Precision Agriculture Practices Improves Soil Aggregation, Aggregate Associated Organic Carbon Fractions and Nutrient Dynamics in Cereal-based Systems of North-West India: An Overview

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Authors’ contributions

This work was carried out in collaboration among all authors. Author RKN designed the study, performed the methodology and wrote the first draft of the manuscript. Authors SKG and MSC managed the analyses of the study. Author KM managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2020/v39i930605

Editor(s):
(1) Dr. Alessandro Buccolieri, University of Salento, Italy.

Reviewers:
(1) Anuj K. S. Panhar, India.
(2) Megahed M. Amer, Agricultural Research Center, Egypt.
(3) Muhammad Raziq Rahimi Kooh Chem Yuan, Universiti Brunei Darussalam, Brunei.
(4) S. Kizza-Nkambwe, Uganda Christian University Mukono, Uganda.

Complete Peer review History: http://www.sdiarticle4.com/review-history/56486

Received 29 February 2020
Accepted 05 May 2020
Published 11 May 2020

ABSTRACT

Precision farming uses proximal and remote sensor surveys to delineate and track in-field variations in soil and crop attributes, directing variable input rate control, such that in-season management can be sensitive, e.g. matching strategic application of nitrogen fertilizer to site-specific conditions. It has the ability to increase productivity in the processing and use of nutrients, ensuring that nutrients do not leach out or accumulate in excessive amounts in areas of the field, causing environmental problems. Tillage systems can change the dynamics of organic carbon in soil and microbial biomass in soil by adjusting aggregate shape and distribution of C within aggregates. The effects of tillage on soil organic carbon (SOC) and soil aggregate nutrient content can differ spatially and temporarily, and for different types of soil and cropping systems. The

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1. INTRODUCTION

Around two-thirds of terrestrial carbon is contained in the soil. In the top 1 m there are about 1500 Pg C (1 Pg = 109 Mg = 1015 g) deposited as SOC [1]. The remaining terrestrial carbon (560 Pg) is contained in plant biomass [2]. Oceans contain the greatest quantity of carbon (38,000 Pg) [1], while atmospheres hold less carbon than in the soil (750 Pg). Over the past 35 years, anthropogenic carbon emissions (e.g., fossil fuel combustion, cement production), in the form of carbon dioxide (CO2), have increased. Anthropogenic carbon emissions were 6 Pg yr⁻¹ in the 1980s [3], and anthropogenic carbon emissions rose to 10 Pg yr⁻¹ by 2014 [4]. Soils are considered a carbon sink, which can help lower the concentration of CO2 in the atmosphere and reduce the greenhouse effect [5]. SOC storage is influenced by temperature, land cover, soil order and texture of the soil [6]. Soils under deserts have been reported to store the lowest amount of SOC [6]. Most of the carbon can be inorganically contained in deserts [7]. Around 8 percent of SOCs are deposited in agricultural soils [8]. Carbon storage is influenced by soil texture and aggregation, and fractions of the silt and clay size are able to protect SOC against decomposition [9]. As organic matter decomposes, organic matter binds to aggregates forming silt and clay that protects the organic matter from decomposition [10]. Hassink [9] found no link between total carbon and clay + silt content, but soil carbon stored at a fraction of 20 μm size increased with clay + silt content. Gabarron Galeote et al. [11] and Tiessen and Stewart [12] find the largest volume of soil carbon in the fractions of silt and clay size and the lowest proportion of sand fractions containing in soil carbon.

The aggregation is both a way of maintaining and protecting soil organic matter (SOM) and allowing the stored organic matter to act as a reservoir of plant nutrients and energy. The varying degrees of protection from decomposition offered by the spatially hierarchical organization of soil aggregate structure is assumed to be a major factor influencing SOM dynamics [13]. Soil aggregates are the basic unit of soil structure and their stability is usually considered to be a soil quality measure. Soil aggregate medium weight diameter (MWD) is also used to measure soil

Keywords: Aggregates; aggregate associated C and N; water soluble carbon; soil organic matter dynamics.
aggregate stability [14]. Soil aggregate stability is influenced by a number of binding agents, including organic materials, iron and aluminum oxides, carbonates, and metal cations [15]. Organic binding agents can greatly increase aggregate water-stability relative to inorganic binding agents in general [16] and these organic binding agents play major roles in soil erosion resistance [17]. Stable aggregates provide SOM with physical protection to minimize microbial attack [15]. Many agro-ecosystem studies have recorded the distribution of soil aggregates, soil aggregate stability, and aggregate-associated SOCs under various types of soil management, including no-tillage, fertilization, natural ecosystem conversion into agricultural land, and vice versa [18,19,20]. While the stability of soil aggregates and SOM sequestration are commonly related phenomena [21], their associations with land use transition, including agricultural abandonment, remain uncertain.

Soil organic carbon (SOC) plays an important role in soil aggregate formation and stabilization [20]. There is a close relationship between soil aggregation and SOC accumulation; typically SOC promotes soil aggregation, while aggregates, in effect, store SOC and minimize the rate of its decomposition. The stable soil aggregates serve as the nuclei for SOC stabilization in the long term. By creating physical barriers between microbes and enzymes, these protect the SOC and thus reduce the SOC turnover rate [22]. The nature and quantity of soil contact with soil particles determines the scale and stability of aggregates [23]. The level of carbon retention soil depends on the type of aggregation [24], the degree of physico-chemical characteristics and the stability of organic carbon within the aggregates [25]. Soil aggregation dynamics and SOCs are highly affected by shifts in land use and its management practices [26]. Changes in land use can alter soil physico-chemical properties, soil microbial composition, and rhizosphere function [27]. These changes can affect soil structural stability, soil aggregation, and often favor one microbial subgroup at the expense of other groups, thus affecting the storage of SOCs and soil nutrient turnover [28].

Tillage practices can also affect soil organic carbon (SOC) distribution patterns. Higher SOC concentration in surface layers was observed in no tillage than traditional tillage practice, but a higher concentration of SOC in deeper soil layers of reduced tilled plots where tillage includes crop stubbles [29,30]. Tillage conservation practices are resource management practices intended to improve SOC [31,32]. In comparison, other studies have stated that no crop residue-free tillage has resulted in lesser to no improvement in SOC [33,34]. So this review study on soil aggregation, strategic nutrient dynamics for soil organic carbon fractions, particularly in subtropical cereal-based system soils, where native C stocks are usually small.

2. DISTRIBUTION OF ORGANIC CARBON INTO THE SOIL

Soil organic matter (SOM) plays an important role in sustaining tropical soil fertility as it provides energy and substrates, and promotes biodiversity that helps sustain soil quality and functionality of the ecosystems. Due to its effect on soil properties SOM directly affects soil quality [35]. Once soil is grown for agricultural production, in particular in tropics and semi-arid regions, SOM is rapidly composed due to changes in conditions such as aeration, temperature, and water content [36]. This can affect many soil functions that are either directly or indirectly connected to SOM, due to their water and nutrient retention ability. While SOM's breakdown rate may be faster in the tropics, frequent inputs of organic modifications may promote SOM build-up [37]. Naresh et al. [20] revealed that the highest SOC stock of 72.2Mg C ha\(^{-1}\) was found in F6 with T6 followed by that of 64Mg C ha\(^{-1}\) in F4 with T2 followed by that of F3 with T4 (57.9Mg C ha\(^{-1}\)) F5 with T1 (38.4Mg C ha\(^{-1}\)) F7 with T5 (35.8Mg C ha\(^{-1}\)) and that of F1 with T7 the lowest (19.9Mg C ha\(^{-1}\)). Relatively low rise in percentage SOC stocks with T6 (56.3Mg C ha\(^{-1}\)) followed by F4 with T2 (51.4Mg C ha\(^{-1}\)) and F3 with T1 (48.4Mg C ha\(^{-1}\)) were observed in F6 [Table 1]. Majumder et al. [38] reported that FYM applied 67.9 per cent of C stabilization in a rice-wheat system in the lower Indo-Gangetic plains.

Liu et al. [39] recorded that the content of SOC and SON under cropland was significantly lower than that of native vegetation at a depth of 0-20 cm, and increased marginally under abandoned cropland (Fig. 1a). As an significant source of SOC and SON, the SOM content in surface soils depends primarily on the dynamics between organic material inputs and microbial decomposition. Leaf litter and plant biomass-related root exudates contribute to SOM but crop residues were not returned to soils which reduced cropland accumulation of SOM. Tillage brings oxygen into the soil and displays organic
matter from deeper soil, speeding the decomposition of SOM. The rate of decomposition of SOM in abandoned croplands typically speeds up with growing time due to increased soil biological activity. Singh et al. [40] observed that that the plots under 50 and 100% straw retention/incorporation had nearly 10 and 16% higher total SOC content compared with 0% straw (~12 g kg\(^{-1}\) soil) in the 0-to 5-cm soil layer (Fig. 1b).

3. RESTORATION OF CARBON IN SOIL PROFILE

Pandey et al. [41] revealed that no-tillage would increase SOC by 0.59 Mg C ha\(^{-1}\) yr\(^{-1}\) before rice and wheat sowing. SOC sequestration levels in rice-based systems in South Asia ranged from 0- to 2114 kg ha\(^{-1}\) yr\(^{-1}\) due to reduced- or no-tillage management [42]. Xue et al. [43] also observed that, over time, the CT system typically experiences a substantial decline in SOC concentration due to soil structure degradation, exposing microbial species to protected SOMs within soil aggregates. Consequently, implementing a no-till method will reduce the loss of SOC resulting in higher or equivalent concentration compared to CT.

Six et al. [44] also found that the concentration of free LF C in cultivated systems was not influenced by tillage, but on average 45 per cent lower than NV. Proportions of crop-derived C in macro-aggregates were comparable in NT and CT but in NT micro-aggregates were three times greater than micro-aggregates from CT. In addition, the rate of macro-aggregates in CT as opposed to NT results in a slower rate of micro-aggregate formation within macro-aggregates and less stabilization of new SOM in free micro-aggregates under CT [Fig. 2a]. Zhao et al. [45] reported that, in the 0-20 cm layer, the SOC content of each aggregate class was significantly higher than in the 20-40 cm layer [Fig. 2b]. Increases in aggregate fractional SOC content were highest in MRWR, followed by MR, and finally WR [Fig. 2b]. Organic particles or colloids derived from crops can be combined with mineral matter which binds micro-aggregates into macro-aggregates. Fresh straw incorporation provides a substratum for microorganisms, and straw input can alter SOC distribution and increase aggregate SOC material, especially in macro-aggregates [46].

Mazumdar et al. [47] also observed that Concentration of C in macro-aggregates was higher than in micro-aggregates. Regardless of the treatments, C concentration was the highest in 1-2 mm followed by macro-aggregates scale of 0.5-1 mm and the concentration decreased as the aggregates became smaller in size [Fig. 3a]. The absorption of organic manures causes the decomposition of organic matter in which the roots hyphae and polysaccharides attach mineral particles into micro-aggregates and then these micro-aggregates attach to form C rich macro-aggregates [Fig.3a]. Zhao et al. [45] revealed that the straw return treatments, particularly MR-WR, increased the proportions of mSOM and fine iPOM within small macro-aggregates and micro-aggregates, especially in the 0–20 cm layer [Fig. 3b]. The carbon content of iPOM was much lower at 20–40 cm than at 0–20 cm [Fig. 3b].

Fig. 1 (a). SOC content (a), SON content (b), K factor (c), and mean weight diameter (MWD) (d) in different soil layer depths at different stages following abandonment of the agricultural sector; Fig. 1 (b). Contribution of SOC accumulation to the percentage of initial SOC content from 0 to 20 cm for soil control and straw adjustment
Table 1. Soil organic carbon (SOC) as influenced by tillage crop residues and nutrient management activities by 18 yr [Source: Naresh et al. [20]]

| Crop residue tillage practices | Initial SOC stock | Fertilization  | Mg C ha\(^{-1}\) |
|-------------------------------|------------------|----------------|-----------------|
|                              |                  | F\(_1\)**     | F\(_2\)          | F\(_3\)          | F\(_4\)          | F\(_5\)          | F\(_6\)          | F\(_7\)          | Mean             |
| T\(_1\)                       | 20.9±1.6         | 19.2±1.3\(^U\) | 26.9±1.6\(^O\)  | 54.1±1.7\(^O\)  | 63.3±2.8\(^O\)  | 36.9±1.5\(^O\)  | 70.5±3.7\(^O\)  | 35.1±1.7\(^O\)  | 43.7±2.0\(^O\)  |
| T\(_2\)                       |                  | 23.0±1.7\(^U\) | 33.5±2.5\(^U\)  | 65.8±2.0\(^U\)  | 70.9±3.7\(^A\)  | 44.9±1.9\(^B\)  | 81.6±4.2\(^B\)  | 39.8±1.3\(^A\)  | 51.4±2.5\(^U\)  |
| T\(_3\)                       |                  | 16.7±1.3\(^O\) | 23.4±1.9\(^B\)  | 52.0±1.6\(^D\)  | 58.6±1.6\(^D\)  | 33.2±1.5\(^C\)  | 63.5±3.3\(^E\)  | 31.3±0.1\(^B\)  | 39.9±1.6\(^D\)  |
| T\(_4\)                       |                  | 20.5±1.5\(^C\) | 30.7±2.4\(^B\)  | 62.6±1.9\(^C\)  | 69.4±3.3\(^B\)  | 39.7±1.3\(^B\)  | 79.1±4.1\(^C\)  | 36.7±1.5\(^C\)  | 48.4±2.3\(^C\)  |
| T\(_5\)                       |                  | 18.0±1.3\(^U\) | 25.5±2.1\(^A\)  | 53.4±1.7\(^U\)  | 61.3±2.1\(^B\)  | 34.4±1.3\(^D\)  | 67.0±1.4\(^B\)  | 32.1±0.1\(^C\)  | 41.7±1.4\(^D\)  |
| T\(_6\)                       |                  | 26.5±1.9\(^A\) | 42.5±3.1\(^A\)  | 68.5±2.1\(^A\)  | 73.0±3.6\(^A\)  | 49.7±1.8\(^C\)  | 85.7±4.5\(^A\)  | 48.2±2.1\(^A\)  | 56.3±2.7\(^A\)  |
| T\(_7\)                       |                  | 15.8±1.2\(^C\) | 19.3±1.8\(^C\)  | 49.0±1.5\(^B\)  | 51.7±2.5\(^C\)  | 29.8±1.2\(^C\)  | 58.0±1.3\(^C\)  | 27.4±1.7\(^D\)  | 28.7±1.6\(^D\)  |
| Mean                          |                  | 19.9±1.5\(^D\) | 28.8±2.2\(^B\)  | 57.9±1.8\(^D\)  | 64.0±2.8\(^C\)  | 38.4±1.5\(^C\)  | 72.2±3.2\(^C\)  | 35.8±1.2\(^D\)  | -                |

** Different column letters vary significantly by \(P=0.05\) according to Duncan Multiple Range Test (DMRT) for means separation
Fig. 2(a). Dynamics of Soil organic matter and aggregates under conventional and No-tillage systems; Fig. 2(b). Organic C content (g kg\(^{-1}\) aggregate) of aggregates: LM, SM, mi and SC in the soil layers 0-20 cm and 20-40 cm below MR-WR, MR, WR, and Control.

Fig. 3(a). Effects of long-term integrated nutrient management practices on soil-associated aggregate carbon; Fig 3 (b). Organic C value (g kg\(^{-1}\) soil) of the SOC fractions: coarse iPOM, fine iPOM, mSOM and free LF of small macro-aggregates and micro-aggregates in soil layers 0-20 cm and 20-40 cm below MR-WR, MR, and WR.

Sapkota et al. [48] found that in the top 0.15 m of soil, the difference in SOC concentration between different treatments was the largest, with values generally decreasing with depth. On average, soil depths of ZTDSR-ZTW+R and PBDSR-PBW+R were 86, 32 and 13 per cent higher than CTR-CTW at 0-0.05, 0.05-0.15 and 0.15-0.3 m, respectively, but 5 per cent lower than CTR-CTW at the lowest soil depth. ZTDSR-ZTW had SOC concentrations 50 and 26 percent higher than CTR-CTW at soil depths of 0-0.05 and 0.05-0.15 m but 5 and 10 percent lower than CTR-CTW at soil depths of 0.15-0.3 and 0.3-0.6 m respectively. Compared to other treatments, the rise in SOC concentration at 0.15 m soil depth in ZT systems may be attributed to (i) surface retention of crop residues (or non-residue stubbles), (ii) higher development of plant biomass. Naresh et al. [20] also found that the NPK+FYM treatment had higher concentration of SOCs in all TCE compared with the RDF treatment as well. The maximum rise in SOC in diagnosis with NPK+FYM has been observed in TCE T6 in F6. Compared to the control, the mean SOC build-up rate during the 18-year cropping duration was the highest in F6 with T6 (50.63 percent) and the lowest in F1 with T7 (9.79 percent) [Table 2]. It has been estimated that 30% of C added through FYM has been stabilized, and the remaining (70%) have been lost through oxidation.

Patra et al. [49] recorded that SOC concentration was the highest under NT-MWMB (12.49 Mg ha\(^{-1}\)), followed by NT-RWMB (12.12 Mg ha\(^{-1}\)), RT-RWMB (11.52 Mg ha\(^{-1}\)) and CT-RW (8.57 Mg ha\(^{-1}\)) at 0-10 cm soil depth. Storage of SOC at a depth of 0-10 cm was substantially lower under CT-RW relative to other treatments, however. SOC capacity was the strongest under
4. CARBON AGGREGATES IN SOIL

Bhattacharyya et al. [50] stated that fertilization in all soil depths had no impact on aggregation at sizes below S3. In 0-15 and 15-30 cm [Fig.4a], and in 30-45 cm soil layers [Fig.4a], it had no effect on S5 and S7 and on S4, S5, S6 and S7. The addition of FYM in all soil layers increased the percentages of large aggregates (2-4.75 and 1-2 mm). The aggregate ratio 2 mm (S1) under NPK was approximately 41 per cent higher? FYM treated plots in the soil layer 0-15 cm above that observed under NPK [Fig.4a]. FYM application increased porosity and thus decreased soil bulk density in all depths. Sharma et al. [51] reported that soil bulk density decrease with additions of organic matter. Due to higher SOC content and increased root biomass produced, the soil bulk density decreased with FYM application which resulted in better soil aeration and improved soil structure. The method of mineral fertilization in all soil layers had no effect on the SOC storage in smaller fractions (S6 and S7). In soil depths of 0-15 and 15-30 cm, plots with NPK had higher SOC storage than NK except for S5-S7 [Fig.4b]. The incorporation of mineral fertilizer FYM (NPK? FYM) greatly increased the storage of SOC over NPK for S1-S7 in 0-15 cm, S1 to S5 in 15-30 cm, and S1-S4 in 30-45 cm [Fig. 4b] depth of soil. In all soil layers, plots under NPK? FYM exhibited the highest SOC storage in S5. Across treatments, mean SOC associated with S5 fraction was nearly 39% of the total aggregate associated-C in the 0–45 cm depth interval [Fig.4b].

Chen et al. [52] reported a decrease in SOC concentration with depth of soil [Fig. 5a]. The SOC concentration in the RP treatment was significantly greater in both 0-10 and 10-20 cm than in the other four treatments, but no major differences among the other four were observed. In general there were no major variations between all the rotation systems in 20-30 cm. For POC, the RW treatment concentration was slightly lower than for RF, RO, and RP treatments, being 22.6 percent, 26.0 percent, and 22.7 percent, respectively, at 0-10 cm, and 12.0 percent, 17.0 percent, and 12.4 percent, respectively, at 10-20 cm. By comparison, in the RF procedure, the DOC concentration was substantially lower than in rotations with plant production, and the DOC decreases ranged from 46% to 140.0% at 0-10 cm and 36.9% to 80.9% at 10-20 cm soil depths. The concentrations of HWC in the 0-10 cm and 10-20 cm depths of the RP and RG rotation systems were substantially higher than those in the RO, RW and RF rotation systems. The concentration of MBC in RO and RW was significantly reduced at depths of 0-10 cm and 10-20 cm compared with RP, RG, and RF. Moreover, the values at 0-10 cm and 10-20 cm depth in RG and RP were substantially greater than in the other rotational treatments. However, at the depth of 20-30 cm, no major variations between the rotations were found [Fig. 5a]. In the RP treatment the quality of DOC, HWC, MBC, and KMnO4-C was comparatively higher than in the other treatments. The improved labile SOC fractions could partly explain soil property improvement.

Table 2. Carbon recovery rate in soil profile, influenced by 18 yrs of tillage crop residue practices and nutrient management practices [Source: Naresh et al. [20]]

| Crop residue tillage practices | A 18 yr SOC Stock | Overall per cent Fertilization |
|-------------------------------|------------------|--------------------------------|
|                               | F1 | F2 | F3 | F4 | F5 | F6 | F7 | Mean |
| T1                            | 10.16<sup>d</sup> | 20.44<sup>b</sup> | 36.64<sup>a</sup> | 46.07<sup>a</sup> | 30.80<sup>a</sup> | 52.19<sup>a</sup> | 17.78<sup>a</sup> | 30.58<sup>a</sup> |
| T2                            | 12.48<sup>ab</sup> | 24.66<sup>c</sup> | 38.28<sup>b</sup> | 51.61<sup>a</sup> | 33.11<sup>a</sup> | 54.02<sup>a</sup> | 18.69<sup>b</sup> | 33.26<sup>a</sup> |
| T3                            | 6.86<sup>d</sup> | 18.94<sup>c</sup> | 34.79<sup>c</sup> | 41.01<sup>ab</sup> | 26.23<sup>bc</sup> | 49.58<sup>a</sup> | 13.72<sup>a</sup> | 27.30<sup>bc</sup> |
| T4                            | 12.14<sup>b</sup> | 21.65<sup>c</sup> | 38.17<sup>c</sup> | 47.96<sup>c</sup> | 31.37<sup>a</sup> | 53.35<sup>a</sup> | 18.43<sup>a</sup> | 31.87<sup>a</sup> |
| T5                            | 8.16<sup>d</sup> | 19.75<sup>c</sup> | 35.25<sup>c</sup> | 42.69<sup>c</sup> | 28.36<sup>a</sup> | 51.91<sup>a</sup> | 15.31<sup>c</sup> | 28.35<sup>b</sup> |
| T6                            | 13.46<sup>ab</sup> | 26.89<sup>c</sup> | 47.43<sup>c</sup> | 53.44<sup>c</sup> | 34.49<sup>c</sup> | 55.39<sup>a</sup> | 18.73<sup>c</sup> | 35.69<sup>c</sup> |
| T7                            | 5.24<sup>c</sup> | 17.17<sup>ab</sup> | 32.03<sup>c</sup> | 12.67<sup>ab</sup> | 25.16<sup>bc</sup> | 39.98<sup>bc</sup> | 12.67<sup>ab</sup> | 24.27<sup>bc</sup> |
| Mean                          | 9.79<sup>d</sup> | 21.36<sup>c</sup> | 37.51<sup>c</sup> | 45.78<sup>c</sup> | 29.93<sup>c</sup> | 50.63<sup>c</sup> | 16.48<sup>c</sup> | - |

<sup>**</sup> Different column letters vary significantly by P=0.05 according to Duncan Multiple Range Test (DMRT) for means separation.
Tripathi et al. [53] also observed that compared to unfertilized control, the aggregate size distribution was significantly influenced by the application of FYM and inorganic fertilizers. An aggregate fraction of 0.25-0.5 mm was the highest (27.36-31.36 per cent), while a fraction of 0.1-0.053 mm made the least contribution (2.10-3.87 per cent) in the total percentage of WSA at two sampling depths [Fig. 5b]. The application of FYM alone or in conjunction with inorganic fertilizers significantly improved macro and meso-aggregate formation compared to unfertilized control at both depths of the sampling. In FYM + inorganic fertilized plots, the proportion of micro-aggregates (0.25-0.1 mm and 0.1-0.053 mm) was smaller than the ones added with inorganic fertilizer alone. FYM application decreased the fraction of the micro-aggregate from 0.25-0.1 mm by 0.35 to 9.94 percent and the fraction of the micro-aggregate by 0.1-0.053 by 0.4-30.63 percent compared to unfertilized control in surface soil. The increase in the proportion of water-stable macro-aggregates (2 mm) by application of FYM + inorganic fertilizer could be attributed to the input of additional organic residues and active C in the soil and the
increase in ECe compared to application of inorganic fertilizer alone and unfertilized control [Fig. 5b].

Gu et al. [54] found that the soil under mulching treatments ST and GT had substantially higher concentrations of LOC, DOC, POC, and EOC in the 0-40 cm surface layer than those without mulching treatment [Fig. 6], possibly due to the inputs of straw, root and its parts. Concentrations of labile C fractions continued to decrease with soil depth in all treatments [Fig. 6]. Ou et al. [55] stated that the tillage systems obviously affected the distribution of different sized soil aggregates [Fig. 7a]. In NT+S, the ratio of the 2 mm aggregate fraction was 7.1 per cent higher than in the 0.00-0.05 m layer in NT-S. In both the 0.05-0.20 and 0.20-0.30 m layers there was no substantial difference in the total sum of all the combined fractions between NT+S and NT-S. NT+S and NT-S displayed a higher 2 mm aggregate ratio and a lower 0.053 mm aggregate ratio as opposed to the 0.00-0.20 m layer MP system. In most cases, the ratio of 0.25 mm macro-aggregate was slightly higher in MP+S than in MP-S, but in all soil layers the ratio of 0.053 mm aggregate was 11.5-20.5 per cent lower in MP+S than in MP-S [Fig. 7a]. Huang et al. [56] and Jiang et al. [57] reported that the NT method influenced the distribution of SOC stocks in the soil profile but did not affect the total quantity. Tillage regimes clearly affected the distribution of soil aggregations in the soil profile.

Vogelmann et al. [58] also found that tillage systems affected the aggregate-associated SOC concentration in different soil layers [Fig. 7b]. The concentration of SOCs in macro-aggregates in the 0.00-0.05 m layer showed the order of NT+S MP+S = NT-S MP-S, while the NT system was superior to the MP system. The NT method drastically reduced the concentration of SOC in the 0.05-0.20 m layer at the 2.00-2.50 mm fraction, however. A similar pattern has been observed in the fraction 0.25-0.503 mm in the 0.20-0.30 m layer. There was no difference in all soil layers in the 0.053 mm fraction between NT-S and MP-S, and between NT+S and MP+S, stating that the NT method did not affect the silt + clay fraction of the SOC concentration. The SOC concentration in the macro-aggregate increased by 13.5 percent in MP+S, 4.4 percent in NT-S and 19.3 percent in NT+S on average across the soil layers, and those in the micro-aggregate (0.25 mm) increased by 6.1 percent in MP+S and by 7.0 percent in NT+S as opposed to MP-S. For all soil layers, the SOC concentration was increased with straw incorporation in all aggregate size classes by 20.0, 3.8 and 5.7 percent under the MP system, and by 20.2, 6.3 and 8.8 percent under the NT system [Fig. 7b]. The higher ratio of 2 mm aggregates and the lower ratio of 0.053 mm aggregates under NT systems may result from higher soil hydrophobicity, low wetting and drying cycles, higher soil C concentration or the physical and chemical characteristics of large macro-aggregates that make them more resistant to breakdown [58].

Fig. 5 (a) and (b). Fractions of labile soil organic carbon (g C kg\(^{-1}\) soil): microbial biomass C (MBC), dissolved organic C (DOC), hot water extractable C (HWC), permanganate-oxidizable C (KMnO\(_4\)-C), and organic particulate C (POC), as affected by soil depth rotation treatments of 0-10, 10-20 and 20-30 cm
5. CONCLUSION

Soil organic matter levels have been recognized to be relatively small and are still decreasing, even in the few instances where suitable management strategies have been implemented. Practices in precision agriculture, i.e. Conservation system (CS) has proven to be highly successful in enhancing SOC within the context of cereal-based systems in North-West India. Minimal mechanical damage to the soil is a long-term management method to improve carbon amount contained on the field. However, soil organic carbon accumulation is a reversible cycle, and no substantial increase in soil organic carbon can result from short-term disruptions such as periodic tillage of land otherwise under the no-tillage. Conventional tillage (CT) greatly
decreases macro-aggregates to smaller ones, thereby decreasing aggregate stability by 35% compared with conservation system (CS), further suggesting that tillage practices have resulted in structural damage to the soil. SOC concentrations and other nutrients in this subtropical environment are also significantly above CS than CT and thus can boost soil structure to preserve SOM and nutrients and hold nutrient levels higher. The SOC concentrations and other nutrients in this sub-tropical Environment are also significantly greater. In summary, SOC and carbon fractions are more sensitive than in micro-aggregates to manure modifications. The study also found that fertilization that increased residue-C and residue-N return to soil also increased the related aggregate SOC and thus long-term sequestration of SOCs. There were good relationships between cumulative levels of C input and macro-aggregate-associated C, and between cumulative levels of C input and associated fraction of silt and clay (53-um). Soil sequestration with organic C in S5 (0.25-0.1 mm) fraction is the optimal long-term sequestration measure for both C and N. The no-tillage method revealed a tendency towards accumulation of organic carbon below the base of the soil surface. Conventional tillage decreased the stocks of C organic soil and its labile fractions in both the top and the subsoil (20-100 cm). The reduction of POC in topsoil was mainly motivated by a decrease in fine POC, while DOC was mainly reduced in the subsoil. The LOC fractions also decreased to SOC ratios, suggesting a decline in C efficiency as a result of tillage and residue management. Reduced LOC fractional stocks in the subsoil may be partly explained by the decline in subsoil fine root biomass, with implications for SOC stocks.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
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http://www.sdiarticle4.com/review-history/56486