.A. 1999. Impact of soil organisms and organic matter on soil erodibility. In: Lal, R. (Ed.), Soil Quality and Soil Erosion. CRC Press/Soil and Water Conservation Society, Boca Raton, FL/Ankeny, IA, pp. 57–74.

Tabatabai, M.A. 1994. Soil enzymes. In: Weaver RW, Angle JS, Bottomley PS (eds) Methods of soil analysis. Part 2. Microbiological and biochemical properties. SSSA book series no. 5. SSSA, Madison, Wis., pp 775–833

Tripathi, R., Nayak, A.K., Bhattacharyya, P., Shukla, A.K., Shahid, M., Raja, R., Panda, B. B., Mohanty, S., Kumar, A., and Thilagam, A.K. 2014. Soil aggregation and distribution of carbon and nitrogen in different fractions after 41 years long-term fertilizer experiment in tropical rice–rice system. *Geoderma* 213: 280–286.

Vineela, C., Wani, S.P., Srinivasarao, CH., Padmaja, B., and Vittal, K.P.R. 2008. Microbial properties of soils as affected by cropping and nutrient management practices in several long-term manurial experiments in the semi-arid tropics of India. *Appl Soil Ecol* 40: 165–173.

Xiaojun, N., Jianhui, Z., and Zhengan, S. 2013. Dynamics of Soil Organic Carbon and Microbial Biomass Carbon in Relation to Water Erosion and Tillage Erosion. *PLoS ONE* 8(5): e64059. doi:10.1371/journal.pone.0064059

Zhang, J., Bo, G., Zhang, Z., Kong, F., Wang, Y., and Shen, G. 2016. Effects of straw incorporation on soil nutrients, enzymes, and aggregate stability in tobacco fields of China. *Sustainability*. 8: 710- 721.

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