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Review Article

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 complied litrature 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 to 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 link 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

[16, 44]. 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 untilled 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 efficeint response of no-tillage for the experimental soil	[82]
Switzerla nd	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]
Zimbabw e	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 CH_4 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]
Zimbabw e	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]

Ireland	9	Haplic luvisol, sandy loam texture, clay loam texture	0-30	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	[78]
Spain	4	Eutric Leptosol	0-25	MP, NT	The short-term NT and MP practices had some positive impacts on plant emergence but also had few adverse effcts on soil quality especially in top layer	[86]
Iran	6	Haplic Calcisols (FAO) or mesic Typic Calcixerep ts	0-20	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-aggregates in the short-term study	[87]
Brazil	12	Rhodic Eutrudox	0-20	CT, NT	The effects of no-tillage on soil carbon stabilization are between the natural ecosystem and conventional tillage	[88]
Finland	11	Vertical Cambisol, Eutric Regosol	0-20	NT, RT, CT	The prospective to store SOC in NT or RT appears partial in boreal agro-ecosystems but augmented aggregate-associated C	[89]
France	18-35	--	0-50	AMG	50 years of the straw management increased SOC stocks by 2.5-10.9% as compared to removal of straw	[90]
Spain	27	Fluventic Xerochrept	0-100	NT, MT, CH, PT, Sub-25, Sub-50, Mb	The conservation tillage system improves the soil water storage in semiarid soil environment	[91]
Italy	28	Typic Xerofluven t	0-30	CT, NT	NT is considered as a valuable substitute in management practice that increasing soil carbon sequestration and soil health system in Mediterranean conditions	[92]
Brazil	7	Typic Haplorthox	0-30	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	[93]
Italy	19	Xeric Chromic Haploxeret	0-15	CT, RT, NT	NT with crop rotation system considerably expand the biochemical properties of SOC in semiarid soils	[58]
Pakistan	3	Sandy clay loam soil	0-20	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	[94]

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]
Northeast 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]
Northwest 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 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 Haploxerep	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]

					aggregates in rice-rape cropping system	
Iran	4	Typic Haplocambids	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 Udurtent	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, Haploeralfs	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-tillage with straw cover plus recommended urea nitrogen rate, **NTM:** No-tillage with straw removed and manure applied plus recommended urea nitrogen rate**, C–C–C–C:** continuous corn (Zea mays L.),

C–C–O: corn, corn, oats (I L.), **C–C–S–S:** corn, corn, soybean (Glycine max L.), soybean, **NT:** No-tillage**, MP:** Moldboard plow, **PL:** Mouldboard ploughing, **ST:** shallow, **GL:** Tillage grassland, **SM:** Sheep manure, **CM:** Cow manure, **RH:** Rice husk (RH), **FCR:** finely chopped reeds, **WS:** wheat straw, **LD**: licorice (root) dregs, **CT**: Control treatment, **MB:** mouldboard tillage, **RT:** Reduced tillage, **N**: Nitrogen, **NW**: no-tillage with weed cover management**, MR:** mulch ripping, **CR:** clean ripping, **TR:** tied ridging (TR), **T1:** Panicum + 100:60:40 (N: P_2O_5:K_2O) + conventional tillage (CT) + chemical method of weed control in both crops. **T2:** Palmarosa + farmyard manure (FYM) at 5 t ha^{-1} + minimum tillage (MT) + 1-live mulch (at 20 days after sowing (DAS) of the maize crop). **T3:** Palmarosa + FYM at 5 t ha^{-1} + vermicompost (VC) at 1.0 t ha^{-1} + MT + 2-live mulch (at 20 and 40 DAS of the maize crop). **T4:** Palmarosa + FYM at 5 t ha^{-1} + VC at 1.0 t ha^{-1} + poultry manure (PM) at 2.5 t ha^{-1} + MT + 3-live mulch (at 20, 40 and 60 DAS of the maize crop), **MT**: Minimum Tillage, **MP:** Moldboard plow, **DP:** disk plow, **CP:** chisel plow, **RP:** Rotary plow, **RP: GC:** Grass coverage, **AT**: Animal traction, **BS:** Bare soil, **ZT:** Zero Tillage: R^+: Residue returned, R^-: Residue removed, **MP – R**: Moldboard plow without residue, **MP + R**: Moldboard plow with residue, **RT + R**: Reduced Tillage with residue, **NT +R:** No-tillage with residue, **TS**: plowing every year with and without residue, **2TS**: plowing every 2 years with, **2T** without residue, **4TS**: plowing every 4 years with residue, **4T**: without residue, **OF**: Organic farming, **CMs**: Cambisols, **LVs**: Luvisols, **RGs**: Regosols, **LPs**: Leptosols, **RT–CT**: Rotary Tillage-Conventional Tillage, **NT–RT:** No-Tillage-Rotary Tillage, **RT–CT–S**: Rotary Tillage-Conventional Tillage plus straw incorporation, **NT–RT–S**: **:** No-Tillage-Rotary Tillage plus straw incorporation, , **CC**: continuous corn, **CS**: corn-soybean, **CSW**: corn-soybean–wheat, CSW), **MD**: The mouldboard plough plus disc, **CD**: Chisel plough plus disc, **KD**: Khishchi tined implement plus disc, **TP**: Till-planting, **CR**: Chisel plough plus rotary tiller, **MD:** Moldboard plowing followed by disc harrowing, **DD**: Disc plowing using disc plow followed by disc harrowing, **OD**: Disking using offset disc followed by disc harrowing, **DL**: Dual-layer, **Ch**: Chisel, **sub-25**: subsoiler up to 25 cm depth, **sub-50**: subsoiler up to 50 cm depth, **Mb**: Mouldboard plow, **ST**: Subsoiling, **HT**: harrow tillage, **RT**: rotary tillage, **AMG**: Evaluating a simple model, **CP**: Conservation tillage 1, **CM**: Conservation tillage 11,

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 a 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 (CO_2 and CH_4). 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

[91, 93, 134, 135]. 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-tillage 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 efficeint 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 (CO_2) 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 (CO_2) 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 CO_2 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 intensice 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.

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