Role of tillage and straw management on SOC sequestration: a sustainable approach of soil conservation

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Abstract
Soil organic carbon (SOC) sequestration can be achieved by changing the conventional practices to less intensive methods, i.e., no-tillage with straw management. The present review aimed to comprehend the existing knowledge on the impact of tillage and straw management practices on SOC sequestration. Along with the benefits/effects of no-tillage and straw management practices, the limitations and prospects in the context of SOC sequestration were also discussed. The present review provided the contemporary synthesis of existing information on the benefits of soil conservative practices over conventional tillage concerning physicochemical and biological properties. No-tillage with straw management have the potential effects for SOC on surface layers. However, additional studies are wanted to investigate the potential influences of tillage and straw management practices on the SOC distribution either in the surface layer or deeper layers. It has been widely reviewed from the compiled literature review that no-till soils have increased the SOC in surface layers but might not be accompanying with increased SOC throughout the soil profile. There is still knowledge gaps exist especially about SOC sequestration, which must be talked, i.e., sampling depth, and study places distribution, etc. Moreover, the mechanisms of SOC sequestration are still not fully understood. The valuation of soil quality is complex, and demands widespread and systematic research. The present review also summarized the suitable options to increase the SOC sequestration by tillage and straw
management practices. Innovative approaches are needed for the application of straw management in combination with no-tillage, require further practical assessment under long-term field experiments. Available evidence still evokes that soil management practices in the agriculture have the potential in long-term studies to increase terrestrial SOC sequestration with potential benefits to environmental ecosystems.

**Keywords:** No-tillage; Organic matter; Soil aggregates; Soil carbon sequestration; Straw management; Tillage

**Introduction**

Soil organic carbon (SOC) plays a vital role in crop productivity, soil health, soil fertility and associated environmental changes [1, 2, 3, 4, 5]. Different tillage methods (conventional tillage and no-tillage) are used for loosening the soils to cultivate the crops, preserve soil structure, conserve soil water, incorporate plant residues [6, 7] but long-term tillage practices are believed to be one of important factor that stimulates marked changes in SOC pools [8]. Intensive tillage system may decrease the SOC sequestration [9] and accelerate the movement of SOC to deeper soils [10]. Recommended management practices (Straw management and tillage practices) are useful tools for reviewing SOC dynamics [11, 12]. Adoption of no-till (NT) management practices has the great prospective to store SOC in croplands, increase the soil and water conservation in cropland soils, save the employment, energy, and budget compared with the CT practices [13]. In additions, NT practices improve the physicochemical and biological properties and lead to a new, different SOC equilibrium and balance of the nutrients [1, 14]. Long-term no-tillage without straw management may lead to less SOC contents due to the influence on soil aggregation [14]. However, straw management along with conservation tillage (minimal tillage or no-tillage) help in improving SOC storage, soil fertility and the soil quality [15, 16].

Several recent researchers have highlighted that NT and straw management practices had a remarkable effect on the SOC, the results might be diverse under different residue management, soil type, climate, and cropping system [17, 18, 19]. The straw management system is different in many countries and regions. In developed countries, straw mulch is usually retained in the field to increase soil fertility and productivity [20, 21]. Unfortunately, in many developing countries farmers like to remove the straw from fields for fuel or burning of crops straw residues [22, 23]. The straw burning in environment is undesirable and prohibited way and has a broad impact on global environmental change and ecosystem through the release of some greenhouse gases, is a significant threat to the stability of soil fertility and environment [24, 25].

In many countries, farmers follow conventional tillage (CT) practice, i.e., moldboard plowing, this kind of exhaustive cultivation has engaged to severe land degradation, decline soil quality and decline of SOC in agro-ecosystem [1, 13]. While NT practice, which protects the soil and water with a minimum disturbance to the soil surface and cover the topsoil with at least 30% or more straw mulches or residues on the surface of soil [26, 27], has been recently promoted in developing countries. Various recent studies have advocated the NT, and straw management is effective management practices to manage the crop residues and has indicated the marked potential for enhancing the soil carbon storage in the cropland soil ecosystem [4, 28]. In the scenario of global climate change, it is imperative to enumerate the benefits observed under NT and straw management practices and to understand their effects on SOC dynamics and sequestration. The objectives of the present review were to comprehend the available knowledge on the impact of
different tillage and straw management practices on SOC sequestration. Along with the benefits/effects of tillage and straw management practices, the limitations and prospects in the context of SOC sequestration were also discussed.

**Soil organic carbon and sequestration dynamics**

Soil organic matter management had a significant role in agriculture ecosystem by retaining and contributing the nutrients, enhancing the soil aggregation, reducing soil erosion, and improving the water holding capacity of soil [29, 30, 31]. The maintenance of SOC in farmland is necessary, not only for the higher production of crops but as well as to reduce SOC emissions [32]. However, due to the temporal and spatial variability, it is difficult to perceive the short-term and medium-term variations of SOC in agriculture ecosystem [33, 34].

Continuous turnover of the SOC in the soil, however, the SOC is not a consistent material, but a complex mixture of the organic compounds at different decomposition stages [35, 36]. It is a suitable way to discrete the total SOC into numerous pools which be governed by on the ease of the decomposition, ordinarily named as slow, inert and labile pool [31, 37, 38]. However, the labile SOC pool rapidly undergo oxidation and play important role in the managing of the soil food web and the effects on nutrient driving for the conservation of quality and efficiency of the soil [39, 40, 41]. The generally labile pool comprises the fresh material of crop residues inputs in the soil along with micro-organism activities. Though slow pool includes the well decomposed soil organic matter (the hummus), the inert pool is the creation of the last stage of the decaying organic matter, denotes to the old, impervious to break down (e.g., charcoal) [31, 42]. Most of the labile organic SOC fractions are used as early indicators of the soil quality, i.e., readily oxidizable carbon (KMnO$_4$-oxidizable), particulate organic carbon, the microbial biomass carbon, dissolved organic carbon and mineralizable organic carbon [43, 44, 45]. These fractions were not only considered as important soil indicators for evaluating the balance of the SOC and play essential roles in the preservation of the soil chemistry, biochemistry and soil fertility [29, 35, 46]. These labile C fractions are often also considered as the most sensitive SOC pools to changes after the agricultural management practices in comparison to the total SOC in soil [47, 48]. These agricultural management changes can stimulate the apparent differences in the SOC pools and the turnover rate of labile C fractions in the soil [21, 49]. Worldwide the researchers had conveyed the consequences of the no-tillage (NT) over conventional tillage (CT) for SOC sequestration (storage). For example, in USA, [50] reported that mean SOC sequestration rate was 0.34 Mg ha$^{-1}$/year from different 76 long-term experiments in 0-30 cm layer over 20 years (Table 1). In Eastern Canada, [51] reported the projected worth under NT of 0.07–0.27 (Mg ha$^{-1}$ yr$^{-1}$) and 0.15–0.32 (Mg ha yr$^{-1}$) for the western Canada. In a Meta-analysis, [52] specified that the storage using NT was 0.13–0.48 (Mg ha$^{-1}$ yr$^{-1}$) (average of 15 years) (Table 1). Furthermore, the contemporary synthesis of existing data on SOC sequestration has been compiled in (Table 1).

SOC sequestration is a conversion in total carbon storage, generally expressed a conversion in the total SOC stocks with time [3, 10, 53]. The residence period of the particles in nature is in line with the mark of physical protection (i.e. no-tillage and straw management practices). Different separation and extraction methods and multiple approaches based physico-chemical principles have been usually used to separate and quantify the C pools [23, 54]. Most significant basis of the soil breathing in the soils is in line for to the decomposition of organic matter in the soil from the crop residues [55, 56], the
sequential variations of the SOC fractions is connected. When soil breathing is measured after tillage practices [57, 58]. It is supposed to hypothesize that tillage has an impact on the effectiveness of relations between the availability of these labile fractions and respiration. This section highlights the importance of soil organic carbon sequestration dynamics in the agro-ecosystem. SOC has a significant role in supplying the plant nutrients, improving the soil aggregation, balance soil fertility and enhancing the water holding capacity of the agricultural land. The SOC sequestration dynamics can be divided into labile, slow and inert carbon pool, the changes in land use practices can bring changes in these C pools and SOC sequestration.

### Table 1. Soil organic carbon sequestration rate with no-tillage and straw management practices

| Country            | SOC sequestration rate (Mg C/ha/year) | Time period (Years) | Depth of soil (cm) | References |
|--------------------|--------------------------------------|---------------------|--------------------|------------|
| Global soils       | 0.13-0.48                            | 15                  | 22                 | [52]       |
| Global soils       | 0.33                                 | 30                  | 30                 | [59]       |
| India              | 0.02                                 | 20                  | 30                 | [60]       |
| USA                | 0.1-0.5                              | 5-10                | 20                 | [61]       |
| China              | 0.63                                 | 7                   | 30                 | [62]       |
| USA                | 0.34                                 | 20                  | 30                 | [50]       |
| Western Canada     | 0.15-0.32                            | --                  | 20                 | [51]       |
| Eastern Canada     | 0.07-0.27                            | --                  | 20                 | [51]       |
| China              | 0.34-0.41                            | 20-40               | 16.5               | [63]       |
| USA                | 0.7                                  | 7                   | 40                 | [64]       |
| USA                | 0.62                                 | 25                  | 20                 | [65]       |
| Brazil             | 0.38                                 | 5                   | 30                 | [66]       |
| USA                | 0.16                                 | 40                  | 15-100             | [10]       |

**Impact of SOC in agriculture ecosystem and decomposition**

Variations in the soil quality that is due to the result from erosion, salinization, and losses of the SOM and the nutrient, the soil compaction also cause decline of the soil quality and had the great concern in the agricultural ecosystem [67]. Worldwide, around 24 billion tons the surface soil is lost annually, which includes about 9.6 million hectares of land [8]. The maintenance of soil health is essential for soil productivity, decomposing of the wastes, sequestration of the SOC, and the exchange of the gases for sustainable agriculture ecosystem [68, 69, 70]. When agriculture straw residue is returned to fields, various organic compounds undergo decomposition [71, 72]. However, decomposition rate may vary depending on the regional climate, soil type, soil microbial processes and environmental variability [1, 19]. Continuous long-term management of straw to soil contributes to soil environmental, biological activities and regulates the carbon cycling process in the soil [26, 32]. However, chemical decomposition of the soil organic matter is a complex and diverse process in the soil system [8, 31]. SOC and its C fractions are considered as early and valuable indicators of variations in SOC stocks, and the use of different soil C fractions with an earlier response to changes in management compared to total SOC has been pointed out as an efficient tool to identify optimized agricultural management practices that increase the stock and quality of soil carbon [49, 59, 67]. Slight changes in the total SOC are difficult to notice due to the large amount of well stable and recalcitrant (non-labile) SOC [37, 46], and this non-labile SOC due its natural variability, changes very slowly.
Soil quality is concerned with the natural resources degradation because of its adverse impact to decline the quality of land, water, soil, plants, and animals; ultimately it effects on the quality of life and food security. NT and straw management practices are an effective management tool to identify optimized land management practices that increase the stock and quality of soil carbon in agro-ecosystem.

**No-Tillage and soil organic carbon**

No-tillage (NT) system had a strong impact on the distribution and magnitude of SOC, acclimatization of crop residues and decaying of soil organic matter [4, 10, 17]. In opposing, the intensive tillage system enhance the soil disturbance and endorses the mineralization rate of SOC, which clues the decrease of the SOC and soil aggregates stability [8, 14, 73]. Chen et al. [74] conveyed that no-tillage in combination with residue resulted 13.7% better SOC stocks in the upper 15 cm of soil in 11 years of the field experiment in northern China. Few authors had reported that NT increased the SOC contents in the top layers, but did not stock the SOC than conventional practices when the complete soil profile was measured [59, 68].

Long-term no-tillage practices are believed to be considered as the factor that stimulates marked changes in SOC pools [6, 36, 75]. However, frequent or heavy tillage practices may terminate the SOM in soil [10] and accelerate the movement of soil organic matter to lower layers of the soil [76]. Soil organic carbon increased in the tillage layer but remained unaffected in the unplowed layer below no-tillage in comparison to conventional tillage [77, 78]. Furthermore, the most of the review on the tillage experiments recommended that typical regional and local environmental conditions mostly influence SOC content. For example, NT practices did not improve the SOC in deep soil layers [4, 14], while the CT practices maintained it to in-depth soil profiles [8].

Soil organic carbon is also regulated by the types, rates and the frequencies of crop residues and straw management practices with tillage [21, 75]. Recently, conventional tillage practices decline SOC levels, this is concerned with the natural resources degradation because of its adverse impact on the quality of land and has caused serious problems in agriculture ecosystem [9, 10]. Nowadays, in recent studies, it has been accepted that the efficient use of management practices are used as tools to accomplish the new and higher levels of production. Thus, it has been broadly accepted that no-tillage could increase SOC sequestration in cropland soils [28, 79, 80].

Soil carbon sequestration can be achieved by using continuing a novel soil, and crop management practices are required to increase SOC storage and improvement of soil quality [11]. For example, Wang et al. [45] accompanied a novel straw return technique ditch-buried straw return (DBSR) and reported that it could be a better straw return technique to improve SOC stocks and soil quality, particularly on surface 0-20 cm soil. [81] Studied tillage and straw management influence on SOC sequestration in cinnamon-brown light loam soil for five years. Who observed that No-till with straw management efficiently reduce soil erosion and enhanced SOC sequestration in dryland farming system in northern China (Table 2). In Canada, Munkholm et al. [82] studied a 30 years experimental trials in a Woolwich silt loam soil establish that diversified crop rotation system was desirable for an active response of the NT under the considered soil. Hati et al. [18] conducted a 7 year experiments in deep heavy clay soil debated that NT and RT systems with residue retention would be suitable practice for sustainable soybean–wheat production in vertisols of central India (Table 2). Additionally, the up-to-date synthesis of current data on the benefits/effects of NT over CT practices on SOC is collected in (Table 2).
Table 2. Influence of tillage, straw management and crop rotation system on soil organic carbon contents and sequestration

| Country       | Study period (Years) | Soil type                        | Soil depth (cm) | Treatments                     | Effects/Reasons                                                                                                                                                                                                                                                                                                                                                     | Ref. |
|---------------|---------------------|----------------------------------|-----------------|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| Northern China| 5                   | Cinnamon-brown, light loam       | 0-20            | NTSM, ASRT, SRT, CT           | Straw incorporation in combination with no-tillage effectively decrease the soil erosion and enhanced SOC sequestration in dryland farming system in northern China                                                                                                                                                                                                 | [81] |
| China         | 9                   | Yellow river delta               | 0-60            | NTS, NTM, CT                  | NT practices had a significant impact on the physico-chemical properties and amended SOC amount in the surface soil.                                                                                                                                                                                                                                               | [77] |
| Canada        | 30                  | Woolwich silt loam               | 0-20            | C–C–C–C, C–C–O, RC, C–C–S–S, NT, MP | Diversified crop rotation system was required for a efficient response of no-tillage for the experimental soil                                                                                                                                                                                                                                                         | [82] |
| Switzerland   | 19                  | Orthic Luvisol (sandy loam)      | 0-40            | PL, ST, NT, GL                | This study suggests that mostly the tillage system for SOC are in small scale and temperate climatic soils.                                                                                                                                                                                                                                                         | [59] |
| Iran          | --                  |                                  | 0-20            | SM, CM, RH, FCR, WS, LD, CT   | In comparison to control treatment the 25 tons ha⁻¹ organic matter source developed the better soil aggregation stability.                                                                                                                                                                                                                                           | [24] |
| India         | 7                   | Deep heavy clay                  | 0-15            | CT, MB, RT, NT, N (50, 100,150 % of recommende d fertilizer | Integration of residue retention with NT and RT systems would be better ecological practice for sustainable soybean–wheat production                                                                                                                                                                                                                                    | [18] |
| Zimbabwe      | 9                   | Chromic Luvisol, Arena Gleyic Luvisol | 0-30    | CT, MR, CR, TR                | The long-term continues tillage practices should be arranged for the conservation of organic C inputs (e.g., residue incorporation) in the agroecosystem of coarse-textured soils                                                                                                                                                                                                 | [83] |
| Japan         | 4                   | Typical Andosol a sandy loam texture | 0-90          | NW,CT,CK, organic fertilizer; (N+: 50 kg N ha⁻¹ and 80 kg N ha⁻¹) | Covering weeds with no-tillage practices contributed to protect the land by decreasing the nitrate leaching through enhancement the annual CH₄ uptake and SOC storage in the soils                                                                                                                                                                                                 | [26] |
| India         | 7                   | Silty clay loam (fine mixed hyperther mic Typic Udorthent) | 0-15          | T1, T2, T3, T4                | This study reported that MT was a suitable management practice to improve the crop productivity and soil quality                                                                                                                                                                                                                                                   | [84] |
| Zimbabwe      | 6                   | Alluvial sandy loam soils        | 0-60            | CT, MT, NT                    | NT and MT improved the soil stability and SOC sequestration. Therefore, NT and MT are sustainable tillage systems than conventional tillage practices.                                                                                                                                                                                                                                                               | [85] |
| Location | Year | Soil Type | 0-20 cm | Tillage | Results |
|----------|------|-----------|---------|---------|---------|
| Ireland  | 9    | Haplic luvisol, sandy loam texture, clay loam texture | CT, RT | RT system attained the SOC mitigation rate from 0.18 to 1.0 Mg C ha$^{-1}$ y$^{-1}$ as compared to CT system |
| Spain    | 4    | Eutric Leptosol | MP, NT | The short-term NT and MP practices had some positive impacts on plant emergence but also had few adverse effects on soil quality especially in top layer |
| Iran     | 6    | Haplic Calcisols (FAO) or mesic Typic Calcixererts | MP, DP, CP, RP | Reduction in the tillage intensity under CP and RP would not enhance SOC, but developed soil structure and moved SOM from the micro-aggregate to macro-aggregate in the short-term study |
| Brazil   | 12   | Rhodic Eutrudox | CT, NT | The effects of no-tillage on soil carbon stabilization are between the natural ecosystem and conventional tillage |
| Finland  | 11   | Vertical Cambisol, Eutric Regosol | NT, RT, CT | The prospective to store SOC in NT or RT appears partial in boreal agro-ecosystems but augmented aggregate-associated C |
| France   | 18-35 | -- | AMG | 50 years of the straw management increased SOC stocks by 2.5-10.9% as compared to removal of straw |
| Spain    | 27   | Fluventic Xerochrept | NT, MT, CH, PT, Sub-25, Sub-50, Mb | The conservation tillage system improves the soil water storage in semiarid soil environment |
| Italy    | 28   | Typic Xerofluvent | CT, NT | NT is considered as a valuable substitute in management practice that increasing soil carbon sequestration and soil health system in Mediterranean conditions |
| Brazil   | 7    | Typic Haplorthox | GC, NT, AT, CT, BS | No-tillage expressively alter the SOC contents compared with grassland, and appeared as suitable conservation practice for vegetable farming on sloping soils |
| Italy    | 19   | Xeric Chromic Haploxeret | CT, RT, NT | NT with crop rotation system considerably expand the biochemical properties of SOC in semiarid soils |
| Pakistan | 3    | Sandy clay loam soil | CT, MT, RT, ZT, R*, R$^+$ | ZT and RT system together with residue returned practices are possible alternatives to CT practices for improving SOC contents and structural stability in loess dryland soils |
| Country          | States | Soil Type                        | Depth (cm) | Treatment       | Summary                                                                                           | Reference |
|------------------|--------|----------------------------------|------------|-----------------|---------------------------------------------------------------------------------------------------|-----------|
| China            | 6      | Argic Rusty Ustic Cambisols       | 0-5        | MP + R, MP + R, RT + R, NT + R                      | The adoption of NT and RT system improved mM formation and enhanced SOC sequestration in the micro-aggregates of surface soil | [95]      |
| Northeas t China | 3      | Typic Hapludoll                   | 30         | MP, RT, NT                                            | NT practices could not significantly increase of SOC in topsoil as compared with MP and RT. The short-term (3-year) NT management system stratify the SOC concentration but not their storage in the plow layer | [96]      |
| Northeast Slavonia | 3  | Albic Luvisol                     | 0-35       | CM, CT, CP, RT, NT                                   | This study confirms that the physical properties of soil were increased in the order CM, CT, CP, NT, and RT treatments | [97]      |
| Vietnam          | --     | Fluvaquentic Humaquept            |            | Tillage practice and rice straw manage with burning, removal | When the rice straw was added to the field, the content of nitrogen and phosphorus was increased in the soil. Other chemicals, such as Ca, Mg, Na, Zn, and Cu, did not change much during three years in the six rice seasons | [98]      |
| Spain            | 20     | Cambisols Regosols Luvisols and Leptosols | 0-20       | CT, OF in four soil types: (CMs), (RGs), (LVs) and (LPs). | The results suggest that high soil quality and management practices have implications for soil organic carbon storage in the Los Pedroches Valley | [99]      |
| Dakota.          | 1      | Frigid Aquic Hapludoll, frigid Calcic Hapludoll |            | NT and the other used chisel tillage CT              | Reduced tillage increased SOM and WSA, which may help to maintain surface erosion resistance conditions | [100]     |
| Italy            | 19     | Xeric Chromic Haploxere p          | 0-15       | NT, DL, CT                                            | The NT and CT practices were the most effective in SOC sequestration. While, SOC was not sequestered in DL system. | [101]     |
| China            | 8      | Aquic inceptisol                  | 0-20       | TS, T, 2TS 2T, 4TS,4T, NTS, NT                       | Residue retention endorsed the formation of macro-aggregates, augmented the macro-aggregate-associated SOC and consequently, increased total SOC stocks | [32]      |
| China            | 10     | Clayey loam, with hydronic, smectite | 0-20       | RT–CT, NT–RT, RT–CT–S, NT–RT–S                       | The results showed that CT in the rice season and RT in the wheat season could reduce greenhouse gas emissions and increase crop yield in rice-wheat cropping areas | [102]     |
| China            | --     | Alfisols                          | 0-40       | CT, CTS, NT, NTS                                      | Combine use of NT with straw returning practices significantly improved SOC and water-stable aggregation. No-tillage and straw returning appeared to be promising and sustainable strategies to conserve SOC sequestration and stable soil | [103]     |
| Location | Year | Soil Type | Depth (cm) | Cropping System | Tillage System | Tillage Description | Summary |
|----------|------|-----------|------------|-----------------|----------------|---------------------|---------|
| Iran     | 4    | Typic Haplocambis bids | 0-30 | MD, CD, CR, CD, KD, drill TP, NT | Chisel plow plus disc (CD) and tined implementation plus disk (KD) treatments did not significantly different from NT and TP treatments. NT treatment began to increase in the late fourth years. Therefore, tillage-planting and NT treatments may be the most suitable tillage measures for the conservation of soil aggregate stability | [104] |
| Pakistan | --   | --        | 0-30       | CT and NT, continuous corn, CC; corn-soybean, CS; and corn-soybean–wheat, CSW | The soil quality index indicator was significantly greater under no-tillage as compared to conventional tillage. Although soil biological quality indicator is a sensitive and reliable indicator of soil quality | [67] |
| Iran     | --   | Typic Hapludalf, Celtic Hapludalf, Typic Udurent | 0-30 | forest soils than tea garden soils | Most of the measured soil characteristics were same in 0-15 and 15-30 cm depths except soil organic matter, permanent wilting point and field capacity | [105] |
| California | 3   | Xerochrept, Haploeralf s | 0-100 | Organic matter amendment and a nonamended control | Single application of organic matter in a grassland soil might increase the SOC and N in the labile and physically protected pools | [106] |
| China    | 12   | Argic Rusty Ustic Cambisols | 0-20 | MP+R, MP-R, RT, NT | Conservation tillage system can improve soil macro-aggregation, TSOC accumulation and SOC sequestration under exhaustive agricultural areas in the North China plain | [107] |
| North China | 8   | Udoll | 0-45 | CT, ST, HT, RT, NT | The integration of crop residue involvement with a suitable tillage practices is an effective way to preserve and develop low-quality soil | [108] |
| Iran     | 1    | Clay Loam | 0-30 | NT, MT, CT | The particle size distribution of diverse soil aggregates beside with aggregates stability indices total SON was suggestively improved under NT system | [109] |
| Northeast China | --- | Typic Hapludoll | 0-20 | NT, RT, CT | The results endorse that NT and RT practices are valuable for soil structure due to its encouraging impacts on aggregation developments in black soil | [75] |

**NTSM:** No-till with straw management, **ASRT:** Management all straw return tillage, **SRT:** Shallow rotary treatment, **NTS:** No-till with straw cover plus recommended urea nitrogen rate, **NTM:** No-till with straw removed and manure applied plus recommended urea nitrogen rate, **C–C–C–C:** continuous corn (Zea mays L.).
Impact of straw management on soil organic carbon

Straw management is an essential way to increase the fertility of the soil and increase the SOC sequestration in soil, also protective and improving the soil quality in agriculture ecosystem. Few recent studies suggested that straw management can improve storage of the SOC in upper layers [21, 36, 84, 93]. Van et al. [78] suggested that straw retaining with no-tillage considerably enhanced the total SOC in the surface soil (0–30 cm) soil. It has also been advocated that the straw management improved the SOC contents and enhanced the SOC stabilization in soil [11]. Though the conventional straw management practices (i.e., straw retaining with rotary tillage) are usually recommended in some regions; these management practices have been revealed some drawbacks in the rice-wheat crop rotation. For instance, rice straw management practices expressively improve the greenhouse gas emissions (CO₂ and CH₄). Whereas, the conventional straw management practices shows some negative influence on the tillage machinery and emergence of seedling (when the crop residues are retained in large amount on the surface of the soil) causes unbalanced crop yields and SOC balance in the soil [15]. To avoid the negative drawbacks of straw management, recently Wang [45] studied a new straw management practice or method (ditch-buried straw management; DBDT) to overcome the negative drawbacks of straw management associated with straw management in the rice-wheat cropping system.

Diverse kind of plant or crop residues as the choice of managing approaches that are directing to improve the SOC content in the global ecosystems and environments has frequently been considered [32, 110]. For instance, rice straw is not only an agricultural residue but also a vital fertilizer resource. Removal of rice straw is generally discouraged due to its negative consequences, however, it has been conveyed in the literature that incorporation of rice straw plays a significant role in maintaining soil fertility [11, 17, 28, 37] and microbial communities in the soil [46]. Many studies reported that plant and crops straw is
abundant with organic and inorganic nutrients, so recently it is used as natural organic fertilizer source which could substitute as chemical fertilizer or reduce the use of expensive inorganic fertilizers [21, 79]. Recent studies have been suggested that without the addition of organic carbon input, tillage practices may reduce the SOC sequestration compared to conventional methods or NT practices alone [41, 84].

Effects of no-tillage and straw management on soil physicochemical properties

Influence of no-tillage and straw management practices on soil physicochemical characteristics may differ on the particular system, amount, and superiority of SOM, soil type, topography, fertilization, tillage, climate, and time of crop rotation [19, 111]. No-tillage practices which covers the soil surface, have been occasioned in a notable alteration in soil physical, chemical and biological characteristics of the soil, mainly in the surface soil [16, 82, 93]. In no-tillage system, organic activities associated with soil organic matter, modify or stratified in the soil layers agreeing to the burial compactness of straw residues and manures in the soil [21, 36, 67]. The amount and quality of straw management and animal manures added determines the total inputs of SOC which becomes accessible in the soil [112, 113, 64]. Therefore, though we can assume that the interactive influences of no-tillage and straw management could increase soil organic matter and subsequently increase the availability of a nutrient in the soil [53, 74]. No-tillage in the existence of straw inspires soil microbial activities to improve the soil aggregates and develop soil structure [114]. Awareness about the soil bulk density is necessary for the land use and management, and knowledge about the soil compaction is also essential for the development of modern farming practices. Bulk density values are also compulsory to compute the soil porosity which is by the amount of pore space in the soil [115]. Sonnleitner et al. [112] reported that straw management improved the aggregation stability of the soil and further physical properties in contrast to farmyard manure. [1, 9] also found that crops straw residues inputs in the agricultural soil had a significant influence on soil aggregation, water content, soil porosity and the bulk density of the soil. Furthermore, most of the tillage practices effect on the SOC and related properties appears to be the site-specific. For instance, Varvel and Wilhelm [116] described that that SOC values were greater in the NT as compared to PT in 0-75 and 15-30 cm in a silty clay loam textured soil after 24 years of the tillage management. Though, on a silt loam textured soil, in 23 years tillage management, NT treatment had 1.3-fold higher SOC content the 0–20 cm layer, but in 20-25 cm layer it had 2.0 fold lower SOC, nonetheless equivalent in the 0–45 cm depth when NT treatment was compared with the plow tillage (PT) (Dolan et al. 2006). Similarly, In a clay loam soil of Canada, NT treatment had greater SOC in the 0–5 cm, smaller at 20–30 cm, and equal in the 0–60 cm depth after 13 years long-term practices as compared with PT treatment [117]. No-tillage and straw returning had a remarkable effect on soil physico-chemical properties, but it may differ liable on the particular system, quality and quantity of soil organic matter, topography, climate, soil type, tillage, fertilization and time of the crop rotation [51, 104].

Effects of no-tillage and straw management on soil aggregation

Soil aggregation and their stability had influence on numerous soil properties, i.e., soil water retention, porosity, hydraulic conductivity, water infiltration, soil carbon stabilization and the capability of soil to combat with water erosion [84, 89, 75, 110, 64, 118]. Stability of soil aggregates is a valuable index of the soil aggregation that can be assessed by many techniques.
and indexes (such as mean weight diameter: MWD, [119]; geometric mean diameter: GMD, [120] and fractal dimensions: FD, [121]. The macro and micro soil aggregation employ physical protection on the soil organic matter accompanying with soil particles sizes [14, 122, 123, 124]. If soil aggregates are water-resistant, they can preserve more SOC [125]. Consequences from a 20-years tillage experimental trial in silty clay soil of central Texas pointed out that SOC was stored more in the macro-aggregate fraction in no-till was improved by 158% as associated with conventional tillage practices, however only 40% in the <0.25 mm fraction [126]. A 7 year study recommended that no-tillage and rotary tillage significantly enhanced the dissemination percentages of soil macro-aggregate (>2 mm and 0.25-2 mm) fractions in comparison with mouldboard plow (MP) including residue (MP+R) and excluding residue (MP-R) treatments [107]. Soil micro-aggregates eroded earlier than larger macro-aggregates [14]. In latest studies, various researchers have been escorted to study the straw residues effects on the soil aggregation [72, 110, 127]. Therefore, SOC accumulation might be attained by beginning no-till practices that enhance the percentage of macro aggregates [10]. Though, development in constancy of soil aggregates after applications of organic residues is apprehensive with decomposition dynamic forces of organic inputs [108, 128]. But, there is further requirement to conduct straw management practices on the soil aggregation and required to generate a combining conceptual model which defining the straw residues management influences on the build-up of the SOC and the soil aggregation.

Relationships among straw management, tillage, soil organic carbon, and soil aggregation

Comprehensive assessments and studies have been focusing on the relationship between soil aggregation and the dynamics of soil organic matter (SOM) [123, 124, 126, 129]. Soil aggregation hierarchy model was developed for temperate soils, whose mineral composition is dominated by layered silicates, assuming that many binding agents play their role at different phases of soil aggregation [130], and the soil macro-aggregates (>0.25 mm) that formed from the microaggregates (<0.25 mm).

Many researchers have been accepted that the practice of crop straw and no-tillage usually pays to the structural environments of the soil [6, 82, 127]. In numerous seasons the consistency of soil aggregates increases or declines due to the decomposition degree of the fresh crop straw inputs. In contemporary theoretical models, enhancement in the strength of soil aggregates after straw incorporation linked with the changing aspects of agricultural biological residues inputs in the soil [36, 128, 131]. SOM is considered as the most critical and well active agent in the determination of the soil aggregate size distribution and stability of soil aggregates than other physical-chemical properties [132]. The experimental accumulation of SOC augmentation has optimistic and significant influence on soil aggregation [132, 133], which could endorse the SOC maintenance by as long as physical obstacles between microbes and enzyme [130]. No-till system supports macro-aggregation with time by decreasing soil disturbance and improving SOC concentration [73]. A better appreciative of SOC spreading among aggregates is important for a comprehensive assessment of continuing SOC sequestration.

Soil organic carbon: global challenges and limitations

Global challenges and prospects

Straw management and tillage practices had a substantial effect on the environment, economic, and social benefits, especially no-tillage combined with straw management practices is gaining global importance for sustainability of the agriculture ecosystem.
Intensive agriculture farming system uses the world’s large share of chemical fertilizers, pesticides, and total irrigation. Consequently, the world’s agriculture system has paid a massive cost of exhaustive farming. Likewise, the groundwater table has been deteriorated the alarming rate in some countries of the world. The depletion of the world’s resources has elevated the apprehensions about the sustainability of the farming practices. No-till with straw management practices can be an essential tool because it saves the labor, energy, time and other inputs, and improves the environmental health and SOC sequestration [1]. It is estimated that world’s land prone to accelerated erosion, has predicted that topsoil could be carried away on rigorously eroded lands by way of the high rate of soil erosion (0.5–1 cm year^{-1}) top soil from the Mollisols areas in Northeast China. Furthermore, water surplus can reduce the concentrations of SOC, and other vital nutrients, deteriorating the soil fertility and dropping the crop yield. In this respect, NT is an efficient amount to control water and wind erosion, enhance SOC stock, and develop soil quality [16, 67, 136]. Future of agriculture land will be in the way of minimum soil disturbance, less input and higher energy production systems [73]. In this background, NT is an auspicious technology for refining the environment and the whole profit margin [1]. A corresponding effort is wanted to improve research, education and extension work about NT in the globe. Investigators must pay attention on knowledge-based agricultural production systems for NT. The agricultural crop production system needs to be high yielding, and cost-effective but simple to use [8, 9]. Agriculturalists must permanently be ready to study innovations and be aware with modern developments. Policymakers must sustenance with researchers for learning the impacts of NT on a long-term basis and must also inspire farmers to adopt NT from side to side payments for ecosystem services [8, 9].

In the future, it is necessary to change the attitudes of farmers and researchers towards the sustainable management practices like NT management system [60, 117]. However Hobbs and [61] reported that the essential approach in the acceptance of no-tillage and straw management practices is about the mindset to other tillage practices. It is claimed in the research interests that to convince the farmers about the successful farming, it could be possible when reduced tillage or no-tillage is considered as significant tillage practice on a large scale. Although, it is a very challenging assignment to inspire the farmers about NT and straw management practices in the fields, about its potential to decrease the production costs. Recently, No-tillage and straw management practices are considered as a necessary route to the sustainability of the environment and agricultural ecosystem. There are some restrictions which may obstruct the adoption of NT and straw management practices, i.e., lack of appropriate seeders, mindset about the use of crop residues for livestock, fuel and burning [75, 114].

**Limitations and restrictions**

No-tillage with straw management practices is gaining much interest since decades. Still, knowledge gaps exist especially about SOC sequestration, which must be addressed, i.e., sample depth, and regional distribution, etc. [11]. Soil degradation processes (wind or water erosion) is affected by NT including straw management practices. Nevertheless, the mechanisms of SOC by decrease of erosion under NT are quiet not completely understood [45]. Global issue is to understand the destiny of SOC delighted by erosional processes (i.e., burial, emissions, deposition, and redistribution) [9]. However, valuation of soil quality is multifaceted and needs comprehensive and systematic research. The sequestration rate of SOC is greatly influenced by various
factors, containing soil type, climate, cropping system, and farming operations [52, 75, 121].

A tillage system can modify the microbial environment, which affects soil biological processes and ultimately SOC sequestration. Soil erosion can increase the loss of SOC ultimately reduce the ability of the soil to sequester the atmospheric carbon [9]. This is due to an increase in the soil erosion which decreases the carbon storage in the soil [1, 9]. The soil organic matter increased or declined in the soil because of the better or less agricultural land use management [88, 100]. The land use practices resulted the reduction in the SOC which leads to release of the carbon dioxide (CO₂) in the atmosphere because one percent decrease of the SOC in 30 cm top layer is occasioned as the losses of about 45 tons of the carbon or 166 tons of the carbon dioxide (CO₂) per hectare in the atmosphere [23, 37]. Agricultural machinery uses the fuel during the farming operations, this fuel burning by agricultural machinery is the primary source of the CO₂ emissions in the atmosphere. That’s why the intensive use of land and tillage practices increases the SOM loss and impacts on the greenhouse gas emissions [89]. Hence, the mechanisms leading by tillage effects on SOC sequestration have not been well-known. The soil C cycle comprises complex processes, the duration of experiments is rather short (conducted for only about five years) [8]. Though, tillage practices influenced the variations in soil properties, particularly soil physical properties, happen over short- and long time periods. Therefore, the date from long-term experiments illustrates that conversion of CT practice to NT practices may play a significant role in SOC sequestration for long-term research [9, 52].

Conclusion
In croplands, SOC sequestration can be increased by modifying tillage practices and management of straw incorporation back to the soils. The less intensive practices such as no-tillage system in the presence of straw creates a suitable biological and ecological protective interface between the soil and atmosphere. Positive improvement in the SOC sequestration could be achieved with the improved tillage and straw management strategies. In contrast, conventional practices with or without straw crop residues result in low carbon sequestration. Therefore, the less intensive practices like NT in combination with management of crop straw are recommended for efficient usage of the soil nutrients and effective long-term sequestration of SOC. Long-term studies should be conducted to access the dynamics of SOC, as effects under short-term studies might be varied. Available evidence still evokes that soil management practices in the agriculture have the potential in long-term studies to increase terrestrial SOC sequestration, with potential benefits to environmental ecosystems.

Authors’ contributions
Conceived and designed the experiments: KA Kubar, L Huang & S Hussain, Performed the experiments: KA Kubar & J Afzal, Analyzed the data: MA Chajjro & M Shaaban, Contributed reagents/materials/ analysis tools: S Bashir, MS Kubar, Wrote the paper: KA Kubar & AA Kubar.

References
1. Lal R (2007). Carbon management in agricultural soils. Mitigation and adaptation strategies for global change 12: 303-322.
2. Luo Z, Wang E & Sun OJ (2010). Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. Agric Ecosyst Environ 139: 224-231.
3. Ghimire R, Adhikari KR, Chen ZS & Shah SC (2012). Soil organic carbon sequestration as affected by tillage, crop residue, and nitrogen application in rice-wheat rotation system. Paddy Water Environ 10: 95-102.
4. Sandeep S, Manjaiah K, Pal S & Singh A (2016). Soil carbon fractions under maize-wheat system: effect of tillage and nutrient management. *Environ Monit Assess* 188: 14.

5. Lemtiri A, Coline G, Alabi T & Bodson B (2018). Short-Term Effects of Tillage Practices and Crop Residue Exportation on Soil Organic Matter and Earthworm Communities in Silt Loam Arable Soil, *Soil Management and Climate Change*. Elsevier. pp. 53-71.

6. Kibet LC, Blanco-Canqui H & Jasa P (2016). Long-term tillage impacts on soil organic matter components and related properties on a Typic Argiudoll. *Soil Till Res* 155: 78-84.

7. Datta A, Mandal B, Basak N & Badole S (2017). Soil carbon pools under long-term rice-wheat cropping system in Inceptisols of Indian Himalayas. *Arch Agron Soil Sci* 1-6.

8. Baker JM, Ochsner TE, Venterea RT & Griffis TJ (2007). Tillage and soil carbon sequestration—What do we really know? *Agric Ecosyst. Environ* 118: 1-5.

9. Lal R (2004). Soil carbon sequestration to mitigate climate change. *Geoderma* 123: 1-22.

10. Blanco-Canqui H, Francis CA & Galusha TD (2017). Does organic farming accumulate carbon in deeper soil profiles in the long term? *Geoderma* 288: 213-221.

11. Kubar KA, Huang L, Lu J, Li X, Xue B, & Yin Z (2018). Integrative effects of no-tillage and straw returning on soil organic carbon and water stable aggregation under rice-rape rotation. *Chilean J Agricultural Res* 78(2): 205-215.

12. Yagioka A, Komatsuzaki M, Kaneko N & Ueno H (2015). Effect of no-tillage with weed cover management versus conventional tillage on global warming potential and nitrate leaching. *Agric Ecosyst Environ* 200: 42-53.

13. Blanco-Canqui H & Lal R, (2007). Impacts of long-term wheat straw management on soil hydraulic properties under no-tillage. *Soil Sci Soc Am J* 71: 1166-1173.

14. Al-Kaisi M, Douelle A & Kwaw-Mensah D (2014). Soil microaggregate and macroaggregate decay over time and soil carbon change as influenced by different tillage systems. *J Soil Water Conser* 69: 574-580.

15. Du Z, Han X, Wang Y & Gu R (2017). Changes in soil organic carbon concentration, chemical composition and aggregate stability as influenced by tillage systems in the semi-arid and semi-humid area of North China. *Canad J Soil Sci* 98(1): 91-102.

16. Kubar, KA, Huang L, Lu J, Li X, Xue B, Yin Z (2018). Long-term tillage and straw returning effects on organic C fractions and chemical composition of SOC in rice-rape cropping system. *Arch. Agron. Soil Sci*. 65: 1–13.

17. Kahlon MS, Lal R & Ann-Varughese M (2013). Twenty two years of tillage and management impacts on soil physical characteristics and carbon sequestration in Central Ohio. *Soil Till Res* 126: 151-158.

18. Hati K, Chaudhary R, Mandal K & Bandyopadhyay K (2015). Effects of tillage, residue and fertilizer nitrogen on crop yields, and soil physical properties under soybean-wheat rotation in vertisols of Central India. *Agric Res* 48:56.

19. Rabbi S, Tighe M & Delgado-Baucizo M (2015). Climate and soil properties limit the positive effects of land use reversion on carbon storage in Eastern Australia. *Scientific Reports* 5: 17866.

20. Liu E, Teclemariam SG, Yan C & Yu J (2014). Long-term effects of no-tillage management practice on soil organic carbon and its fractions in the northern China. *Geoderma* 213: 379-384.

21. Zhu L, Hu N, Yang M & Zhan X (2014). Effects of different tillage and
straw return on soil organic carbon in a rice-wheat rotation system. *PloS one* 9: e88900.

22. Bhattacharyya R, Prakash V, Kundu S & Srivastva A (2009). Soil aggregation and organic matter in a sandy clay loam soil of the Indian Himalayas under different tillage and crop regimes. *Agric Ecosyst Environ* 132: 126-134.

23. Wang X, Yang H, Liu J & Wu J (2015b). Effects of ditch-buried straw return on soil organic carbon and rice yields in a rice-wheat rotation system. *Catena* 127: 56-63.

24. Karami A, Homae M, Afzalinia S & Ruhipour H (2012). Organic resource management: impacts on soil aggregate stability and other soil physico-chemical properties. *Agric Ecosyst Environ* 148: 22-28.

25. Moharana P, Sharma B & Biswas D (2012). Long-term effect of nutrient management on soil fertility and soil organic carbon pools under a 6-year-old pearl millet-wheat cropping system in an Inceptisol of subtropical India. *Field Crops Res* 136: 32-41.

26. Yagioka A, Komatsuzaki M, Kaneko N & Ueno H (2015). Effect of no-tillage with weed cover management versus conventional tillage on global warming potential and nitrate leaching. *Agric Ecosyst Environ* 200: 42-53.

27. Zhu L, Hu N, Zhang Z, Xu J & Tao B (2015). Short-term responses of soil organic carbon and carbon pool management index to different annual straw return rates in a rice-wheat cropping system. *Catena* 135: 283-289.

28. Virk HK, Singh G & Sharma P (2017). Effect of Tillage, Crop Residues of Preceding Wheat Crop and Nitrogen Levels on Biological and Chemical Properties of Soil in the Soybean-Wheat Cropping System. *Commun Soil Sci Plant Anal* 48: 1764-1771.

29. Haynes R (2005). Labile organic matter fractions as central components of the quality of agricultural soils: an overview. *Adv Agron* 5: 221-268.

30. Motschenbacher JM, Brye KR & Anders MM (2013). Rice Rotation and Tillage Effects on Water-Stable Soil Macroaggregates and Their Associated Carbon and Nitrogen Contents in a Silt-Loam Soil. *Soil Sci* 178: 596-611.

31. Lefèvre C, Rekik, F, Alcantara V & Wiese L (2017). Soil organic carbon: the hidden potential. Food and Agriculture Organization of the United Nations (FAO).

32. Xin S, Zhu AN, Zhang JB & Yang WL (2015). Changes in soil organic carbon and aggregate stability after conversion to conservation tillage for seven years in the Huang-Huai-Hai Plain of China. *J Inte Agric* 14: 1202-1211.

33. Blair GJ, Lefroy RD & Lisle L (1995). Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. *Aus J Agric Res* 46: 1459-1466.

34. Li CF, Yue LX, Kou ZK & Zhang ZS (2012). Short-term effects of conservation management practices on soil labile organic carbon fractions under a rape-rice rotation in central China. *Soil Till Res* 119: 31-37.

35. Margenot AJ, Calderón FJ & Bowles TM (2015). Soil organic matter functional group composition in relation to organic carbon, nitrogen, and phosphorus fractions in organically managed tomato fields. *Soil Sci Soc Am J* 79: 772-782.

36. Li J, Zhang Q, Li Y & Liu Y (2017a). Effects of long-term mowing on the fractions and chemical composition of soil organic matter in a semiarid grassland. *Biogeosci* 14: 2685.

37. Plaza-Bonilla D, Álvaro-Fuentes J & Cantero-Martinez C, (2014). Identifying soil organic carbon fractions sensitive to agricultural management practices. *Soil Till Res* 139: 19-22.
38. Li Z, Zhao B, Wang Q, Cao X & Zhang J (2015). Differences in chemical composition of soil organic carbon resulting from long-term fertilization strategies. *PloS one* 10: e0124359.

39. Li Y, Zhang J., Chang SX & Jiang P (2013). Long-term intensive management effects on soil organic carbon pools and chemical composition in Moso bamboo (Phyllostachys pubescens) forests in subtropical China. *For Ecol Manag* 303: 121-130.

40. Guo LJ, Zhang ZS, Wang DD & Li CF (2015). Effects of short-term conservation management practices on soil organic carbon fractions and microbial community composition under a rice-wheat rotation system. *Biol Fert Soils* 51: 65-75.

41. Moharana P, Naitam R, Verma, T & Meena R (2017). Effect of long-term cropping systems on soil organic carbon pools and soil quality in western plain of hot arid India. *Arch Agron Soil Sci* 63: 1661-1675.

42. Purakayastha T, Rudrappa L & Singh D (2008). Long-term impact of fertilizers on soil organic carbon pools and sequestration rates in maize-wheat-cowpea cropping system. *Geoderma* 144: 370-378.

43. Ghani A, Dexter M & Perrott K (2003). Hot-water extractable carbon in soils: a sensitive measurement for determining impacts of fertilisation, grazing and cultivation. *Soil Biol Biochem* 35: 1231-1243.

44. Roper MM, Gupta V & Murphy DV (2010). Tillage practices altered labile soil organic carbon and microbial function without affecting crop yields. *Soil Res* 48: 274-285.

45. Zhang P, Wei T, Jia Z & Han Q (2014). Effects of straw incorporation on soil organic matter and soil water-stable aggregates content in semiarid regions of Northwest China. *PloS One* 9: e92839.

46. Tobiašová E, Barančíková G, Gömöryová E & Makovnikova J (2016). Labile Forms of Carbon and Soil Aggregates. *Soil Water Res* 1-11.

47. Andruschkewitsch R, Geissteller D, Koch HJ & Ludwig B (2013). Effects of tillage on contents of organic carbon, nitrogen, water-stable aggregates and light fraction for four different long-term trials. *Geoderma* 192: 368-377.

48. Tatzber M, Schlatter N & Baumgarten A. (2015). KMnO4 determination of active carbon for laboratory routines: three long-term field experiments in Austria. *Soil Res* 53: 190-204.

49. Luo S, Zhu L, Liu J & Bu L (2015). Sensitivity of soil organic carbon stocks and fractions to soil surface management in semiarid farmland. *Eur J Soil Biol* 67: 35-42.

50. West TO & Marland G (2002). A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. *Agric. Ecosyst Environ* 91: 217–232.

51. VandenBygaart A, Gregorich E & Angers D (2003). Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. *Canad J Soil Sci* 83: 363-380.

52. West TO & Post WM (2002). Soil organic carbon sequestration rates by tillage and crop rotation. *Soil Sci Soc Am J* 66: 1930-1946.

53. Bogužas V, Mikučionienė R, Šlepetiienė A & Sinkevičienė A (2015). Long-term effect of tillage systems, straw and green manure combinations on soil organic matter. *Zemdirbyste-Agric* 102: 243-250.

54. Jagadamma S & Lal R (2010). Distribution of organic carbon in physical fractions of soils as affected by agricultural management. *Biol Fert Soils* 46: 543-554.

55. Boeni M, Bayer C, Dieckow J & Conceição PC (2014). Organic matter
composition in density fractions of Cerrado Ferralsols as revealed by CPMAS 13C NMR: Influence of pastureland, cropland and integrated crop-livestock. Agric Ecosyst & Environ 190: 80-86.

56. Li Q, Jin Z, Chen X & Jing Y (2017b). Effects of biochar on aggregate characteristics of upland red soil in subtropical China. Environ Earth Sci 76: 372.

57. Walmsley DC, Siemens J & Kindler R (2011). Dissolved carbon leaching from an Irish cropland soil is increased by reduced tillage and cover cropping. Agric ecosyst environ 142: 393-402.

58. Laudicina VA, Novara A, Gristina L & Badalucco L (2014). Soil carbon dynamics as affected by long-term contrasting cropping systems and tillages under semiarid Mediterranean climate. Appl Soil Ecol 73: 140-147.

59. Hermle S, Anken T, Leifeld J & Weisskopf P (2008). The effect of the tillage system on soil organic carbon content under moist, cold-temperate conditions. Soil Till Res 98: 94-105.

60. Grace PR, Antle J, Aggarwal PK & Ogle S (2012). Soil carbon sequestration and associated economic costs for farming systems of the Indo-Gangetic Plain: a meta-analysis. Agric Ecosyst Environ 146: 137-146.

61. Lal R (2002). Soil carbon dynamics in cropland and rangeland. Environ Poll 116: 353-362.

62. Pan L, Che H, Geng F, Xia X, Wang Y, Zhu C & Guo J (2010). Aerosol optical properties based on ground measurements over the Chinese Yangtze Delta Region. Atmospheric Environ 44: 2587-2596.

63. Rui W & Zhang W (2010). Effect size and duration of recommended management practices on carbon sequestration in paddy field in Yangtze Delta Plain of China: A meta-analysis. Agric Ecosyst Environ 135: 199-205.

64. Al-Kaisi MM & Yin X (2005). Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn-soybean rotations. J Environ Quality 34: 437-445.

65. Tan, Z, & Lal R. (2005). Carbon sequestration potential estimates with changes in land use and tillage practice in Ohio, USA. Agric Ecosystems & Environ 111: 140-152.

66. Carvalho J, Cerri C, Feigl B & Piccolo M (2009). Carbon sequestration in agricultural soils in the Cerrado region of the Brazilian Amazon. Soil Till Res 103: 342-349.

67. Aziz I, Mahmood T & Islam KR (2013). Effect of long term no-till and conventional tillage practices on soil quality. Soil Till Res 131: 28-35.

68. Hobbs PR & Govaerts B (2010). How conservation agriculture can contribute to buffering climate change. Climate Change and Crop Production 1: 177-199.

69. Piccoli I, Chiarini F, Carletti P & Furlan L (2016). Disentangling the effects of conservation agriculture practices on the vertical distribution of soil organic carbon. Evidence of poor carbon sequestration in North-Eastern Italy. Agric Ecosyst Environ 230: 68-78.

70. Menšík L, Hlisnikovský L & Pospíšilová L (2018). The effect of application of organic manures and mineral fertilizers on the state of soil organic matter and nutrients in the long-term field experiment. J Soils and Sediments 1: 1-10.

71. Li YE, Shi S, Waqas MA & Zhou X (2017c). Long-term (≥ 20 years) application of fertilizers and straw return enhances soil carbon storage: a meta-analysis. Mitigation and Adaptation Strategies for Global Change 1-17.

72. Sarker TC, Incerti G & Spaccini R (2018). Linking organic matter chemistry with soil aggregate stability:
Insight from 13 C NMR spectroscopy. Soil Biol Bioch 117: 175-184.

73. Six J, Elliott E & Paustian K (2000). Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Soil Biol Bioch 32: 2099-2103.

74. Chen H, Hou R, Gong Y & Li H (2009). Effects of 11 years of conservation tillage on soil organic matter fractions in wheat monoculture in Loess Plateau of China. Soil Till Res 106: 85-94.

75. Zhang S, Li Q, Zhang X, Wei K, Chen L & Liang W (2012). Effects of conservation tillage on soil aggregation and aggregate binding agents in black soil of Northeast China. Soil and Tillage Res 124: 196-202.

76. Moussa-Machraoui SB, Errouissi F & Ben-Hammouda M (2010). Comparative effects of conventional and no-tillage management on some soil properties under Mediterranean semi-arid conditions in northwestern Tunisia. Soil Till Res 106: 247-253.

77. Huang M, Liang T, Wang L & Zhou C (2015). Effects of no-tillage systems on soil physical properties and carbon sequestration under long-term wheat-maize double cropping system. Catena 128: 195-202.

78. Van Groenigen KJ, Hastings A & Forristal D (2011). Soil C storage as affected by tillage and straw management: An assessment using field measurements and model predictions. Agric Ecosyst Environ 140: 218-225.

79. Das T, Saharawat Y, Bhattacharyya R & Sudhishri S (2018). Conservation agriculture effects on crop and water productivity, profitability and soil organic carbon accumulation under a maize-wheat cropping system in the North-western Indo-Gangetic Plains. Field Crops Res 215: 222-231.

80. Si P, Liu E, He W, Sun Z & Zhang Y (2018). Effect of no-tillage with straw mulch and conventional tillage on soil organic carbon pools in Northern China. Arch Agron Soil Sci 64: 398-408.

81. Liu S, Yan C, He W & Chen B (2015). Effects of different tillage practices on soil water-stable aggregation and organic carbon distribution in dryland farming in Northern China. Acta Ecol Sinica 35: 65-69.

82. Munkholm LJ, Heck RJ & Deen B (2013). Long-term rotation and tillage effects on soil structure and crop yield. Soil Till Res 127: 85-91.

83. Chivenge P, Murwira H, Giller K & Mapfumo P (2007). Long-term impact of reduced tillage and residue management on soil carbon stabilization: Implications for conservation agriculture on contrasting soils. Soil Till Res 94: 328-337.

84. Ghosh B, Meena V, Alam N & Dogra P (2016). Impact of conservation practices on soil aggregation and the carbon management index after seven years of maize–wheat cropping system in the Indian Himalayas. Agric Ecosyst Environ 216: 247-257.

85. Gwenzi W, Gotosa J, Chakanetsa S & Mutema Z (2009). Effects of tillage systems on soil organic carbon dynamics, structural stability and crop yields in irrigated wheat (Triticum aestivum L.) cotton (Gossypium hirsutum L.) rotation in semi-arid Zimbabwe. Nutr Cycl Agroecosyst 83: 211.

86. López-Garrido, Rosa, Engracia M, Murillo JM & Moreno F (2011) Short and long-term distribution with depth of soil organic carbon and nutrients under traditional and conservation tillage in a Mediterranean environment (southwest Spain). Soil use Management 27: 177-185.

87. Kabiri V, Raiesi F & Ghazavi MA (2015). Six years of different tillage systems affected aggregate-associated SOM in a semi-arid loam soil from
96. Liang A (2007). Short-term effects of tillage practices on organic carbon in clay loam soil of northeast China. Pedosphere 17: 619-623.
97. Husnjak S, Filipovic D & Kosutic S (2002). Influence of different tillage systems on soil physical properties and crop yield. Rostlinna Vyroba-UZPI (Czech Republic).
98. Quang & Pham ST (2001). Effects of straw management, tillage practices on soil fertility and grain yield of rice. Omonrice 9: 74-78.
99. Parras-Alcántara L, & Lozano-García B (2014). Conventional tillage vs. organic farming in relation to soil organic carbon stock in olive groves in Mediterranean rangelands (Southern Spain). Solid Earth Discussions 6: 1-9.
100. Pikul Jr, J. L., Chilom, G., Rice, J., Eynard, A., Schumacher, T., Nichols, K. A., ... & Ellsbury, M. M. (2006, November). Soil aggregate stability and components of organic matter affected by tillage. In Meeting Abstract for pp: 12-16.
101. Barbera V, Poma I, Cristina L & Novara A (2012). Long-term cropping systems and tillage management effects on soil organic carbon stock and steady state level of C sequestration rates in a semiarid environment. Land Degrad Develop 23: 82-91.
102. Zhang L, Zheng J, Chen L, Shen M, Zhang X, Zhang M & Zhang W (2015). Integrative effects of soil tillage and straw management on crop yields and greenhouse gas emissions in a rice-wheat cropping system. European J of Agron 63: 47-54.
103. Pirmoradian N, Sepaskhah AR & Hajabbasi MA (2005). Application of fractal theory to quantify soil aggregate stability as influenced by tillage treatments. Biosystems Engineering 90: 227-234.
104. Barzegar A, Hashemi A, Herbert S & Asoodar M (2004). Interactive effects of tillage system and soil water content on aggregate size distribution for seedbed preparation in Fluvisols in southwest Iran. *Soil Till Res* 78: 45-52.

105. Abrishamkesh S, Gorji M & Asadi H (2011). Long-term effects of land use on soil aggregate stability. *Int Agrophys* 25: 103-108.

106. Ryals R, Kaiser M, Torn MS, Berhe AA & Silver WL (2014). Impacts of organic matter amendments on carbon and nitrogen dynamics in grassland soils. *Soil Biology and Biochem* 68: 52-61.

107. Du Z, Ren TS, Hu CS & Zhang QZ (2013). Soil aggregate stability and aggregate-associated carbon under different tillage systems in the North China Plain. *J Integ Agric* 12: 2114-2123.

108. Tian S, Wang Y, Ning T, Li N, Zhao H, Wang B & Chi S (2014). Continued no-till and subsoiling improved soil organic carbon and soil aggregation levels. *Agron J* 106: 212-218.

109. Boogar, Aminollah M, Mohammad RJ, & Mohammad R (2014). Soil aggregate size distribution and stability following conventional-till, minimum-till and no-till systems. *Int J Farming Allied Sci* 3: 512-7.

110. Chen X, Mao A, Zhang Y & Zhang L (2017a). Carbon and nitrogen forms in soil organic matter influenced by incorporated wheat and corn residues. *Soil Sci Plant Nutr* 63: 377-387.

111. Chen S, Xu C, Yan J & Zhang X (2016). The influence of the type of crop residue on soil organic carbon fractions: An 11-year field study of rice-based cropping systems in southeast China. *Agric Ecosyst Environ* 223: 261-269.

112. Sonnleitner R, Lorbeer E & Schinner F, (2003). Effects of straw, vegetable oil and whey on physical and microbiological properties of a chernozem. *App Soil Ecol* 22: 195-204.

113. Salahin N, Alam K & Mondol ATMAI (2017). Effect of Tillage and Residue Retention on Soil Properties and Crop Yields in Wheat-Mungbean-Rice Crop Rotation under Subtropical Humid Climate. *Open J Soil Sci* 7: 1-9.

114. Maillard É & Angers DA (2014). Animal manure application and soil organic carbon stocks: A meta-analysis. *Global Change Biol* 20: 666-679.

115. Blake GR & Hartge KH (1986). Bulk density. Methods of soil analysis: Part 1 Physical and mineralogical methods. 5: 363-375.

116. Varvel GE & Wilhelm WW (2010). Long-term soil organic carbon as affected by tillage and cropping systems. *Soil Sci Soc of America J* 74: 915-921.

117. Poirier P, Alpert MA, Fleisher LA, Thompson PD, Sugerman HJ, Burke LE & Franklin BA (2009). Cardiovascular evaluation and management of severely obese patients undergoing surgery: a science advisory from the American Heart Association. *Circulation* 120: 86-95.

118. Zhang X, Xin X, Zhu A & Yang W (2018). Linking macroaggregation to soil microbial community and organic carbon accumulation under different tillage and residue managements. *Soil Till Res* 178: 99-107.

119. Ojeda G, Alcañiz JM & Le Y (2008). Differences in aggregate stability due to various sewage sludge treatments on a Mediterranean calcareous soil. *Agric, Ecosystems & Environ* 125: 48-56.

120. Gómez C, José A, Juan VG, & Tom V (2008). "Comments on “Is soil erosion in olive groves as bad as often claimed? by L. Fleskens and L. Stroosnijder."
121. Rieu M & Garrison S (1991) Fractal fragmentation, soil porosity, and soil water properties: I. Theory. Soil Sci Soc of America J 55: 1231-1238.

122. Zhao H, Shar AG, Li S & Chen Y (2018). Effect of straw return mode on soil aggregation and aggregate carbon content in an annual maize-wheat double cropping system. Soil Till Res 175: 178-186.

123. Šimanský V, Balashov E & Horák J (2016). Water stability of soil aggregates and their ability to sequester carbon in soils of vineyards in Slovakia. Arch Agron Soil Sci 62: 177-197.

124. Udom B, Nuga B & Adesodun J (2016). Water-stable aggregates and aggregate-associated organic carbon and nitrogen after three annual applications of poultry manure and spent mushroom wastes. App Soil Ecol 101: 5-10.

125. Devine S, Markewitz D, Hendrix P & Coleman D (2014). Soil aggregates and associated organic matter under conventional tillage, no-tillage, and forest succession after three decades. Plos one 9: e84988.

126. Wright AL & Hons FM (2005). Tillage impacts on soil aggregation and carbon and nitrogen sequestration under wheat cropping sequences. Soil Till Res 84: 67-75.

127. Huang R., Lan M, Liu J & Gao M (2017). Soil aggregate and organic carbon distribution at dry land soil and paddy soil: the role of different straws returning. Environ Sci Poll Res 24: 27942-27952.

128. Abiven S, Menasseri S & Chenu C (2009). The effects of organic inputs over time on soil aggregate stability-A literature analysis. Soil Biol Bioch 41: 1-12.

129. Pikul JL, Chilom G, Rice J & Eynard A (2006). Soil aggregate stability and components of organic matter affected by tillage, Meeting Abstract for, pp: 12-16.

130. Tisdall Judith M &JM Oades (1982). Organic matter and water-stable aggregates in soils. J of Soil Sci 33: 141-163.

131. Fuentes M, Hidalgo C, Etchevers J & De León F (2012). Conservation agriculture, increased organic carbon in the top-soil macro-aggregates and reduced soil CO 2 emissions. Plant and Soil 355: 183-197.

132. Yu H, Ding W, Luo J, Geng R & Cai Z (2012). Long-term application of organic manure and mineral fertilizers on aggregation and aggregate-associated carbon in a sandy loam soil. Soil Till Res 124: 170-177.

133. Cates AM, Ruark M.D, Hedtcke JL & Posner JL (2016). Long-term tillage, rotation and perennialization effects on particulate and aggregate soil organic matter. Soil Till Res 155: 371-380.

134. Shafi M, Bakht J, Jan MT & Shah Z (2007). Soil C and N dynamics and maize (Zea may L.) yield as affected by cropping systems and residue management in North-western Pakistan. Soil Till Res 94: 520-529.

135. Nayak A, Gangwar B, Shukla AK & Mazumdar SP (2012). Long-term effect of different integrated nutrient management on soil organic carbon and its fractions and sustainability of rice–wheat system in Indo Gangetic Plains of India. Field Crops Res 127: 129-139.

136. Datta A, Basak N, Chaudhari S & Sharma D (2015). Soil properties and organic carbon distribution under different land uses in reclaimed sodic soils of North-West India. Geoderma Regional 4: 134-146.