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# Minimal soil disturbance and residue retention increasing soil organic stocks and soil microbial biomass in Typic Ustochrept soil: A review

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## 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. 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. Moreover, NT treatments significantly increased SOC concentration of bulk soil, >0.25 aggregate, and <0.25 mm aggregate in the 0−5 cm soil layer by 5.8%, 6.8% and 7.9% relative to CT treatments, respectively. S treatments had higher SOC concentration of bulk soil (12.9%), >0.25 mm aggregate (11.3%), and <0.25 mm aggregate (14.1%) than NS treatments. Compared with CT treatments, NT treatments increased MBC by 11.2%, 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. Compared with NS treatments, S treatments significantly increased MBC by 29.8%, 30.2%, and 24.1%, and DOC concentration by 23.2%, 25.0%, and 37.5% of bulk soil, >0.25 mm aggregate, and <0.25 mm aggregate in the 0−5 cm soil layer, respectively. In conclusion, soil organic carbon fractions (SOC), and microbial biomasses 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 in Typic Ustochrept soil.

**Keywords:** Microbial biomass, tillage, soil organic matter, soil aggregates

## Introduction

Agricultural SOC accumulation is influenced by numerous factors, such as tillage practices (Zhang *et al*., 2013; Liu *et al*., 2014) [36, 17] soil aggregate size (Zhang *et al*., 2013; Devine *et al*., 2014) [36] and microbial functional diversity (Stirling *et al*., 2010; Pritchett *et al*., 2011) [31, 25]. Tillage practices can affect the stability or composition of SOC (Zhang *et al*., 2013; Devine *et al*., 2014) [36, 3] and thus affect SOC concentration and SOC density of the plough layer (Zhang *et al*., 2013) [36]. Conventional intensive tillage (CT) can decrease soil aggregate stability and accelerate soil organic matter oxidation (Gathala *et al*., 2011) [8, 14] thereby threatening sustainable crop production (Mathew *et al*., 2012) [21]. Sustainable soil management can be achieved through conservation tillage practices, including NT and crop residue returning (Hobbs *et al*., 2008) [12]. Conservation tillage significantly reduces soil physical disturbance (Uri, 1999) [32] promotes soil aggregation, and improves soil microorganism dynamics because of more beneficial environmental conditions (Guo *et al*., 2015) [10]. Therefore, investigating the effects of conservation tillage on SOC is necessary for further understanding soil sequestration.

Soil aggregates that control the dynamics of soil organic matter and nutrient cycling are structural units within the soil (Six *et al*., 2004) [28]. The aggregate hierarchy model shows that soil C accumulation in a given system may comprise a hierarchy of biological processes at the

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spatial dimension of soil physical structure (Lavelle *et al*., 2004) [15]. Ettema and Wardle, (2002) [15] reported that soil biota should be recognized at different spatial scales to understand their functions better in the ecosystem. Zhang *et al*. (2013) [36] also reported that previous studies mainly focused on the effects of microorganisms on the vertical and horizontal orientations of soil profiles and ignored the effects on the micro-spatial dimension of soil physical structure. Therefore, investigation of SOC driven by soil microbial community processes within soil aggregates will help elucidate the regulation of soil biota in soil C storage.

Soil microorganisms significantly affect the health of an agro-ecosystem through their functions in residue decomposition and nutrient cycling, as well as their associations with other organisms Dong *et al*. (2014) [4]. The activities and compositions of soil microbial community and their interactions with environmental factors affect SOC dynamics and crop productivity (Dong *et al*., 2014) [4]. Direct measurements of metabolic diversity of soil microbial communities are likely to provide more relevant information regarding soil functions compared with measurements of species diversity Giller *et al*. (1997) [9] because soil micro-organisms generally present in resting or dormant stages, in which they are not functionally active White and MacNaughton, (1997) [34]. Biology system, a rapid community-level approach for assessing patterns of sole C source utilization, is used to study microbial community metabolic activities (Nautiyal *et al*., 2010) [24]. Several studies used the biology system to differentiate microbial communities from diverse habitats (Nautiyal *et al*., 2010) [24]. However, only a few these studies determined the relationship between soil microbial metabolic activities and SOC, especially within aggregates, in rice–wheat cropping systems. The effects of conservation tillage on rice–wheat cropping systems are well demonstrated (Guo *et al*., 2015; Kumari *et al*., 2011; Naresh *et al*., 2012) [10, 14, 22]. However, limited attention has been given to the relationship between SOC and microbial metabolic characteristics within aggregate fractions under conservation tillage in the rice–wheat system. Thus, this paper reviewed that (1) microbial metabolic activity is improved by conservation tillage at the small-scale in soil in the plow layer, and (2) the potential associations among tillage systems (straw systems), microbial metabolic activities, organic C fractions, and SOC to elucidate the relationship better between soil microbial metabolic diversity and SOC within aggregates.

Bolat *et al*., (2016) [2] 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.1]. 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. 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) [13], the higher input of root exudates and plant residues (García-Orenes *et al*., 2010) [7], and the chemical composition of litter.

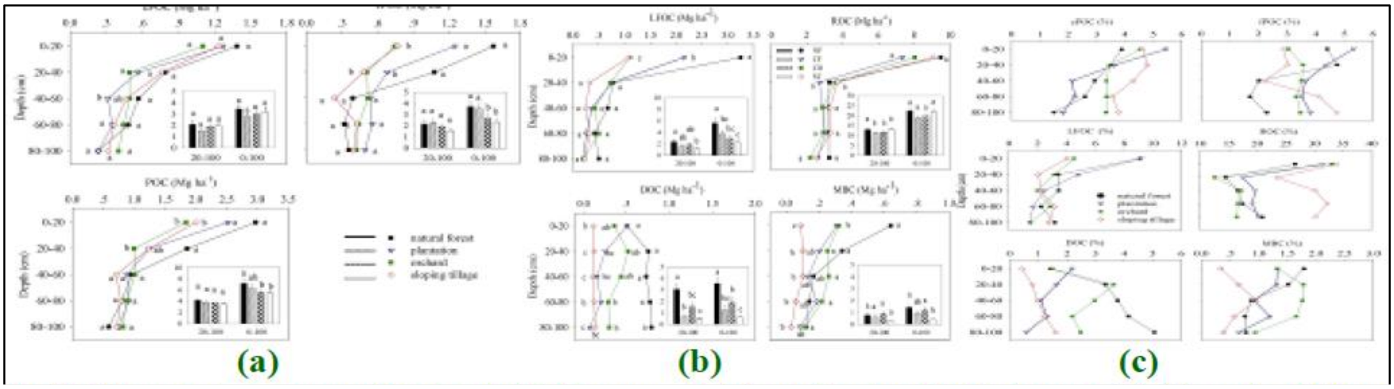


**Fig 1:** Changes in mean soil microbial biomass C (a), soil microbial biomass N (b) and soil basal respiration (c) in the soil at the control and afforestation [Source: Bolat *et al*., 2016] [2]

Xiaojun *et al*. (2013) [35] also found that both SOC and MBC contents increased downslope in a roughly consecutive increment [Fig.2a]. 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.2a] 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.2a].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) [33]. Ma *et al*., (2016) [19] 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.2b]. Malviya, (2014) [20] 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.2c]. Malviya, (2014) [20] 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.2c]. Spedding *et al*., (2004) [30] 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.

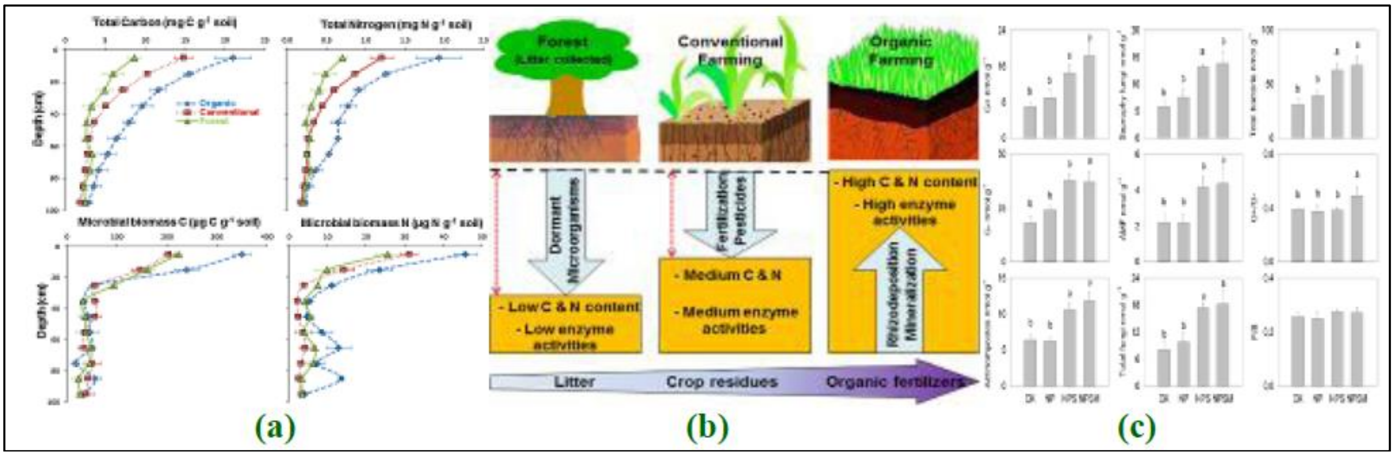
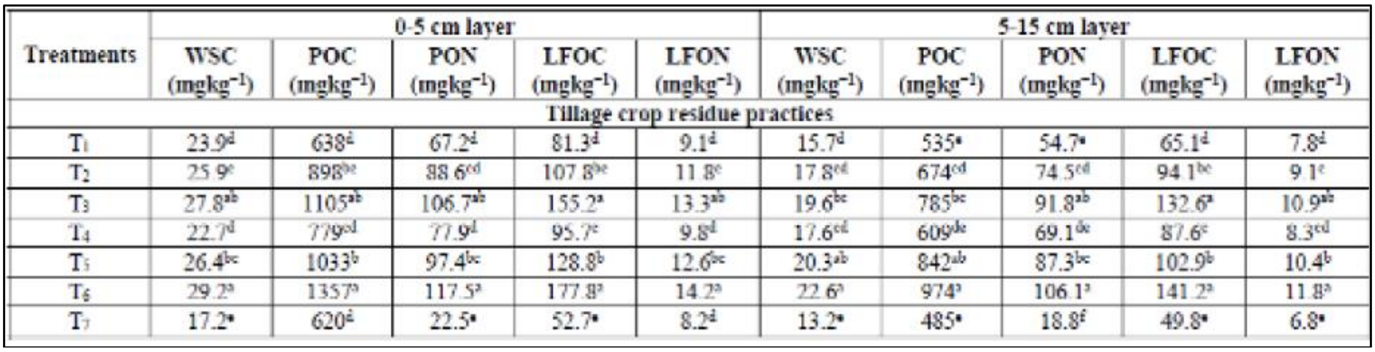


**Fig 2 (a):** Distribution of SOC and MBC contents over eroded slopes. (a) Gentle slope landscape; (b) steep slope landscape [Source: Xiaojun *et al*., 2013] [35] **(b):** Microbial biomass carbon content with depth under traditional tillage (TT), flat raised bed with controlled traffic and zero tillage (FB) and permanent raised bed (PRB) [Source: Ma *et al*., 2016] **(c):** Effect of soil microbial biomass carbon (µg c $g^{-1}$ of soil) under different tillage systems [Source: Malviya, 2014] [20]

Naresh *et al*., (2017) [23] 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].

**Table 1:** Effect of 15 years of application of treatments on contents of various labile fractions of carbon in soil [Naresh *et al*., 2017] [23]



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

Sheng *et al*. (2015) [27] 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.3a]. POC stock in topsoil was more sensitive to land use change than that in subsoil [Fig.3a]. Regarding the different POC components, only $_{f}$POC stock in 0-20 cm topsoil decreased by 21%, 53%, and 51% after natural forest conversion to plantation, orchard, and sloping tillage, respectively [Fig. 3a]. Significant loss of LFOC occurred not only in topsoil, but also in subsoil below 20 cm following land use change [Fig.3b]. The decrease in ROC stock through the soil depth profile following land use change was smaller than that of LFOC [Fig.3b]. 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.3b]. 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 $_{f}$POC, LFOC, and MBC to SOC decreased, while those of ROC and $_{c}$POC increased following land use change [Fig.3c]. In subsoil, only the ratio of DOC to SOC decreased, the ratios POC, $_{f}$POC and ROC to SOC increased, and those of LFOC and MBC remained constant following land use change. In the topsoil, ratios $_{f}$POC, LFOC, DOC and MBC to SOC were more sensitive to conversion from natural forest to sloping tillage than SOC [Fig.3c].

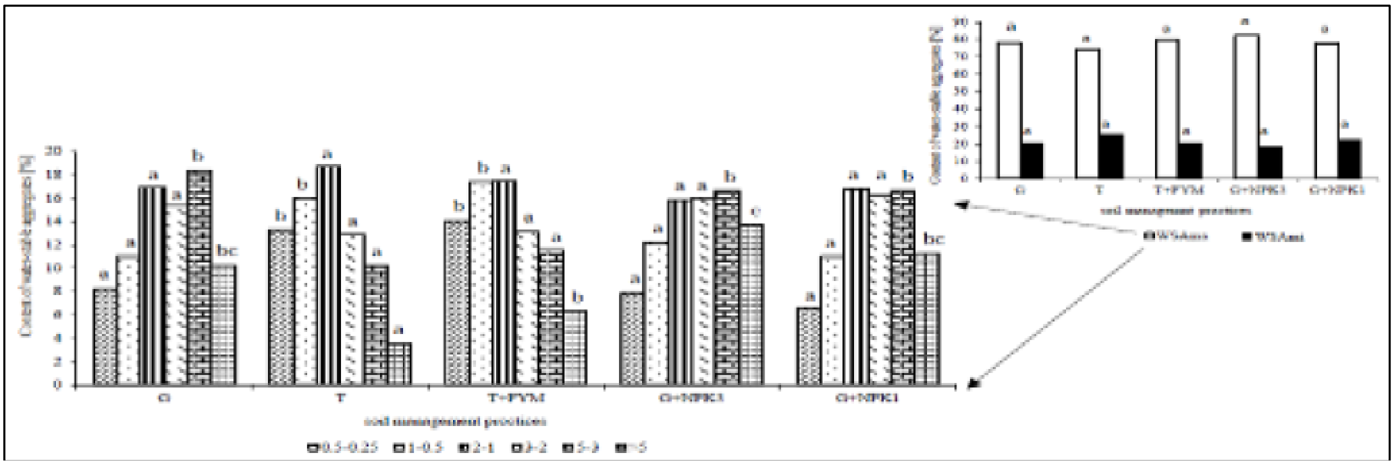
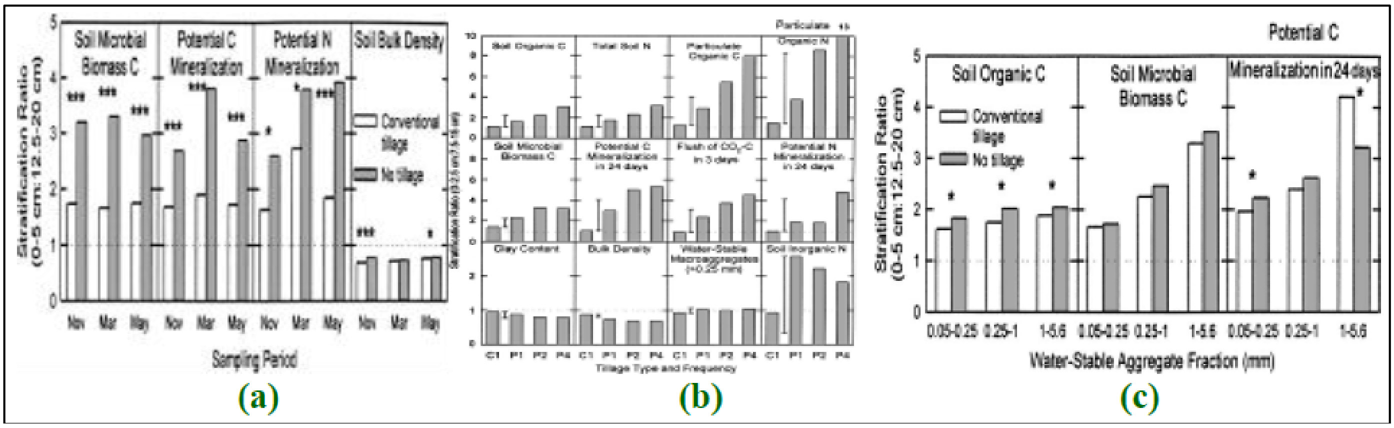


**Fig 3(a)**: POC stocks and those of its components ($_c$POC, $_f$POC) in relation to depth and land use systems in subtropical condition [Source: Sheng *et al*., 2015] [27] **(b)**: LOC fraction stocks in relation to depth and land use systems in subtropical condition [Source: Sheng *et al*., 2015] [27] **(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] [27]

Liu *et al*., (2016) [18] 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. 4a & 4b]. 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) [6] and arable land. At the top 0–5 cm depth, the MBC: MBN ratio was highest under grassland and lowest under PT [Fig.4c]. 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. 4c]. At the 15–25 cm depth, the MBC: MBN ratios were generally lower under PT and NT than grassland and forestland [Fig.4c]. 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. 4c]. 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.



(a)

(b)

(c)

**Fig 4:** 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] [18]

Zhao *et al*. (2018) [37] also found that relative to the control, the proportion of large and small macro-aggregates in the 0–20 cm soil layer increased the most in MR-WR (32% and 24%), followed by MR (22% and 13%), and WR (11% and 10%). Straw return significantly increased the SOC content in each soil aggregate size class relative to no straw return. The order of SOC fractions with respect to SOC content was $_m$SOM > fine $_i$POM > coarse $_i$POM > free LF. Straw return significantly increased the C stock in $_i$POM and $_m$SOM relative to the control. Coarse $_i$POM was the most sensitive indicator of C change and $_m$SOM was the main form of SOC under long-term straw return [Fig. 5a & 5b], [Fig.6a & 6b]. Soil depth had a significant influence on almost all measurements, with greater values observed in the 0–20 cm layer than in the 20–40 cm layer. All three straw return treatments (MR-WR, MR and WR) largely improved the SOC stock in each aggregate fraction in the 0–20 cm depth; increases were highest in MR-WR, followed by MR, and finally WR [Fig. 5b]. In the 20–40 cm layer, the SOC stock of small macro-aggregates significantly increased in MR-WR, but the SOC stock in the silt plus clay fraction decreased relative to other three treatments. Higher OC content of micro-aggregates due to straw return may be beneficial to long-term SOC sequestration because micro-aggregates have a longer turnover time and higher stability relative to macro-aggregates (Qiao *et al*., 2015) [26] [Fig. 5a]. The carbon content of soil aggregates was much lower in the 20–40 cm layer than in the 0–20 cm layer because the field machinery used mainly distributed straw within the topsoil. Fine particulate OC of small macro-aggregates tended to increase with increasing straw input in the 0–20 cm layer [Fig. 6a], indicating that increased straw input is conducive to the formation of micro-aggregates due to the positive role of intra-POM on the formation and stability of micro-aggregates (Six and Paustian, 2014) [29]. The proportions of $_m$SOM (29.1–32.9%) and $_i$POM (8.9–13.2%) [Fig. 6b] suggest that $_m$SOM and $_i$POM promote a longer turnover time and preferential storage conditions, resulting in a long-term C stock (Li *et al*., 2016) [16].

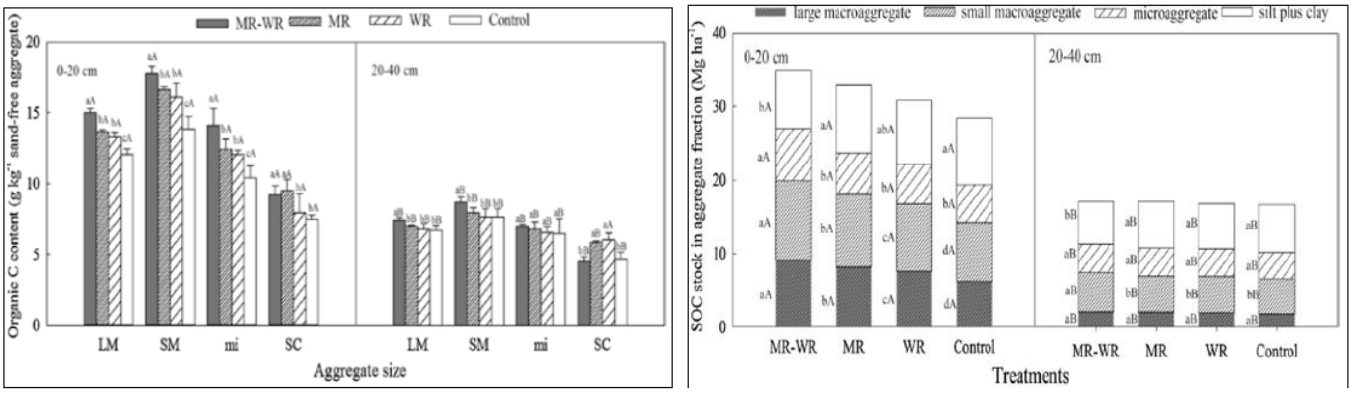


**Fig 5 (a):** Organic C content (g kg$^{-1}$ aggregate) of aggregates: LM, SM, mi, and SC in the 0–20 cm and 20–40 cm soil layers under MR-WR, MR, WR, and Control [Source: Zhao *et al*., 2018] [37]. **(b):** SOC stock of aggregate fractions (Mg ha$^{-1}$): large macro-aggregates, small macro-aggregates, micro-aggregates, and silt plus clay in the 0–20 cm and 20–40 cm soil layers under MR-WR, MR, WR, and Control [Source: Zhao *et al*., 2018] [37].

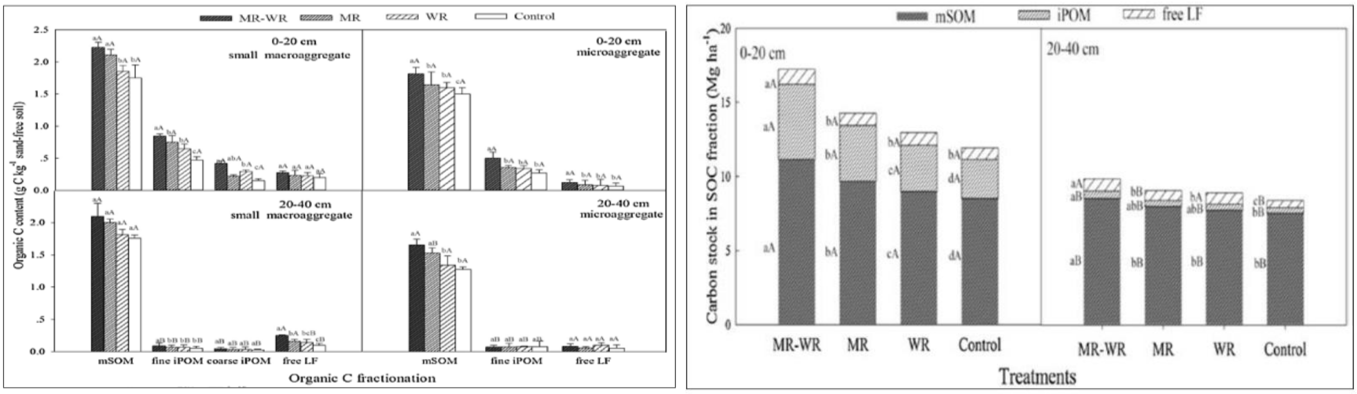


**Fig 6(a):** Organic C content (g kg$^{-1}$ soil) of the SOC fractions: coarse iPOM, fine iPOM, mSOM, and free LF of small macro-aggregates and micro-aggregates in the 0–20 cm and 20–40 cm soil layers under MR-WR, MR, and WR [Source: Qiao *et al*., 2015] [26]. **(b):** Carbon stock of $_m$SOM, $_i$POM, and free LF (small macro-aggregates and micro-aggregates) in the 0–20 and 20–40 cm soil layers under MR-WR, MR, WR, and Control [Source: Qiao *et al*., 2015] [26].

## Conclusion

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 $_f$POC, 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.

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.

## References

1. Agnelli A, Ascher J, Corti G, Ceccherini MT, Nannipieri P, Pietramellara G. 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. 2004; 36:859-868.
2. Bolat I, Kara Ö, Sensoy H, Yüksel K. Influences of Black Locust (*Robinia pseudoacacia* L.) afforestation on soil microbial biomass and activity. Forest. 2016; 9:171-177.
3. Devine S, Markewitz D, Hendrix P, Coleman D. Soil aggregates and associated organic matter under conventional tillage, no-tillage, and forest succession after three decades. Plos One 9:e84988. 2014, doi: 10.1371/journal.pone.0084988 PMID: 24465460
4. Dong HY, Kong CH, Wang P, Huang QL. Temporal variation of soil friedelin and microbial community under different land uses in a long-term agro-ecosystem. Soil Bio Biochem. 2014; 69:275-281
5. Ettema CH, Wardle DA. Spatial soil ecology. Trends in Ecology & Evolution. 2002; 17:177-183.
6. Fierer N, Schimel JP, Holden PA. Variations in microbial community composition through two soil depth profiles. Soil Bio. Biochem. 2003; 35:167-176.
7. García-Orenes F, Guerrero C, Roldán A, Mataix-Solera J, Cerdà A, Campoy M *et al*. Soil microbial biomass and activity under different agricultural management systems in a semiarid Mediterranean agro-ecosystem. Soil Tillage Res. 2010; 109(2):110-115.
8. Gathala MK, Ladha JK, Saharawat YS, Kumar V, Sharma PK. Effect of tillage and crop establishment methods on physical properties of a medium-textured soil under a seven-year rice-wheat rotation. Soil Water management conservation. Soil Sci Soc Am J. 2011; 75:851-1862.
9. Giller KE, Beare MH, Lavelle P, Izac AMN, Swift MJ. Agricultural intensification, soil biodiversity and agro-ecosystem function. Appl Soil Ecol. 1997; 6:3-16
10. Guo LJ, Zhang ZS, Wang DD, Li CF, Cao CG. Effects of short-term conservation management practices on soil organic carbon fractions and microbial community composition under a rice-wheat rotation system. Bio. Fertility Soils. 2015; 51:65-75
11. Guo LJ, Lin S, Liu TQ, Cao CG, Li CF. Effects of Conservation Tillage on Topsoil Microbial Metabolic Characteristics and Organic Carbon within Aggregates under a Rice (*Oryza sativa* L.) –Wheat (*Triticum aestivum* L.) Cropping System in Central China. *PLoS ONE* 2016; 11(1):e 0146145. doi:10.1371/journal.pone.0146145
12. Hobbs PR, Sayre K, Gupta R. The role of conservation agriculture in sustainable agriculture. Philosophical Transactions of the Royal Society. 2008; B363:543-555.
13. Kara O, Bolat I. Soil microbial biomass C and N changes in relation to forest conversion in the north-western Turkey. Land Degrad Dev. 2008; 19(4):421-428
14. Kumari M, Chakraborty D, Gathala MK, Pathak H, Dwivedi BS, Tomar RK *et al*. Soil aggregation and associated organic carbon fractions as affected by tillage in a rice-wheat rotation in North India. Soil Bio Biochem. 2011; 75:560-567.
15. Lavelle P, Bignell D, Austen MC, Brown VK, Behan-Pelletier V, Garey JR *et al*. Vulnerability of ecosystem services at different scales: role of biodiversity and implications for management. In: Wall DH (Ed.), Sustaining Biodiversity and Functioning in Soils and Sediments. Island Press, New York, 2004.
16. Li S, Gu X, Zhuang J, An T, Pei J, Xie H *et al*. Distribution and storage of crop residue carbon in aggregates and its contribution to organic carbon of soil with low fertility. Soil Tillage Res. 2016; 155:199-206.
17. Liu C, Lu M, Cui J, Li B, Fang C. Effects of straw carbon input on carbon dynamics in agricultural soils: a meta-analysis. Glob Change Biol. 2014; 20:1366-1381.
18. Liu M, David AN, Ussiri, Lal R. Soil Organic Carbon and Nitrogen Fractions under Different Land Uses and Tillage Practices. Comm Soil Sci Plant Anal. 2016; 47(12):1528-1541.
19. Ma Z, Chen J, Lyu X, Liu Li-li, Siddique KHM. 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. 2016; 163:274-281.
20. Malviya SR. 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., 2014.
21. Mathew RP, Yu CF, Githinji L, Githinji L, Ankumah R, Balkcom KS. Impact of no-tillage and conventional tillage systems on soil microbial communities. Appl Environ Soil Sci. 2012. doi:10.1155/ 2012/548620
22. Naresh RK, Singh SP, Chauhan P. Influence of conservation agriculture, permanent raised bed planting and residue management on soil quality and productivity in maize–wheat system in western Uttar Pradesh. Int. J Life Sc. BT & Pharm. Res. 2012; 1(4):27-34.
23. Naresh RK, Arvind Kumar, Bhaskar S, Dhaliwal SS, Vivek, Satendra Kumar *et al*. 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. 2017; 6(6):670-683
24. Nautiyal CS, Chauhan PS, Bhatia CR. Changes in soil physico-chemical properties and microbial functional diversity due to 14 years of conversion of grassland to organic agriculture in semi-arid agro-ecosystem. Soil Tillage Res. 2010; 109:55-60
25. Pritchett K, Kennedy AC, Cogger CG. Management effects on soil quality in organic vegetable systems in western Washington. Soil Sci Soc Am J. 2011; 75:605-615.
26. Qiao YF, Miao SJ, Li N, Xu YL, Han XZ, Zhang B. Crop species affect soil organic carbon turnover in soil profile and among aggregate sizes in a Mollisol as estimated from natural C-13 abundance. Plant Soil. 2015; 392:163-174.
27. Sheng H, Zhou P, Zhang Y, Kuzyakov Y, Zhou Q, Ge T *et al*. Loss of labile organic carbon from subsoil due to land-use changes in subtropical China. Soil Biol Biochem. 2015; 88:148-157
28. Six J, Bossuyt H, Degryze S, Denef K. A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. Soil Tillage Res. 2004; 79:7-31.
29. Six J, Paustian K. Aggregate-associated soil organic matter as an ecosystem property and a measurement tool. Soil Biol. Biochem. 2014; 68:A4-A9.
30. Spedding TA, Hamel C, Mehuys GR, Madramootoo CA. Soil microbial dynamics in maize-growing soil under

different tillage and residue management systems. Soil Biol. Biochem. 2004; 36:499-512.

31. Stirling FR, Moody PW, Stirling AM. The impact of an improved sugarcane farming system on chemical, biochemical and biological properties associated with soil health. Appl Soil Ecol. 2010; 46:470-477.
32. Uri ND. Factors affecting the use of conservation tillage in the United States. Water, Air, Soil Pollu. 1999; 116:621-638.
33. Vineela C, Wani SP, Srinivasarao CH, Padmaja B, Vittal KPR. 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. 2008; 40:165-173.
34. White DC, MacNaughton SJ. Chemical and molecular approaches for rapid assessment of the biological status of soils. In: Pankhurst CE, Doube BM, and Gupta VVSR (Eds.), Biological Indicators of Soil Health. CAB, Wallingford, 1997, 371-396
35. Xiaojun N, Jianhui Z, Zhengan S. Dynamics of Soil Organic Carbon and Microbial Biomass Carbon in Relation to Water Erosion and Tillage Erosion. PLoS ONE 2013; 8(5):e64059. doi:10.1371/journal.pone.0064059
36. Zhang S, Li Q, Lü Y, Zhang X, Liang W. Contributions of soil biota to C sequestration varied with aggregate fractions under different tillage systems. Soil Biol Biochem. 2013; 62:147-156.
37. Zhao H, Shar AG, Li Shuo, Chen Y, Shi J, Zhang X *et al*. Effect of straw return mode on soil aggregation and aggregate carbon content in an annual maize-wheat double cropping system. Soil Tillage Res. 2018; 175:178-186.