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Conservation tillage and residue management induced changes in soil organic carbon dynamics and soil microbial biomass in sub-tropical ecosystem: A review

Lali Jat, RK Naresh, Mohan Lal Jat, Swati Chaturvedi, Richa Tiwari and Alka Dev

Abstract
Tillage systems can changes in soil organic carbon dynamics and soil microbial biomass by changing aggregate formation and C distribution within the aggregate. However, the effects of tillage method or straw return on soil organic C (SOC) have showed inconsistent results in different soil/climate/ cropping systems. Soil TOC and labile organic C fractions contents were significantly affected by straw returns, and were higher under straw return treatments than non-straw return at three depths. At 0–7 cm depth, soil MBC was significantly higher under plowing tillage than rotary tillage, but EOC was just opposite. Rotary tillage had significantly higher soil TOC than plowing tillage at 7–14 cm depth. However, at 14–21 cm depth, TOC, DOC and MBC were significantly higher under plowing tillage than rotary tillage except for EOC. Compared with conventional intensive tillage (CT) and no tillage (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 preceding crop residue returning (S, 2100−2500 kg C ha^{-1} treatments, and removal (NS, 0 kg C ha^{-1}) 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. Conservation tillage (NT and S) increased microbial metabolic activities and microbial index in >0.25 and <0.25 mm aggregates in the 0−5 cm soil layer. Responses of macro-aggregates to straw return showed positively linear with increasing SOC concentration. Straw-C input rate and clay content significantly affected the response of SOC. Overall, straw return was an effective means to improve SOC accumulation, and soil quality. Straw return-induced improvement of soil nutrient availability may favor crop growth, which can in turn increase ecosystem C input. Tillage reduction and residue retention 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.

Keywords: Microbial biomass, conservation tillage, organic matter dynamics, straw return, soil sequestration rate

Introduction
Soil organic C is a dynamic pool determined by the opposing processes of C inputs and losses. Promoting accretion of soil organic C depends mainly on modifying the input–output relationships, i.e. by increasing inputs or decreasing losses, or by a combination of both. Conservation tillage is promoted, in part, for its beneficial effects on carbon retention that occur with time. Reducing tillage affects several aspects of the soil. With time, conservation tillage improves soil quality indices (Lal *et al*., 1998) [46], including soil organic C storage (Potter *et al*., 1998) [62]. Several factors probably contribute to the rate of soil improvement when tillage is reduced. Clay content, soil fertility, and crop diversity (Bruce *et al*., 1995) [8] influence the changes in soil properties. Grisi *et al*. (1998) [29] concluded that organic matter in tropical soils is more humified than that in temperate soils. This is an important aspect of C sequestration since humified C is reported to be the largest and least variable fraction of soil organic C (Rosell *et al*., 2000) [68], and constitutes the longest lived soil C fraction.
The slight positive effect of tillage reduction and the fact that fertilization had little effect on organic C sequestration in that study suggest that the physical environment, characterized by hot and relatively dry conditions constitutes a great challenge to increasing soil organic matter content. Another mechanism by which soil organic matter is retained in conservation-tillage

systems may be due to reduced oxygen availability below the surface of no-till systems, which affects decomposition rates (Wershaw, 1993) [84] and the distribution of aerobic and anaerobic microbes and microbial processes (Doran, 1980) [17]. Slower subsurface decomposition rates would lower oxidative losses of organic C. Residues left onthe surface often undergo wider fluctuations in moisture content, ranging from wet to dry (Franzluebbers *et al*., 1994) [24], and these extremes are a clear contrast to the environmental conditions of buried residues (Schomberg *et al*., 1994) [69]. Buried residues decomposed at 3.4 times the rate of residues left on the soil surface (Beare *et al*., 1993) [3]. This suggests that reduced oxygen availability may not decrease decomposition rate as much as greater soil–residue contact and improved moisture conditions accelerate it.

Reduced residue–soil contact and extreme variation in moisture and temperature at the soil surface undoubtedly play significant roles in reducing surface residue decomposition rates. However, surface (0–30 cm) soil itself in a no-till system was shown to contain more moisture and to be cooler than a comparable plow tillage soil (Doran *et al*., 1998) [18]. In addition to increases in soil organic matter concentration (Martens, 2001) [53], changes attributable to a reduction in tillage intensity have also been demonstrated for soil microbes and microbial activity (Martens, 2001) [53], and for soil physical properties, including soil structure. The biological component of soil can be a good integrator of factors that affect soil quality (Potter *et al*., 1998) [62]. Microbial biomass is the smallest portion of organic C in soil (Martens, 2001) [53]. Microbial biomass is more sensitive to changes in soil conditions than is the content of total C (Sparling, 1992) [77], and it has been proposed that the ratio of microbial C to total C in the soil (C_{mic}: C_{org}) may be a sensitive index of changes in soil organic matter dynamics (Wardle, 1992) [83]. Tillage greatly affects the size of soil microbial biomass (Martens, 2001) [53].

It is well known that bacteria play important roles in several biogeochemical soil processes (Falkowski *et al*., 2008) [21]. The soil is a heterogeneous matrix with a vast diversity of physical and chemical characteristics, which lead to a wide range of different niches that can sustain a large microbial diversity. Agriculture is one of the most impacting anthropogenic activities that affect the soil physical, chemical and biological properties of the soils, and consequently, their functioning. Conservational agriculture practices, i.e. reduced tillage, crop residue retention, and crop rotation, have been proposed as alternative to monoculture, crop removal and tillage as they improve soil structure, increase soil organic matter content and increase yields (Ussiri *et al*., 2009) [81]. Improved soil structure facilitates soil aeration, diffusion of water and nutrients through the soil profile, moderates soil temperatures and reduces erosion (Doran *et al*., 1998) [18]. These improvements in soil quality and organic matter content can also increase soil microbial diversity, and it is then expected that soils with conventional agricultural practices will contain different bacterial communities in terms of structure, diversity and abundance than those with conservation practices.

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) [17]. Holland and Coleman (1987) [32] 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) [9], 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) [78] and by increasing cropping intensity (Doran *et al*., 1998) [18]. Stratification of soil properties is a natural consequence of soil development that can become accentuated in soils subjected to reduced tillage. Unger (1991) [80] 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) [5]. Naresh *et al*. (2017) [59] 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) [15] 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) [82] in which carbon accretion was not apparent in all soils in that trial. Plowing was shown to move dispersed organic C from the 0–20 cm soil depth down to the 60– 80 cm depth in corn plots (Romkens *et al*., 1999) [67]. Therefore, the review paper would be beneficial for determining how tillage and residue management practices influence soil organic carbon dynamics and soil microbial biomass.

Zibilsk *et al*. (2002) reported that the No-till resulted in significantly greater soil organic C in the top 4 cm of soil, where the organic C concentration was 58% greater than in the top 4 cm of the plow-till treatment. In the 4–8 cm depth, organic C was 15% greater than the plow-till control [Fig.1a]. The differences were relatively modest, but consistent with organic C gains observed in hot climates where conservation tillage has been adopted. Higher concentrations of total soil N occurred in the same treatments; however a significant reduction in N was detected below 12 cm in the ridge-till treatment [Fig.1c]. The relatively low amount of readily oxidizable C (ROC) in all tillage treatments suggests that much of the soil organic C gained is humic in nature which would be expected to improve C sequestration in this soil [Fig.1b].

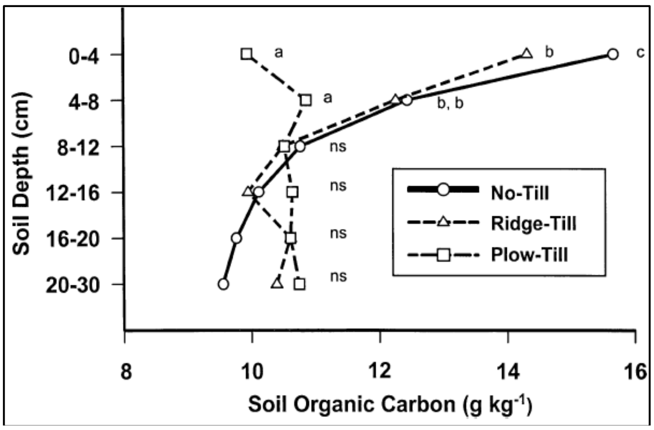

Fig 1(a): Soil organic carbon by depth after 9 years of no-till, ridge-till or plow-till treatment [Source: Zibilsk *et al*., 2002]

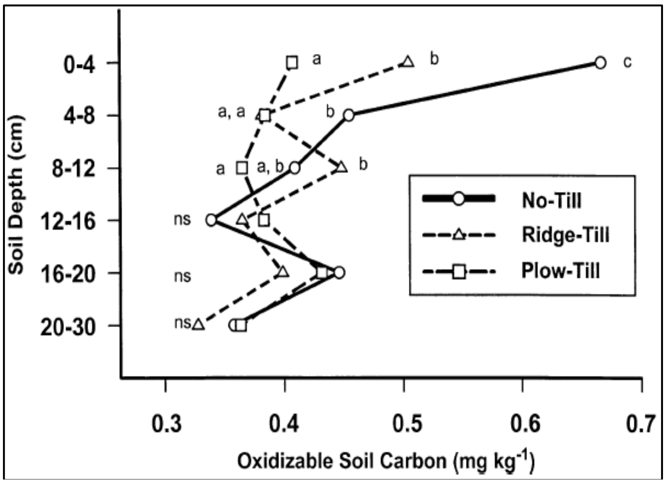

Fig 1(b): Readily oxidizable soil carbon by depth after 9 years of no-till, ridge-till or plow-till treatment [Source: Zibilsk *et al*., 2002]

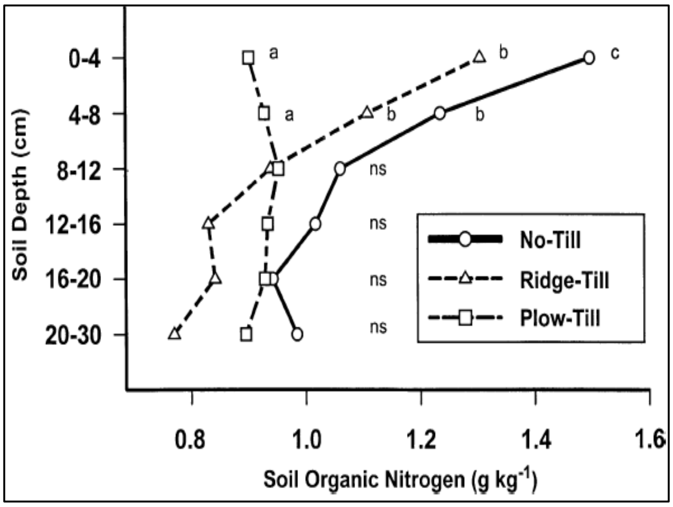

Fig 1(c): Total soil nitrogen by depth after 9 years of no-till, ridge-till or plow-till treatment [Source: Zibilsk *et al*., 2002]

Huggins *et al*. (2014) [34] revealed that tillage by crop sequence interactions occurred as treatments with MP and SS as well as fallow averaged 135 Mg SOC ha^{-1} (0- to 45-cm depth), while CP treatments with corn (CC and CS) and NT with CC averaged 164 Mg SOC ha^{-1}. Crop sequence effects on SOC (0- to 45-cm depth) occurred when tillage was reduced with CP and NT averaging 15% greater SOC in CC than SS [Fig.2a]. Depth distributions of SOC provide further data on interactive effects of tillage and differences in crop C inputs associated with crop sequence. Under reduced tillage (CP and NT), the SOC in CC was significantly greater than in SS at all depths with the exception of the 15- to 30-cm depth in NT [Fig.2a]. In addition to less C inputs than CC, SS accelerated rates of SOC decomposition. Tillage effects on SOC were greatest in CC where CP had 26% and NT 20% more SOC than MP, whereas SOC in SS was similar across tillage treatments [Fig.2b]. Up to 33% of the greater SOC under CC for CP and NT, compared with MP, occurred below tillage operating depths. Substantial losses of SOC were estimated (1.6 Mg SOC ha^{-1} yr^{-1}) despite lowering SOC decay rates with reduced tillage and high levels of C inputs with CC. Jacinthe and Lal, (2009) [38] also found that the soil properties were strongly correlated with recent SOC, but moderately with geogenic C [Fig.2c]. However, significant effects of tillage on SOC, $_t$-MBC, $_a$-MBC, and metabolic quotient (q_{CO2}) were detected in the 0- to 5-cm soil layer in conjunction with the lower q_{CO2} in the surface soil layer of NT, suggests a more efficient C utilization by soil microbes under NT than under MP [Fig.2c].

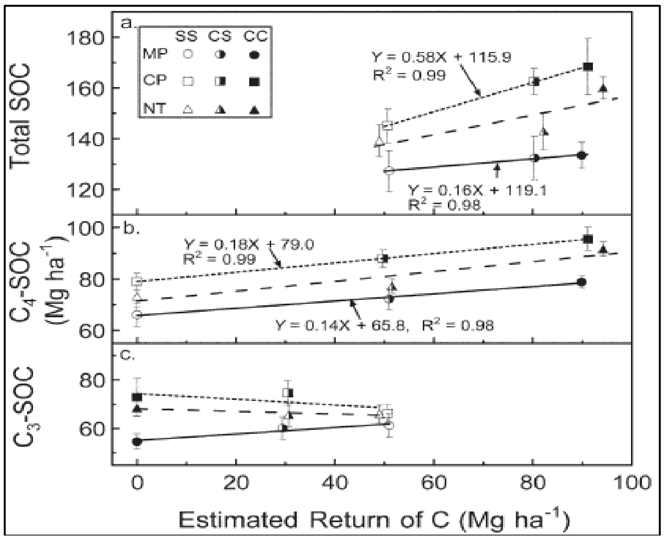

Fig 2(a): Tillage and crop sequence effects on total soil organic C (0–45 cm), C_4–derived SOC (0–45 cm), C_3–derived SOC (0–45 cm) and relationship to estimated C return [Source: Huggins *et al*., 2014].

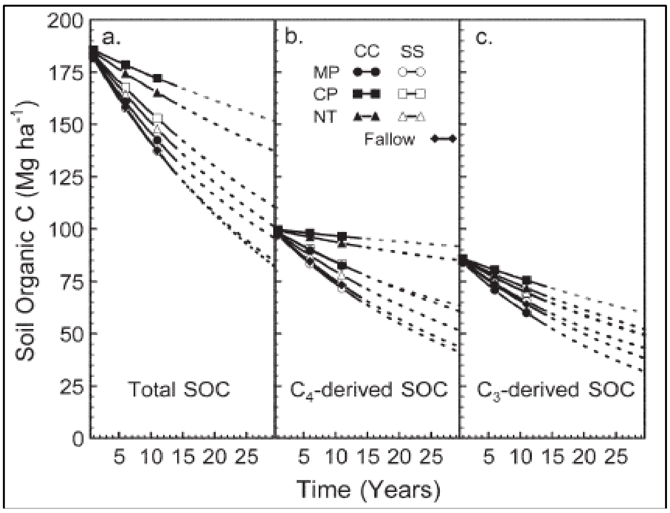

Fig 2(b): Thirty year simulation of tillage and crop sequence effects on total soil organic C, C_4 derived SOC and C_3–derived SOC [Source: Huggins *et al*., 2014].

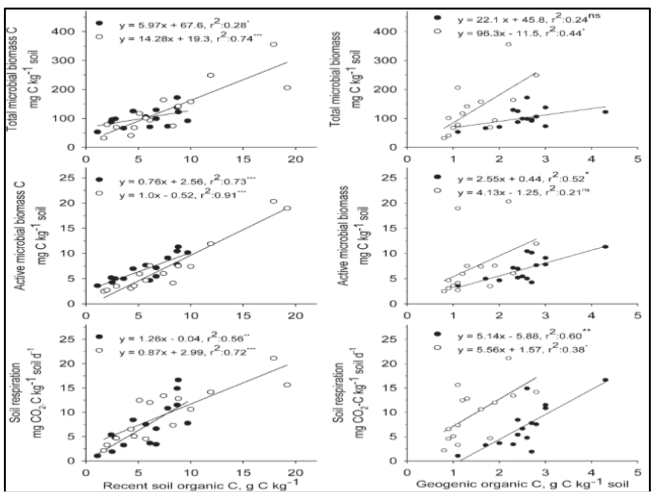

Fig 2(c): Relationships between soil microbial biomass and activity, and recent soil organic carbon and geogenic carbon in reclaimed farmland soils under no-till and conventional tillage [Source: Huggins *et al*., 2014 [34]].

Jacinthe and Lal, (2009) [38] concluded that the rates of C sequestration were estimated from the temporal trend in the recent SOC pool (0– 40 cm in NR (23.2 Mg C ha^{-1}), 9-yr MP (32.9 Mg C ha^{-1}) and 13-yr MP (33 Mg C ha^{-1}), and ranged between 0.8 and 0.25 Mg C ha^{-1} yr^{-1} during the first and second decades of restoration. Despite a similar amount of crop residue returned (2.8 Mg C ha^{-1} yr^{-1}), recent SOC under 13-yr NT (36.8 Mg C ha^{-1}) exceeded that under 13-yr MP by 3.8 Mg C ha^{-1} [Fig.3a]. Liu *et al*. (2014) reported that a strong negative relationship existed between the decomposition of wheat straw and clay content. One possible reason was that biodegradation rates of straws were probably slower in the soil with higher clay content which may lead to lower efficiency of C transferring from straws to soil minerals, i.e., less humified SOC formed in these soils [Fig.3b].

Kushwaha *et al*. (2000) [45] observed that the highest levels of soil MBC and MBN (368±503 and 38.2±59.7µg g^{-1}, respectively) were obtained in minimum tillage residue retained (MT+R) treatment and lowest levels (214±264 and 20.3±27.1µg g^{-1}, respectively) in conventional tillage residue removed (CT-R, control) treatment. Along with residue retention tillage reduction from conventional to zero increased the levels of MBC and MBN (36±82 and 29±104% over control, respectively [Fig.4a]. This increase (28% in of C and 33% N) was maximum in MT+R and minimum (10% for C and N both) in minimum tillage residue removed (MT-R) treatment. In all treatments concentrations of N in microbial biomass were greater at seedling stage, thereafter these concentrations decreased drastically (21±38%) at grain-forming stage of both crops. In residue removed treatments, N-mineralization rates were maximum during the seedling stage of crops and then decreased through the crop maturity [Fig.4a]. The increase in the level of MBC from the seedling to grain-forming stage of crops was probably a result of increased C input from the rhizosphere products to the soil before and during flowering (Xu and Juma, 1993) [86]. When flushes of C were supplied into the soil in the form of crop residue or root, the microbial biomass increased in size until the substrate was depleted and then it decreased due to limitation of C (Singh and Singh, 1993) [74]. In residue retained treatments, however, N-mineralization rates were lower than in residue removed treatments at seedling stage of both crops. At grain-forming stage in all instances the N-mineralization rates in residue retained treatments considerably exceeded the rates in corresponding residue removed treatments [Fig.4b]. Tillage reduction and residue retention both increased the proportion of organic C and total N present in soil organic matter as microbial biomass [Fig.4b]. Hoyt *et al*. (1980) [33] reported greater proportion of soil nitrate-N to ammonium-N in conventional tillage compared to no-tillage and concluded that nitrification was inhibited in no-tillage soils. Commonly two mechanisms of nitrification inhibition in zero tillage are suggested; Acceleration of acidification of the soil surface in zero tillage (Blevins and Frye, 1993) [6] perhaps inhibits nitrifies in some cases, or substrate (NH_4) limitation to nitrifies may be more severe in zero tillage due to less mineralization or less favorable spatial distribution. Doran (1980) [17] pointed out that the microbial population is more anaerobic under no-tillage. Under such conditions slower mineralization and nitrification and greater immobilization and de-nitrification are expected. Soil compaction is also known to reduce N-mineralization rate from the added organic materials and increased N retention in microbial biomass and soil organic matter (Breland and Hansen, 1996) [7]. Miao *et al*. (2018) [54] reported that the contents of SMBC and SSOC decreased with soil depth [Fig.4c]. The SMBC content at the 0–60 cm depth under the SM and RF treatments was significantly higher than that of the FA soil. The SSOC content of soil samples subjected to the CC, SM, and RF treatments was greater than that of the FA soil. The N fertilization rates showed no distinct effect on the content of SMBC or SSOC at the 0–60 cm soil depth [Fig.4c].

Awale *et al*. (2013) [65] also found that compared with CT, ST and NT had significantly higher SOC concentration by 3.8 and 2.7%, SOC stock by 7.2% and 9.2%, CPOM-C by 22 and 25%, and $KMnO_4$-C by 4.8 and 4.1%, respectively in Expt 2 and had significantly higher SOC concentration by 3.9 and 6.6%, SOC stock by 11.9 and 8.7%, and CPOM-C by 33 and 45%, respectively in Expt 3. The $KMnO_4$-C and 30 d cumulative C_{min} were greater under ST than CT by 3.3 and 23%, respectively in Expt 3 [Fig.5a]. Comparatively lower SOC with CT than ST and NT could also be attributed to higher soil temperature favoring rapid C mineralization – resulted from increased soil microbial activities – under CT (Dou *et al*., 2008) [19]. Campbell *et al*. (1996) [10], who documented about 14.5% increment in SOC under NT as compared with CT after 11 years. The amounts of C_{min} were consistently higher under ST and NT than CT throughout the incubation period except at 7 d, in Expt3. Across the study, CPOM-C was 16.3–22.1%, MBC was 3.4–4.5%, cumulative Cmin was 0.7–1.4%, and $KMnO_4$-C was 1.6–1.7% of the total SOC [Fig.5b]. Reduced tillage practices allow C to build-up in the plow layer by enhancing soil aggregation and reducing oxidation (Carpenter-Boggs *et al*., 2003) [12]. Higher C_{min} under NT and ST could be attributed to higher availability of C substrates for decomposition by microbial biomass (Chen *et al*., 2009) [14]. Senapati *et al*. (2014) [70] showed that SOC storages in 2012 were 35.5, 42.6, 40.1 Mg C ha^{-1} under CC/CT, CC/MT and CW/MT, respectively, indicating a loss of SOC under cotton-based cropping systems by 0.69–0.96 Mg C ha^{-1} yr^{-1}. The results represent a higher loss of SOC (31–34%) of the initial SOC storage within 19 years under CC/CT and CW/MT, and comparatively lower loss (24%) under CC/MT [Fig.5c]. Loss of SOC in cotton based cropping systems under intensive conventional tillage is common across the world including Australia. For example, Franzluebbers *et al*. (2012) [25] estimated a loss of SOC by 0.31 ±0.19 Mg C ha^{-1} yr^{-1} in the 0–0.20 m soil depth under conventionally tilled cotton in the cotton belt of the southern USA. Kintche´ *et al*. (2010) [40] observed a loss of SOC by 2.9–3.2 Mg C ha^{-1} in the top 0.20 m soil layer within 30 years in cotton-based cropping systems under conventional tillage and fertilizer application in Togo, semi-arid western Africa. Hulugalle and Scott (2008) [35] reported a loss of SOC by 2.2–3.5 Mg C ha^{-1} yr^{-1} under some cotton-based cropping systems in sub-tropical Australia. Insufficient return of crop residue to the soil, intensive tillage, burning of crop stubble, long bare fallow, excessive water and nitrogen inputs, hot summers and extreme climatic events such as floods and droughts were listed as the reasons of the loss of SOC under cotton cropping systems in Australia.

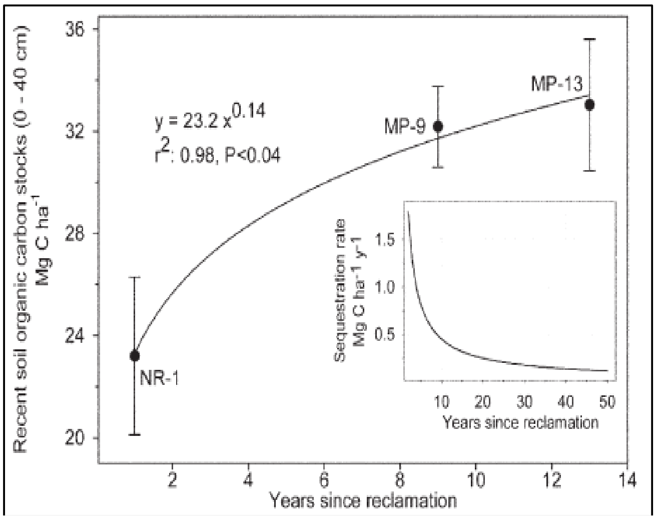

Fig 3(a): Temporal evolution of recent organic carbon (SOC) pools in mineland reclaimed to agricultural land-use under conventional tillage [Source: Jacinthe and Lal, 2009 [38]]

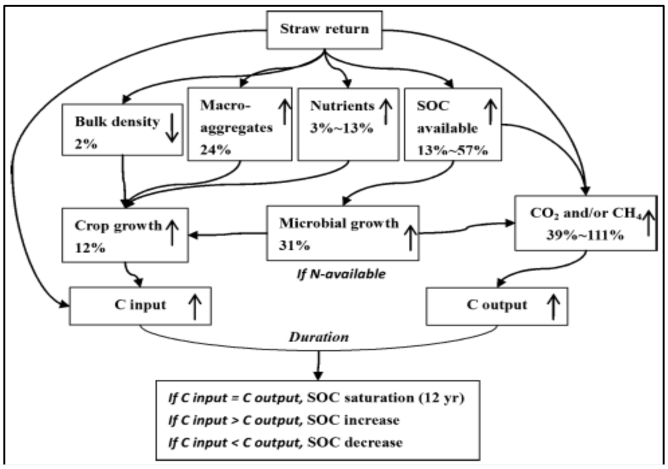

Fig 3(b): A simple mechanism for the responses of soil C dynamics to straw return in agro-ecosystems [Source: Liu *et al*., 2014].

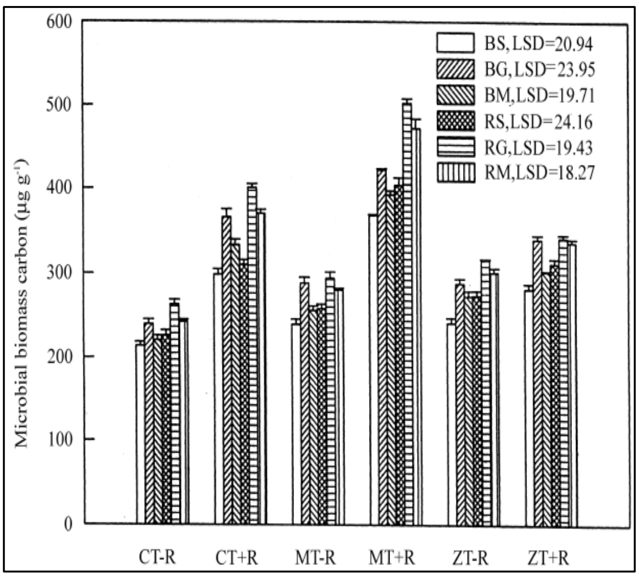

Fig 4(a): Responses of soil microbial biomass carbon (μg g^{-1}) to different tillage and residue manipulation treatments during barley and rice crop periods in a dry-land agro-ecosystem; code: BS, barley seedling stage; BG, barley grain-forming stage; BM, barley maturity stage; RS, rice seedling stage; RG, rice grain-forming stage; RM, rice maturity stage [Source: Kushwaha *et al*., 2000 [45]]

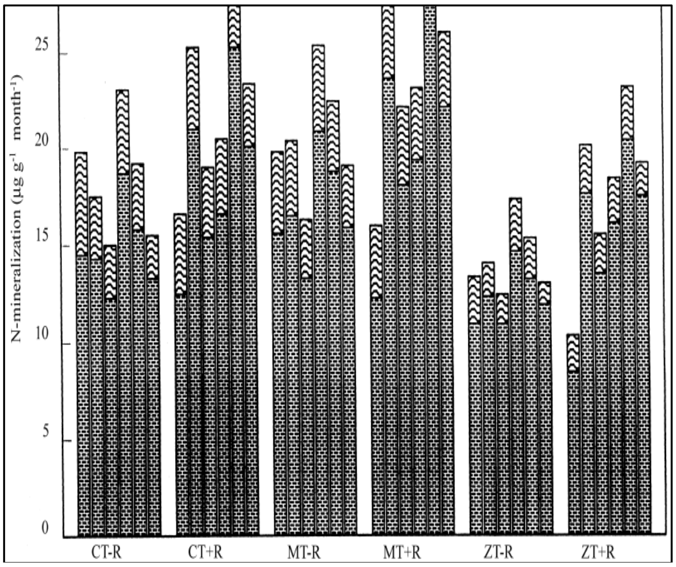

Fig 4(b): Changes in N-mineralization rates (μg g^{-1} per month) due to different tillage and residue manipulation treatments during barley and rice crop periods in a dry-land agro-ecosystem; each bar cluster from left to right represents: barley seedling, barley grain-forming, barley maturity, rice seedling, rice grain-forming and rice maturity stages [Source: Kushwaha *et al*., 2000 [45]]

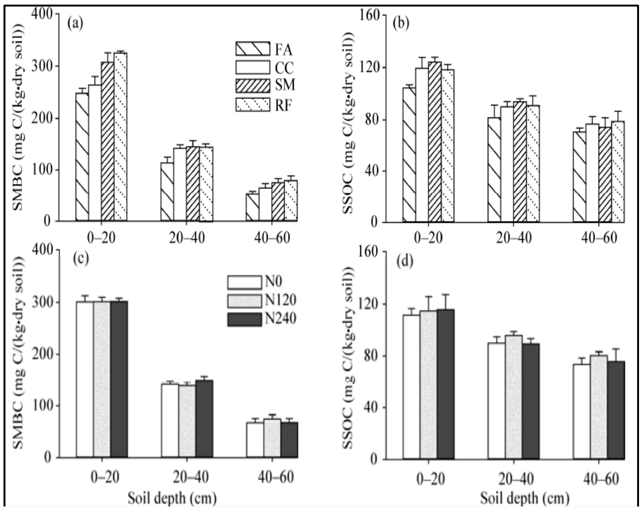

Fig 4(C).

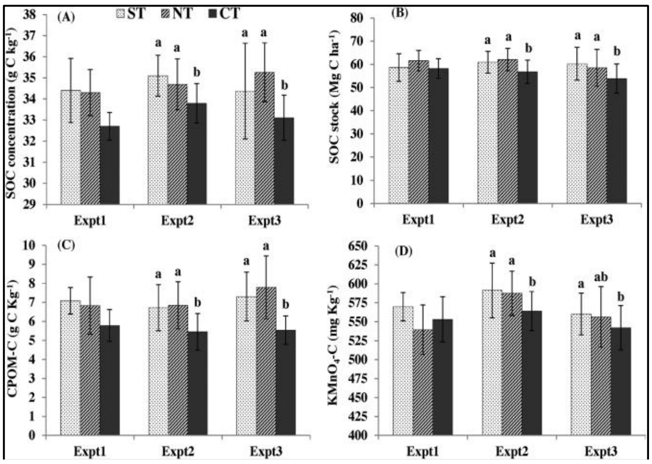

Fig 5 (a): Effect of tillage practices (strip-till [ST], no-till [NT], and conventional till [CT]) on (A) SOC concentration (g kg^{-1}), (B) SOC stock (Mg ha^{-1}), (C) CPOM-C (g kg^{-1}), and (D) $KMnO_4$-C (mg kg^{-1}) under three experiments within 0–15 cm soil depth [Source: R. Awale *et al*., 2013 [65]]

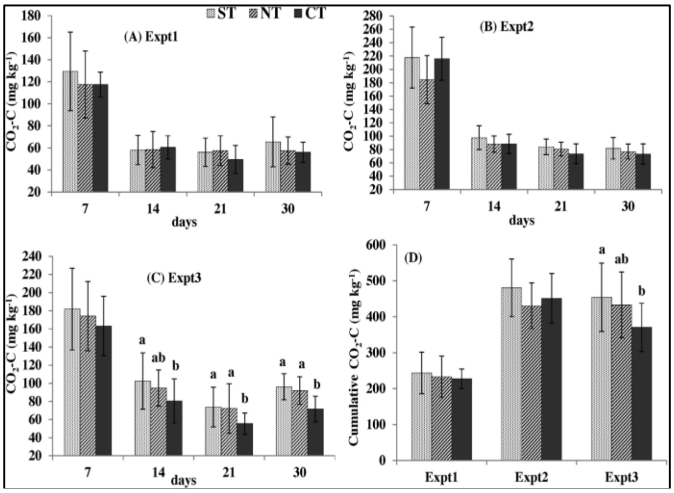

Fig 5(b): Soil C mineralized (CO_2–C, mg kg^{-1}) within 30 days of incubation period in (A) Expt1, (B) Expt2, and (C) Expt3 and (D) Cumulative C mineralized (CO_2–C, mg kg^{-1}) in three experiments, as affected by strip-till (ST), no-till (NT), and conventional till (CT) [Source: R. Awale *et al*., 2013 [65]].

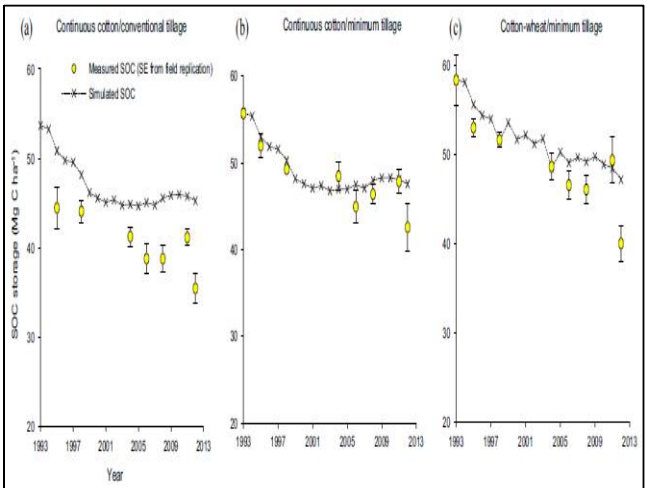

Fig 5(c): soil organic carbon storages in the 0–0.30 m soil depth on irrigated Vertisols under different cotton cropping/tillage systems [Source: Senapati *et al*., 2014 [70]]

Kumar *et al*. (2018) [43, 44] reported that after 2 years of the experiment, potentially mineralizable nitrogen (PMN) and microbial biomass nitrogen (MBN) content showed that in 0-15 cm soil layer T_1 and T_3 treatments increased from 6.7 and 11.8 mgkg^{-1} in conventional tillage (T_6) to 8.5, 14.4 and 7.6, 14.1 mgkg^{-1} in ZT and RT without residue retention and 12.4, 10.6, 9.3 and 20.2, 19.1,18.2 mg kg^{-1} ZT and RT with residue retention and CT with residue incorporation (T_1, T_3, T_5), respectively [Table 1]. In 15 -30 cm layer, the increasing trends due to the use of tillage crop residue practices were similar to those observed in 0 -15 cm layer however, the magnitude was relatively lower [Table 1].Continuous retention of crop residue resulted in considerable accumulation of PMN and MBN in 0–15 cm soil layer than unfertilized control plots [Table 1]. Soils under the 200 kg Nha^{-1} (F_4), treated plots resulted in higher PMN in the 0–15 cm soil layer over those under the 120 kg Nha^{-1} and 80 kg Nha^{-1} treated plots. The PMN in surface soil were in the order of 200 kg Nha^{-1} (F_4), 10.4 mgkg^{-1} > 160 kg Nha^{-1} (F_3), 9.8 mgkg^{-1}>120 kg Nha^{-1} (F_2), 8.9 mgkg^{-1}>80 kg Nha^{-1} (F_1), 7.3 mgkg^{-1}>unfertilized control (3.6 mgkg^{-1}). However, increase in PMN was more in surface as compared to sub-surface soil, which indicate that higher accumulation of organic carbon due to retention of crop residue was confined to surface soil. The increase in PMN in 160 kg Nha^{-1} (F_3) and 120 kg Nha^{-1} (F_2) treatments in surface layer was 63.3 and 59.6% over unfertilized control, while they were 25.5 and 17.9% greater over 80 kg Nha^{-1} (F_1) treatment, respectively [Table 1]. Highest DOC change (28.2%) was found in ZT with residue retention (T1) plots followed by RT with residue retention (T3) plots (23.6%).The use of ZT and RT with residue retention (T1 andT3) plots for two wheat crop cycle increased DOC by 21.2 and 16.1% more than that of ZT and RT without residue retention and conventional tillage (T2, T4 and T6), respectively [Table1]. Lack of soil disturbance under ZT provides steady source of organic C substrates for soil microorganisms, which enhances their activity and accounts for higher soil MBC as compared with CT – where a temporary flush of microbial activity with tillage events results in large losses of C as CO_2 (Balota *et al*., 2003). Dalal *et al*., (1991) [16] studied the effects of 20 years of tillage practice, CR management and fertilizer N application on microbial biomass and found that MBN was significantly affected by tillage, residue and fertilizer N individually as well as through their interaction. Lewis *et al*., (2011) increasing tillage intensity could reduce DOC levels in soils as a result of destruction of soil macro-aggregates and elevated respiration. Lower amount of DOC, hence is likely under CT due to increased soil disturbances subjecting aggregated protected SOC fraction to rapid decomposition via oxidation

Table 1: Effect of different treatments on contents of various biological fractions of carbon in soil [Kumar *et al*., 2018 [43, 44]]

Treatments	PMN (mgkg^{-1})		MBC (mgkg^{-1})		MBN (mgkg^{-1})		DOC (mgkg^{-1})	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Tillage Practices								
T_1 ZTR	12.4	11.2	562.5	471.1	20.2	18.9	198.6	183.6
T_2 ZTWR	8.5	7.6	350.4	302.1	14.1	12.6	167.1	159.2
T_3 RTR	10.6	9.9	490.2	399.3	19.1	17.2	186.4	171.6
T_4 RTWR	7.6	6.6	318.1	299.8	14.4	13.7	159.5	148.7
T_5 CTR	9.3	8.5	402.9	354.4	18.2	16.6	175.9	168.9
T_6 CT	6.7	5.6	307.9	289.5	11.8	9.7	142.5	134.6
Nitrogen Management								
F_0 Control	3.6	2.8	218.3	202.9	10.8	10.4	103.7	92.3
F_1 80 kg N ha^{-1}	5.3	4.4	241.1	199.4	14.9	12.2	128.3	116.9
$F_2$120 kg N ha^{-1}	8.9	7.6	282.7	220.9	16.5	16.1	136.8	123.6
F_3 160 kg N ha^{-1}	9.8	8.4	343.9	262.9	19.4	18.1	164.8	148.9
F_4 200 kg N ha^{-1}	10.4	9.7	346.3	269.6	22.7	21.7	155.7	136.4

Values in a column followed by the same letter are not significantly different ($P < 0.05$).
PMN = potentially mineralizable nitrogen, MBC = microbial biomass carbon, MBN = microbial biomass nitrogen, DOC = dissolved organic carbon

Mandal *et al*. (2012) reported that the SOC stock was highest within 0–15-cm soil and gradually decreased with increase in depth in each land use systems. In 0–15 cm depth, highest SOC stock (16.80 Mg ha^{-1}) was estimated in rice–fallow system and the lowest (11.81 Mg ha^{-1}) in the soils of guava orchard. In 15–30 cm, it ranged from 8.74 in rice–rice system to 16.08 Mg ha^{-1} in mango orchard. In the 30–45-cm soil depth, the SOC stock ranged from 6.41 in rice–potato to 15.71 Mg ha^{-1} in rice–fallow system. The total SOC stock within the 0–60-cm soil profile ranged from 33.68 to 59.10 Mg ha^{-1} among rice-based systems, highest being in soils under rice–fallow system and the lowest for rice–rice system. The mango and guava orchard soils had 68.53 and 54.71 Mg ha^{-1} of SOC, respectively, in the 0–90-cm soil depth [Fig.6a]. Liang *et al*. (2011) observed that in the 0–10 cm soil layer, SMBC and SMBN in the three fertilized treatments were higher than in the unfertilized treatment on all sampling dates, while microbial biomass C and N in the 0−10 cm soil layers were the highest at grain filling. In the same soil layer, soil-soluble organic C generally decreased in the order MNPK > SNPK > NPK > CK, while soluble organic N was the highest in the MNPK followed by the SNPK treatment. There was no significant difference in soluble organic N in the NPK and CK treatments throughout most of the maize growing season. Changes in soluble organic N occurred along the growing season and were more significant than those for soluble organic C. Soluble organic N was the highest at grain filling and the lowest at harvest. Overall, microbial biomass and soluble organic N in the surface soil were generally the highest at grain filling when maize growth was most vigorous [Fig.6b]. Murugan *et al*. (2013) revealed that the GRT and NT treatments increased the stocks of SOC (+7 %) and microbial biomass C (+20 %) in comparison with the MBT treatment. The differences between the GRT and NT were small, but there were more positive effects for the GRT treatment in most cases (Fig.6c].

Bijay- Singh, (2018) reported that fertilizer N, when applied at or below the level in the build-up of SOM and microbial biomass by promoting plant growth and increasing the amount of litter and root biomass added to soil. Only when fertilizer N was applied at rates more than the optimum, increased residual inorganic N accelerated the loss of SOM through its mineralization. Soil microbial life was also adversely affected at very high fertilizers rates. Optimum fertilizer use on agricultural crops reduces soil erosion but repeated application of high fertilizer N doses may lead to soil acidity, a negative soil health trait [Fig. 7a]. Application of optimum doses of all nutrients is important, but due to fundamental coupling of C and N cycles, optimization of fertilizer N management is more closely linked to build-up of SOC and soil health. Concepts emerging from the work of Poffenbarger *et al*. (2017) and depicted in [Fig.7a] suggest that when N inputs are below the optimum rate at which maximum yield is obtained, applied N stimulates crop growth, increasing crop residue inputs to the soil and thereby increasing SOC. Zhu *et al*. (2014) [91] revealed that the Soil TOC and labile organic C fractions contents were significantly affected by straw returns, and were higher under straw return treatments than non-straw return at three depths. At 0–7 cm depth, soil MBC was significantly higher under plowing tillage than rotary tillage, but EOC was just opposite. Rotary tillage had significantly higher soil TOC than plowing tillage at 7–14 cm depth. However, at 14–21 cm depth, TOC, DOC and MBC were significantly higher under plowing tillage than rotary tillage except for EOC [Fig.7b]. Compared to conventional tillage (CT), no-tillage and reduced tillage could significantly improve the SOC content in cropland. Frequent tillage under CT easily exacerbate C-rich macro-aggregates in soils broken down due to the increase of tillage intensity, then forming a large number of small aggregates with relatively low organic carbon content and free organic matter particles. Free organic matter particles have poor stability and are easy to degradation, thereby causing the loss of SOC (Yang *et al*., 2003) [87]. Hurisso *et al*. (2013) [36] also found that the positive residuals reflected observations with POXC values greater than those predicted by the least squares line, whereas negative residuals reflected observations with greater-than-predicted mineralizable C values [Fig.7c].

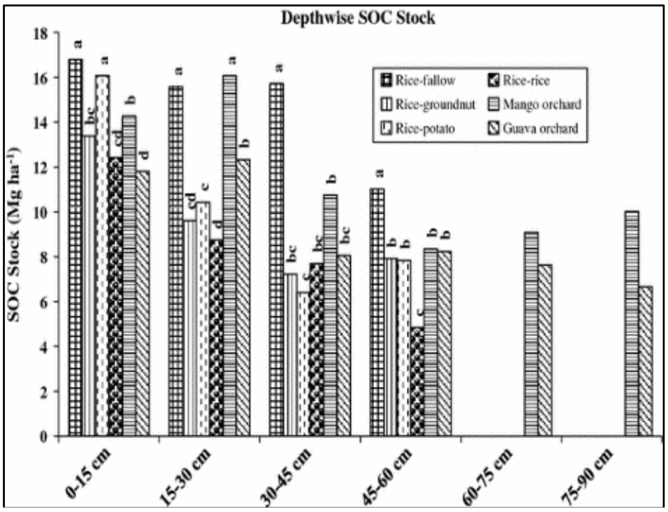

Fig 6(a): Effects of cropping on soil properties and organic carbon stock [source: Mandal *et al*., 2012]

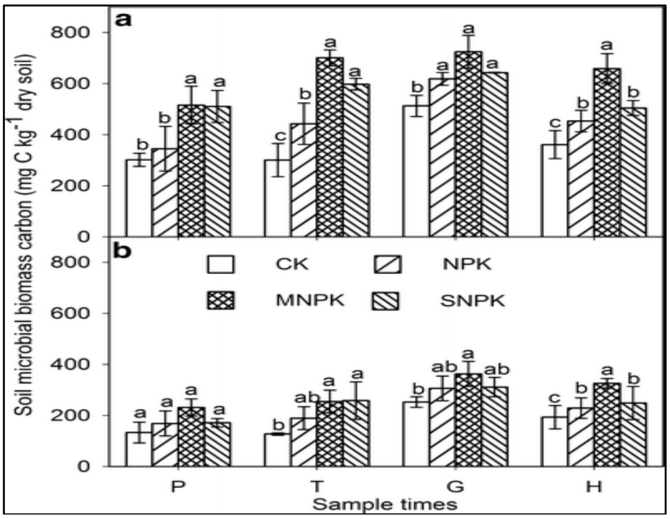

Fig 6 (b): Effects of fertilization on soil microbial biomass C and N and soluble organic C and N [Source: Liang *et al*., 2011]

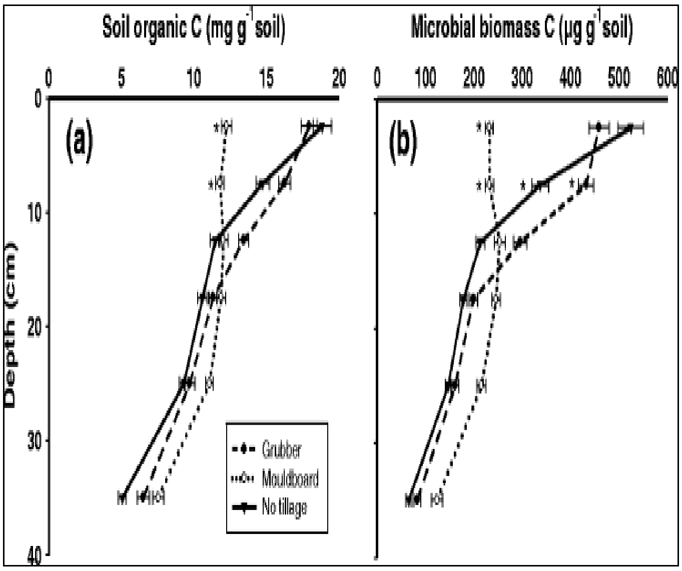

Fig 6(c): Influence of different tillage intensities on soil microbial biomass at different depths (Source: Murugan *et al*., 2013]

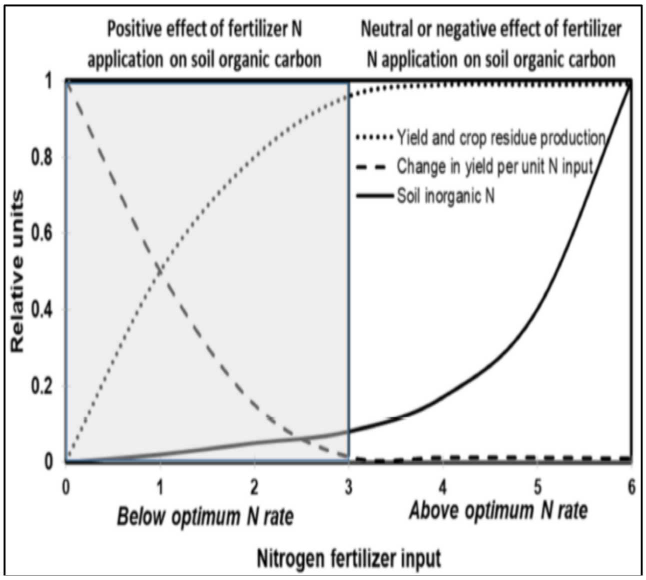

Fig 7(a): Effects of fertilizer application to crops on SOC [Source: Bijay- Singh, 2018]

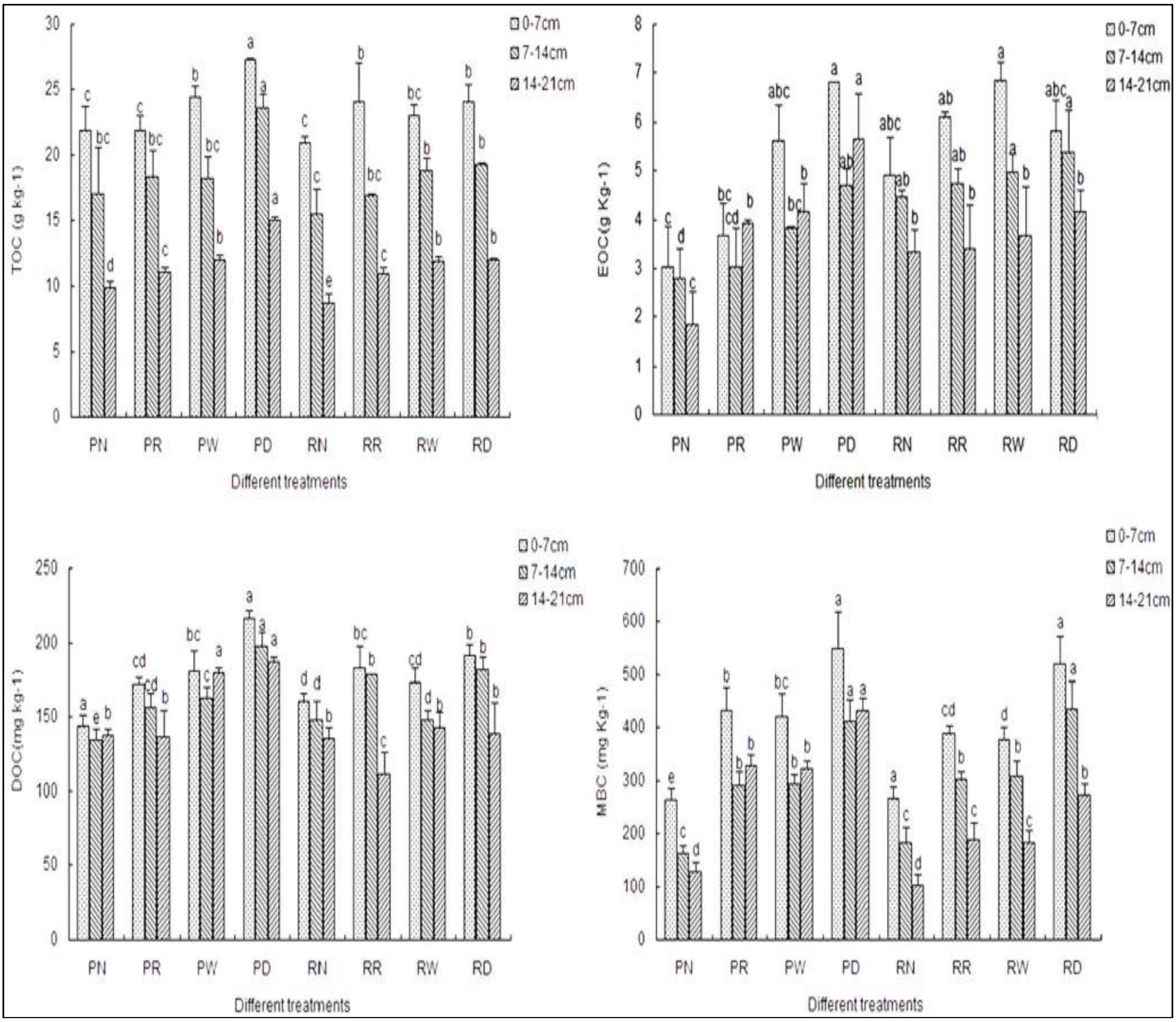

Fig 7 (b): Effects of eight treatments on soil TOC, EOC, DOC and MBC contents at three depths [Source: Zhu *et al*., 2014 [91]]

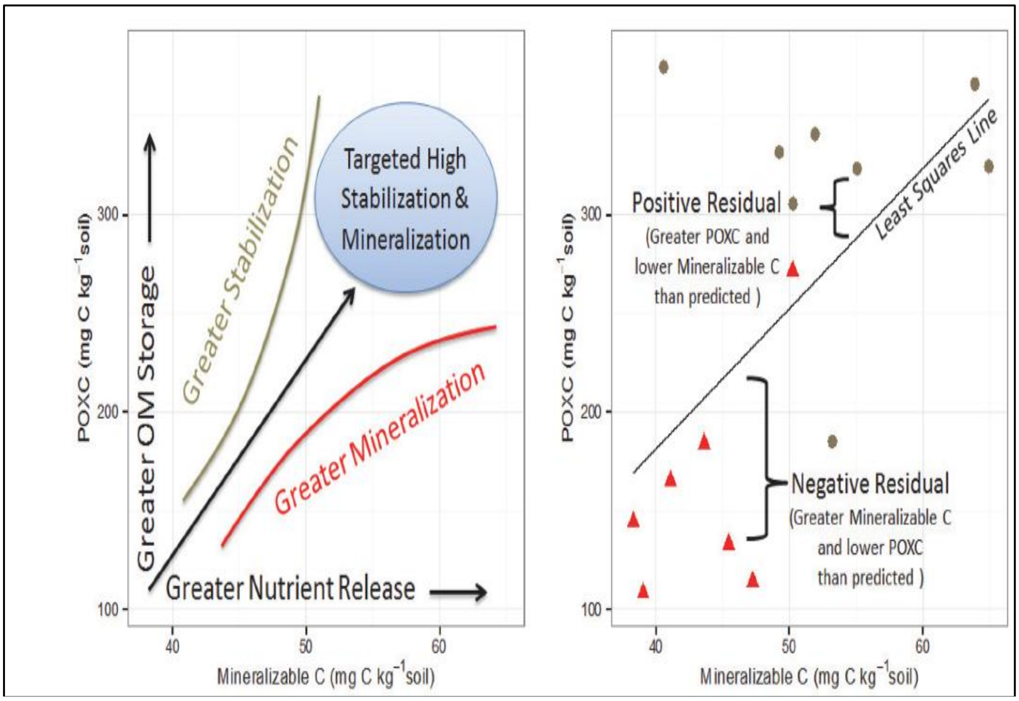

Fig 7(c): Permanganate-oxidizable C (POXC) vs. mineralizable C [adopted from Culman *et al*, 2013].

Kumar *et al*. (2018) [43, 44] also found that the ZTR (zero till with residue retention) (T_1) and RTR (Reduced till with residue retention) (T_3) showed significantly higher BC, WSOC, SOC and OC content of 24.5%, 21.9%,19.37 and 18.34 gkg^{-1}, respectively [Table 2] as compared to the other treatments. Irrespective of residue retention, wheat sown in zero till plots enhanced 22.7%, 15.7%, 36.9% and 28.8% of BC, WSOC, SOC and OC, respectively, in surface soil as compared to conventional tillage [Table 2]. Simultaneously, residue retention in zero tillage caused an increment of 22.3%, 14.0%, 24.1% and 19.4% in BC, WSOC, SOC and OC, respectively over the treatments with no residue management. Similar increasing trends of conservation practices on different forms of carbon under sub-surface (15–30 cm) soil were observed however, the magnitude was relatively lower [Table1]. Zhu *et al*., (2011) [90] compared to conventional tillage (CT) and zero-tillage (ZT) could significantly improve the SOC content in cropland. Frequent tillage under CT easily exacerbate C-rich macro-aggregates in soils broken down due to the increase of tillage intensity, then forming a large number of small aggregates with relatively low organic carbon content and free organic matter particles. Free organic matter particles have poor stability and are easy to degradation, thereby causing the loss of SOC Song *et al*., (2011) [76].

Table 2: Effect of tillage and nitrogen management on distribution of different forms of carbon in soil [Kumar *et al*., 2018 [43, 44]]

Treatments	WSOC (gkg^{-1})		SOC (gkg^{-1})		OC (g kg^{-1})		BC (gkg^{-1})	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Tillage Practices								
T_1 ZTR	28.8	26.2	23.1	19.3	9.61	9.13	4.69	4.28
T_2 ZTWR	25.3	24.6	18.4	14.8	7.87	7.21	3.76	3.19
T_3 RTR	27.0	25.9	22.4	18.2	8.68	8.17	4.13	3.87
T_4 RTWR	23.7	21.8	18.1	14.2	7.66	7.07	3.12	2.96
T_5 CTR	26.1	24.4	21.8	17.4	8.49	7.96	3.82	3.48
T_6 CT	21.8	20.9	16.1	13.1	6.21	5.64	2.89	2.63
Nitrogen Management								
F_0 Control	21.1	14.9	16.1	13.1	6.13	5.48	1.58	1.07
F_1 80 kg N ha^{-1}	28.3	21.2	17.8	14.7	6.46	6.16	2.46	1.75
$F_2$120 kg N ha^{-1}	29.5	22.1	19.1	16.1	7.25	6.71	3.26	2.18
F_3 160 kg N ha^{-1}	30.2	23.1	20.8	18.2	7.75	7.28	3.82	2.66
F_4 200 kg N ha^{-1}	31.1	25.4	21.3	18.7	7.93	7.48	4.15	3.42

Different small letters within the same column show the significant difference at P = 0.05 according to Duncan Multiple Range Test for separation of mean.
WSOC= Water soluble organic carbon, SOC =Total soil organic carbon, OC =Oxidizable organic carbon, BC =Black carbon

Fang *et al*. (2015) [22] observed that the cumulative carbon mineralization (C_{min}, mg CO_2-C kg^{-1} soil) varied with aggregate size in BF and CF top soils, and in deep soil, it was higher in larger aggregates than in smaller aggregates in BF, but not CF. The percentage of soil OC mineralized (SOC_{min},% SOC) was in general higher in larger aggregates than in smaller aggregates. Meanwhile, SOC_{min} was greater in CF than in BF at topsoil and deep soil aggregates. In comparison to topsoil, deep soil aggregates generally exhibited a lower C_{min}, and higher SOC_{min} [Fig.8a]. The deep soil may be more readily decomposed in CF than in BF, potentially as a result of a higher dead fine root biomass, since fresh carbon may accelerate soil OC decomposition (Fontaine *et al*., 2007) [23]. Causarano *et al*. (2006) [13] also concluded that the variation in SOC was explained by management (41.6%), surface horizon clay content (5.2%), and mean annual temperature (1.0%). Higher clay content and cooler temperature contributed to higher SOC. Management affected SOC primarily at the soil surface (0–5 cm). All SOC fractions (i.e., total SOC, particulate organic C, soil microbial biomass C, and potential C mineralization) were strongly correlated across a diversity of soils and management systems [Fig.8b].

Murphy *et al*. (1998) [55] concluded that about half the microbial biomass is located in the surface 10 cm of a soil profile and most of the nutrient release also occurs here [Fig.8c]. Generally, up to 5 % of the total organic carbon and N in soil is in the microbial biomass. When microorganisms die, these nutrients are released in forms that can be taken up by plants.

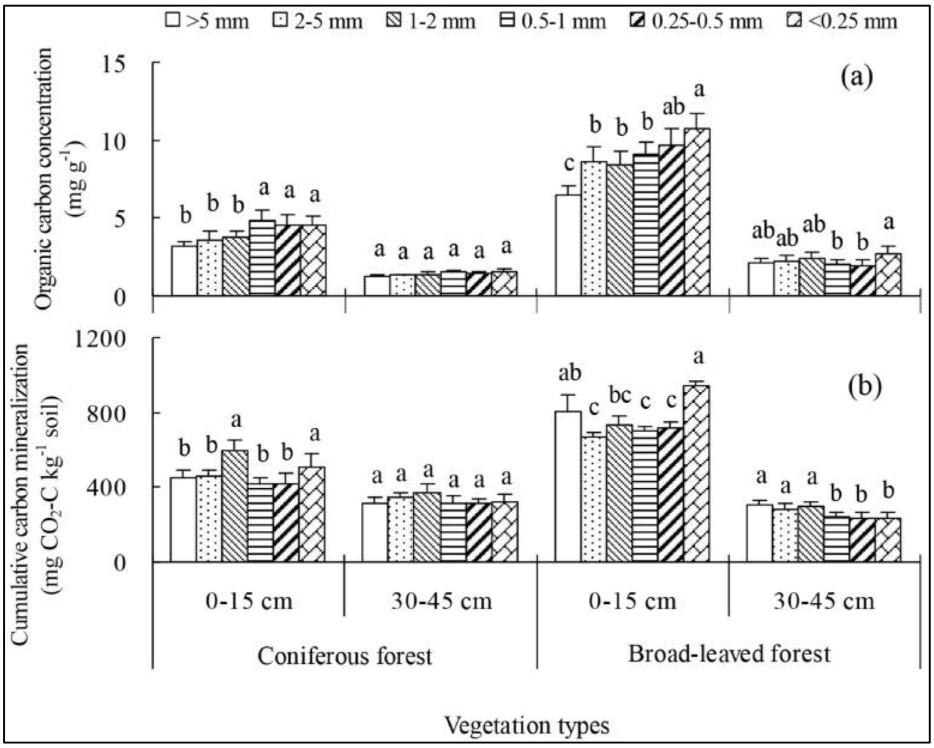

Fig 8(a): The organic carbon concentration and mineralization of aggregate soil [Source: Fang *et al*., 2015 [22]]

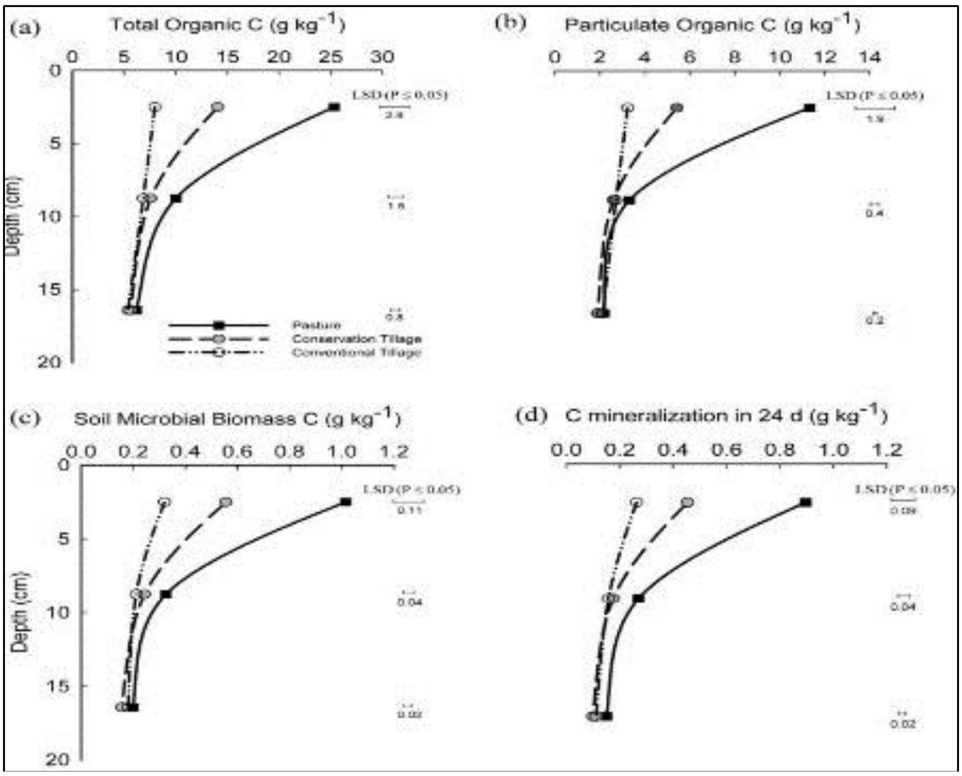

Fig 8(b): Effects of tillage and residue management on Soil Organic Carbon Fractions and Aggregation [Source: Causarano *et al*., 2006 [13]]

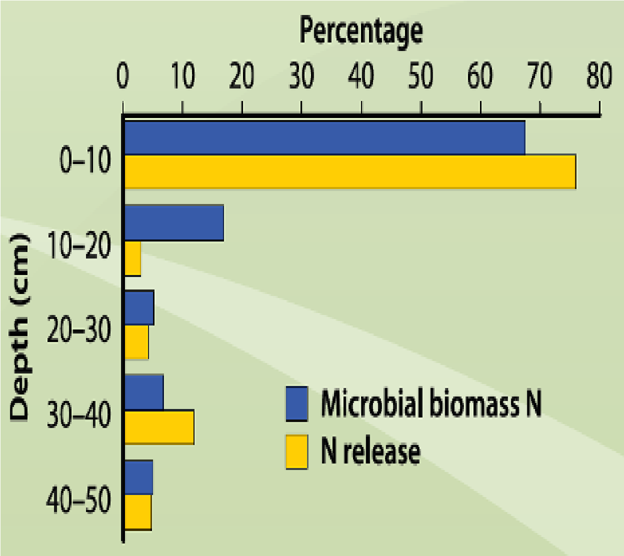

Fig 8 (c): Soil organic carbon (SOC) and nitrogen content (g kg^{-1}) of sand-free aggregates from two depths under conventional tillage with residue removal (CT), shallow tillage with residue cover (ST), and no-tillage with residue cover (NT) [Source: Chen *et al*., 2009 [14]]

Fig. 8(c): Microbial biomass nitrogen and release of nitrogen decreasing with depth [Source: Murphy *et al*., 1998 [55]]

Kumar *et al*. (2018) [43, 44] revealed that at the 0–15 and 15-30 cm, POC, PON, LFOC and LFON content under ZT and RT with residue retention was greater than under without residue and conventional sown plots, respectively. The decrease in the disruption of soil macro-aggregates under ZT plots permitted a greater accumulation of SOC between and within the aggregates. Thus, less soil disturbance is the major cause of higher POC in the ZT and RT plots compared with the CT plots in the 0-15cm and 15-30 cm soil layers [Table 3]. This phenomenon might lead to micro-aggregate formation within macro-aggregates formed around fine intra-aggregate POC and to a long-term stabilization of SOC occluded within these micro-aggregates. The sequestration rate of POC, PON, LFOC and LFON in all the treatments followed the order 200 kg Nha^{-1}(F_4) > 160 kg Nha^{-1} (F_3) > 120 kg Nha^{-1}(F_2) >800 kg Nha^{-1} (F_1) > control (unfertilized) (F_0) [Table 3]. Chen *et al*., (2009) [14] also found that single effect of residue application was not significant but its significance became apparent after its interaction with tillage system.

Table 3: Effect of different treatments on contents of various labile fractions of carbon in soil [Kumar *et al*., 2018 [43, 44]]

Treatments	POC (mgkg^{-1})		PON (mgkg^{-1})		LFOC (mgkg^{-1})		LFON (mgkg^{-1})	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
Tillage Practices								
T_1 ZTR	1342.8	967.9	119.5	108.1	194.7	154.8	14.8	12.3
T_2 ZTWR	981.1	667.4	94.6	86.5	120.5	104.7	11.8	10.3
T_3 RTR	1230.2	836.9	109.7	97.8	170.9	144.9	13.7	11.6
T_4 RTWR	869.4	604.4	82.6	76.6	107.1	97.3	9.7	8.6
T_5 CTR	1099.1	779.4	98.4	89.3	143.8	115.9	12.8	10.9
T_6 CT	617.5	481.8	69.2	57.6	90.8	73.6	9.6	7.9
Nitrogen Management								
F_0 Control	709.7	658.6	31.7	26.3	123.9	104.3	6.4	5.8
F_1 80 kg N ha^{-1}	860.7	785.6	68.4	56.2	132.8	116.1	7.6	6.9
$F_2$120 kg N ha^{-1}	952.2	808.9	89.5	78.5	150.6	127.6	9.7	8.6
F_3 160 kg N ha^{-1}	1099.5	823.8	96.8	83.4	168.5	145.7	10.2	9.8
F_4 200 kg N ha^{-1}	1153.1	898.4	103.9	97.3	176.2	152.9	11.7	10.6

Values in a column followed by the same letter are not significantly different ($P < 0.05$).
POC = particulate organic carbon, PON = particulate organic nitrogen, LFOC = labile fraction organic carbon, and LFON = labile fraction organic nitrogen.

Puttaso *et al*. (2011) [64] observed that the residue decomposition was sensitive to indigenous soil organic nitrogen (SON), particularly during later stages [Fig.9a]. Thirteen years' addition of residues led to largest soil organic carbon (SOC) (8.41 Mg ha^{-1}) accumulation in topsoil (0–20 cm), while rice straw yielded only 5.54 Mg ha−1 followed by the control (2.72 Mg ha^{-1}). The highest SON (0.78 Mg N ha^{-1}) was observed in the groundnut treatment [Fig.9a]. Xiao *et al*. (2016) [85] showed that the SOC concentrations were significantly higher in macro-aggregates than micro-aggregates; the MBC and C_{mic}: C_{org} ratios were highest in small macro-aggregates. Therefore, small macro-aggregates might have more active C dynamics [Fig.9b]. In agricultural ecosystems, decreases in SOC are mainly induced by frequent soil disturbance (e.g. tillage, fertilization, and weed control) and crop removal (Kocyigit and Demirci, 2012) [42]. MBC in aggregates and bulk soil in other land uses decreased compared with that in enclosure land [Fig.9c]. Further, the maize field had the lowest MBC. Moreover, the MBC in small micro-aggregates of prescribed-burning land (1850.62 mg kg^{-1}) was significantly higher than that of enclosure land (1219.90 mg kg^{-1}). The pasture and maize fields had much lower MBC in micro-aggregates (623.36 mgkg^{-1} and 514.30 mgkg^{-1}, respectively). However, the MBC in large macro-aggregates did not differ significantly among all land uses. In the three aggregates, MBC was the highest in small macro-aggregates, followed by large macro-aggregates and micro-aggregates [Fig.9c]. The C_{mic}: C_{org} ratios ranged between 1.71% and 3.44% [Fig.9c]. Compared to enclosure land, the ratios in other land uses increased in aggregates and bulk soil. The highest C_{mic}: C_{org} ratio (3.44%) was observed in small macro-aggregates. This is mainly because the large radius of large aggregates could limit the O2 concentration and gas diffusion required by microbes (Gupta and Germida, 2015; Jiang *et al*., 2011) [31, 39]. Thus, large macro-aggregates might diminish the impacts of land uses and facilitate the maintenance of a stable microbial biomass.

Dou *et al*. (2008) [19] reported that SMBC was 5 to 8%, mineralized C was 2%, POM C was 14 to 31%, hydrolyzable C was 53 to 71%, and DOC was 1 to 2% of SOC. No-till significantly increased SMBC in the 0- to 30-cm depth, especially in the surface 0 to 5 cm [Fig.10a]. Under NT, SMBC at 0 to 5 cm was 25, 33, and 22% greater for CW, SWS, and WS, respectively, than under CT, but was 20 and 8% lower for CW and WS, respectively, than under CT at the 5- to 15-cm depth. At the 15- to 30-cm depth, no consistent effect of tillage was observed [Fig.10a]. Enhanced cropping intensity increased SMBC only under NT, where SMBC was 31 and 36% greater for SWS and WS than CW at 0 to 30 cm. Increases in SMBC due to enhanced cropping intensity were also reported by Thompson (1992) [79]. Mineralized C was significantly greater under NT than CT at 0 to 30 cm, except for CW where no difference was observed [Fig.10b]. At 0 to 5 cm, mineralized C was 27, 34, and 42% greater for CW, SWS, and WS, respectively, under NT than under CT. Similar results were observed for the 15- to 30-cm depth. At the 5- to 15-cm depth, however, mineralized C was greater under CT than NT. Cropping intensity had less effect on mineralized C than tillage. The greatest difference in mineralized C between CT and NT was observed at the 0- to 5-cm depth, where NT increased mineralization by 35% compared with CT. Mineralized C as a fraction of SOC, however, was greater at 0 to 15 cm for CT than NT [Fig.10b]. This fraction ranged from 1.9 to 3.1% for CT and from 1.6 to 2.7% for NT. No difference was observed at 15 to 30 cm. Mineralized N was highly correlated with mineralized C in all cropping sequences, but was more closely related to SMBN at 0 to 15 cm, indicating that biomass may also serve as a significant source of labile N [Fig.10c]. No-till significantly increased POM carbon over CT except for CW at 0 to 30 cm [Fig.10d]; however, tillage effects varied with soil depth. At the 0- to 5-cm depth, NT significantly increased POM C compared with CT. Particulate organic matter C at this depth under NT was 51, 65, and 107% greater for CW, SWS, and WS, respectively, than under CT. The relationship between tillage and POM C in the 5- to 15-cm depth, however, was different from the surface soil. Particulate organic matter C for the above cropping sequences at this depth was 35, 42, and 51% lower for NT than CT, but at 15 to 30 cm showed a similar pattern as in the surface soil [Fig.10d]. Cambardella and Elliott (1992) [9] suggested that lower particulate organic matter under CT was due to more rapid decomposition than under NT.

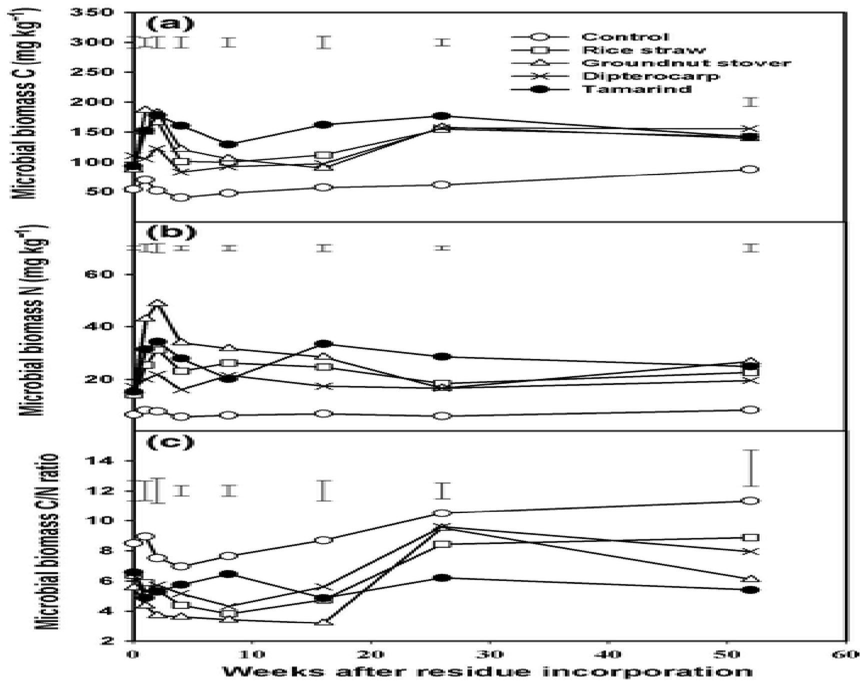

Fig 9(a): Relationship between residue quality, decomposition patterns, and soil organic matter accumulation in a tropical sandy [Source: Puttaso *et al*., 2011 [64]]

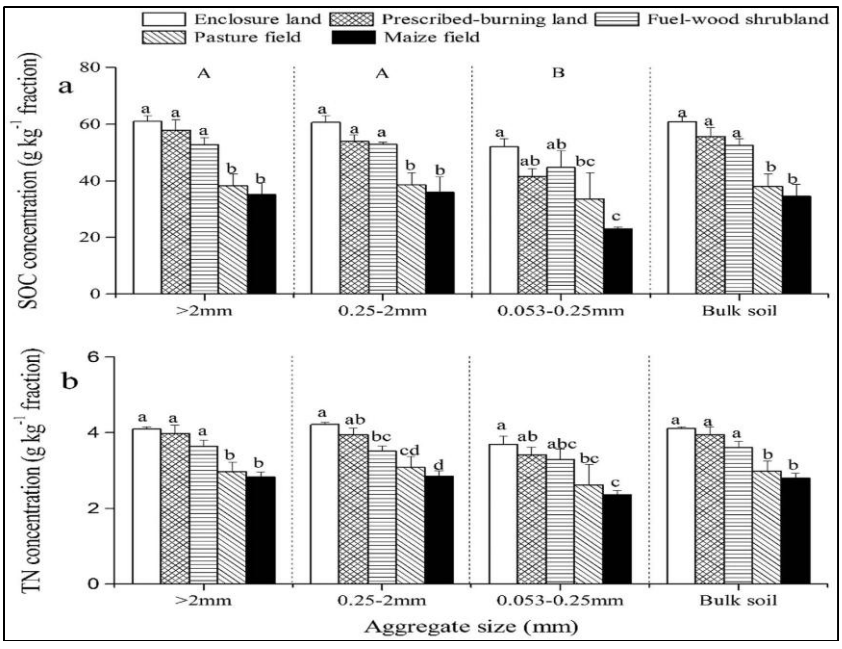

Fig 9(b): Soil organic carbon (SOC) (a) and total nitrogen (TN) (b) concentrations in the three sizes of soil aggregates and in bulk soil of different land uses [Source: Xiao *et al*., 2016 [85]]

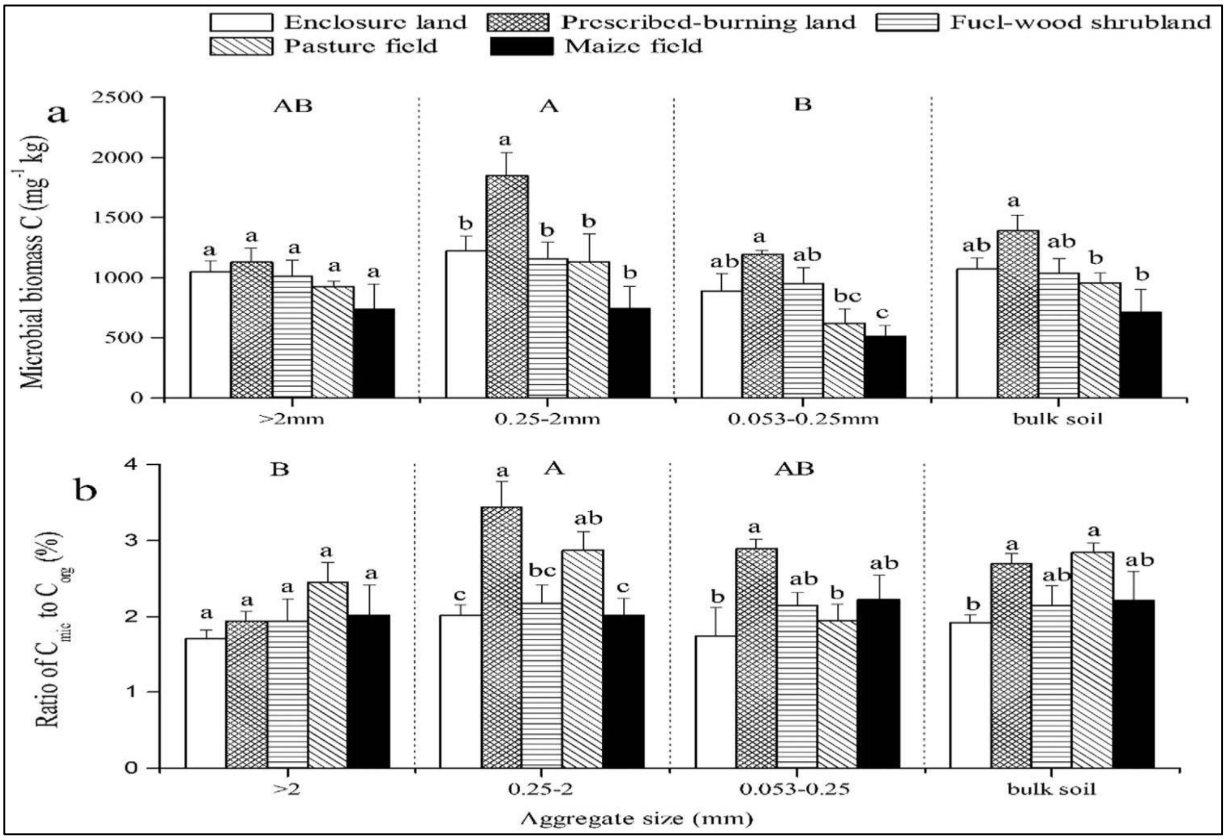

Fig 9(c): Microbial biomass carbon (MBC) (a) and the C_{mic}: C_{org} ratios (b) of the three sizes of soil aggregates and bulk soil of different land uses [Source: Xiao *et al*., 2016 [85]]

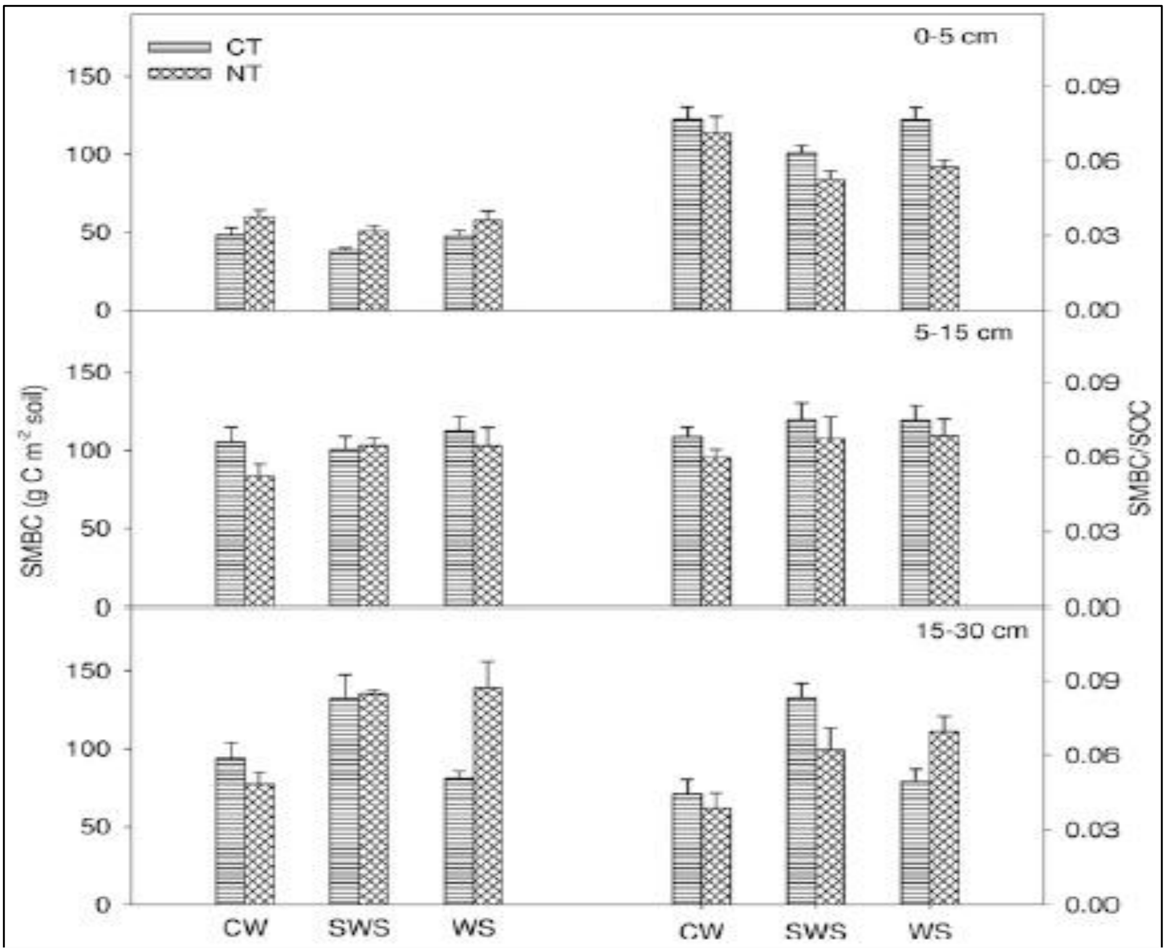

Fig 10(a): Soil microbial biomass C (SMBC) and its proportion of soil organic C (SOC) as affected by cropping sequence and tillage at 0- to 5-, 5- to 15-, and 15- to 30-cm depths [Source: Dou *et al*., 2008[19]]

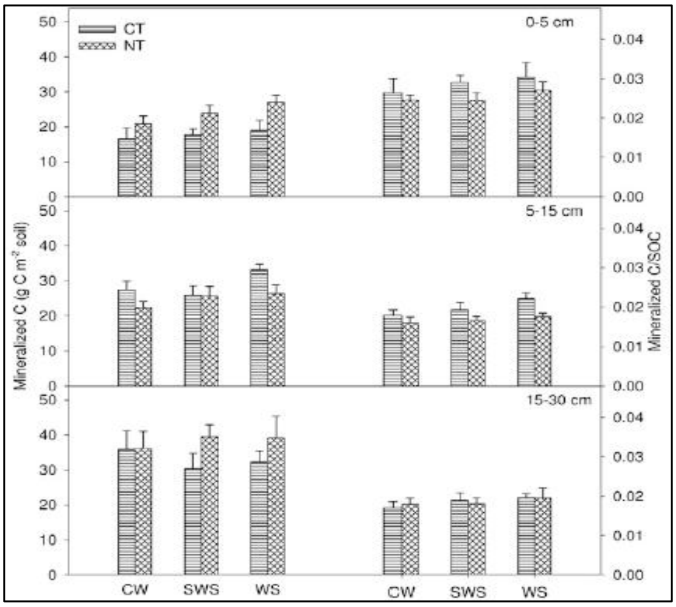

Fig 10(b): Mineralized C from 24-d incubation and its proportion of soil organic C (SOC) as affected by cropping sequence and tillage at 0- to 5-, 5- to 15-, and 15- to 30-cm depths [Source:Dou *et al*., 2008 [19]]

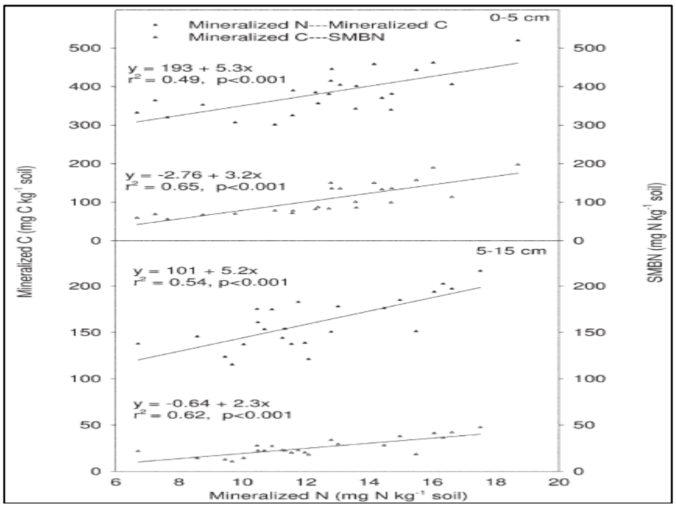

Fig 10(c): Mineralized soil N with mineralized C or soil microbial biomass N (SMBN) at 0- to 5- and 5- to 15-cm depths [Source: Dou *et al*., 2008 [19]]

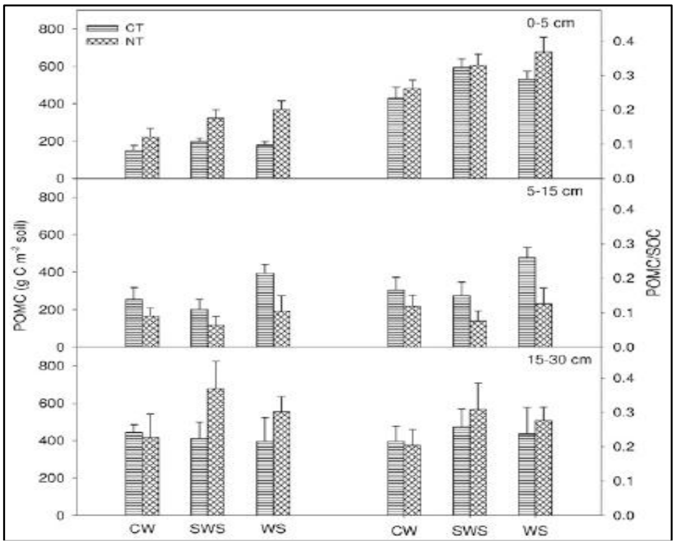

Fig 10(d): Particulate organic matter C (POM C) and its proportion of soil organic C (SOC) as affected by cropping sequence and tillage at 0- to 5-, 5- to 15-, and 15- to 30-cm depths [Source: Dou *et al*., 2008 [19]]

Naresh *et al*. (2017) [59] reported that the T_3 treatment resulted in significantly increased 66.1%, 50.9%, 38.3% and 32% LFOC, PON, LFON and POC, over T_7 treatment and WSC 39.6% in surface soil and 37.4% in subsurface soil [Table 4].LFOC were also significantly higher following the treatments including organic amendment than following applications solely of chemical fertilizers, except that the F_5, F_6 and F_7 treatments resulted in similar LFOC contents. Application solely of chemical fertilizers had no significant effects on LFOC compared with unfertilized control plots. Nevertheless, application of F_5 or F_6 significantly increased contents of POC relative to F_1 (by 49.6% and 63.4%, respectively). Rajan *et al*., (2012) [66] concluded that FYM can increase the root biomass and microbial biomass debris which is the main source of POC. It is suggested that the greater biochemical recalcitrance of root litter. Puget *et al*. (1995) [63] might have also increased the POC contents in soil depending upon the root biomass produced. The continuous replacement of organic manure on the soil creates a favorable environment for the cycling of C and formation of macro-aggregates. Furthermore, POC acts as a cementing agent to stabilize macro-aggregates and protect intra-aggregate C in the form of POC Six *et al*., (2002) [75].

Table 4: Effect of 15 years of application of treatments on contents of various labile fractions of carbon in soil [Naresh *et al*., 2017 [59]]

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}
Nutrient Management Practices										
F_1	21.9^{e}	631^{d}	24.7^{e}	89.2^{c}	6.8^{d}	15.1^{e}	585	17.3^{e}	47.9^{f}	5.9^{e}
F_2	29.2^{cd}	869^{c}	92.5^{c}	96.4^{c}	9.5^{c}	20.2^{cd}	789	73.5^{cd}	85.9^{d}	8.9^{c}
F_3	29.8^{c}	956^{bc}	96.8^{c}	108.1^{bc}	10.5^{bc}	21.9^{bc}	813	79.4^{c}	96.9^{cd}	9.6^{bc}
F_4	28.4^{d}	788^{cd}	72.9^{d}	91.3^{c}	7.9^{d}	18.8^{d}	728	59.4^{d}	66.7^{e}	7.2^{d}
F_5	32.5^{a}	1381^{a}	130.8^{a}	183.9^{a}	13.8^{a}	26.4^{a}	1032a	112.1^{a}	152.9^{a}	12.4^{a}
F_6	31.6^{ab}	1156^{ab}	114.2^{ab}	160.5^{a}	12.6^{ab}	23.6^{ab}	905ab	96.7^{ab}	139.7^{a}	11.9^{a}
F_7	30.9^{b}	1102^{b}	103.9^{bc}	123.5^{b}	11.5^{b}	22.7^{b}	826b	88.3^{bc}	103.2^{bc}	10.1^{b}

Values in a column followed by the same letter are not significantly different ($P < 0.05$).

WSC = water soluble C, POC = particulate organic C, PON = particulate organic N, LFOC = light fraction organic C, and LFON = light fraction organic N.

Ge *et al*. (2014) [26] observed a significant, soil type- and depth-dependent effect of tillage on the incorporation rates of labelled C to the labile carbon pool. Concentrations of labelled C in the carbon pool significantly decreased with soil depth, irrespective of tillage. Additionally, quantitative PCR assays revealed that for most soils, total bacteria and *cbbL*-carrying bacteria were less abundant in CT versus NT treatments, and tended to decrease in abundance with increasing depth. However, specific CO_2 fixation activity was significantly higher in CT than in NT soils, suggesting that the abundance of *cbbL*-containing bacteria may not always reflect their functional activity. The amount of ^{14}C-SOC was, on average, 87% higher in CT soils when compared with NT soils at depths of 0–1 cm, and 210% higher at 1–5 cm [Fig.11a]. At 5–17 cm, the ^{14}C-SOC concentration was 141% greater in P1 (paddy) soils under CT relative to the NT treatment, and no ^{14}C-SOC content was detected under NT treatments of three other soils [Fig.11a]. Generally, different types of soils responded differently to tillage treatments: CT treatment had a greater impact on upland soils than on paddy soils [Fig.11a].

Under both CT and NT treatments, the overall ^{14}C-SOC concentrations decreased with increasing soil depth, with deeper soil layers being more sensitive to tillage practices. The incorporation rates of autotrophically fixed ^{14}C into microbial biomass carbon (MBC) and dissolved organic carbon (DOC) were modulated by soil tillage [Fig.11b & 11c]. Larger amounts of ^{14}C-MBC were recovered from CT soils than from NT soils, but the difference was not significant in P2 (0–1 cm) and U1 (upland soil; 0–1 cm) [Fig.11b]. Compared with NT treatments, CT also significantly increased ^{14}C-DOC concentration in the 0–1 cm depth by an average of 33%, whereas the effect of tillage on ^{14}C-DOC contents at greater depths was highly dependent on soil type [Fig.11c]. Under both CT and NT treatments, larger amounts of ^{14}C-MBC and ^{14}C-DOC were observed in paddy soils when compared with upland soils at 0–1 cm and 1–5 cm [Fig.11b], with a significant soil type × soil tillage interaction.

Zhao *et al*. (2018) [89] observed that an increasing C input through return of crop residues can increase SOC concentration before the soil C is saturated. Moreover, average straw/stover C inputs were minimal at first in 1980 and then increased since the early 1990s, whereas root C inputs increased continuously but at a slower rate [Fig.12a]. On average, the net increments of cumulative C inputs by crop roots and straw/stover were 7.96 and 10.67 Mg C ha^{-1}, respectively, during the periods of 1980 and 2010 [Fig.12a]. Changes in average crop residue C inputs during 1980–1989 were characterized by small net C input [Fig.12a]. Straw/stover C inputs in this period were minimal, stabilized at a low level (mean C input was only 0.005 Mg C ha^{-1} y^{-1}, whereas root C inputs were 0.57 Mg C ha^{-1} y^{-1}). From 1990 to 1999, both straw/stover and root C inputs increased steadily, with a rate of 0.023 and 0.018 Mg C ha^{-1} y^{-1}, respectively. After 2000, straw/ stover C inputs increased rapidly, with a rate of 0.077 Mg C ha^{-1} y^{-1}, while the rate of root C inputs stabilized at 0.016 Mg C ha^{-1} y^{-1} during this period [Fig.12a]. Cardinael *et al*. (2018) [11] also found that the reduction in crop OC inputs was offset by OC inputs from the tree roots and tree litter-fall. Total root OC inputs in the alleys (crop + tree roots) and in the control plot (crop roots) were very similar, respectively 2.43 and 2.29 $tCha^{-1}$ yr^{-1}. Alleys received 0.60 $tCha^{-1}$ yr^{-1} more total aboveground biomass (crop residues + tree litter-fall) than the control, which was added to the plough layer. Tree rows received 2.35 $tCha^{-1}$ yr^{-1} more C inputs in the first 0.3m of soil compared to the control plot, mainly from the herbaceous vegetation. Down the whole soil profile, tree rows received 2 times more OC inputs compared to the control plot [Fig.12b] and 65% more than alleys. Overall, the agro-forestry plot had 41% more OC inputs to the soil than the control plot to 2m of depth (3.80 $tCha^{-1}$ yr^{-1} compared to 2.69 $tCha^{-1}yr^{-1}$). Geraei *et al*. (2016) reported that the P soils showed a better and different quality of organic C than other land use systems, which was indicated by the highest proportion of microbial biomass C (3.3%), permanganate oxidizable C (4.8%), and cold- (0.55%) and hot-water extractable organic C (3.7%), but the lowest proportion of non-labile C (95.2%) to the TOC contents of the soils [Fig.12c]. In contrast, the agricultural land use systems with conventional tillage practices showed the minimum contents of microbial biomass C [Fig.12c], and microbial quotient. The conventional tillage practices have been shown to enhance soil aeration. The oxidation of organic C is accelerated through exposure of the organic matter to microbial attack, (Sharma *et al*., 2014) [71].

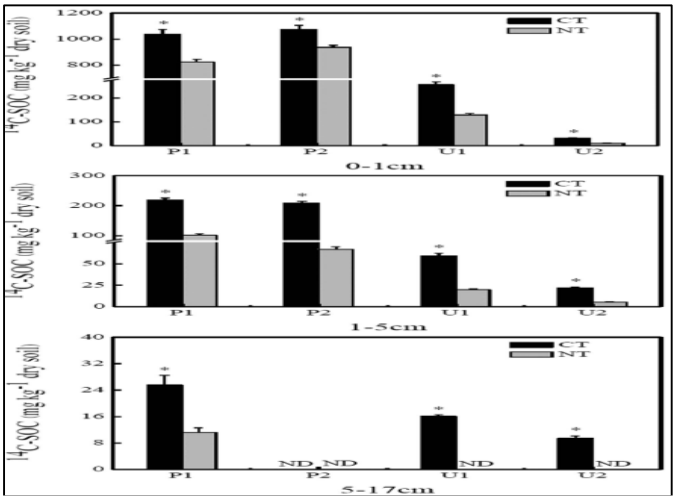

Fig 11(a): The ^{14}C-SOC concentrations recovered at different depths (0–1 cm, 1–5 cm, and 5–17 cm) in conventional tillage (CT) and no-till (NT) soils [Source: Ge *et al*., 2014]

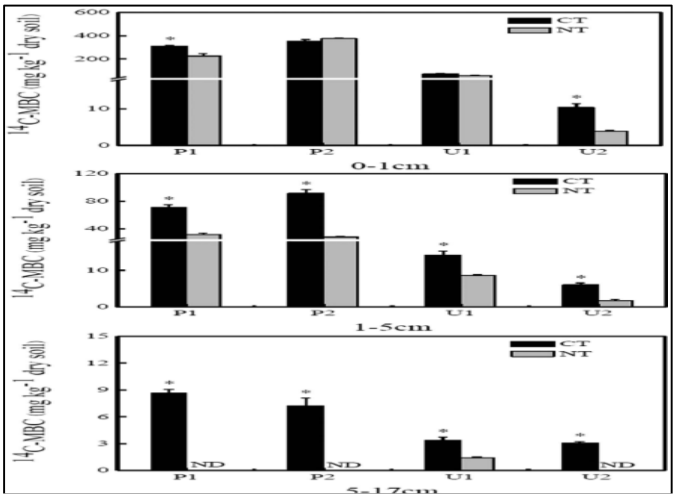

Fig 11(b): The ^{14}C-MBC concentrations recovered at different depths (0–1 cm, 1–5 cm, and 5–17 cm) in conventional tillage (CT) and no-till (NT) soils [Source: Ge *et al*., 2014]

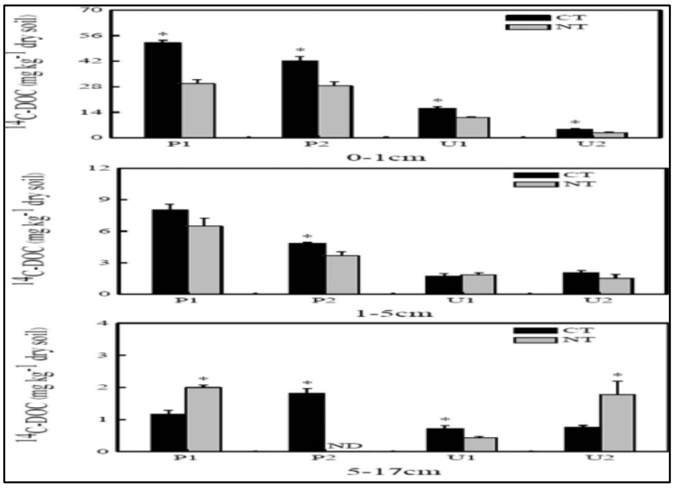

Fig 11(c): The ^{14}C-DOC concentrations recovered at different depths (0–1 cm, 1–5 cm, and 5–17 cm) in conventional tillage (CT) and no-till (NT) soils [Source: Ge *et al*., 2014]

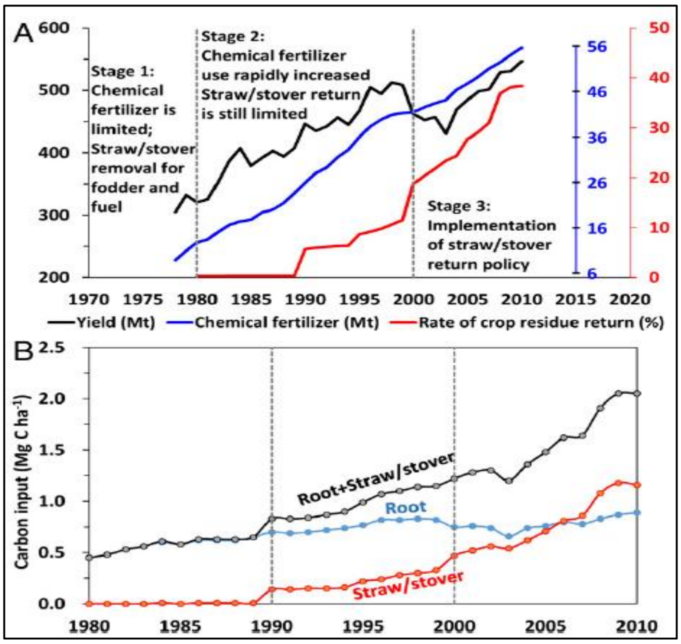

Fig 12(a): Changes in agricultural managements and crop residue C inputs, chemical fertilizer consumption, and the rate of straw/stover return to soils [Source: Zhao *et al*., 2018 [89]]

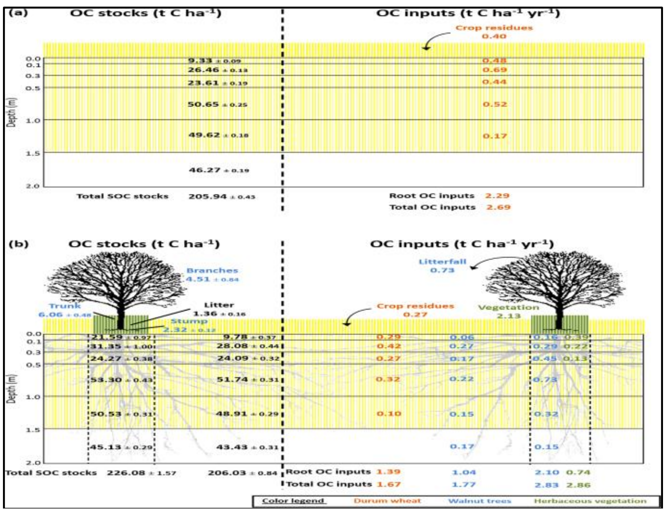

Fig 12(b): Measured soil organic carbon stocks and organic carbon inputs to the soil (a) in the agricultural control plot and (b) in the 18-yearold agro-forestry plot [Source: Cardinael *et al*., 2018 [11]]

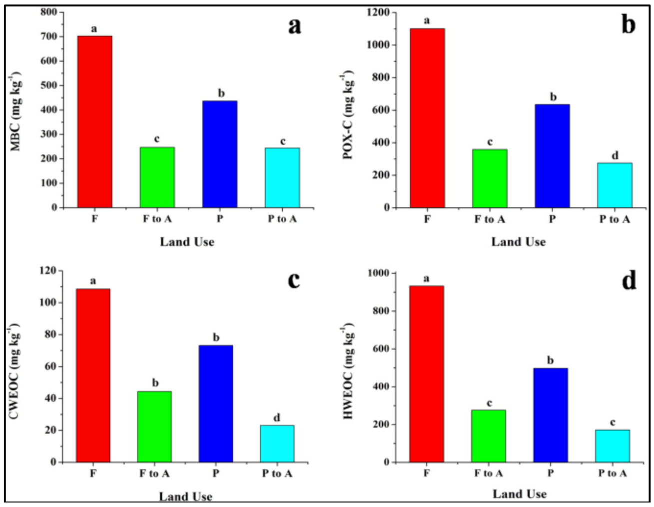

Fig 12(c): Distribution of (a) microbial biomass C (MBC), (b) permanganate oxidizable C (POX-C), (c) cold-water extractable organic C (CWEOC) and (d) hot-water extractable organic C (HWEOC) as affected by different land use systems [Source: Geraei *et al*., 2016]

McGonigle and Turner, (2017) concluded that the MBC in cropland increased from 210 µg g^{-1} at 15 g kg^{-1} SOC to only 530 µg g^{-1} at 45 g kg^{-1} SOC [Fig.13a]. In contrast, MBC in grassland increased from 440µg g^{-1} at 15 g kg^{-1} SOC to 1190 µg g^{-1} at 45 g kg^{-1}, thereafter increasing further to 1800µg g^{-1} at 65 g kg^{-1} SOC [Fig.13a]. The slope of increase of MBC in response to increasing SOC was 2.5-fold higher in grassland at 27.2 (µg g^{-1})/ (g kg^{-1}) compared to 10.7 (µg g^{-1})/ (g kg^{-1}) for cropland [Fig.13a]. Zheng *et al*. (2018) [88] also found that the aggregate D varied with soil depth for different treatments and was more variable in the topsoil as compared to lower soil layers [Fig.13b]. Aggregate D for the ST and NT treatments were significantly lower than for the MP and CT treatments at the 0±10cm depth. This effect for the NT treatment disappeared with increased soil depth; however, the ST treatment still showed lower D for the 10±20 and 20±30cm depths. This variation dwindled at lower depths until 50±60cm, where there was no significant difference in D between ST, NT, and MP; however, D was significantly lower for the CT than for the ST and NT treatments. Kumar and Babalad, (2018) [43, 44] observed that the soil microbial biomass carbon and nitrogen were significantly higher in all the tillage systems except conventional tillage without crop residue [Fig.13c]. The positive response of conservation tillage practices as compared to conventional tillage systems were probably due to higher levels of C substrates available for microorganism growth, as well as better soil physical conditions and higher water retention due to the altered land configurations and applied residues (Singh *et al*., 2009) [37]. The improvement in SMB- C and N is mainly due to rate of organic carbon input from plant biomass which is the dominant factor controlling the amount of SMB in soil. Reduction in loss of soil organic carbon in conservation tillage and continuous, uniform supply of carbon from crop residues serves as an energy source for microorganisms.

Shi-chao *et al*. (2018) [72] revealed that the NPKS treatment resulted in significantly higher soil carbon sequestration rates (CSR) than the NPK treatment. The equilibrium value of the CSR for the NPKS treatment equated to cultivation times of 17, 11, and 8 years at the different sites. Straw return did not significantly increase the SOC stocks in regions with low SOC densities, but did enhance the C pool in regions with high SOC densities. Additional cultivations and fertilization practices should be used when straw return is considered as an approach for the long-term improvement of the soil organic carbon pool [Fig 14 a, 14b & 14c].

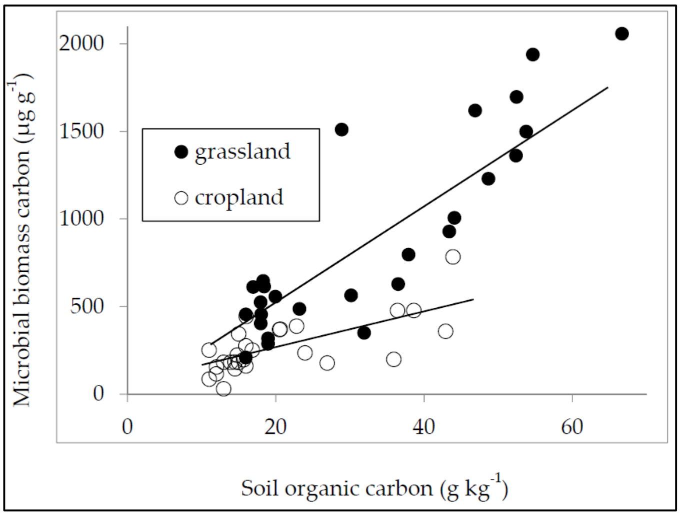

Fig 13 (a): Microbial biomass carbon in relation to soil organic carbon for grassland and cropland [Source: McGonigle and Turner, 2017]

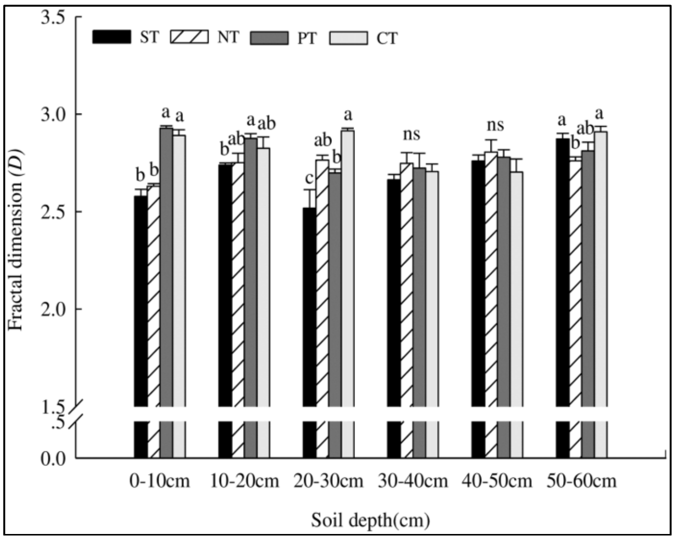

Fig 13(b): Effect of tillage methods on fractal dimension (D) of water-stable aggregates [Source:

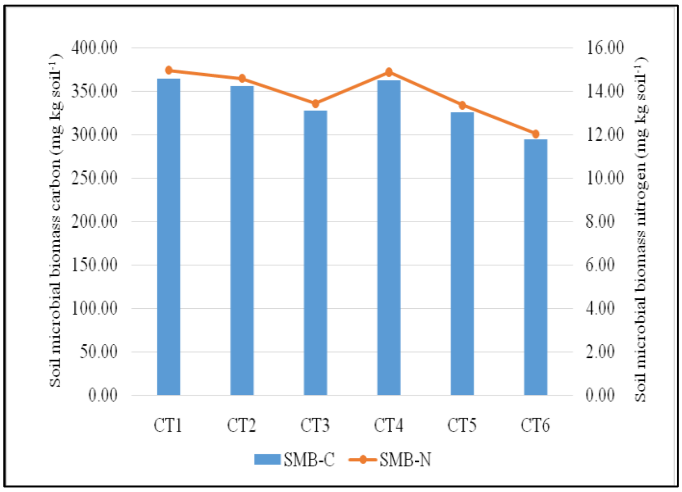

Fig 13(c): Soil microbial biomass carbon (SMB-C) and soil microbial biomass nitrogen (SMB-N) as influenced by conservation agricultural practices [Source: Kumar and Babalad, 2018 [43, 44]]

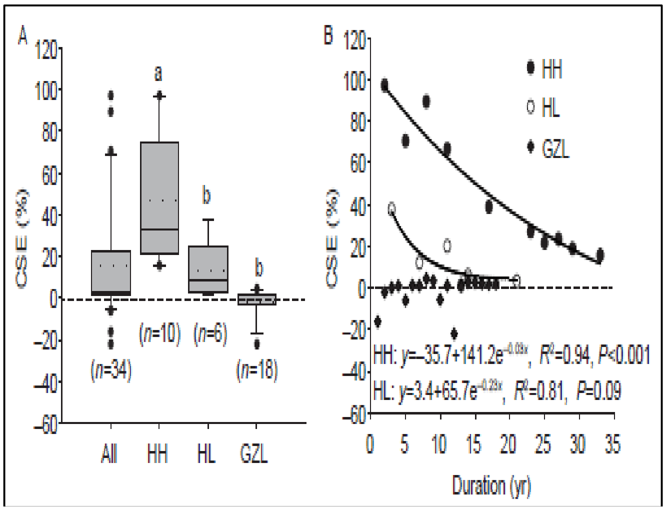

Fig 14(a): Straw-C sequestration efficiency (CSE) in the treatment with straw [Source: Shi-chao *et al.*, 2018]

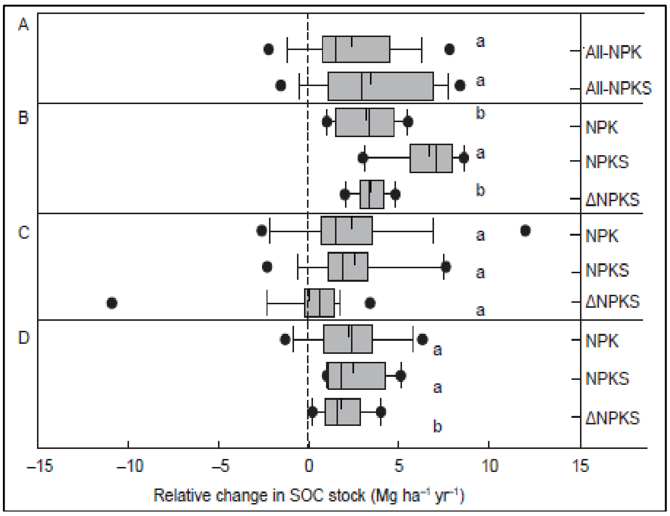

Fig 14 (b): Average relative changes in soil organic carbon (SOC) stocks for two different fertilization management practices over the experimental period [Source: Shi-chao *et al.*, 2018]

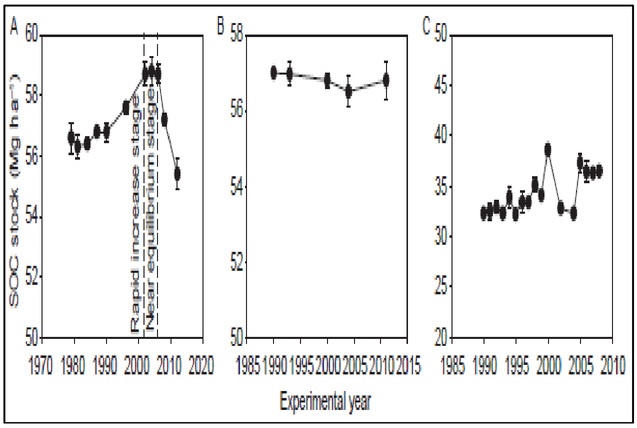

Fig 14(c): Soil organic carbon (SOC) stock dynamics under straw return in the black soils [Source: Shi-chao *et al.*, 2018 [72]]

The SOC storage in macro-aggregates under different treatments significantly decreased with soil depth [Table 5]. However, no significant variation was observed in the micro-aggregate associated C storage with depth. SOC storage increased with aggregate size from 1±2 to > 2mm and decreased with a decrease in aggregate size. The SOC storage in macro-aggregates of all sizes from 0-30cm depth was higher in the ST treatment than in other treatments. From 30-

60cm, trends were less clear. SOC storage in micro-aggregates showed the opposite trend, with significantly higher levels in the CT treatment from 0-30cm, and no significant differences between treatments below this depth. Soil aggregates have three major effects on soil (Kladivko, 2001) [41]. They regulate and maintain water, fertilizer, gas, and heat in the soil, affect the types and activity of the soil enzymes, and also maintain and stabilize the loose arable layer (Ismail *et al*., 1994) [37]. Almost 90% of SOC exists in the form of aggregates in the topsoil. Protection and maintenance of the macro-aggregate stability and ratio are of great importance in the sustainability of soil fertility (Nimmo and Perkins, 2002) [60]. In addition, the contributing rate of SOC in differently sized aggregates decreased, consistent with the trend of soil aggregate-associated C storage and SOC with increasing soil depth.

Table 5: Distribution of soil organic carbon storage in water-stable aggregates in different soil layers and tillage treatments [Zheng *et al*., 2018 [88]]

Depth (cm)	Treatments	Macro-aggregate (t ha^{-1})				Micro-aggregate (t ha^{-1})			
		> 2 mm	2–1 mm	1–0.25 mm	Sum	0.25–0.053 mm	0.053–0.002 mm	< 0.002 mm	Sum
0–10	ST	2.65±0.74a¶	5.87±0.34a	7.75±0.23a	16.28±0.85a	1.38±0.11c	0.26±0.02c	0.26±0.08b	1.90±0.08c
	NT	1.40±0.07b	5.82±0.36a	7.78±0.40a	15.00±0.11a	1.26±0.10c	0.23±0.02c	0.25±0.04b	1.75±0.08c
	MP	0.35±0.01b	3.98±0.29b	5.91±0.43b	10.24±0.17b	2.44±0.06b	0.73±0.05b	0.69±0.07a	3.86±0.08b
	CT	0.44±0.04b	4.43±0.22b	6.11±0.54b	10.99±0.37b	2.88±0.08a	1.96±0.23a	0.44±0.14ab	5.28±0.20a
10–20	ST	2.43±0.03a	6.85±0.19a	9.14±0.16ab	18.42±0.29a	0.61±0.01ab	1.54±0.10c	0.72±0.01ab	2.86±0.11b
	NT	1.62±0.02b	5.04±0.25b	8.49±0.10b	15.15±0.22b	0.49±0.10b	1.40±0.03c	0.67±0.14b	2.56±0.27b
	MP	0.59±0.03d	4.02±0.31c	7.67±0.31c	12.28±0.16c	0.82±0.01a	3.27±0.06b	0.97±0.02ab	5.05±0.07a
	CT	1.35±0.09c	4.69±0.09bc	9.42±0.19a	15.46±0.36b	0.73±0.11ab	3.56±0.08a	1.05±0.17a	5.35±0.23a
20–30	ST	3.06±0.10a	6.77±0.51a	9.92±0.17a	19.75±0.47a	1.70±0.56a	0.96±0.28b	0.21±0.11c	2.87±0.44b
	NT	1.41±0.03b	6.32±0.47a	8.30±0.10ab	16.02±0.34c	1.99±0.13a	0.98±0.10b	0.54±0.11bc	3.51±0.32b
	MP	2.15±0.26b	6.52±1.23a	9.03±1.10ab	17.71±0.38b	2.03±0.22a	0.59±0.21b	0.59±0.06b	3.20±0.37b
	CT	2.09±0.46b	3.48±0.36b	7.76±0.11b	13.33±0.07d	1.88±0.07a	1.73±0.09a	2.12±0.14a	5.73±0.06a
30–40	ST	1.92±0.03a	5.74±0.61a	7.01±0.57a	14.67±0.09a	1.29±0.26a	0.68±0.24a	0.33±0.04a	2.31±0.10a
	NT	1.06±0.25ab	4.00±0.54a	4.43±0.15b	9.50±0.34b	1.27±0.15a	0.93±0.34a	0.26±0.10a	2.45±0.27a
	MP	1.12±0.45ab	4.71±0.42a	7.72±0.57a	13.56±0.23a	1.20±0.06a	0.56±0.14a	0.31±0.12a	2.07±0.12a
	CT	0.60±0.14b	2.87±1.53a	5.83±1.19ab	9.30±1.01b	2.00±0.58a	0.95±0.26a	0.10±0.02a	3.05±0.86a
40–50	ST	0.66±0.23ab	3.29±0.90a	4.60±0.55a	8.55±0.39a	0.79±0.35a	0.48±0.18a	0.26±0.06a	1.53±0.58a
	NT	0.23±0.07b	1.66±0.24a	4.02±0.36ab	5.90±0.23c	1.09±0.26a	0.16±0.04a	0.21±0.06a	1.46±0.35a
	MP	0.87±0.24a	2.97±0.60a	3.35±0.26b	7.18±0.27b	0.93±0.16a	0.25±0.19a	0.34±0.07a	1.53±0.26a
	CT	0.55±0.19ab	1.71±0.20a	4.85±0.04a	7.11±0.33b	1.35±0.29a	0.33±0.11a	0.15±0.06a	1.83±0.27a
50–60	ST	0.23±0.15a	1.99±0.21a	3.48±0.31a	5.69±0.05a	0.80±0.04b	0.22±0.04b	0.33±0.06a	1.34±0.12b
	NT	0.34±0.07a	1.06±0.06b	3.50±0.17a	4.90±0.06b	1.33±0.08a	0.19±0.04b	0.17±0.03a	1.69±0.10b
	MP	0.31±0.11a	2.21±0.25a	3.20±0.35ab	5.72±0.14a	1.29±0.03a	0.20±0.06b	0.23±0.07a	1.71±0.15b
	CT	0.15±0.03a	1.83±0.10a	2.38±0.06b	4.36±0.05c	1.21±0.02a	0.96±0.06a	0.26±0.04a	2.44±0.12a

¶ Data are represented as means ± S.D., and data with the same letters within each column indicate no significant difference at $P = 0.05$ level.

Crop residues provide a source of organic matter, so when returned to soil the residues increase the storage of organic C and N in soil, whereas their removal results in a substantial loss of organic C and N from the soil system (Malhi and Lemke 2007) [51]. Therefore, one would expect a dramatic increase in organic C in soil from a combination of ZT, straw retention and proper/ balanced fertilization (Malhi *et al*., 2011b). Naresh *et al*., 2016 [58] also found significantly higher POC content was probably also due to higher biomass C. Results on PON content after 3-year showed that in 0-5 cm soil layer of CT system, T_1, and T_5 treatments increased PON content from 35.8 mgkg^{-1} in CT (T_9) to 47.3 and 67.7 mg·kg^{-1} without CR, and to 78.3, 92.4 and 103.8 mgkg^{-1} with CR @ 2, 4and 6 tha^{-1}, respectively. The corresponding increase of PON content under CA system was from 35.9 mgkg^{-1} in CT system to 49 and 69.6 mgkg^{-1} without CR and 79.3, 93.0 and 104.3mgkg^{-1} with CR @ 2, 4 and 6 tha^{-1}, respectively. Small improvement in PON content was observed after 4 years of the experiment. Singh *et al*., 2014 found that carbon stock of 18.75, 19.84 and 23.83Mg ha^{-1} in the surface 0.4 m soil depth observed under CT was increased to 22.32, 26.73 and 33.07Mg ha^{-1} in 15 years of ZT in sandy loam, loam and clay loam soil. This increase was highest in clay loam (38.8%) followed by loam (34.7%) and sandy loam (19.0%) soil. The carbon sequestration rate was found to be 0.24, 0.46 and 0.62 Mg ha^{-1} yr^{-1}in sandy loam, loam and clay loam soil under ZT over CT. Thus, fine textured soils have more potential for storing carbon and ZT practice enhances carbon sequestration rate in soils by providing better conditions in terms of moisture and temperature for higher biomass production and reduced oxidation (Gonzalez-Sanchez *et al*., 2012) [28]. Gupta Choudhury *et al*. (2014) [30] revealed that the residue incorporation or retention caused a significant increment of 15.65%in total water stable aggregates in surface soil (0–15 cm) and 7.53% in sub-surface soil (15–30 cm), which depicted that residue management could improve 2.1-fold higher water stable aggregates as compared to the other treatments without residue incorporation/retention. Bhattacharya *et al*. (2013) reported that tillage-induced changes in POM C were distinguishable only in the 0- to 5-cm soil layer; the differences were insignificant in the 5- to 15-cm soil layer. Plots under ZT had about 14% higher POM C than CT plots (3.61 g kg^{-1} bulk soil) in the surface soil layer.

Naresh *et al*. (2015a) [57] also found that conservation tillage practices significantly influenced the total soil carbon (TC), total inorganic carbon (TIC), total soil organic carbon (SOC) and oxidizable organic carbon (OC) content of the surface (0 to 15 cm) soil. Wide raised beds transplanted rice and zero till wheat with 100% (T_9) or with 50% residue retention (T_8) showed significantly higher TC,SOC content of 11.93 and10.73 g kg^{-1} in T_9 and 10.98 and 9.38 gkg^{-1}, respectively in T_8 as compared to the other treatments. Irrespective of residue incorporation/ retention, wide raised beds with zero till wheat enhanced 40.5, 34.5, 36.7 and 34.6% of TIC, TC, SOC and OC in surface soil as compared to CT with transplanted rice cultivation. Aulakh *et al*. (2013) [1] showed that PMN content after 2 years of the experiment in 0-5 cm soil layer of CT system, T_2, T_3 and T_4 treatments increased PMN content from 2.7 mgkg^{-1} 7d^{-1} in control (T_1) to 2.9, 3.9 and 5.1 mgkg^{-1} 7d^{-1} without CR, and to 6.9, 8.4 and 9.7 mg kg^{-1} 7d^{-1} with CR (T_6, T_7 and T_8), respectively. The corresponding increase of PMN content under CA system was from 3.6 mgkg^{-1} 7d^{-1} in control to 3.9, 5.1 and 6.5 mgkg^{-1} 7d^{-1} without CR and to 8.9, 10.3 and 12.1 mgkg^{-1} 7d^{-1} with CR. PMN, a measure of the soil capacity to supply mineral N, constitutes an important measure of the soil health due to its strong relationship with the capability of soil to supply N for crop growth.

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 macro-aggregates 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 0.25-1 and 1-2mm aggregates were the main sites of SOC storage and were also the important indices of the soil C pool saturation.

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. 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 l tillage and residue management options.

References

1. Aulakh MS, Garg Ashok K, Kumar Shrvan. Impact of Integrated Nutrient, Crop Residue and Tillage Management on Soil Aggregates and Organic Matter Fractions in Semiarid Subtropical Soil under Soybean-Wheat Rotation. Am. J Plant Sci. 2013; 4:2148-2164.
2. Balota EL, Colozzi-Filho A, Andrade DS, Dick RP. Microbial biomass in soils under different tillage and crop rotation systems. Biol Fertility Soils. 2003; 38:15-20.
3. Beare MH, Pohland BR, Wright DH, Coleman DC. Residue placement and fungicide effects on fungal communities in conventional and no-tillage soils. Soil Sci. Soc. Am. J. 1993; 57:392-399
4. Bhattacharyya R, Pandey SC, Bisht JK, Bhatt JC, Gupta HS, Tuti MD, *et al*. Tillage and Irrigation Effects on Soil Aggregation and Carbon Pools in the Indian Sub-Himalayas. Agro J. 105(1):101-112
5. Blevins RL, Smith MS, Thomas GW. Changes in soil properties under no-tillage. In: Phillips, R.E., Phillips, S.H. (Eds.), No-tillage Agriculture: Principles and Practices. Van Nostrand Reinhold, New York, 1984, 190-230
6. Blevins RL, Frye WW. Conservation tillage: an ecological approach to soil management. Adv. Agron. 1993; 51:33-78**.**
7. Breland TA, Hansen S. Nitrogen mineralization and microbial biomass as affected by soil compaction. Soil Biol. Biochem. 1996; 28:655-663.
8. Bruce RR, Langdale GW, West LT, Miller WP. Surface soil degradation and soil productivity restoration and maintenance. Soil Sci. Soc. Am. J. 1995; 59:654-660
9. Cambardella CA, Elliott ET. Particulate soil organic matter changes across a grassland cultivation sequence. Soil Sci. Soc. Am. J. 1992; 56:777-783.
10. Campbell CA, McConkey BG, Zentner RP, Selles F, Curtin D. Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. Canadian J Soil Sci. 1996; 76:395-401.
11. Cardinael R, Guenet B, Chevallier T, Dupraz C, Cozzi T, Chenu C. High organic inputs explain shallow and deep SOC storage in a long-term agro-forestry system – combining experimental and modeling approaches. *Biogeosci*. 2018; 15:297-317.
12. Carpenter-Boggs L, Stahl PD, Lindstrom MJ, Schumacher TE. Soil microbial properties under permanent grass, conventional tillage, and no-till management in South Dakota. Soil Tillage Res. 2003; 71:15-23.
13. Causarano HJ, Franzluebbers AJ, Shaw JN, Reeves DW, Raper RL, Wood CW. Soil Organic Carbon Fractions and Aggregation in the Southern Piedmont and Coastal Plain. Soil Sci. Soc. Am. J. 2006; 71(1):221-230.
14. Chen H, Hou R, Gong Y, Li H, Fan M, Kuzyakov Y. Effects of 11 years of conservation tillage on soil organic matter fractions in wheat monoculture in Loess Plateau of China. Soil Tillage Res. 2009; 106:85-94.
15. Clapp CE, Allmaras RR, Layese MF, Linden DR, Dowdy RH. Soil organic carbon and ^{13}C abundance as related to

tillage, crop residue, and nitrogen fertilization under continuous corn management in Minnesota. Soil Tillage Res. 2000; 55:127-142.
16. Dalal RC, Henderson PA, Glasby JM. Organic Matter and Microbial Biomass in a Vertisol after 20 yr of Zero-Tillage. Soil Bio Biochem. 1991; 23(5):435-441.
17. Doran JW. Soil microbial and biochemical changes associated with reduced tillage. Soil Sci. Soc. Am. J. 1980; 44:765-771.
18. Doran JW, Elliott ET, Paustian K. Soil microbial activity, nitrogen cycling, and long-term changes in organic carbon pools as related to fallow tillage management. Soil Tillage Res. 1998; 49:3-18.
19. Dou F, Wright AL, Hons FM. Sensitivity of labile soil organic carbon to tillage in wheat-based cropping systems. Soil Sci Soc Am J. 2008; 72:1445-1453.
20. Ellert BH, Bettany JR. Calculations of organic matter and nutrients stored in soil under contrasting management. Can. J Soil Sci. 1995; 75:529-538
21. Falkowski PG, Fenchel T, Delong EF. The microbial engines that drive Earth’s biogeochemical cycles. *Science* 2008; 320:1034-1039.
22. Fang XM, Chen FS, Wan SZ, Yang QP, Shi JM. Topsoil and Deep Soil Organic Carbon Concentration and Stability Vary with Aggregate Size and Vegetation Type in Subtropical China. PLoS ONE 2015; 10(9):e0139380.doi:10.1371/journal.pone.0139380
23. Fontaine S, Barot S, Barre P, Bdioui N, Mary B, Rumpel C. Stability of organic carbon in deep soil layers controlled by fresh carbon supply. Nature. 2007; 450:277-281.
24. Franzluebbers K, Weaver RW, Juo ASR, Franzluebbers AJ. Carbon and nitrogen mineralization from cowpea plant parts decomposing in moist and in repeatedly dried and wetted soil. Soil Biol. Biochem. 1994; 26:1379-1387
25. Franzluebbers AJ, Hubbs MD, Norfleet ML. Evaluating soil organic carbon sequestration potential in the Cotton Belt with the soil conditioning index. J Soil Water Conserv. 2012; 67:378-389.
26. Ge T, Wu X, Liu Q, Zhu Z, Yuan H, Wang W, *et al*. Effect of simulated tillage on microbial autotrophic CO_2 fixation in paddy and upland soils. Sci. Rep, 2014; 6:19784 | DOI: 10.1038/srep19784
27. Geraei DS, Hojati S, Landi A, Cano AF. Total and labile forms of soil organic carbon as affected by land use change in southwestern Iran. Geoderma Regional. 2016; 7:29-37.
28. Gonzalez-Sanchez EJ, Ordonez-Fernandez R, Carbonell-Bojollo R, Veroz-Gonzalez O, Gil- Ribes JA. Meta-analysis on atmospheric carbon capture in Spain through the use of conservation agriculture. Soil Till age Res. 2012; 122:52-60.
29. Grisi B, Grace C, Brookes PC, Benedetti A, Dell’Abate MT. Temperature effects on organic matter and microbial biomass dynamics in temperate and tropical soils. Soil Biol. Biochem. 1998; (10, 11):1309-1315
30. Gupta Choudhury, Shreyasi, Sonal Srivastava, Ranbir Singh, Chaudhari SK, Sharma DK, *et al*. Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice–wheat cropping system under reclaimed sodic soil. Soil Tillage Res. 2014; 136:76-83
31. Gupta V, Germida JJ. Soil aggregation: Influence on microbial biomass and implications for biological processes. Soil Biol. Biochem. 2015; 80:A3-A9.
32. Holland EA, Coleman DC. Litter placement effects on microbial and organic matter dynamics in an agro-ecosystem. Ecol. 1987; 68:425-433.
33. Hoyt JD, Todd RL, Leonard RL. Nitrogen cycling in conventional and no-tillage systems in the southeastern coastal plains. Agron. Abst. 1980; 1:154.
34. Huggins DR, Allmaras RR, Clapp CE, Lamb JA, Randall GW. Corn-Soybean Sequence and Tillage Effects on Soil Carbon Dynamics and Storage. Soil Sci. Soc. Am. J. 2014; 71(1):145-154.
35. Hulugalle NR, Scott F. A review of the changes in soil quality and profitability accomplished by sowing rotation crops after cotton in Australian Vertosols from 1970 to 2006. Aust. J Soil Res. 2008; 46:173-190.
36. Hurisso TT, Culman SW, Horwath WR, Wade J, Cass D, Beniston JW, *et al*. Comparison of Permanganate-Oxidizable Carbon and Mineralizable Carbon for Assessment of Organic Matter Stabilization and Mineralization. Soil Sci Soc Am J. 2013; 80:1352-1364.
37. Ismail I, Blevins RL, Frye WW. Long-term no-tillage effects on soil properties and continuous corn yields. Soil Sci. Soc. Am. J. 1994; 58:193-198.
38. Jacinthe PA, Lal R. Tillage Effects on Carbon Sequestration and Microbial Biomass in Reclaimed Farmland Soils of Southwestern Indiana. Soil Sci. Soc. Am. J. 2009; 73:605-613.
39. Jiang X, Wright AL, Wang J, Li Z. Long-term tillage effects on the distribution patterns of microbial biomass and activities within soil aggregates. Catena. 2011; 87:276-280.
40. Kintche K, Guibert H, Sogbedji JM, Leveque J, Tittonell P. Carbon losses and primary productivity decline in savannah soils under cotton-cereal rotations in semiarid Togo. Plant Soil. 2010; 336:469-484.
41. Kladivko EJ. Tillage systems and soil ecology. Soil Tillage Res. 2001; 61:61-76.
42. Kocyigit R, Demirci S. Long-term changes of aggregate-associated and labile soil organic carbon and nitrogen after conversion from forest to grassland and cropland in northern Turkey. Land Degrad. Develop. 2012; 23:475-482.
43. Kumar BTN, Babalad HB. Soil Organic Carbon, Carbon Sequestration, Soil Microbial Biomass Carbon and Nitrogen and Soil Enzymatic Activity as Influenced by Conservation Agriculture in Pigeonpea and Soybean Intercropping System. Int. J Curr. Microbiol. App. Sci. 2018; 7(3):323-333.
44. Kumar V, Naresh RK, Satendra Kumar, Sumit Kumar, Sunil Kumar, Vivak, *et al*. Tillage, crop residue, and nitrogen levels on dynamics of soil labile organic carbon fractions, productivity and grain quality of wheat crop in Typic Ustochrept soil. J. Pharmacog Phytochem. 2018; 7(1):598-609.
45. Kushwaha CP, Tripathi SK, Singh KP. Variations in soil microbial biomass and N availability due to residue and tillage management in a dry-land rice agro-ecosystem. Soil Tillage Res. 2000; 56:153-166.
46. Lal R, Kimble JM, Follett RF, Cole CV. The Potential of US Cropland to Sequester Carbon and Mitigate the Greenhouse Effect. Ann Arbor Press, Chelsea, MI, 1998.
47. Lewis DB, Kaye JP, Jabbour R, Barbercheck ME. Labile carbon and other soil quality indicators in two tillage systems during transition to organic agriculture. Renewable Agri Food Sys. 2011; 26:342-353.

48. Liang B, Yang X, He X, Zhou J. Effects of 17-year fertilization on soil microbial biomass C and N and soluble organic C and N in loessial soil during maize growth. *Biol.* Fertility Soils. 2011; 47(2):121-128.
49. Liu C, Lu M, Cu 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.
50. Malhi SS, Nyborg M, Goddard T, Puurveen D. Long-term tillage, straw and N rate effects on some chemical properties in two contrasting soil types in Western Canada. *Nutr.* Cycling Agro ecosyst. 2011a; 90:133-146.
51. Malhi SS, Lemke R. Tillage, crop residue and N fertilizer effects on crop yield, nutrient uptake, soil quality and greenhouse gas emissions in the second 4-yr rotation cycle. Soil Tillage Res. 2007; 96:269-283.
52. Mandal KG, Baral U, Padhi JP, Majhi P, Chakraborty H, Kumar A. Effects of cropping on soil properties and organic carbon stock in Deras region, India. Reg. Environ. Change. 2012; 12(4):899-912.
53. Martens DA. Nitrogen cycling under different soil management systems. Adv. Agron. 2001; 70:143-192.
54. Miao C, Zhujun C, Jianbin Z, Jichang H, Qianyun S. Effects of long-term cultivation practices and nitrogen fertilization rates on carbon stock in a calcareous soil on the Chinese Loess Plateau. J Arid Land. 2018; 10(1):129-139.
55. Murphy DV, Sparling GP, Fillery IRP. Stratification of microbial biomass C and N and gross N mineralization with soil depth in two contrasting Western Australian Agricultural soils. Aust J Soil Res. 1998; 36:45-55.
56. Murugan R, Josef Koch H, Joergensen RG. Long-term influence of different tillage intensities on soil microbial biomass, residues and community structure at different depths**.** Biol. Fertility Soils. 2013; 50(3):487-498.
57. Naresh RK, Gupta Raj K, Gajendra Pal, Dhaliwal SS, Kumar, Dipender, *et al*. Tillage crop establishment strategies and soil fertility management: resource use efficiencies and soil carbon sequestration in a rice-wheat cropping system. Eco. Env. & Cons. 2015a; 21:127-134
58. Naresh RK, Gupta Raj K, Singh SP, Dhaliwal SS, Ashish Dwivedi, Onkar Singh, *et al*. Tillage, irrigation levels and rice straw mulches effects on wheat productivity, soil aggregates and soil organic carbon dynamics after rice in sandy loam soils of subtropical climatic conditions. J Pure Appl MicrobioI, 2016; 10(2):1061-1080.
59. 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. Pharmacog Phytochem. 2017; 6(6):670-683.
60. Nimmo JR, Perkins KS. Aggregate stability and size distribution. In: Dane JH, Topp GC, editors. Methods of Soil Analysis: Part 4±Physical Methods. Madison, Wisconsin, USA: Soil Sci Soc Am, Inc; 2002, 317-328.
61. Poffenbarger HJ, Barker DW, Helmers MJ, Miguez FE, Olk DC, Sawyer JE, *et al*. Maximum soil organic carbon storage in Midwest US cropping systems when crops are optimally nitrogen-fertilized. PLoS ONE 12, e0172293, 2017.
62. Potter KN, Torbert HA, Jones OR, Matocha JE, Morrison Jr JE, Unger PW. Distribution and amount of soil organic C in long-term management systems in Texas. Soil Tillage Res. 1998; 47:309-321
63. Puget P, Chenu C, Balesdent J. Total and young organic matter distributions in aggregates of silty cultivated soils. Eur J Soil Sci. 1995; 46:449-459.
64. Puttaso A, Vityakon P, Saenjan P, Trelo-ges V, Cadisch G. Relationship between residue quality, decomposition patterns, and soil organic matter accumulation in a tropical sandy soil after 13 years. Nutri Cycl Agroecosyst. 2011; 89(2):159-174.
65. Awale R, Chatterjee A, David Franzen. Tillage and N-fertilizer influences on selected organic carbon fractions in a North Dakota silty clay soil. Soil Tillage Res. 2013; 134:213-222.
66. Rajan G, Keshav RA, Zueng-Sang C, Shree CS, Khem RD. Soil organic carbon sequestration as affected by tillage, crop residue, and nitrogen application in rice–wheat rotation system. Paddy Water Environ. 2012; 10:95-102.
67. Romkens PFAM, van der Plicht J, Jassink J. Soil organic matter dynamics after the conversion of arable land to pasture. Biol. Fertil. Soils. 1999; 28:277-284.
68. Rosell RA, Galantini JA, Suner LG. Long-term crop rotation effects on organic carbon, nitrogen, and phosphorus in Haplustoll soil fractions. Arid Soil Res. Rehabil. 2000; 14:309-315
69. Schomberg HH, Steiner JL, Unger PW. Decomposition and nitrogen dynamics of crop residues: residue quality and water effects. Soil Sci. Soc. Am. J. 1994; 58:372-381
70. Senapati N, Hulugalle NR, Smith P, Wilson BR, Yeluripati JB, Daniel H, *et al*. Modelling soil organic carbon storage with RothC in irrigated Vertisols under cotton cropping systems in the sub-tropics. Soil Tillage Res. 2014; 143:38-49.
71. Sharma V, Hussain S, Sharma KR, Arya VM. Labile carbon pools and soil organic carbon stocks in the foothill Himalayas under different land use systems. Geoderma 2014; (232-234):81-87.
72. Shi-Chao W, Ya-Wen Z, Jin-Zhou W, Ping Z, Xian C, Xiao-zeng H, *et al*. The efficiency of long-term straw return to sequester organic carbon in Northeast China’s cropland. J Inte Agri. 2018; 17(2):436-448
73. Singh G, Marwaha TS, Kumar D. Effect of resource conserving techniques on soil microbiological activities parameters under long term maize (*Zea mays*) – wheat (*Triticum aestivum*) crop rotation. Indian J Agri Sci. 2009; 79(2):94-100.
74. Singh H, Singh KP. Effect of residue placement and chemical fertilizer on soil microbial biomass under tropical dry-land cultivation. Biol. Fertil. Soils 1993; 16:275-281.
75. Six J, Conant RT, Paul EA, Paustian K. Stabilization mechanisms of soil organic matter: Implications for C saturation of soils. Plant Soil. 2002; 241:155-176.
76. Song MW, Li AZ, Cai LQ, Zhang RS. Effects of different tillage methods on soil organic carbon pool. J Agro-Enviro Sci. 2011; 27(2):6222-626.
77. Sparling GP. Ratio of microbial biomass carbon to soil organic carbon is a sensitive indicator of changes in soil organic matter. Aust. J Soil Res. 1992; 30:195-207.
78. Studdert GA, Echeverr´ıa HE, Casanovas EM. Crop-pastures rotation for sustaining the quality and productivity of a Typic Argiudoll. Soil Sci. Soc. Am. J. 1997; 61:1466-1472.
79. Thompson JP. Soil biotic and biochemical factors in a long-term tillage and stubble management experiment on

a Vertisol: 2. Nitrogen deficiency with zero tillage and stubble retention. Soil Tillage Res. 1992; 22:339-361.

80. Unger PW. Organic matter, nutrient, and pH distribution in no- and conventional-tillage semiarid soils. Agron. J. 1991; 83:186-189.
81. Ussiri DAN, Lal R, Jarecki MK. Nitrous oxide and methane emissions from long-term tillage under continuous corn cropping system in Ohio. Soil Tillage Res. 2009; 104:247-255.
82. Wander MM, Bidart MG, Aref S. Tillage impacts on depth distribution of total and particulate organic matter in three Illinois soils. Soil Sci. Soc. Am. J. 1998; 62:1704-1711
83. Wardle DA. A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in soil. Biol. Rev. 1992; 67:321-358.
84. Wershaw RL. Model for humus in soils and sediment. Environ. Sci. Technol. 1993; 27:814-816
85. Xiao SS, Zhang W, Ye Y, Zhao J, Wang K. Soil aggregate mediates the impacts of land uses on organic carbon, total nitrogen, and microbial activity in a Karst ecosystem. Sci Rep. 2016; 7:41402 DOI: 10.1038/srep41402
86. Xu JG, Juma NG. Above- and below-ground transformation of photosynthecically fixed carbon by two barley (*Hordeum vulgare* L.) cultivars in typic cryoboroll. Soil Biol. Biochem. 1993; 25:1263-1272.
87. Yang JC, Han XG, Huang JH, Pan QM. The dynamics of soil organic matter in cropland responding to agricultural practices. Acta Ecologica Sinica. 2003; 23(4):787-796.
88. Zheng H, Liu W, Zheng J, Luo Y, Li R, Wang H, *et al*. Effect of long-term tillage on soil aggregates and aggregate-associated carbon in black soil of Northeast China. *Plos One*. 2018; 13(6):e0199523.
89. Zhao Y, Wang M, Hu S, Zhang X, Ouyang Z, Zhang G, *et al*. Economics- and policy-driven organic carbon input enhancement dominates soil organic carbon accumulation in Chinese croplands. *PNAS*, 2018; 115(16):4045-4050.
90. Zhu LQ, Zhang DW, Bian XM. Effects of continuous returning straws to field and shifting different tillage methods on changes of physical-chemical properties of soil and yield components of rice. Chinese J Soil Sci. 2011; 42(1):81-85.
91. Zhu L, Hu N, Yang M, Zhan X, Zhang Z. Effects of Different Tillage and Straw Return on Soil Organic Carbon in a Rice-Wheat Rotation System. Plos One 9 2014; (2):e88900. doi:10.1371/journal.pone.0088900