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Fertilization and Soil Ploughing Practices under Changing Physical Environment Lead to Soil Organic Carbon Dynamics under Conservation Agriculture in Rice-Wheat Cropping System: A Scoping Review

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Abstract

Ploughing and fertilization practices in rice-wheat system have deteriorated the soil carbon (C) pools. Conservation agriculture (CA) based management approaches have proven to enhance C sequestration and reverse the loss of soil-organic-carbon (SOC), which further enhances soil fertility. Different fractions of SOC pools react to the alterations in management practices and indicate changes in SOC dynamics as compared to total C in the soil. Higher SOC levels in soil have been observed in case of reduced/no-till (NT) practices than conventional tillage (CT). However, between CT and zero tillage/NT, total SOC stocks diminished with an increase in soil depth, which demonstrated that the benefits of SOC are more pronounced in the topsoil under NT. Soil aggregation provides physical protection to C associated with different-sized particles, thus, the improvement in soil aggregation through CA is an effective way to mitigate soil C loss. Along with less soil disturbance, residual management, suitable crop rotation, rational application of manures and fertilizers, and integrated nutrient management have been found to be effective in not only improving soil C stock but also enhancing the soil health and productivity. Thus, CA can be considered as a potential method in the build-up of SOC of soil in rice-wheat system.

Keywords

Tillage, Conservation Agriculture, Soil Organic Carbon, Carbon Fractions, Rice-Wheat System, Organic Amendments

1. Introduction

In the 21st century, the extenuation of greenhouse gases (GHGs) emission is a vital challenge to reduce the detrimental impacts of global warming as well as climate change. Atmospheric carbon-dioxide (CO_2) concentration has amplified from 280 mg·kg^{-1} (in pre-industrial era) to 412.48 mg·kg^{-1} (in 2020) and CO_2 concentrations are expected to double by 2050 considering the industrial scenarios involved in high carbon emissions [1] [2]. The upsurge in the level of CO_2 is attributed to fossil fuel combustion, cutting of trees, along with deposition of wastes etc. The extravagant global demand for energy (475 Quads) as well as its increased rate of consumption (2.5% per year), particularly in developing countries, is ultimately resulting in an increase in fossil fuel combustion. Various researchers have used different models to investigate the effect of inhabitants, affluence, and technological advances on CO_2 emission. A direct positive relation between CO_2 production and population development helps to monitor the rise in CO_2 levels with the increase in population. At an annual increment rate of 1.3 %, the world population might increase from 6.7 billion as in 2008 to 9.5 billion in 2050 [3]. The maximum impact of affluence on CO_2 emissions is observed at $10,000 in per capita gross domestic product and is found to decline with increasing levels of affluence [4]. This suggested that the population and economic growth predicted over the coming years intensify GHG emissions, thus threatening to produce disruptive changes in global climate. Agricultural soils have a pivotal role in regulating the carbon (C) cycle as soil organic carbon (SOC) nearly accounts for 10% of the total terrestrial C storage [5]. The sequestration of atmospheric CO_2 into terrestrial soils is one of the possible solutions for mitigating climate change.

Global plant biomass captures approximately 110 billion metric tons of C yr^{-1} via photosynthesis where an equal amount of C is returned to the atmosphere in the form of CO_2 through respiration (both autotrophic and heterotrophic respiration) and decomposition of plant and animal residues simultaneously. Soil stocks about 1600 billion metric tons of C in organic matter (OM) and 700 billion metric tons of C is stored in the soil as carbonate minerals in the layer up to 1 m depth. About 800 billion metric tons of C is contained in the atmosphere in the form of CO_2 which has been gradually increasing since the beginning of the

20th century [6].

Different agricultural practices lead to the emission of GHG's consisting of CO_2 resulting from SOC, methane (CH_4) emission from enteric fermentation, along with the release of nitrous oxide (N_2O) from synthetic fertilizers and manures [7]. Estimation of GHG emissions suggested that the potential of global warming per hectare in terms of CO_2 equivalent (CO_2-eq) varied significantly among different cropping systems. The global warming potential of the rice-wheat cropping system is reported to be equal to 1823 kg CO_2-eq, while on the contrary, the global warming potential for other cropping systems involving fodder, horticulture, vegetables, and maize-wheat was observed to be 245, 117, 188, and 410 kg CO_2-eq [8]. Moreover, the diversified cropping system (1547 kg CO_2-eq ha^{-1}) had only 46% global warming potential per hectare as compared to the rice-wheat system (2862 kg CO_2-eq ha^{-1}) [8].

The Indian Indo-Gangetic Alluvial Plains (IGP) (21˚45'N, 74˚15'E to 31˚0'N, 91˚30'E) cover a large region of about 43.7 m ha which extends over 8 agro-ecological regions (AERs) and 14 agro-ecological sub-regions (AESRs) which includes the states like Punjab, Uttar Pradesh, Haryana, Uttarakhand, Delhi, Bihar, West Bengal, Himachal Pradesh, northern parts of Rajasthan, along with Tripura [9]. The IGP comprises 13% of the geographical coverage in India, which contributes to 50% of grain production. The rice-wheat cropping system is the most prevalent crop rotation in the IGP, although this cropping system jeopardizes agricultural sustainability and farm profitability. This is because the rice-wheat cropping system is associated with lower yield, degradation of soil health, declining water table, and air pollution due to residue burning [10].

Soil organic carbon (SOC) has a crucial role in upholding the fertility of soil, environmental conservation, along with sustainable agriculture [11] [12] [13]. Therefore, SOC is considered as an important soil component and is regarded as the determinant for monitoring ecological functions [14]. Generally, the soil of Indian farmland possesses lower SOC content, and the amount is lower than the world average and that of Europe by more than 30% and 50% respectively [15]. Thus, enhancement of SOC in agricultural soils is considered a huge matter of concern in the field of agricultural sciences. Other than environmental factors like weather and soil conditions, the change in SOC storage is mainly affected by human activities [16] [17] [18].

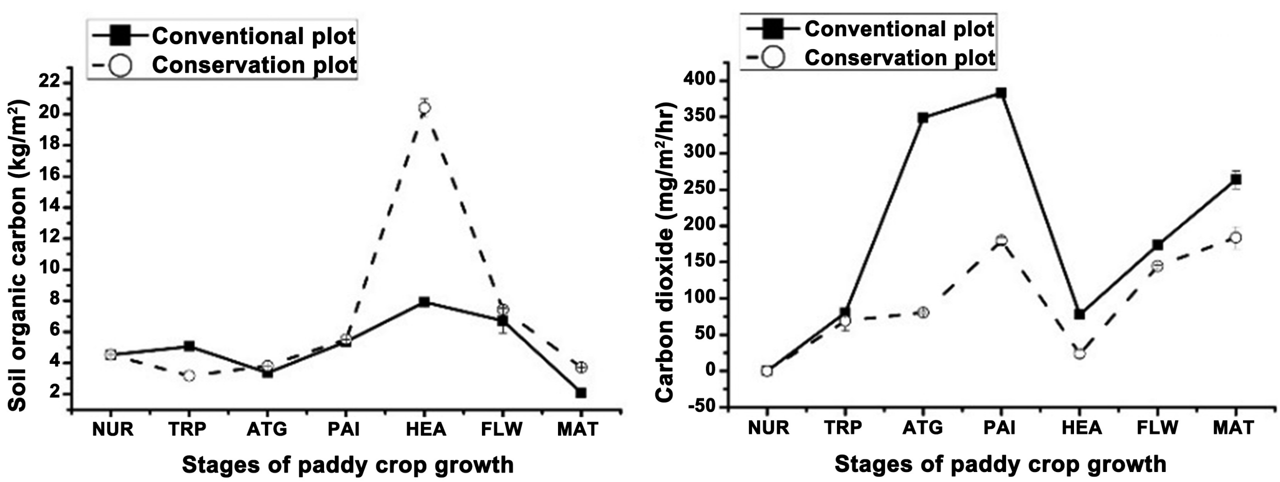
The promising ways to build-up soil organic C (SOC) contents are: 1) increasing the rate of OM application to the soils, 2) reduction in the rate of decomposition of OM which ultimately would facilitate the SOC storage, and 3) providing mechanical protection to SOC by improving the stability of intra-aggregate and organo-mineral complexes [19]. The residence time of C in soil is greatly influenced by several factors including soil texture, native vegetation, climatic and drainage conditions. Such factors govern the amount and even the quality of sequestered C. Aggregates are the principal determinant of soil structure as well as pore characteristics which in turn influence the capacity of soil C storage [20]. Thus, better aggregation provides greater protection to C within aggregates. On the other hand, the alteration in various pools of soil C and their distribution in different-sized aggregates are much more sensitive to tillage operations, fertilizer application, manuring, and other management practices. Hence, a detailed experiment on the dynamics of SOC and evaluation of early signals under several conservation practices, fertilization, and manuring is needed for planning and policy-making for remediation of degraded lands and maintaining soil health and sustainability.

2. Tillage and Conservation Practices Affecting Total Soil Organic Carbon and Its Transformations

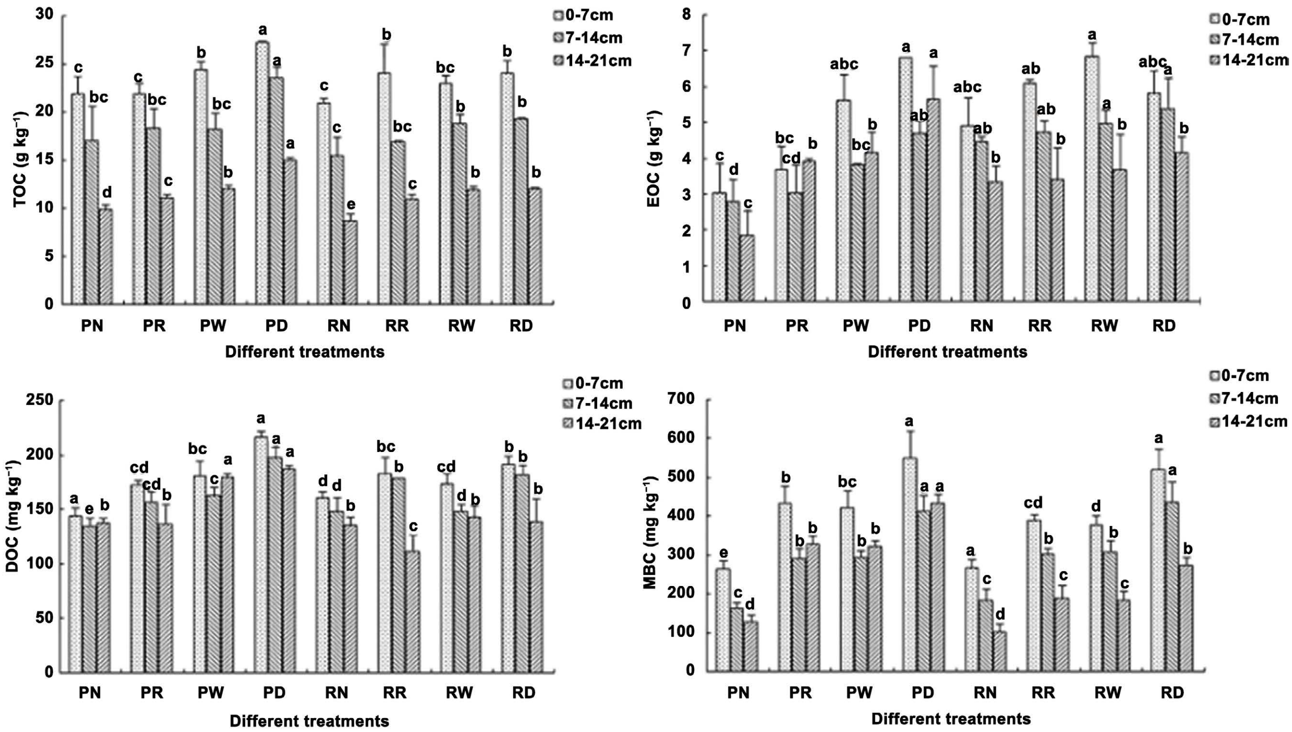
Soil conservation tillage systems are considered major components of sustainable agriculture involving the reduction of tillage operations and retaining at least 30% of plant remains at the soil surface [21]. Intensive agriculture markedly lowers the C content of soils especially in upper layers, as traditional tillage operations significantly enhance soil temperature and aeration, thus hastening the vulnerability of C breakdown in soil and its losses through augmented rate of oxidation and enhanced microbial activity [22] [23] [24] [25]. Soil structure refers to the arrangement of soil particles into certain units known as soil aggregates [26]. Tillage operations are observed to directly disintegrate soil aggregates and scrap away mycelium network in soil [27] [28], and indirectly undermines soil aggregate formation as well as stability due to the negative impact on soil organic matter content, growth and activity of soil microorganisms and their community structure [28]-[33]. Dutta and Gokhale [34] observed that the bulk density (BD) of soil can be affected by tillage operations and crop rotation involved with greater impact on surface soil layers; lower values of bulk density are reported for conservation plots as compared to conventional and this is due to the reduced amount of soil compaction owing to least soil disturbance in conservation plots. According to several researchers, the introduction of conservation tillage replacing conventional tillage practices could not only raise the soil C stock by lowering the loss of SOC [35] [36] but also at the same time could deplete the GHG emission to an appreciable extent [37] [38]. Parihar *et al.*, [39] also found that the global warming potential under the CT system was greater in comparison to other treatments. Higher values of SOC were reported in conservation plots as compared to other plots where SOC content ranged from 3.17 to 20.42 $kg\cdot m^{-2}$ (**Figure 1(a)**) as reported by Dong *et al.* [40]. The minimal disturbance in the topsoil of conservation plots helps in greater accumulation of OM which might be the reason for greater SOC levels. The minimal disturbance in the top layer also reduces the microbial attack on soil, thus preventing the decay of OM (**Figure 1(a)**). Levels of SOC in plots with conventional tillage were low and ranged from 2.08 to 7.92 $kg\cdot m^{-2}$. Under conservation tillage, an increment of 0.21 and 0.51 g C kg $soil^{-1}$ yr^{-1} over conventional tillage was found by Wang *et al.*, [41] in the case of dry croplands and rice cultivation respectively. Mikha *et* *al.*, [42] documented around 19.7 % enhancement in SOC level in surface soils up to 30 cm depth in seven years of conservation tillage. A significant rise in SOC in the topsoil layers (30 cm) under no-tillage in comparison to conventional tillage has also been observed by Zhang *et al.*, [43]. The continuous tillage disrupts the soil aggregates exposing more soil to microbial attack leading to an increased rate of OM and SOC decay which could be the reason for low SOC content in conventional plots [44].

Additionally, straw return treatments are reported to enhance the amounts of soil organic matter and fine intra-aggregate particulate organic matter (iPOM) in small macro as well as micro-aggregates in soil. The concentration of C associated with iPOM was significantly less in deeper layers as compared to the top layer of soil [45]. Zhu *et al.*, [46] revealed that total organic carbon (TOC) and labile organic carbon fractions in soil are influenced by straw management and reported a greater extent of TOC and labile C at 0 - 21 cm soil depth in treatments with crop straw return in comparison to the treatments without crop straw return. Significantly lesser amounts of TOC, dissolved organic carbon (DOC), microbial biomass carbon (MBC), and easily oxidizable organic carbon (EOC) have been exhibited by plowing tillage with no straw return (PN) treatment plots at soil depths of 0 - 7 cm and 7 - 14 cm, while on comparing other treatments, rotary tillage with no straw return (RN) exhibited least TOC and MBC at 14 - 21 cm soil depth (**Figure 1(b)**). Tillage operations facilitate phenomena of drying-rewetting and freezing-thawing on soil that augments disintegration of macro-aggregates into micro-aggregates which ultimately encourages EOC loss through mineralization of labile C as well as SOC [46] [47]. The study of croplands implies a significant positive effect of conservation tillage (no-tillage and reduced tillage) on SOC build-up. A rise in tillage intensity aggravates the breakdown of C-rich macro-aggregates into micro-aggregates with lower C contents.

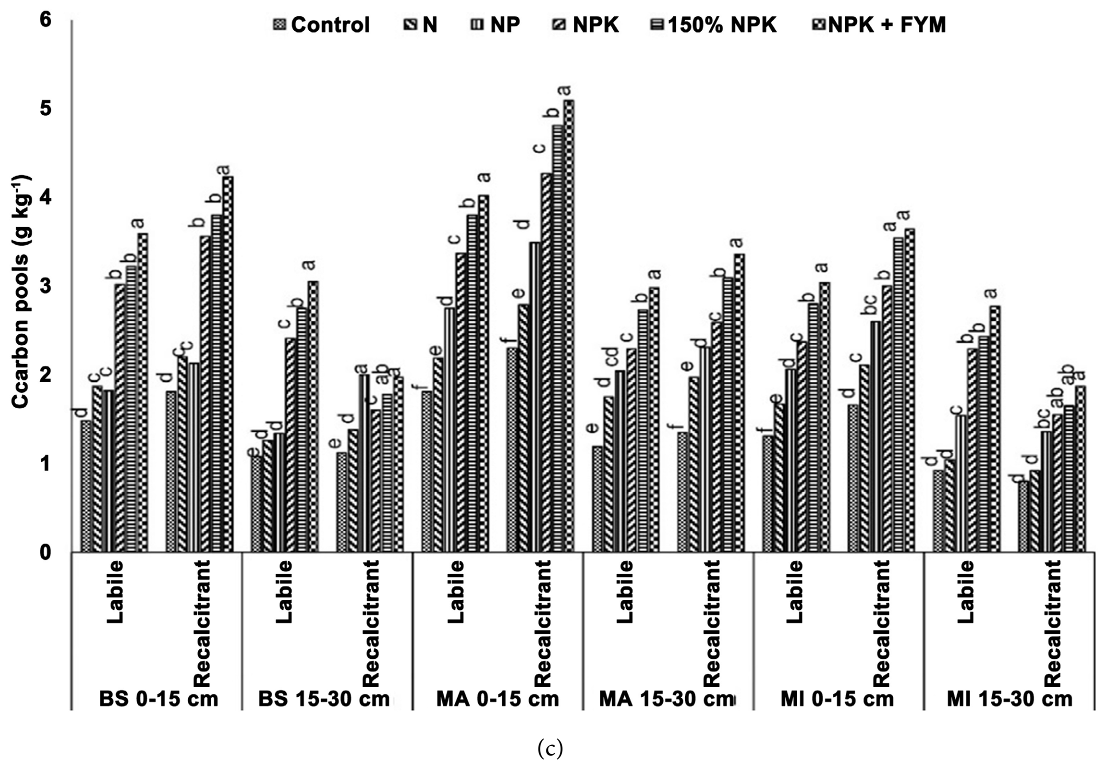
Soil surface layer (0 - 15 cm) exhibits a notable influence of conservation tillage



(a)



(b)



(c)

Figure 1. (a) Variation of (a) soil organic carbon and (b) carbon dioxide observed in the conventional and conserved plots, during the various stages of paddy crop growth [34] (b) Effects of eight treatments on soil TOC, EOC, DOC and MBC contents at three depths [46] (c) Labile and recalcitrant carbon pools in bulk soils and aggregates as affected by long-term fertilization in the 0 - 15 and 15 - 30 cm soil layers under a wheat based cropping system in an Inceptisol. BS = Bulk soils; MA = Macro-aggregates; MI = Micro-aggregates; BS 0 - 15 cm = Bulk soil of 0 - 15 cm soil depth, and so on [12].

on total carbon (TC), total inorganic carbon (TIC), TOC, and oxidizable soil organic carbon (SOC) [48]. The TC and SOC contents were equal to 11.93 and 10.73 g·kg^{-1} for wide raised bed transplanted rice and zero-till wheat with 100% residue management respectively, and 10.98 and 9.38 g·kg^{-1} for wide-raised bed transplanted rice and zero-till wheat with 50% residue management respectively. In comparison with the transplanted rice cultivation under conventional tillage, wide-raised beds wheat cultivation with zero tillage exhibited about 53.6%, 33.3%, 38.7%, and 41.9% rise in TC, TIC, SOC, and OC contents respectively, irrespective of residue incorporation or residue retention. On the other hand, an enhancement of 6.4%, 7.4%, 8.7%, and 10.6% regarding TC, TIC, SOC, and OC contents respectively were recorded in case of residue retention in comparison to treatments involving no residue management.

Kumar *et al.*, [49] reported lower SOC along with labile C fractions under conventional tillage without residue retention than zero-tillage without residual retention and reduced-tillage with residual retention. Whereas significant increases in labile C fraction (32% - 52%) except for particulate organic carbon (POC) was observed in zero tillage with residue retention treatment relative to reduced tillage with residual retention treatment. Additionally, zero tillage with residue retention and reduced tillage with residual retention treatments exhibited identical SOC levels (21.2 g·kg^{-1} and 20.3 g·kg^{-1}, respectively). Among studied fractions of soil C, light fraction organic carbon (LFOC), and dissolved organic carbon (DOC) were marked as most sensitive as they indicate the alterations in SOC as affected by the tillage crop practices. In zero tillage with residue retention, SOC levels followed the trend *i.e.*, 200 kg N ha^{-1} > 160 kg N ha^{-1} > and 120 kg N ha^{-1} plots, and were strikingly greater than those in control plots (by 37%, 33% and 21%, respectively). Labile C pools were also notably higher in case of treatments with residue retention/incorporation than the treatments where chemical fertilizers are applied solely (**Table 1**) [49].

Sandy loam, loam, and clay loam soils of northern India exhibited 0.44, 0.51, and 0.60% SOC concentration under conventional tillage in rice-wheat cropping system whereas an increment of 0.60 and 0.70% was observed under zero tillage (ZT) practice [50]. Under both the tillage practices, a significant reduction in OC with depth was observed in all three soils where the abrupt reduction in OC at 15 - 30 cm layer as compared to the surface layer (0 - 15 cm) was found under conventional tillage which was not so pronounced under zero tillage. A rise in the heavy fraction of C in both surface and sub-surface soils was noted under ZT which was pronounced under coarse-textured soils.

Ghosh *et al.*, [51] observed a notable seasonal change in labile C that exhibited maximum value during the period from February to March, and declined subsequently up to October. Lesser content of labile fraction of C during April to September might be attributed to the fast decomposition rate of fresh inputs of C in the form of OM and greater loss through runoff during the rainy season [52]. Prominent deviation in C fractions was observed by Awanish [53] particularly in

Table 1. Effect of different treatments on contents of various biological fractions of carbon in soil (modified after Kumar *et al.* 2018).

Treatments	PMN ($mg \cdot kg^{-1}$)		MBC ($mg \cdot kg^{-1}$)		MBN ($mg \cdot kg^{-1}$)		DOC ($mg \cdot kg^{-1}$)	
	Depths (cm)							
	0 - 15	15 - 30	0 - 15	15 - 30	0 - 15	15 - 30	0 - 15	15 - 30
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

PMN = potentially mineralizable nitrogen; MBC = microbial biomass carbon; MBN = microbial biomass nitrogen; DOC = dissolved organic carbon; ZTR = Zero tillage with residue retention; ZTWR = Zero tillage without residue retention; RTR = Reduced tillage with residue retention; RTWR = Reduced tillage without residue retention; CTR = Conventional tillage with residue incorporation; CT = Conventional tillage without residue incorporation.

the surface layer (0 - 5 cm). On comparing C fractions, an order of F_4 (non-labile) > F_1 (very labile) > F_2 (labile) = F_3 (less labile) was observed in 0 - 5 cm which were $F_4 > F_1 > F_3 > F_2$ and $F_4 > F_1 > F_2 > F_3$ for soil depth below 5 cm and 15 - 30 cm, respectively. On an overall basis, a depth-wise decrease in C contents was noted which was more pronounced for the very labile fraction (F_1). The contribution of F_1 fraction was around 40% or more at 0 - 5 and 5 - 15 cm soil depths than that for deeper soil depths (15 - 30 and 30 - 45 cm) whereas in deeper soil layers, greater than 50% of TOC was contributed by less labile and non-labile fractions indicating a recalcitrant form of C in the soil. The increase in TOC concentration at the surface layer might be due to the combined effect of reduced soil disturbance and increased residual return to the soil surface under conservation tillage. Thus, this section summarises the different tillage and conservation practices affecting total SOC.

3. Fertilization and Manuring on Total SOC and Its Transformations

The fertilizers and manure quantity has a key influence on SOC content and its transformations. Brar *et al.*, [11] revealed that SOC in the topsoil layer increased significantly with the application of the recommended dose of fertilizers alone or the recommended dose of fertilizers along with farm yard manure (FYM). The sequestration of C and its rate significantly increased from 3.30 to 4.10 Mg C ha^{-1} and 0.37 to 0.46 Mg C ha^{-1} yr^{-1}, respectively when FYM along with the recommended dose of fertilizers were applied. Tong *et al.*, [54] reported that the treatment of NPK and NP to the soil significantly improved SOC stocks.

Significantly greater concentrations of labile and recalcitrant C in NPK + FYM treatment over control and NP treated plots were reported by Ghosh *et al.*, [12] in both the soil depths of 0 - 15 and 15 - 30 cm (**Figure 1(c)**). In the sub-surface layer (15 - 30 cm depth) plots with NPK + FYM treatment exhibited a greater proportion of labile C than that of 150% NPK while both the treatments were at par in terms of recalcitrant C. On average, the macro-aggregates of NPK + FYM treated plots exhibited a labile C: recalcitrant C ratio of 1.38:1 while within macro-aggregates, a gradual reduction in labile C was observed under NP, N, and control plots.

In a study on wheat crop, Mazumdar *et al.*, [55] observed that the plots with NPK + FYM treatment exhibited SOC levels of 19% and 138% higher than NPK and control plots, respectively, for surface soil (0 - 15 cm) (**Table 2**). However, the plots with 150% NPK and NPK treatments showed identical levels of SOC in the same soil layer. Similarly, plots with NPK + FYM treatment resulted in 136% and 24% increased SOC level in the 15 - 30 cm soil layer followed by 130% and 18% increased SOC level in the soil depth of 30 - 60 cm, and 80% and 29% more SOC concentration in soil depth of 60 - 90 cm as compared to control and NPK treated plots, respectively (**Table 2**). The total SOC content was reported to be higher in plots with NP treatment as compared to N plots in all layers (**Table 2**). Application of manure and P fertilizers greatly influence soil microbial activity

Table 2. The effect of fertilization for 44 years under a wheat based cropping system on total SOC levels and total SOC stock in bulk soils [12].

Treatments	0 - 15 cm			15 - 30 cm			30 - 60 cm			60 - 90 cm		
	SOC ($g·kg^{-1}$)	SOC-Stock ($Mg·ha^{-1}$)	Bulk density ($Mg·m^{-3}$)	SOC ($g·kg^{-1}$)	SOC-Stock ($Mg·ha^{-1}$)	Bulk density ($Mg·m^{-3}$)	SOC ($g·kg^{-1}$)	SOC-Stock ($Mg·ha^{-1}$)	Bulk density ($Mg·m^{-3}$)	SOC ($g·kg^{-1}$)	SOC-Stock ($Mg·ha^{-1}$)	Bulk density ($Mg·m^{-3}$)
Control	3.29^{e}	7.69^{d}	1.56^{a}	2.13^{d}	5.06^{d}	1.59^{a}	1.92^{e}	9.50^{d}	1.65^{a}	1.74^{d}	8.72^{c}	1.67^{a}
N	4.05^{d}	9.30^{c}	1.53^{ab}	2.64^{d}	6.14^{cd}	1.55^{b}	2.33^{d}	11.32^{c}	1.62^{ab}	1.94^{d}	9.54^{c}	1.64^{b}
NP	3.93^{d}	8.91^{cd}	1.51^{b}	3.33^{c}	7.65^{bcd}	1.53^{b}	2.94^{c}	14.55^{b}	1.65^{a}	2.22^{c}	11.06^{b}	1.66^{a}
NPK	6.57^{bc}	14.59^{b}	1.48^{c}	4.06^{b}	9.13^{abc}	1.50^{c}	3.75^{c}	18.45^{ab}	1.64^{a}	2.43^{c}	12.10^{b}	1.66^{a}
150% NPK	7.02^{b}	15.48^{ab}	1.47^{c}	4.51^{ab}	10.01^{ab}	1.48^{cd}	4.14^{b}	20.62^{a}	1.66^{a}	2.91^{b}	14.67^{a}	1.68^{a}
NPK + FYM	7.82^{a}	16.77^{a}	1.43^{d}	5.02^{a}	10.91^{a}	1.45^{d}	4.42^{a}	21.08^{a}	1.59^{b}	3.13^{a}	15.02^{a}	1.60^{c}

See materials and methods section for treatment details. Means with similar lower-case letters within a column are not significantly different at $p < 0.05$ according to Tukey's HSD test.

which might be attributed to a greater degree of soil aggregation. Better aggregation and macro-aggregates with a larger radius could bind O_2 level and diffusion of gas necessary for microbial activities as described by Gupta and Germida [56]. In this way, a stable microbial biomass is maintained in manure and P treated soils. They also reported the reduction in POC which was driven by the reduction of fine POC in top-soil, whereas DOC mostly declined in the sub-soil. Mean SOC level of control was increased from 0.54% to 0.65% with the application of recommended dose of fertilizer while it reached about 0.82% where application of FYM was performed along with the recommended dose of fertilizer.

In a rice-wheat rotation, Tiwari *et al.*, [57] reported that soil aggregation strongly associated organic carbon fractions which in turn affected the microbial activities by tillage and straw management practices. Similarly, the field investigation by Naresh *et al.*, [48] showed that treatment with FYM/GM/SPM remarkably increased the SOC concentration at 0 - 5 and 5 - 15 cm soil depths. The maximum SOC values were recorded in 50% RDN as CF + 50% RDN as FYM (F_5) followed by 50% RDN as CF + 50% RDN as GM/SPM (F_6) treatments and was least in untreated F_1 plots (**Table 3**). Carbon intake in the form of plant residues is an important aspect responsible for the stability of C in soil [58]. Reorganization of C in bed planting has zero damage to the same residual storage

Table 3. Effect of 15 years of application of treatments on total organic C (TOC), total N (TN), and soil organic carbon (SOC) (Kumar *et al.* 2018).

Treatments	0 - 5 cm layer				5 - 15 cm layer			
	TOC (gkg^{-1})	TN ($mg{\cdot}kg^{-1}$)	SOC ($g{\cdot}kg^{-1}$)	SOC stock ($Mg\ ha^{-1}$)	TOC ($g{\cdot}kg^{-1}$)	TN ($mg{\cdot}kg^{-1}$)	SOC ($g{\cdot}kg^{-1}$)	SOC stock ($Mg\ ha^{-1}$)
Tillage crop residue practices								
T1	19.30^{c}	539^{c}	5.9^{c}	19.79^{e}	14.37 d	489^{c}	4.5^{d}	14.91^{c}
T2	23.00^{b}	590^{b}	6.5^{b}	30.05^{c}	17.98^{c}	561^{bc}	5.8^{bc}	27.70^{b}
T3	25.68^{a}	696^{ab}	7.2^{a}	35.40^{a}	21.63 a	643^{ab}	6.6^{a}	30.97^{a}
T4	18.50^{c}	516^{c}	4.5^{d}	22.18^{d}	14.32 d	483^{c}	4.6^{d}	16.79^{c}
T5	23.01^{b}	584^{bc}	6.1^{bc}	31.63^{bc}	18.89^{bc}	546^{bc}	5.4^{c}	25.99^{b}
T6	23.87^{ab}	845^{a}	6.8^{ab}	33.52^{ab}	19.98^{ab}	765^{a}	6.1^{ab}	29.26^{ab}
T7	9.28^{d}	422^{c}	3.6^{e}	14.91^{f}	7.36^{e}	328^{d}	3.2^{e}	9.46^{d}
Nutrient management practices								
F1	10.99^{d}	406^{cd}	7.9^{c}	29.16^{c}	9.01^{d}	349^{d}	6.8^{c}	23.74^{c}
F2	17.78^{b}	577^{c}	8.4^{bc}	30.70^{c}	15.13^{c}	554^{bc}	7.3^{bc}	26.15^{c}
F3	19.64^{b}	621^{bc}	8.5^{b}	31.97^{bc}	15.64^{bc}	568^{bc}	7.5^{bc}	27.75^{bc}
F4	13.56^{c}	544^{cd}	8.1^{c}	29.67^{c}	13.37^{c}	514^{c}	7.0^{bc}	29.55^{c}
F5	23.65^{a}	896^{a}	9.6^{a}	36.14^{a}	19.08^{a}	783^{a}	8.3^{a}	34.19^{a}
F6	21.47^{a}	737^{ab}	9.0^{ab}	34.59^{a}	18.80^{a}	694^{ab}	8.1^{a}	31.17^{ab}
F7	21.40^{ab}	645^{bc}	8.6^{b}	32.62^{b}	17.30^{ab}	608^{b}	7.6^{ab}	29.86^{b}

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

area in this planting system may be due to the previous drying, a small amount of OM and a small deterioration in the bed during the wheat season.

Khan *et al.*, [59] observed higher SOC sequestration rates in minimum till (MT) treatment as compared to deep till (DT). It was observed that the application of FYM results in more SOC levels in the soil as compared to soybean residue (SR) whereas total nitrogen in soil was more with SR than FYM. The SOC levels of both FYM and SR were more than control and urea treated plots. Hijbeek *et al.*, [60] suggested that the integrated use of organic fertilizers and mineral fertilizers for 41 years resulted in higher C stocks in soils in comparison to the treatments involving the sole application of organic or mineral fertilizers (**Figure 2(a)**). The increase becomes more noticeable when the sole addition of

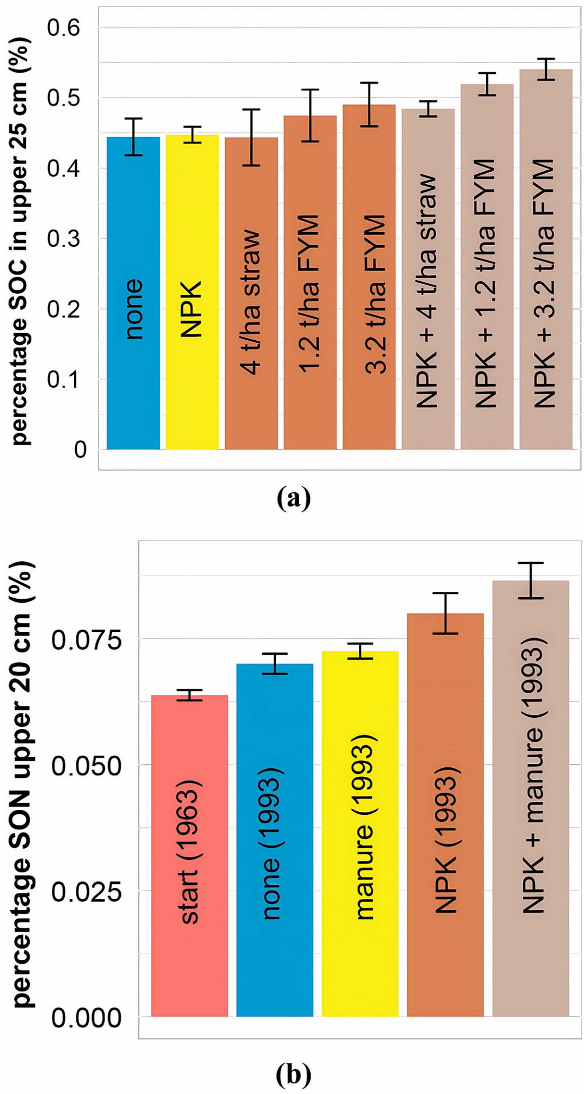


Figure 2. (a) Percentage soil organic carbon in the upper 25 cm after 41 years of different nutrient management combinations. FYM = farmyard manure; SOC = soil organic carbon [60] (b) Percentage of soil organic nitrogen in the upper 20 cm after 30 years of different nutrient management combinations. SON = soil organic nitrogen [60].

straw was made @ 4 ton·ha^{-1} every year. Also, after 30 years, C stocks in soil were recorded as highest with organic inputs integrated with inorganic fertilizer, in comparison to the sole application of organic or inorganic fertilizer (**Figure 2(b)**). Sepehya *et al.*, [61] suggested applying half of the N through organic inputs such as green manure, FYM, and supplying the remaining NPK using chemical fertilizers as compared to other treatments to get better returns of soil organic carbon. Application of FYM under rice-wheat system resulted in more available NPK levels in soil as compared to control after three years [62]. Lal *et al.*, [63] reported higher NPK availability with FYM application along with chemical fertilization. The increased soil N and P levels could be directly related to the decomposition of the FYM added to the soil [64].

A definite pattern *i.e.*, very labile > less labile > non-labile > labile C fractions was observed contributing around 41.4%, 20.6%, 19.3% and 18.7% to the TOC, respectively [65]. Compared to the control, FYM treated plant (FYM @ 10 Mg ha^{-1} season^{-1}) exhibited a 40.5% increase in build-up of C while the plant treated with 100% NPK + FYM showed 16.2% more C content. On the other hand, a net decline in C stock was recorded under the system treated with 50% NPK (1.2 Mg ha^{-1}) and control treatments (1.8 Mg ha^{-1} reduction in C stock). It was observed that for maintaining the SOC level, at least 2.34 Mg C ha^{-1} yr^{-1} of input was required (**Table 4**). Greater values of C management index (CMI), microbial

Table 4. Distribution of various oxidisable organic carbon fractions at different depths (cm) in soils (g·kg^{-1}) (Anantha *et al.* 2018).

Treatment	Very labile C				Labile C			
	Depths (cm)							
	0 - 15	**15 - 30**	**30 - 45**	Total	0 - 15	15 - 30	30 - 45	Total
Control	3.6 ± 0.5^{c}	1.4 ± 0.3^{b}	1.3 ± 0.2^{a}	6.3 ± 0.4^{b}	2.4 ± 0.3^{a}	1.0 ± 0.2^{a}	0.8 ± 0.4^{a}	4.2 ± 0.6^{a}
50% NPK	4.6 ± 0.3^{bc}	2.1 ± 0.7^{ab}	1.5 ± 0.1^{a}	8.1 ± 0.9^{a}	1.7 ± 0.4^{ab}	0.9 ± 0.5^{a}	0.7 ± 0.2^{a}	3.3 ± 0.7^{a}
100% NPK	4.4 ± 0.3^{bc}	2.3 ± 0.2^{a}	1.4 ± 0.5^{a}	8.0 ± 0.7^{a}	1.8 ± 0.4^{ab}	0.8 ± 0.5^{a}	0.6 ± 0.3^{a}	3.2 ± 0.8^{a}
150% NPK	5.0 ± 0.2^{ab}	2.6 ± 0.2^{a}	1.5 ± 0.1^{a}	9.0 ± 0.3^{a}	1.2 ± 0.3^{b}	0.7 ± 0.2^{a}	0.9 ± 0.2^{a}	2.8 ± 0.4^{a}
100% NPK + FYM	4.8 ± 0.2^{ab}	2.0 ± 0.2^{ab}	1.3 ± 0.3^{a}	8.1 ± 0.2^{a}	1.9 ± 0.3^{ab}	0.7 ± 0.2^{a}	0.7 ± 0.3^{a}	3.4 ± 0.2^{a}
FYM	5.9 ± 1.3^{a}	2.2 ± 0.2^{a}	1.4 ± 0.3^{a}	9.5 ± 1.6^{a}	2.5 ± 0.9^{a}	0.7 ± 0.3^{a}	0.7 ± 0.2^{a}	3.9 ± 0.9^{a}
Fallow	4.2 ± 0.7^{bc}	1.5 ± 0.5^{b}	0.7 ± 0.3^{b}	6.3 ± 0.8^{b}	2.2 ± 1.0^{ab}	1.0 ± 0.3^{a}	1.0 ± 0.4^{a}	4.1 ± 1.1^{a}
	Less labile C				Non labile C			
Control	1.5 ± 0.3^{c}	0.6 ± 0.4^{c}	0.4 ± 0.0^{c}	2.6 ± 0.7^{d}	1.2 ± 0.5^{b}	1.2 ± 0.3^{a}	0.2 ± 0.2^{b}	2.6 ± 0.5^{b}
50% NPK	1.8 ± 0.1^{c}	0.4 ± 0.1^{c}	0.5 ± 0.2^{c}	2.7 ± 0.1^{cd}	1.2 ± 0.9^{b}	1.7 ± 0.8^{a}	0.7 ± 0.4^{ab}	3.5 ± 1.8^{ab}
100% NPK	2.5 ± 0.3^{ab}	0.8 ± 0.1^{bc}	1.1 ± 0.2^{ab}	4.4 ± 0.1^{b}	1.3 ± 0.6^{b}	1.5 ± 0.6^{a}	0.5 ± 0.2^{ab}	3.3 ± 1.0^{ab}
150% NPK	2.6 ± 0.2^{a}	0.9 ± 0.1^{bc}	0.4 ± 0.2^{c}	3.9 ± 0.1^{b}	1.4 ± 0.3^{b}	1.5 ± 0.2^{a}	0.8 ± 0.1^{a}	3.7 ± 0.3^{ab}
100% NPK + FYM	2.7 ± 0.6^{a}	1.5 ± 0.2^{a}	1.4 ± 0.1^{a}	5.6 ± 0.7^{a}	2.0 ± 0.8^{b}	1.3 ± 0.1^{a}	0.3 ± 0.3^{ab}	3.5 ± 0.7^{ab}
FYM	1.9 ± 0.7^{bc}	1.7 ± 0.2^{a}	1.0 ± 0.2^{b}	4.5 ± 0.7^{ab}	3.7 ± 1.3^{a}	1.0 ± 0.2^{a}	0.5 ± 0.5^{ab}	5.1 ± 1.9^{a}
Fallow	1.5 ± 0.3^{c}	1.3 ± 0.7^{ab}	0.9 ± 0.4^{b}	3.8 ± 1.2^{bc}	2.1 ± 0.2^{b}	1.4 ± 0.7^{a}	0.4 ± 0.2^{ab}	3.9 ± 0.9^{ab}

Values in the same column followed by different letters are significantly different at $P < 0.001$, ± indicates the standard deviation values.

biomass, and other labile pools of C were observed under organic treated systems as compared to others.

In surface soil layer (0 - 40 cm depth), notably higher light organic carbon (LOC), particulate organic carbon (POC), dissolved organic carbon (DOC), and easily oxidizable organic carbon (EOC) under straw mulch (ST) and grass mulch (GT) treatments has been observed than the treatments with no mulch which might be due to lesser OM inputs through straw and roots [66]. A depth-wise decrease in labile C fractions has been reported irrespective of treatments. According to Liu *et al.*, [31], the plausible reason behind this could be due to seasonal dynamic changes and lower residence time of TC and labile C fractions irrespective of treatments as its main constituent is free-state carbon [19].

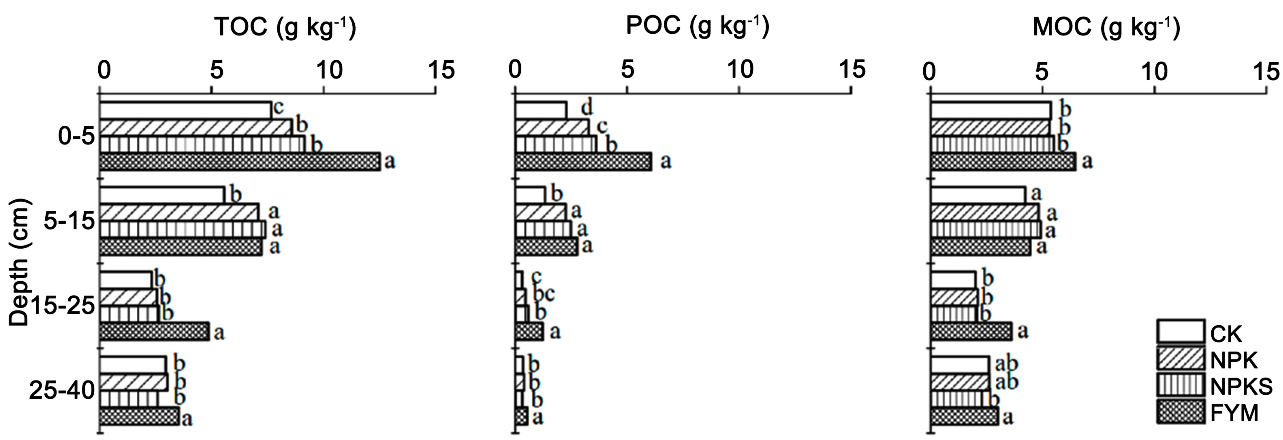
The mean upsurge in TOC, POC, and mineral-associated organic carbon (MOC) levels at 0 - 40 cm soil depth after long-term application of mineral or organic fertilizers were 14.8% - 51.9%, 48.9% - 146.9% and 3.9% - 23.3% as compared to control plots [67]. Mineral-associated organic carbon (MOC) signifies majority of the SOC that contributes about 51.5% - 88.2% of TOC in upper soil layer while POC has a minor TOC proportion *i.e.*, 11.8% - 48.5% (**Figure 3(a)**). Overall, the enhancement might be ascribed to the positive impact of manure and straw residues.

4. Conservation Tillage Practices, Fertilization, and Manuring Impact on Aggregation and Aggregate Associated Organic Carbon in Soil

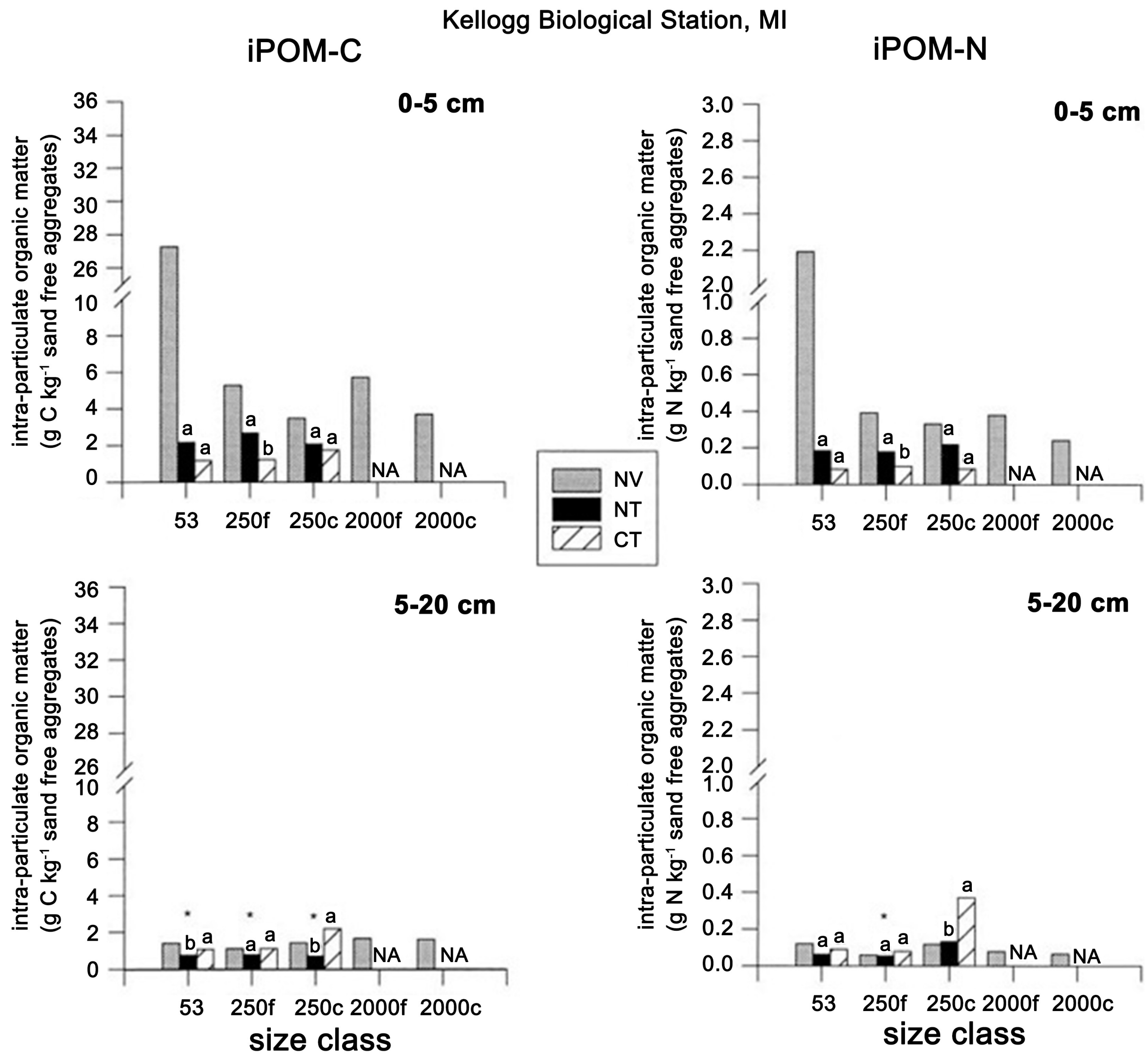
4.1. Tillage Practices Affecting Soil Aggregation

Individual soil particles are bound together in the form of aggregates in most of the soils, and the size distribution of the aggregates has a major impact on OC. Tillage practices did not affect the concentration of free light fraction organic carbon, but it was found to be 45% less in the cultivated system as compared to no tillage system [68]. Percentage of C derived from crop in macro-aggregates was alike in NT as well as CT, but was 3 times higher in micro-aggregates from NT as compared to micro-aggregates from CT. Additionally, macro-aggregate level in CT as compared to NT resulted in the slow formation of micro-aggregates within macro-aggregates and lower stability of the new SOM to micro-aggregates under CT (**Figure 3(b)**). Organic matter from crop residue may combine with minerals, thus binding micro-aggregates to macro-aggregates [69].

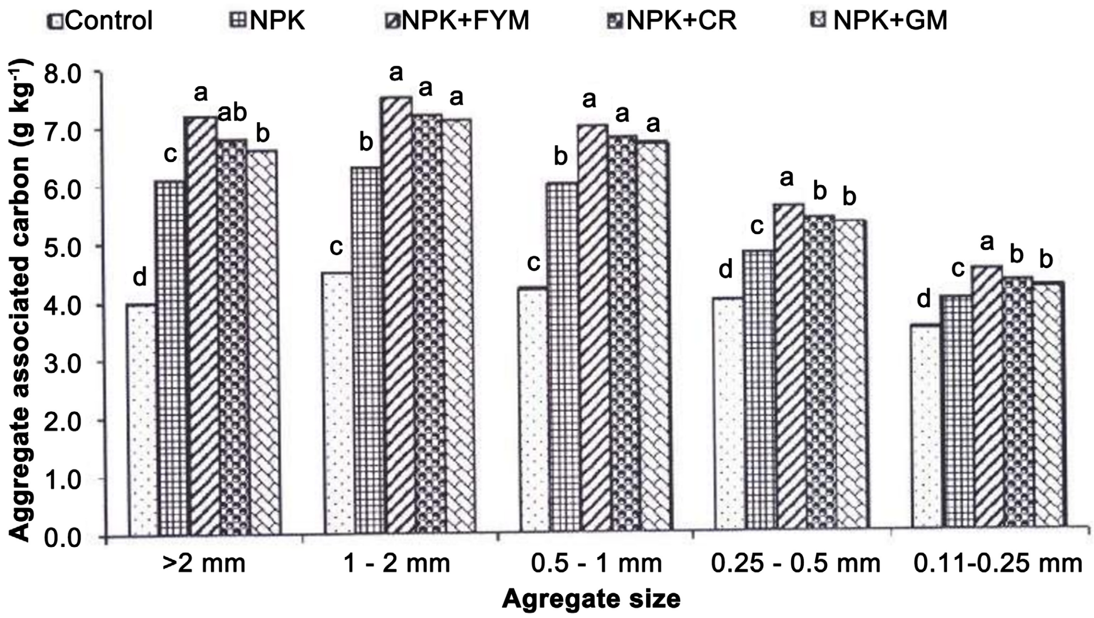
Higher C contents in macro-aggregates as compared to micro-aggregates [55]. In all studied treatments, maximum C content was recorded in 1 to 2 mm sized aggregates followed by 0.5 to 1 mm sized aggregates, and the amount of C content reduced with the reduction in aggregate sizes (**Figure 3(c)**). The addition of organic manures facilitates the breakdown of OM where roots hyphae and polysaccharides act as binding materials that facilitate the aggregation of mineral particles into micro-aggregates and subsequently augment the formation of macro-aggregates containing a higher amount of C (**Figure 3(c)**). Naresh *et al.*, [48]


TOC (g kg-1)
POC (g kg-1)
MOC (g kg-1)
Depth (cm)
0-5
5-15
15-25
25-40
CK
NPK
NPKS
FYM

(a)


Kellogg Biological Station, MI
iPOM-C
iPOM-N
0-5 cm
5-20 cm
intra-particulate organic matter (g C kg-1 sand free aggregates)
intra-particulate organic matter (g N kg-1 sand free aggregates)
NV
NT
CT
NA
53
250f
250c
2000f
2000c
size class

(b)



(c)

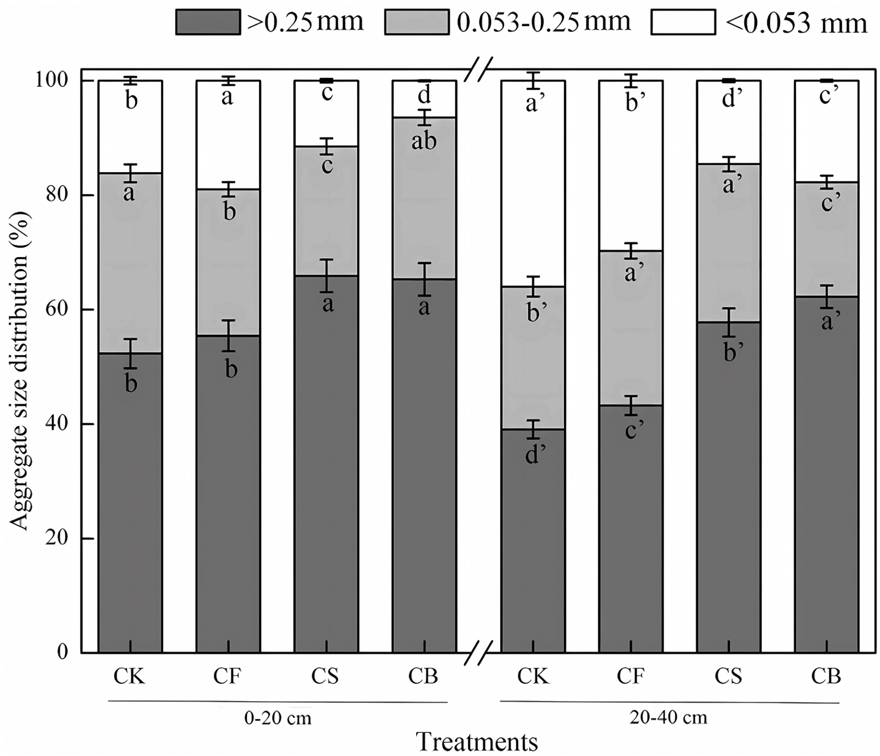
Figure 3. (a) Effects of fertilizer system on soil organic carbon content [67] (b) Aggregate and soil organic matter dynamics under conventional and no-tillage systems [68] (c) Effects of long term integrated nutrient management practices on aggregate associated carbon in the soil [55].

also reported the suppression in the process of formation of larger stable macro-aggregates found in sandy loam soil in western parts of Uttar Pradesh, which are considered important for indicating soil physical quality. Tillage reduced the proportion of macro-aggregates (2 - 0.25 mm) with the enhanced micro-aggregate (0.25 - 0.05 mm) proportion as compared to the conservation tillage treatments. Thus, this section summarizes the impact of various tillage practices on soil aggregation.

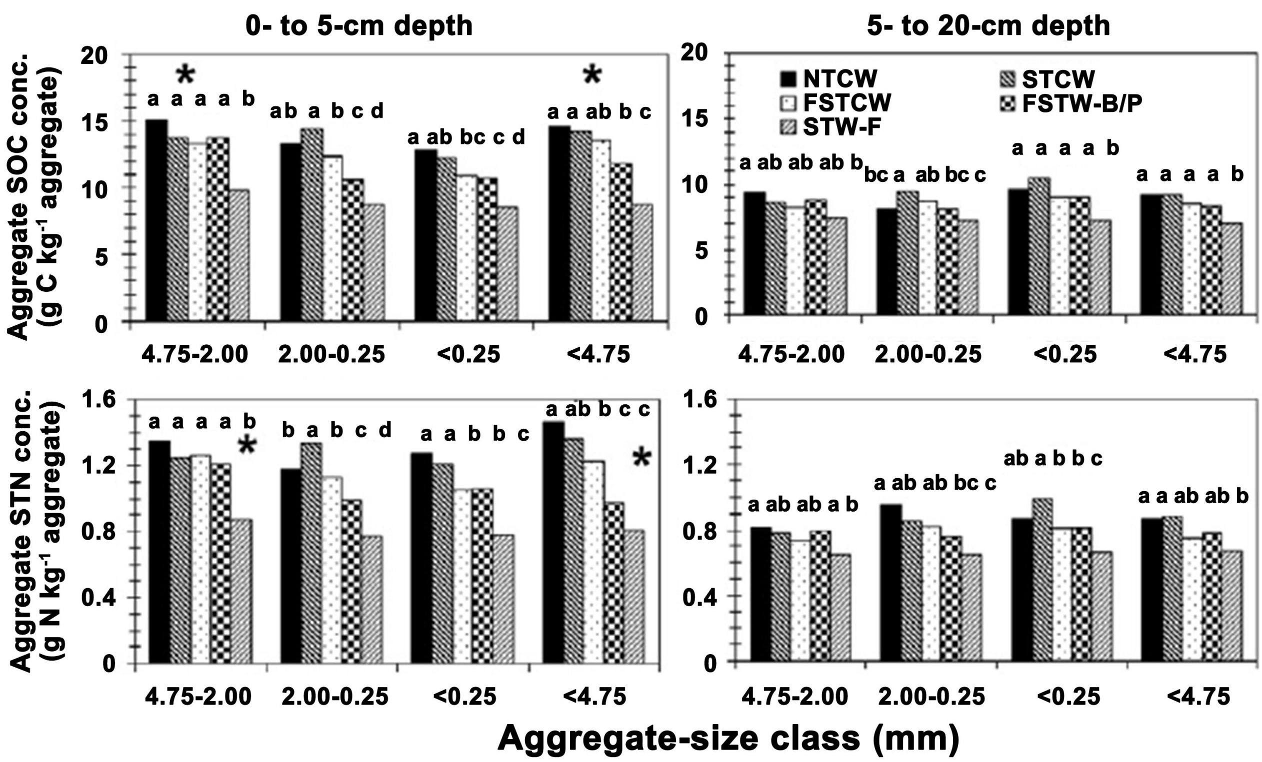
4.2. Distribution of Organic Carbon in Various Aggregate Sizes Affected by Tillage Practices

The impact of tillage on SOC and concentration of nutrients in soil aggregates can differ spatially and temporally, depending on various types of soil and crops involved. According to Šimanský *et al.*, [70], soil-management practices significantly affect SOC in water-stable aggregates (WSA). The SOC content in WSA enhanced in the following order *i.e.* tillage (T) < grass without fertilisation as control (G) < G + NPK_1 < G + NPK_3 < T + FYM. Variations in application of fertilizers (NPK) and organic manures (FYM, green manures etc.) lead to significant changes in the build-up of SOC in various-sized aggregates [71] [72]. A reduction in mean SOC values was reported with the size of stable aggregates and water-stable aggregates. Also, the SOC values were higher in surface soil in comparison to bulk soil [73].

Macro-aggregates are the dominant aggregate size class in the upper two layers (*i.e.*, 0 - 20 and 20 - 40 cm) (**Figure 4(a)**) [74]. The easily oxidized organic



(a)



(b)

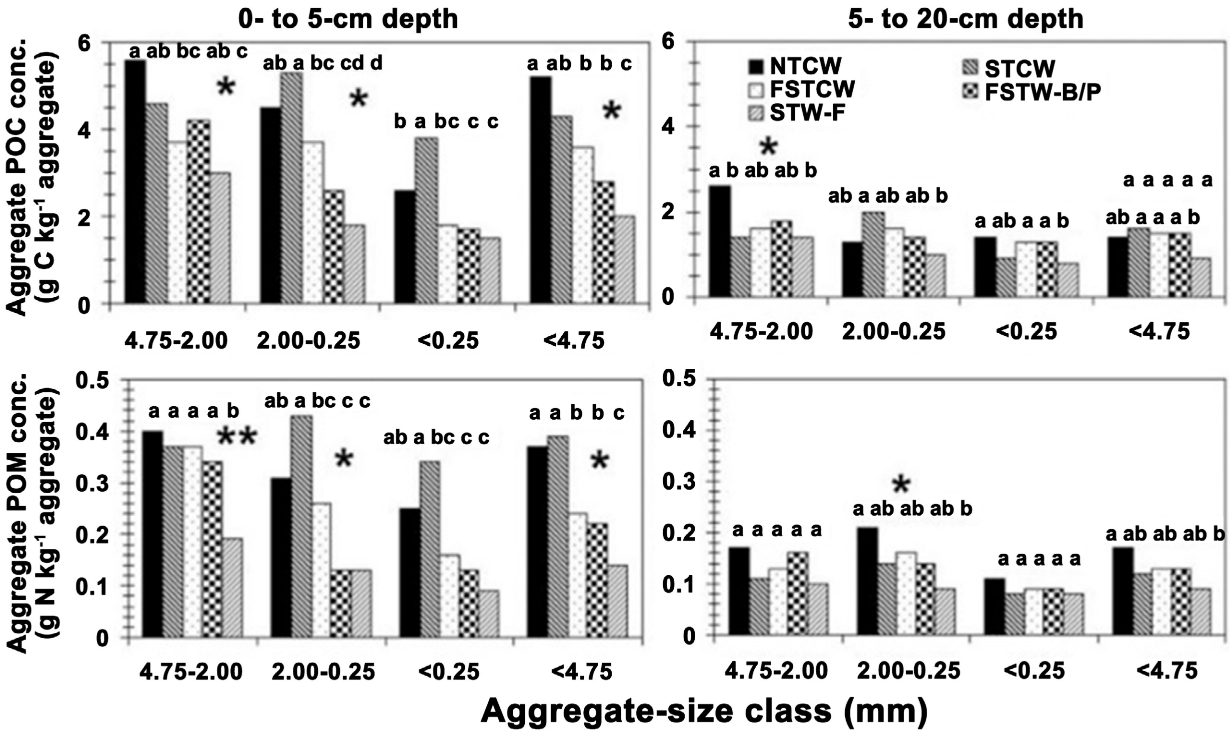
Figure 4. (a) Effects of different treatments on the distribution of soil water-stable aggregates [74] (b) Effects of tillage and cropping sequence on dry-land soil organic C (SOC) and total N (STN) concentrations in aggregates at the 0 - 5 and 5 - 20-cm depths [32].

carbon (EOC) concentrations in the soil for different treatments *i.e.*, S_{400} (400 kg·ha^{-1} straw), S_{800} (800 kg·ha^{-1} straw), S_{1200} (1200 kg·ha^{-1} straw) and S_{1600} (1600 kg·ha^{-1} straw) varied from 7.58 - 11.23 g·kg^{-1} [75]. The EOC level in soil was maximum in plots with S_{800} treatment and was least in the control plots for every soil depth studied. Considerable variations were observed in straw return for various treatments, the decreasing pattern of various treatments for EOC levels is: $S_{800} > S_{400} > S_{1200} > S_{1600} >$ CK.

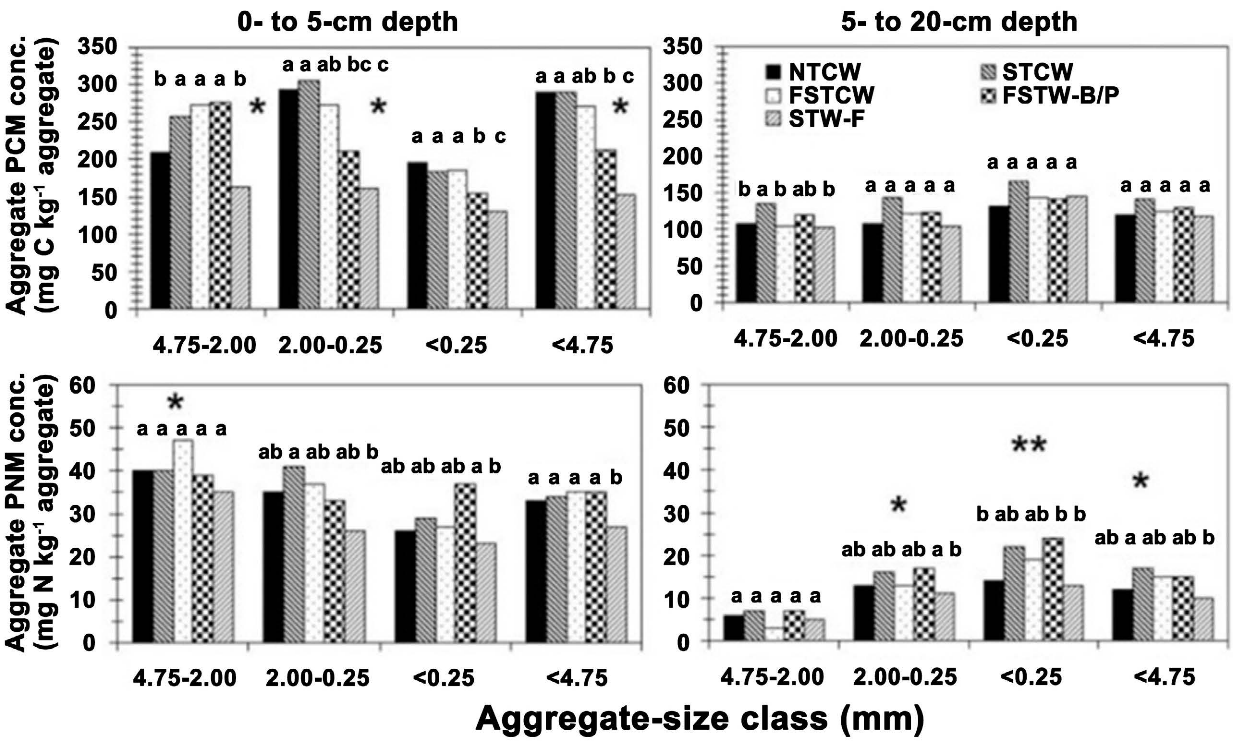
The study of Jiang *et al.*, [76] in sub-tropical soil also revealed a lower proportion of macro-aggregates (>2.00 mm) under tillage which resulted in about 35% reduction in aggregate stability than that of RNT treatment, suggesting an alteration in soil structure due to tillage practices. The maximum SOC was found in the 1.00 - 0.25 mm fraction (35.7 and 30.4 mg·kg^{-1} for RNT and CT, respectively), whereas the least SOC was recorded in micro-aggregate (<0.025 mm) and silt + clay (<0.053 mm) fractions (19.5 and 15.7 mg/kg for RNT and CT, respectively). In the surface soil layer, 50.13% increase in water-stable macro-aggregates and a decrease of 10.1% in the case of water-stable micro-aggregates was observed under conservation tillage over conventional tillage under wheat cultivation along with direct-seeded rice (DSR) [30]. A positive incline of 15.65% for water-stable aggregates was observed under residue incorporation in 0 - 15 cm soil layers which was about 7.53% in 15 - 30 cm soil depth. In surface soil, >2 mm and 0.1 - 0.05 mm sized aggregates were found to be the carriers of the maximum and minimum portion of total aggregates associated organic carbon.

A significant influence of tillage systems on aggregate-associated SOC was mentioned in various reports [76] [77]. Ou *et al.*, [77] found no tillage (NT) system to be superior as compared to moldboard plow (MP) and also observed a trend of no tillage with straw (NT + S) > mouldboard plow with straw (MP + S) = no tillage without straw (NT − S) > mouldboard plough without straw (MP − S) regarding SOC concentration in macro-aggregates in 0 - 5 cm soil layer. Whereas a significant reduction in SOC associated with 2.00 - 0.25 mm fraction in NT system was also found in the 5 - 20 cm layer. In the case of silt + clay fraction, no effect of NT regarding SOC concentration distribution was noted as there was no difference between NT − S and MP − S, and between NT + S and MP + S in <0.053 mm sized fraction. On comparing with MP − S, rise in the percentage of SOC in macro-aggregates was 13.5%, 4.4%, and 19.3% under MP + S, NT − S, and NT + S while in the case of micro-aggregates (<0.25 mm), 6.1% and 7.0% increase under MP + S and NT + S was observed across the studied profile. In all three soil layers under the MP system, 20.0%, 3.8%, and 5.7% increase in concentration of SOC was observed in all aggregate sizes which were about 20.2%, 6.3%, and 8.8% under the NT system. Previous studies revealed that in soil depth of 0 - 20 cm, NT system revealed the classification of SOC whereas the MP system was associated with a homogeneous system [78] [79].

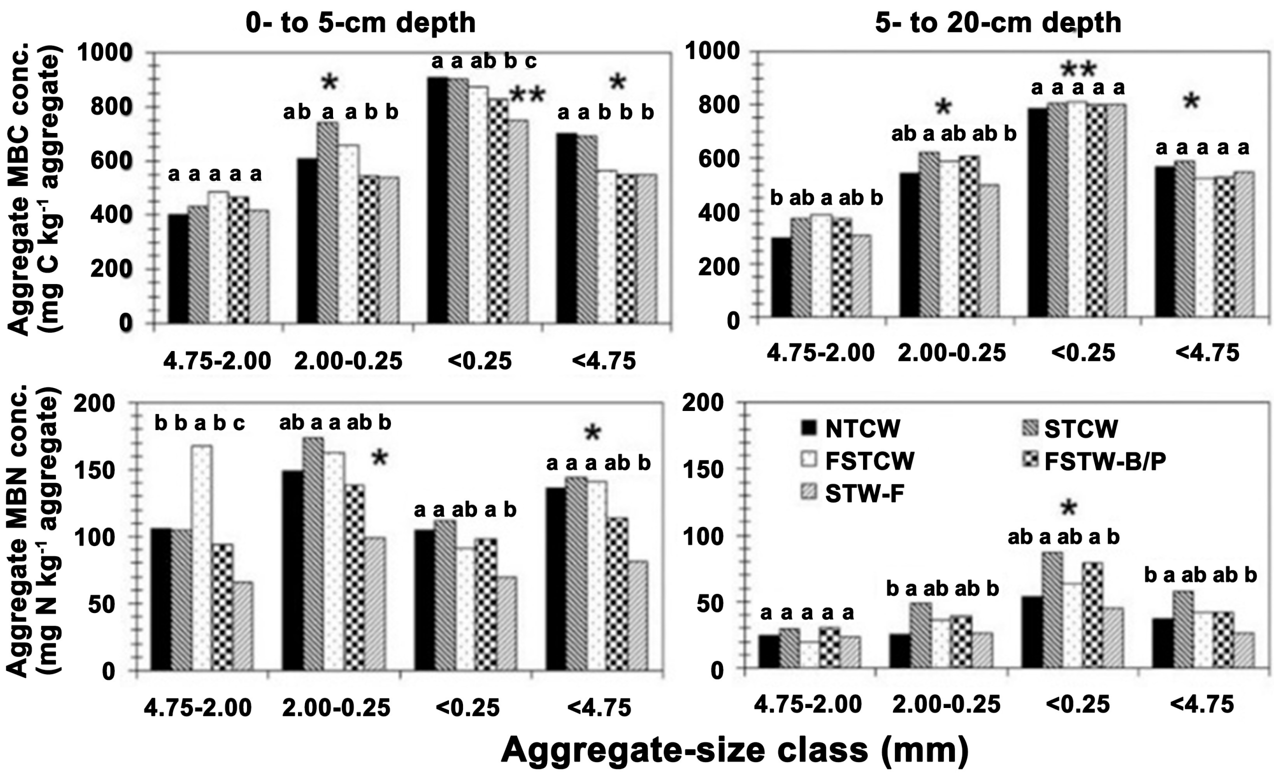
Alterations in SOC, soil total nitrogen (STN), particulate organic carbon (POC), and particulate organic nitrogen (PON) concentrations were observed in whole soil as well as in aggregates due to different tillage practices and cropping sequences (Figure 4(b) and Figure 5(a)) [80]. Irrespective of aggregate-size classes, the least concentrations were found under spring-tilled spring wheat-fallow



(a)



(b)



(c)

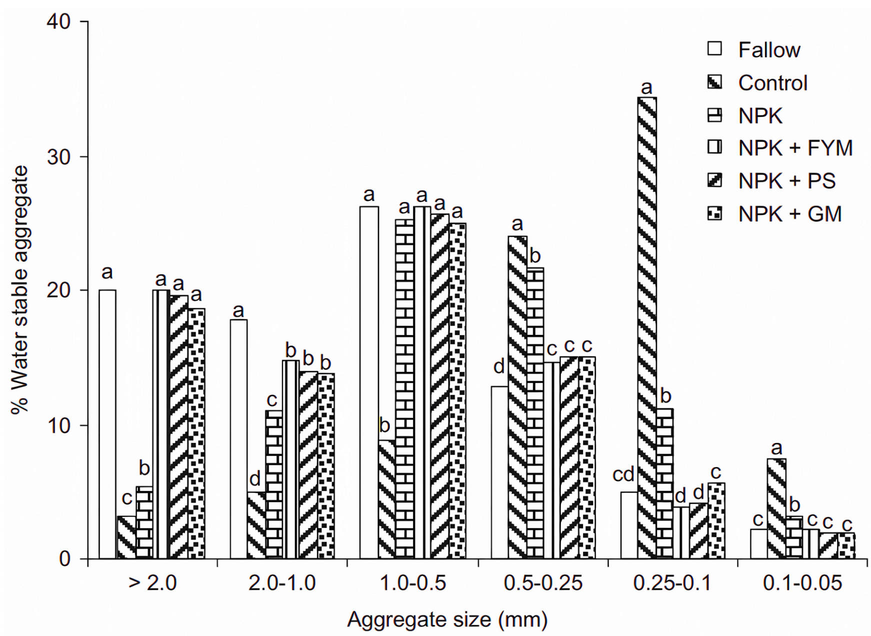
Figure 5. (a) Soil particulate organic C and N (POC and PON) concentrations(b) Soil potential C and N mineralization (PCN and PNM) and (c) Soil microbial biomass C and N (MBC and MBN) concentrations in aggregates at the 0 - 5 cm and 5 - 20 cm depths affected by tillage and cropping sequence on dry-land [32].

(STW-F) system which might be because of intensive tillage frequency and reduced crop residue return in soil. In the case of continuous spring wheat system compared to the no-tillage, reduction in SOC and STN in the <0.25-mm size aggregates were found in conventional tillage at 0 - 5 cm depth while the reduction in POC was observed in the 2.00 - 4.75 mm sized aggregates at both soil depths of 0 - 5 cm and 5 - 20 cm. They also observed mineralization of slow fractions of C and N within micro-aggregates due to tillage in case of surface soil while mineralization of intermediate fractions within macro-aggregates was observed both in the surface as well as subsurface soils.

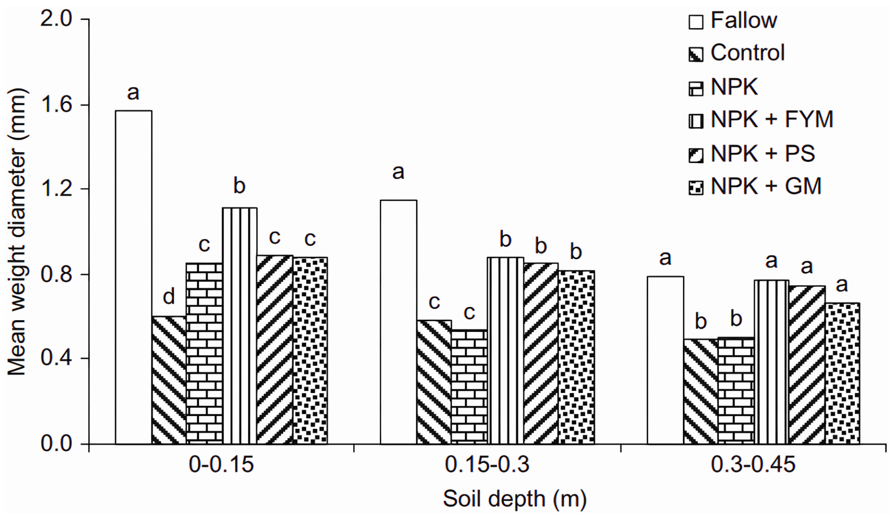
Lower contents of PCM, PNM, MBC, and MBN were observed in STW-F treatments as compared to other treatments in whole soil as well as all aggregate sizes particularly in the upper soil layer (0 - 5 cm depth) (Figure 5(b) and Figure 5(c)) [33]. This could be attributed to a decline in microbial biomass and a greater degree of N mineralization under fallow conditions than that of annual cropping and additionally due to the diminishing substrates (SOC and STN) as there was fewer inputs beneath fallow. Contrarily, greater PCM and MBC were recorded under NTCW or STCW as compared to FSTWB/P in the <2.00-mm sized aggregates in surface soils (0 - 5 cm) and the plausible reason behind it might be the quality difference of organic matter incorporated into the soil as crop residue input. This section included the different studies reporting the effect of tillage practices on variation in organic carbon distribution in different soil aggregates.

4.3. Fertilization and Manuring Practices Affecting Soil Aggregation

Reduction in tillage operations and organic fertilizer application generally leads to an enhanced stability of soil aggregates and this effect depends majorly on the soil properties and type of season during the study period. Bandyopadhyay *et al.*, [81] found a significant increment in the proportion of >2, 1 - 2, and 0.5 - 1 mm sized soil aggregates under NPK-treated plots than that of control plots. Water stable aggregate (WSA) values of control were recorded to be 27.9%, 28.7%, and 29.6% less as compared to FYM, PS, and GM treated plots, respectively. Whereas NPK treated plots recorded 68.2%, 70.3%, and 72.5% less values as compared to FYM, PS, and GM treated plots, respectively. Regarding 0.5 - 1.0-mm sized aggregates, treatments were found at par except for the control while in the case of smaller aggregates (0.25 - 0.5 and 0.1 - 0.25 mm), aggregate distribution percentages under fallow, organically amended, and NPK treated plots were lesser as compared to control treatment (**Figure 6(a)**). Organic matter application might facilitate the activities of microbes in the soil which ultimately hastened the binding of micro-aggregates into macro-aggregates that are more stable as compared to the former. In macro-aggregates, binding agents are generally the humic substances formed from fungal hyphae, fibrous roots, and polysaccharides. The mean weighted diameter (MWD) of control and NPK treatments were about 38.0% - 61.8% and 36.7% - 53.0% as compared to fallow but no significant differences were found regarding the values at 0.15 - 0.45-m (**Figure 6(b)**). Disturbance



(a)



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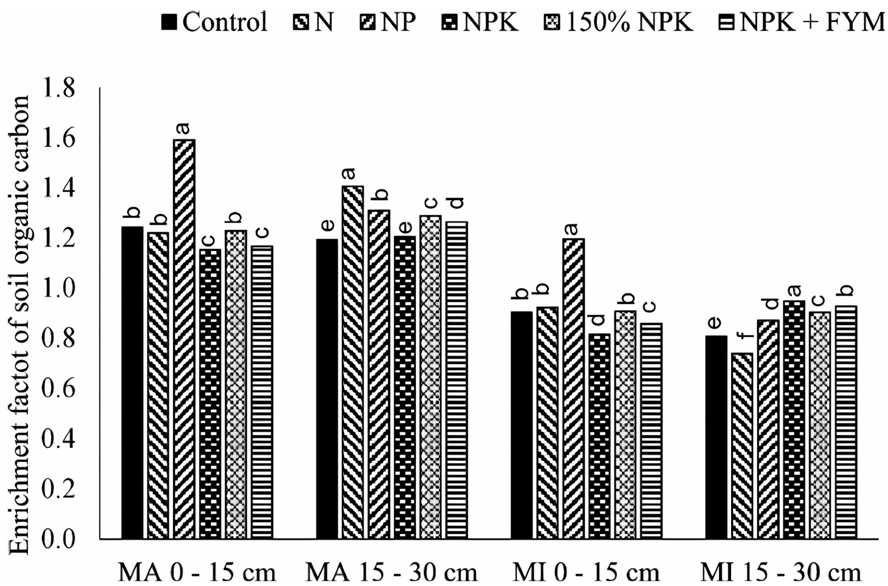

(c)

Figure 6. (a) Percentage of various size fractions of WSA and (b) Dispersal of mean weight diameter within WSA in the 0 - 0.15 m soil depth as affected by long-term application of different type of manure along with fertilizer [81], (c) Effect of 44 years of fertilization on enrichment factor of SOC in aggregates. MA: macro-aggregates, MI: micro-aggregates, MA 0 - 15 cm: macro-aggregates of 0 - 15 cm soil depth, and so on [12].

of soil due to tillage along with the absence of C addition augments the decay of soil native OM and also leads to the exposure of OM to soil microbial activity which has a considerable impact on MWD as well [82].

Aggregate size distribution was considerably influenced by FYM application and chemical fertilizers in comparison to the control plot [83]. An aggregate fraction with size 0.25 - 0.5 mm is the largest fraction *i.e.* (27.36% - 31.36%), whereas the fraction of 0.1 - 0.053 mm sized aggregates were the least contributing fraction (2.10% - 3.87%). When FYM is applied alone or integrated with chemical fertilizers, it results in a significant enhancement in macro and meso-aggregates formation in comparison to control. The incorporation of simple FYM increases the macro-aggregates (5 - 2 mm) and meso-aggregates (2 - 1 mm) by 165.33 % and 130.68 % respectively. In 0 - 5 cm soil layer, Ou *et al.*, [77] noted 7.1% higher percentage of >2 mm sized aggregates under NT + S than that of under NT − S. In most of the cases irrespective of soil depths, a significantly higher proportion of macro-aggregates (>0.25 mm sized) under MP + S as compared to MP − S was observed whereas the concentration of <0.053 mm sized aggregates was 11.5% - 20.5% lesser in MP + S as compared to MP-S system.

Fertilization had a very slight influence on aggregation with aggregate sizes less than S_3 irrespective of soil depths [84]. No major impact on aggregate sizes S_5 and S_7 had been found in soil depths of 0 - 15 and 15 - 30 cm. The use of FYM enhanced the aggregate proportion of bigger sizes (2 - 4.75 and 1 - 2 mm). It also increased the porosity, thus reduced soilbulk density. Sharma *et al.*, [85] also found a decline in bulk density (BD) of the soil with the addition of OM. The decrease in soil BD with FYM application can be related to the enhanced SOC levels and root biomass which resulted in improved aeration in soil and enhanced soil structure.

In comparison to the control plots, the application of manure significantly enhanced the proportion of bigger macro-aggregates (>2 mm) *i.e.*, through 2.4% as compared to control while a significant reduction (12.4%) in the number of micro-aggregates than that of the control was also observed by Wang *et al.*, [86]. In both control as well as treatments involving manure application, the proportion of various aggregate classes reduced with the reduction in size. Large macro-aggregates (>2 mm) were present in the highest proportion and micro-aggregates (>0.25 mm) were present in the lowest proportion. Thus, this section summarizes the effect of fertilization and manuring practices on soil aggregation.

4.4. Distribution of Organic Carbon in Various Sized Aggregates as Influenced by Fertilization and Manuring

Application of fertilizers and manures further affect organic carbon distribution in various soil aggregates which are discussed in this section. Around 19% and 46% higher recalcitrant C was reported in macro-aggregates of NPK + FYM system over NPK and NP treated ones [12]. The trend of C concentration in micro-aggregates was found almost similar as in the case of macro-aggregates (**Figure 6(c)**). Study of distribution of C fractions revealed a higher proportion of C with respect to total C concentration in macro-aggregates as compared to micro-aggregates which might be because of the greater degree of SOC accumulation in the case of macro-aggregates which act as a barrier amongst microbes and the substrates, thus protecting SOC mechanically from microbial decomposition [83].

5. Combined Application of Fertilization and Tillage on Transformation of Carbon in Soil

Tillage practices in combination with fertilization may significantly affect soil organic pools. The budget assessment of total plant assimilated C by Bhardwaj *et al.*, [87] revealed that the percentage contribution of C input in the soil towards the assimilation of C in the system was recorded highest in the case of green manure (GM) (36%) and minimum was recorded in O and F (15%). However, in the upper soil layer, FYM treatments had the highest concentration of oxidizable C followed by GM and crop residue (WS, RS) treatments while treatments were at par in the lower layer. A reduction of about 46% to 65% from shallower to deeper layer was observed regarding oxidizable C. Carbon sequestration potential (CSP) was found notably higher under treatments of FYM, GM, and WS in the surface layer, whereas management treatments were at par in the lower studied soil layer. Significant variations in bulk density were observed while comparing various management practices only in surface soil and were not found in the deeper layer. Additionally, this may be because of the incorporation of organic inputs in the soil during puddling for transplantation of crop, these being lighter fractions, would try to concentrate on the surface. The tillage (dry-plowing) for sowing of crops is not as rigorous as puddling in order to combine the organic matter.

According to Naresh *et al.*, [48], the WSC was 5.48% higher in top-layer soil in comparison to sub-surface soil. Amongst the given treatments, T_6 showed a significantly higher percentage of WSC (19.73%) than the rest of the studied treatments. Retention of residue leads to higher WSC in comparison to the non-residue treatments in the top (22.56%) and sub-surface soil (25.61%). Microbial biomass carbon (MBC) is a vital component of SOM which regulates the nutrient conversion and its storage. Soil MBC controls all SOM modifications and is a key component of an active SOM pool. It is reported that the content of MBC throughout the surface and subsoil was significantly high at sites receiving 100% RDN in form of CF + VC @ 5 ton·ha^{-1} (F_5) and 75% RDN as CF + VC @ 5 ton·ha^{-1} (F_4).

A study by Naresh *et al.*, [88] revealed that the maximum concentration of SOC (5.8 g·kg^{-1}) was observed in surface layer. The treatments involving organic amendments confined more SOC levels as compared to other treatments. Tillage systems resulted in variations in SOC. The SOC was significantly higher under no-tillage than with CT and MT, respectively. Hence, efficient management practices are proved to be a good catalyst for soil C sequestration.

6. Conclusion

Residue retention and minimum disturbance to soil enhance OC content in no-tillage as well as reduced tillage systems in comparison to conventional ones. The no-tillage system exhibited a trend of accumulating OC near the surface of soil, while conventional tillage decreased the SOC storage in the top as well as sub soil layers. Decreased LOC fraction stocks in sub-soil layers might be attributed to the reduced root biomass in sub-surface layers of soil, with consequences for SOC stock. The adverse impact of conventional tillage is not only viewed in the decline of SOC, but it is also responsible for the suppression in the formation of soil aggregates and strength throughout continuous wet conditions, leading to sediment losses and water quality concerns. The micro-aggregate within macro-aggregate fraction indicates the quick detection of alterations in soil C resulting from variations in management practices. A higher C percentage was observed in all aggregate size classes with conservation tillage treatments as compared to conventional tillage, especially at the depth of 0 - 5 cm. However, at the 10 - 15 cm depth, the maximum percentages of C were observed in aggregates from conventional tillage and reduced tillage treatments, reflecting a feasible decreased C deposition due to the NT treatment at the lower depth. Under semi-arid conditions, conservation tillage was found to be most effective in increasing SOC level. Thus, the addition rate of organic amendments needs to be doubled to decrease depletion of SOC and increase SOC stocks. The SOC is a major determinant in assessing the effect of natural resources and management practices on soil quality and ecosystem services. Also, conservation management practices aiming at minimal soil disturbance and better biological activity could be achieved only with better crop choices and production goals. The success can be achieved only when all the constraints *i.e.*, agronomic, ecological, environmental, and economic are considered. Moreover, these approaches would definitely help in addressing the issues of reducing profitability in farms, diminishing water resources, and declining soil health by implementing crop management approaches based on conservation agriculture for the rice-wheat system.

7. Future Perspectives

Conservation agriculture (CA) will assist in the build-up of SOC and its fractions for improvement in soil fertility in the rice-wheat cropping system. Management and conservation of rice straw residue is a major problem for all rice growing countries through residue retention and minimum soil disturbance enhanced soil organic carbon content as compared to conventional agricultural practices. Further, the conventional tillage suppressed soil aggregate formation and strength under continuous wet conditions resulting in sediment losses and poor soil quality. There is a need of alternate cropping system choices and site-specific management practices to improve soil biological activity and fertility.

Declarations

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Conflicts of Interest

The authors have no conflicts of interest/competing interests to declare that are relevant to the content of this article.

Ethics Approval

Not applicable.

Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Data Availability

All data generated or analysed during this study are included in this published article.

Code Availability

Not applicable.

Authors' Contributions

All authors contributed for formatting the design of the review publication. SSD, SKD, SKB and GK were involved in conceptualization and overall supervision of work. Literature search and data analysis was performed by SSD, AKS, SKB, SS, SSW, SKD, MKR and AST. Important editing and intellectual inputs were given by SSD, MKR, AST and SSW. All authors read and approved the final manuscript.

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