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Effect of conservation tillage and crop rotations on soil organic carbon fractions and soil microbial biomass carbon: A review

Rashmi Priyadarshi and Alisha Kumari

Abstract

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 effects of tillage and residue management on labile soil organic carbon fractions and soil organic carbon stocks can vary spatially and temporally, and for different soil types and cropping systems. The maximum enhancement effects were recorded in the minimum tillage along with residue retained treatment. The conservation tillage (ST and NT) treatments effectively improved the soil structure and strengthened the stability of water-stable soil aggregates. In addition, they increased the SOC content and storage in aggregates of different sizes with comparison of MP and CT. Furthermore, long-term adoption of conservation tillage methods significantly increased the content of water-stable macro aggregates and of aggregate MWD, and increased the SOC content, ratio of, and storage in the macro-aggregates. In addition, correlation analysis suggested a significant correlation between SOC and aggregate- associated C in differently sized aggregates. The no-tillage system showed a trend to accumulate organic carbon near the soil surface layer. Conventional tillage reduced soil organic C stocks and that of its labile fractions both in top and subsoil (20-100 cm). POC reduction was mainly driven by a decrease in fine POC in topsoil, while DOC was mainly reduced in subsoil. Fine POC, LFOC and microbial biomass can be useful early indicators of changes in topsoil organic C. In contrast, LFOC and DOC are useful indicators for subsoil. Reduced proportions of fine POC, LFOC, DOC and microbial biomass to soil organic C reflected the decline in soil organic C quality caused by tillage. The LOC fractions to SOC ratios also decreased, indicating a reduction in C quality as a consequence of tillage and residue management.

Keywords: Microbial biomass, conservation tillage, organic matter dynamics, tillage, soil organic matter, soil aggregates

Introduction

Soil contains the largest carbon (C) pool of the global terrestrial ecosystem. The total soil organic carbon (SOC) pool is approximately 1500 Pg C, which is three times that of the atmospheric carbon pool (Song *et al.*, 2014) [32]. Therefore, the balance between soil carbon inputs and outputs has critical influence on the concentration of atmospheric. The rate at which carbon is cycled between the soil atmospheres is partly dependent on the carbon compounds present in Soil organic matter (Lal, 1997; Izaurralde *et al.*, 2001) [30, 26]. Stable, intermediate and active carbon compounds comprise the SOM pool. These three forms are found in varying proportion in soil with the least digestible (lignin) and chemically stable organic matter (humus) making almost all of the stable organic matter pool (Jastrow *et al.*, 1996; Amelung *et al.*, 1998) [27, 2]. Live and dead organisms and partially decomposed organic matter (Bremer *et al.*, 1994; Paul and Clark, 1996) [7, 42] make up the active fraction. The chemical association of organic matter and mineral particles in soil make the sequestered carbon less accessible to soil organisms, thereby leading to less carbon mineralization determined the effects of long-term elevated N on the stability of five organic matter pools and indicated the stabilization of organic matter in all soil fractions over the years.

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.

SOC dynamics are strongly influenced by agricultural management practices, such as fertilization, crop residue return, and tillage (Naresh *et al*., 2017) [38]. Many studies indicate that various tillage systems have a strong effect on labile SOC, soil aggregation, and SOC distributions in aggregates size fractions, Tillage also affects the distribution of the soil microbial biomass, being displaced toward the soil surface with no tillage, and toward lower depths with plow tillage. Specific microbial population distributions may also be affected by tillage (Doran, 1980) [15].

Holland and Coleman (1987) [25] reported an increase in the fungal to bacterial ratio with no tillage, which may have implications for C and N cycling in the soil. Tillage has been shown to disproportionately affect the more labile forms of organic carbon in soil (Cambardella and Elliott, 1992) [10], including the fraction that accounts for most of the simpler polymers involved in macro-aggregate formation. Soil organic C loss with tillage and continuous cropping may be minimized by proper residue management and crop selection (Studdert *et al*., 1997) [49] and by increasing cropping intensity (Doran *et al*., 1998) [16]. Stratification of soil properties is a natural consequence of soil development that can become accentuated in soils subjected to reduced tillage. Unger (1991) [51] and Bruce *et al*. (1995) [8] reported that soil nutrients become stratified when no-till management is employed. There is a marked stratification of soil organic matter with soil depth under no-tillage (Blevins *et al*., 1984) [8].

Naresh *et al*. (2017) [39] determined that reducing tillage and maintaining surface residues in a long-term study increased soil organic C and N in the surface 2.5 cm of soil. When corn stover was returned to the soil, Clapp *et al*. (2000) [12] reported a 14% increase in soil organic C in the top 15 cm, but soil organic C content decreased in the 15–30 cm depth. Similar apparent re-distributions of soil C, where increases in surface organic C generated by conservation tillage were offset by decreases in subsurface organic C content, have been documented (Ellert and Bettany, 1995) [20]. Soil-specific responses to tillage-induced C storage were reported by Wander *et al*. (1998) [53] in which carbon accretion was not apparent in all soils in that trial. Zibilsk *et al*. (2002) [54] reported that the No-till resulted in significantly greater soil organic improve C sequestration in this soil. Such effects varied depending on regional climate, soil type, residue management practice, and crop rotation. 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) [37]. Soil microbial biomass carbon and microbial biomass nitrogen refers to the C and N in the microorganisms in soil, which are the most active and labile (Powlson, Prookes, and Christensen 1987) [43]. Although microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) are less in quantity, they are significant source and sink for soil available nutrients (Powlson, Prookes, and Christensen 1987) [43]. 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) [43] 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) [4]. 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) [48].

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 are impact of different tillage practices on soil organic carbon fractions and soil microbial biomass carbon, in sub-tropical climatic conditions.

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) [3].

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) [3].

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) [17].

Dutta and Gokhale, (2017) [19] 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.1]. 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 decreased soil disturbance leads to lesser soil compaction, which increases pore space.

Causarano *et al*., (2014) [11] also found that the pastures contained significantly greater SOC than cropland at 0 to 5 cm depth. Aboveground residues decompose more slowly than incorporated residues because reduced contact with the soil increases drying and rewetting and reduces interactions with soil fauna and microbes. Causarano *et al*., (2014) [11] observed that there was a significant impact of management on water stable Mean weight diameter (MWD) and Aggregate-size distribution (ASD), however, following the order: pasture > CsT > CvT.

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. 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.

Franzluebbers, (2002) [21] 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 conventional tillage 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. However, the stratification ratio of the more biologically active pools of potential C and N mineralization did increase with increasing cropping intensity. Under no tillage (NT), stratification ratios of soil C and N pools also tended to increase with increasing cropping intensity. Para plowing loosened soil in the autumn followed by NT planting. Shallow cultivation controlled weeds in the summer following NT planting.

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, 1996) [22]. 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})

Soil Microbial biomass carbon (Cmic)

SMB is defined as the small (0-4 %) living component of soil organic matter excluding macro-fauna and plant roots (Dalal, 1998) [13]. Soil microbial biomass carbon (Cmic) 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) [47].

Ma *et al*., (2016) [33] reported that the proportion of soil microbial biomass carbon (SMBC) to total organic carbon (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 permanent raised bed (PRB) in the surface soil layer (0–10 cm) than in traditional tillage (TT) and zero tillage (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) [50] 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) [14]; 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) [36]. Liu *et al*., (2012) [31] 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) [29] 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 plow tillage (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) [6] 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 CO2-C g^{-1} h^{-1}; control: 0.167 μg CO_2-C g^{-1} h^{-1}) [Fig.2]. 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) [9], the presence and diversity of tree species (Kara & Bolat 2008) [28], the higher input of root exudates and plant residues (García-Orenes *et al*., 2010) [24], and the chemical composition of litter.

Maharjan *et al*., (2017) [34] also found that the total 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.

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-compostin. 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

In gentle slope landscapes, both SOC and MBC contents increased downslope in a roughly consecutive increment. 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 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. 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) [52].

Ma *et al*., (2016) [33] reported that the differences in SMBC were limited to the surface layers (0–5 and 5–10 cm) in the PRB treatment. 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.

Malviya, (2014) [35] 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. Malviya, (2014) [35] 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. 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) [40] also showed that in Northeast India, in rice-rape seed rotation for two years soil enzyme activities were highest when fertilizers, composts and bio-fertilizers were added together [Table 1]. 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) [23] 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. 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%).

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 para plow tillage. 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. 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) [29] 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. 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) [1], 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.

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.

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 macroaggregates, (>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 macroaggregates.

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 “hotspots” 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

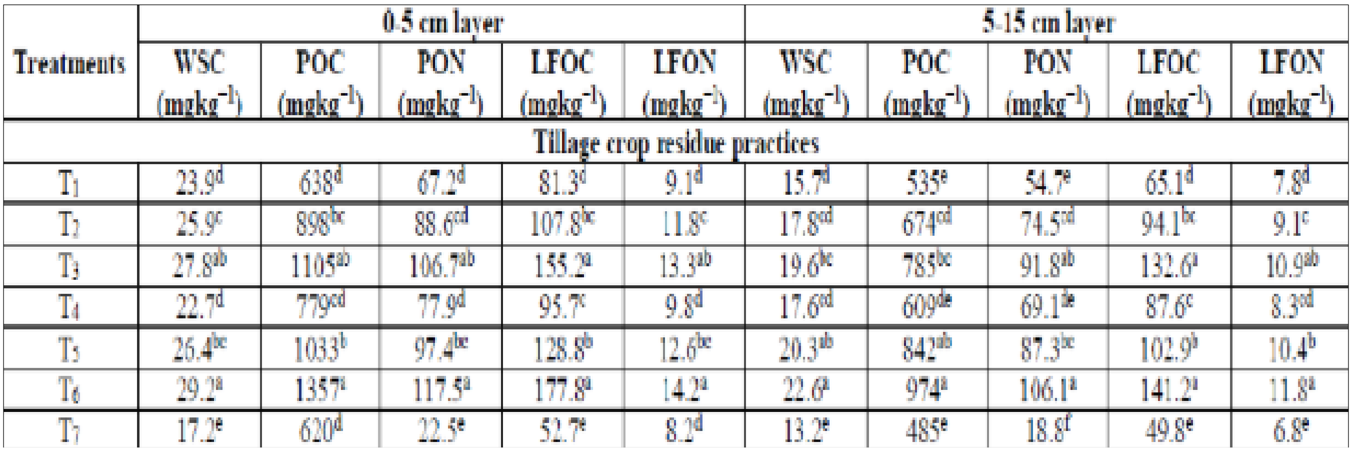
Conclusion

Soil microbial biomass, the active fraction of soil organic matter which plays a central role in the flow of C and N in ecosystems responds rapidly to management practices, and serves as an index of soil fertility. The practices of crop residue retention and tillage reduction provided an increased supply of C and N which was reflected in terms of increased levels of microbial biomass, N-mineralization rate in soil. Residue retention and tillage reduction both increased the proportion of organic C and total N present in soil organic matter as microbial biomass. Microbial immobilization of available-N during the early phase of crops and its pulsed release later during the period of greater N demand of crops enhanced the degree of synchronization between crop demand and N supply.

The maximum enhancement effects were recorded in the minimum tillage along with residue retained treatment. The conservation tillage (ST and NT) treatments effectively improved the soil structure and strengthened the stability of water-stable soil aggregates. In addition, they increased the SOC content and storage in aggregates of different sizes with comparison of MP and CT. Furthermore, long-term adoption of conservation tillage methods significantly increased the content of water-stable macroaggregates and of aggregate MWD, and increased the SOC content, ratio of, and storage in the macro-aggregates. In particular, the ST treatment increased the SOC content and enriched the newly formed C in macro-aggregates. In addition, correlation analysis suggested a significant correlation between SOC and aggregate- associated C in differently sized aggregates. The organic carbon content under no-tillage and reduced tillage system increased compared to conventional tillage due to retention of residues and minimum disturbance in the former system.

The no-tillage system showed a trend to accumulate organic carbon near the soil surface layer. Conventional tillage reduced soil organic C stocks and that of its labile fractions both in top and subsoil (20-100 cm). POC reduction was mainly driven by a decrease in fine POC in topsoil, while DOC was mainly reduced in subsoil. Fine POC, LFOC and microbial biomass can be useful early indicators of changes in topsoil organic C. In contrast, LFOC and DOC are useful indicators for subsoil. Reduced proportions of fine POC, LFOC, DOC and microbial biomass to soil organic C reflected the decline in soil organic C quality caused by tillage. The LOC fractions to SOC ratios also decreased, indicating a reduction in C quality as a consequence of tillage and residue management.

Table 1: Effect of 15 years of application of treatments on contents of various labile fractions of carbon in soil [Naresh *et al*., 2017] [39]



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

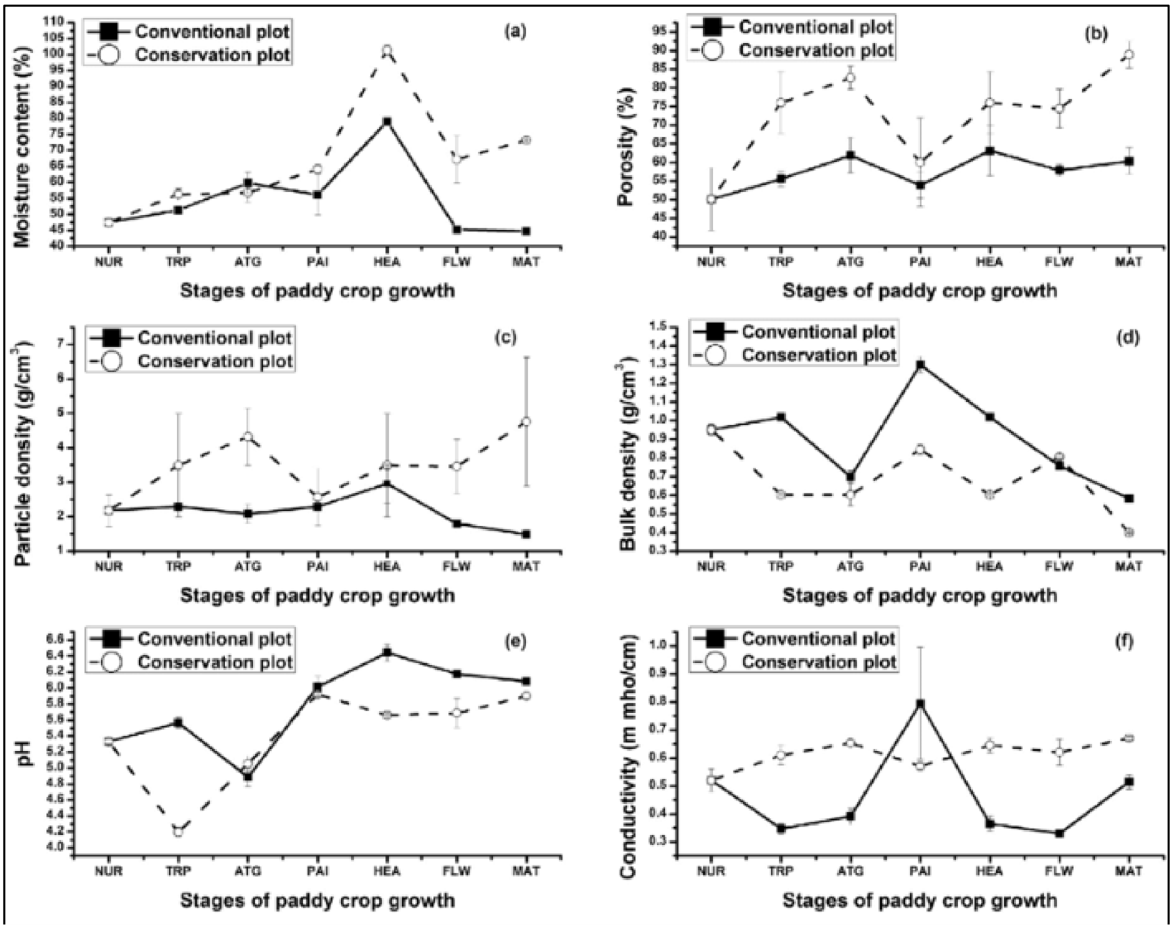


Fig 1: Variation of the soil parameters (a) moisture content (b) porosity (c) particle density (d) bulk density (e) pH (f) conductivity observed in the two experimental plots, during the various stages of paddy crop growth (NUR: Nursery stage, TRP: Transplantation, ATG: Active tillering, PAI: Panicle initiation, HEA: Heading, FLW: Flowering, MAT: Maturation) [Source: Dutta and Gokhale, 2017] [18]

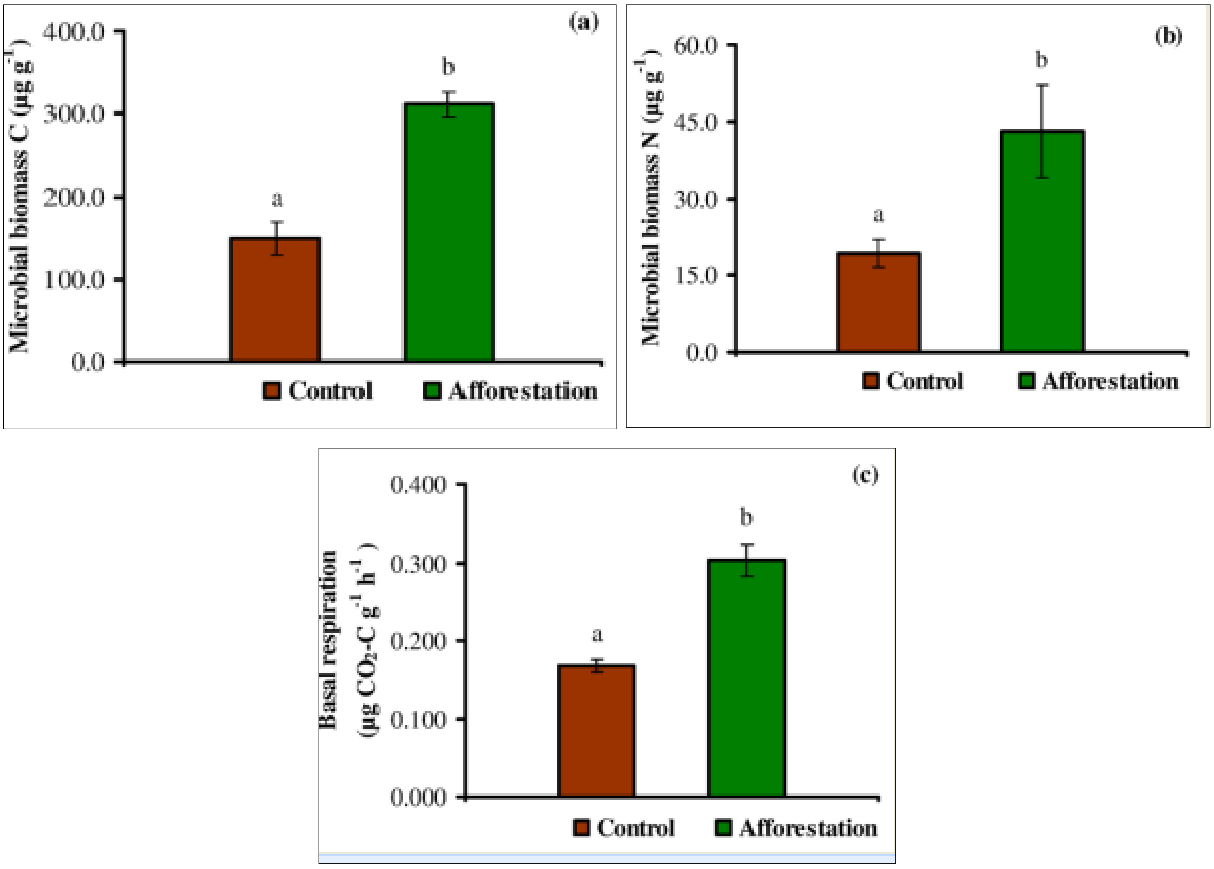


Fig 2: Changes in mean soil microbial biomass C (a), soil microbial biomass N (b) and soil basal respiration (c) in the soil at the control and afforestation [Source: Bolat *et al*., 2016] [6]

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