Catena 199 (2021) 105102

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Long term impact of different tillage systems on carbon pools and stocks, soil bulk density, aggregation and nutrients: A field meta-analysis

Denis Topa [a], Irina Gabriela Cara [b,*], Gerard Jităreanu [a]

[a] "Ion Ionescu de la Brad" University of Agricultural Sciences and Veterinary Medicine, Faculty of Agriculture, Aleea Mihail Sadoveanu Street, No. 3, 700490 Iasi, Romania

[b] "Ion Ionescu de la Brad" University of Agricultural Sciences and Veterinary Medicine, Research Institute for Agriculture and Environment, Aleea Mihail Sadoveanu Street, No 9, 700490 Iasi, Romania

ARTICLE INFO

Keywords:
Tillage management
Carbon fractions
Aggregate stability methodolgies
Bulk density
Soil affection

ABSTRACT

Intensive tillage frequently has adverse impact on soil physical quality and soil organic carbon stocks in temperate regions. A consequence of this has been a reduction in crop production over the years demonstrating the necessity of effective and sustainable agriculture. This study aimed to evaluate soil organic carbon (SOC) storage and pools, soil bulk density, aggregation and nutrient availability under different tillage systems (no-tillage, chisel and conventional tillage), based on a long field experiment. After 10 years of crop rotation, in 0–30 cm soil depth, no-tillage system had higher total organic carbon over conventional tillage treatment. Plots under no-till and chisel treatments in 0–10 cm depth, had 7–13%, 34–35% and 9–15% higher non-labile fraction ($Cfrac_4$), very-labile fraction ($Cfrac_1$) and total organic carbon (TOC), respectively compared to that of conventional ones. Also, no-till system had higher passive carbon pool and carbon management index than conventional system. In addition, the conservative tillage, reduced soil bulk density compared with conventional tillage in the surface layer. The stability of slow-wetting and room storage aggregates from conservative tillage were significantly higher ($p < 0.05$) than conventional tillage. Overall, stability of soil aggregates is improved under conservative tillage. Tillage system, crop rotation and residues, increased soil available nutrients N, P and K in the 0–10 cm depth, with the highest values in no-tillage system. Therefore, conservation tillage could be recommended as a tillage practices that improve fertility soil characteristics and production sustainability.

1. Introduction

Conservation tillage systems, here outlined as no-tillage (or zero tillage) with residue retention, has been accepted as a promising strategy (and a key management system) that preserve and restore soil physical and soil organic pools and dynamics (Vazquez et al., 2019). Due to their convenience in minimizing input costs, improving water storage and preserving soil carbon (C), conservation tillage is recognized as a long-term sustainable practice for agricultural ecosystems (Li et al., 2019). As in most parts of Europe, the application of conservation tillage in Romania is limited but the interest is growing continuously.

In the context of conservation agriculture practices, no-tillage system can also enhance soil quality by improving soil structure, intensifying soil biological activity, improving the nutrient cycle, increasing the soil water holding capacity and the water infiltration characteristics (Hellner et al., 2018, Borges et al., 2018) and also plays a crucial role in sustaining agricultural productivity and preserving environmental quality (Raus et al., 2016, Amezketa, 1999). Lampurlanes et al. (2016), Jat et al. (2019), Zuber and Villamil (2016), Li et al. (2018) found that conservative tillage showed promising trends in improving soil enzyme and microbial activity and enhance soil structure and crop yields. An issue based on long-term tillage in North America showed that the larger SOC content in the 21–35 cm soil under CT did not completely equilibrate the gain in the 0–20 cm soil under NT (Angers and Eriksen-Hamel, 2008). The main challenges with the adoption of NT include soil compaction, weed management, and stratification of organic matter and nutrients. Therefore, further research is still needed to evaluate the effects and mechanisms of conservation tillage practices on changes in soil quality along the soil profile (Angers and Eriksen-Hamel, 2008).

Soil physical property dynamics within different tillage system are

* Corresponding author at: Institute for Agriculture and Environment, Ion Ionescu de la Brad University of Agricultural Science and Veterinary Medicine, Faculty of Agriculture, Aleea Mihail Sadoveanu Street, No. 9, 700490 Iasi, Romania.

E-mail addresses: topadennis@yahoo.com (D. Topa), coroirina@yahoo.com (I.G. Cara), gerardj@uaiasi.ro (G. Jităreanu).

https://doi.org/10.1016/j.catena.2020.105102
Received 22 May 2020; Received in revised form 23 November 2020; Accepted 11 December 2020
Available online 25 December 2020
0341-8162/

well documented but a systematic synthesis is needed to enhance how these practices affect soil physical properties on a global scale and how these changes in soil physical properties are linked to multiple ecological components at cropping system level (Li et al., 2019).

Soil structure, the spatial arrangement of primary soil particles and aggregates with associated pore networks, is a key parameter for soil sustainability management; it provides vital functions and acts as an optimum medium for plant growth (Lehmann et al., 2017). Soil aggregation plays an important role in soil structure and organic matter stabilization, which furthermore supports soil fertility through minimizing soil erosion, mediating air permeability, infiltration and nutrient cycling (Zhang et al., 2018). In addition, soil aggregate stability can defend soil organic carbon from mineralization because it physically reduces the accessibility of organic compounds for microorganism, enzymes and oxygen. The process of soil carbon associated aggregate destabilization vary with macro and microaggregates. The degree of mineralization can be intensified by macroaggregate conversion to dimension of microaggregates (Jat et al., 2019). The soil organic matter associated with macroaggregates was more labile and less processed than that associated with the microaggregates. Organic matter is also an important agent responsible for binding soil mineral particles together (Jat et al., 2019).

Conventional tillage usually involves heavy tillage practices down to 20–25 cm soil depths (Pittelkow et al., 2015); this reliable management practice has resulted in reduced soil bulk density, increased porosity, and improved weed control (Pagliai et al., 2004). Conventional tillage can also adversely affect soil structure, when the process of aggregate formation is disturbed due to destruction of aggregates (Six et al., 2002). Soil aggregates are directly affected through physical disturbance of the macroaggregates and indirectly by alteration of biological and chemical factors (Gupta Choudhury et al., 2014, Li et al., 2019, Bronick and Lal, 2005).

Poor aggregate structure and stability can decrease water infiltration and reduce soil carbon and nutrients in macro and microaggregates. Higher soil aggregation can be achieved by decreasing tillage and increasing residue retention through conservation tillage. Gupta Choudhury et al. (2014) found that the applications of the organics in the form of residues combined with conventional or conservative tillage improved the percent of macroaggregates compared to microaggregates. A positive correlation was reported between aggregate size and soil organic carbon content, so the larger aggregate with higher soil organic carbon minimized the intensity of disintegration of aggregate exposed to water (Blevins et al., 1998).

Soil physical quality has been widely approached by bulk density, to evaluate various soil processes or to estimate soil carbon reserves (Vereecken et al., 2016). Generally, bulk density might be considered an important parameter that reflect soil structure, being an indicator of soil compaction related to total soil and pore space volume (Hernanz et al., 2000).

In addition to environmental services, soil organic carbon is a valuable indicator which maintain soil fertility, soil sustainability, crop yield, and contributes to mitigate climate warming and ensure food safety. Conservation agriculture has proved to be an excellent alternative to conventional agriculture in the long term of sustainable crop production and SOC sequestration. No-tillage/ reduced tillage decreases the carbon oxidation process and soil disturbance with the loss of soil organic carbon and nutrient availability (Kan et al., 2020, Modak et al., 2019). Crop residues behave as a barrier between soil and environment which may have a great role in soil erosion reduction and soil quality indicators (Jat et al., 2019). Maintained good physical, chemical and biological properties particularly those related to soil carbon sequestration are necessary for production sustainability (Martin et al., 2019).

The general objective of this study was the assessment of soil quality-based management practices and parameter identification that are sensitive to soil disturbance. The specific objectives were to investigate the impact of long-term tillage systems on soil aggregate stability, nutrient availability and soil carbon storage pools and dynamics. We hypothesized that the conservation tillage improves soil physical properties and organic carbon stocks.

Table 1
Soil physico-chemical properties (0–30 cm depth) at the beginning of the experiment (2009).

Initial Soil properties	Soil characteristics value
Sand (g.kg^{-1})	**372.6** ± 12.45
Silt (g.kg^{-1})	**263.2** ± 7.15
Clay (g.kg^{-1})	**364.2** ± 1.23
Bulk density (g cm^{-3})	**1.33** ± 0.02
Penetration resistance (MPa)	**0.5–2.6** ± 0.01
pH (1:2.5)	**6.68** ± 0.03
Organic carbon (%)	**1.08** ± 0.01
Total - N (%)	**0.12** ± 0.02
Available – P (mg Kg^{-1})	**13.3** ± 0.11
Available – K (mg Kg^{-1})	**199** ± 12.3
DTPA – extractable Zn (mg Kg^{-1})	**1.12** ± 0.01
DTPA – extractable Fe (mg Kg^{-1})	**24.2** ± 0.01
DTPA – extractable Mn (mg Kg^{-1})	**28.4** ± 0.05
DTPA – extractable Cu (mg Kg^{-1})	**1.89** ± 0.01
The data represents means ± SD	

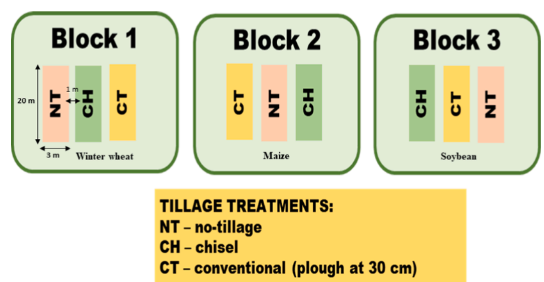

Fig. 1. Schematic overview of the experimental plot.

2. Materials and methods

2.1. Study site description

This study was part of a long field experiment conducted during 2009–2019, at the Research Farm of the Agricultural University Iasi - Romania (47°07′ N latitude, 27°30′ E longitude). The climate in the experimental area is a temperate-continental type; the mean values precipitation of the last 20 years at this site reaches 517.8 mm with an average air temperature of 9.4 °C. Significant deviations from the long-term average and temperature have been observed in the last 10 years. The experimental soil is clay-loam in texture and classified as Chernozem (according to WRB soil classification). The field had been subjected to monoculture maize cropping under conventional tillage management, before the tillage experiment was initiated. In autumn of 2009, before the start of the experiment, 15–20 soil samples were collected from 5 random position and then blended for a representative soil sample.

The main soil properties in the ploughed layer (0–20 cm) of the experimental site are given in Table 1.

Selected physical and chemical properties of the soil were determined using routine methods (total organic carbon was measured by Walkley and Black method, total nitrogen was determined by the Kjeldahl method while pH was determined in water, 1:2.5 w/v).

2.2. Tillage systems

The experiment was designed as a randomized block design, replicated three times (Fig. 1). Each plot covered an area of 60 m^2 with a rotation of soybean (*Glycine* max *L.)* - winter wheat (*Triticum aestivum L.)* – maize (*Zea mays L.)* with the current experiment in winter wheat. All plots were separated by a 1 m buffer zone. The experiment was performed with three tillage practices: no-tillage (NT), chisel (CH) and conventional tillage (CT) as main plot treatment.

For NT only the crop seed was harvested, and all biomass was evenly distributed across the plot to cover the surface. Maize and soybean were planted with a FABIMAG FG01 no-till planter every year between April 20 and May 1. Winter wheat was planted with the same no-till seeding machine set to small and large seeds, each time between September 20 and October 2. There were no other soil tillage practices used. For CT the above-ground biomass was partly removed, and moldboard plowing was conducted annually to a 30 cm depth followed by a disc harrow treatment. For CH treatment the tillage was performed to a 25 cm depth and was followed by a disc harrow treatment also. The biomass was left on soil surface to prevent water and wind erosion.

Except for the soil tillage and seeding, all other technology sequences were identical in all the variants. The nutrients were supplied mainly through common dose of urea (46% N), di-amonium phosphate (DAP: 18% N and 46% P) and NPK complex fertilizer (12:32:16% NPK). Appropriate herbicides were used to control weeds as needed.

2.3. Soil sampling

After ten (10) years of rotation, in spring of 2019, 180 soil samples were collected from the cultivated layer (0–30 cm) with a flat, square cornered spade, from winter wheat crop. The field moist soil samples were gently broken up along natural weak planes, while visible plant residues were removed manually with tweezers. For each treatment, 20 soil samples were collected using the S-sampling method and then mixed for a representative soil sample. The samples were air dried and passed through a 2 mm sieve to obtain the fraction used for each soil analysis and then stored at 4°C.

The processed air-dried soil sample collected from surface soil depth (0–30 cm) was analyzed for soil C-fractions, pH and available nutrients while for water stable aggregates were randomly selected in triplicates, from 0 to 10 cm depth, 10–20 cm and 20–30 cm depth layer. Undisturbed soil samples, for bulk density analysis were taken by stainless steel rings with 100 cm^3 volume, from ~10, ~20, ~30 cm depth, 2–3 days after wheat harvesting. For each plot, four soil cores were taken for each treatment and each depth. The rings were carefully retrieved from the soil to avoid disturbing the soil cores.

2.4. Soil analysis

2.4.1. Carbon fractions and C – Pools

The modified Walkley and Black method was used for soil oxidizable Organic Carbon-fractions analysis. The fractions of soil organic carbon were determined by wet oxidation using the method described by Chan et al., (2001). In brief, 5, 10 and 20 mL concentrated H_2SO_4 was added to 25 mL Erlenmeyer flask, resulting in three acid-aqueous solution with ratios of 0.5:1, 1:1, and 2:1; this corresponded to a solution with different normality of H_2SO_4 i.e. 12, 18 and 24 N, respectively (Nandan et al., 2019). Here, 20 mL H_2SO_4 represents the original wet oxidation method of Walkley and Black. 10 mL 1 N potassium dichromate ($K_2Cr_2O_7$) solution was used as oxidizer for 0.1 g soil and then the mixture was diluted with 100 mL of ultra pure water. Then $Cr_2O_7^{2-}$ excess was determined by titrating with 0.5 N ferrous ammonium sulfate [$Fe(NH_4)_2(SO_4)_2 6H_2O$]. Following, four distinct C – fractions of decreasing oxidizability ($Cfrac_1$, $Cfrac_2$, $Cfrac_3$ and $Cfrac_4$) were obtained:

Very – labile fraction ($Cfrac_1$): the part of organic C oxidized under 12 N H_2SO_4.
Labile fraction ($Cfrac_2$): organic C oxidized with 18 N H_2SO_4 – organic C oxidized with 12 N H_2SO_4.
Less – labile fraction ($Cfrac_3$): organic C oxidized with 24 N H_2SO_4 – organic C oxidized with 18 N H_2SO_4.
Non – labile/recalcitrant fraction ($Cfrac_4$): total SOC – organic C oxidized with 24 N H_2SO_4.

Further, the active C – pool was derived from the sum of very - labile fraction ($Cfrac_1$) and labile fraction ($Cfrac_2$), while the less – labile fraction ($Cfrac_3$) and non – labile fraction ($Cfrac_4$) together defined as passive C – pool.

For easy interpretation, the lability index (LI) was determined using very labile, labile, and less – labile fraction of total SOC, by giving the weight of 3, 2 and 1 to $Cfrac_1$ $Cfrac_2$ $Cfrac_3$, respectively (Blair et al., 1995; Hazra et al., 2018).

$$LI = (\text{very labile C/TOC})*3 + (\text{labile C/TOC})*2 + (\text{less labile C/TOC})*1$$

Then, the carbon pool index (CPI) was derived as follows,

$$CPI = \text{Sample TOC}(g\ kg^{-1})/\text{Reference TOC}\ (g\ kg^{-1})$$

Where, conventional tillage practice was taken as reference.

Finally, the carbon management index (CMI) was calculated using the following formula:

$$CMI = CPI*LI*100$$

Soil moisture content was obtained by drying a 10 g subsample of the soil at 105 °C for 24 h.

2.4.2. Analysis of soil wet aggregate stability

An Eijkelkamp wet sieving apparatus (08.13, Eijkelkamp Soil & Water, Giesbeek - The Netherlands) was used as standard instrument for defining wet aggregate stability (WAS). Briefly, 4.0 g of air-dried soil aggregates (with diameter between 1 and 2 mm) were submerged in water on a sieve with 0.25 mm mesh size for 3 min and 35 cycles min^{-1} frequency. The aggregate remaining on the sieves were submerged again in sodium hexametaphospate solution (2 g L^{-1}) for 15 min and 35 cycles min^{-1} to isolate the sand fractions. After drying, aggregate fractions (from water and hexametaphospate) were weighed to obtain the WSA (water stable aggregates) percentage. The initial and final weights of aggregates were corrected for the weight of coarse particles (Kemper and Rosenau, 1986).

For the initial treatment of the aggregates we used 9 modified pre-wetting or pre-treatment (storage) techniques with the goal of giving a precise, reproducible and reliable measure of aggregate resistance to breakdown during wet sieving (Table 2). Aggregate stability is

Table 2
Summary of the applied methodologies for evaluating WSA.

Variant	Aggregates Drying Method	Treatments before wet sieving	Additional treatments
V_1	Soil dried at 85 °C, in oven	Slow wetting - Water Vapor pre-wetting	–
V_2	Soil dried 15 days at room temperature	Slow wetting - Water Vapor pre-wetting	–
V_3	Soil dried at room temperature and stored 7 days at 5 °C in refrigerator	Slow wetting - Water Vapor pre-wetting	–
V_4	Soil dried 15 days at room temperature	Slow wetting - Water Vapor pre-wetting	Sieved in tap water
V_5	Soil dried 15 days at room temperature	Direct immersion of soil aggregates into water	–
V_6	Soil dried at room temperature and stored 7 days at −18 °C	Fast wetting - Water spray	–
V_7	Soil dried 6 weeks at room temperature	Direct immersion of soil aggregates into water	–
V_8	Soil dried 6 weeks at room temperature	Slow wetting - Water Vapor pre-wetting	–
V_9	Soil dried 15 days at room temperature	Fast wetting - Water spray	Ultrasonic vibration

Table 3
Total organic carbon (TOC), soil carbon fractions and carbon indices by different tillage systems.

Parameter	Depth (cm)	Tillage system					
		No tillage		Chisel		Conventional tillage	
C_{frac1} g kg^{-1}	0–10	±0.01	13.0a	±0.03	12.9a	±0.08	9.7b
	10–20	±0.03	9.7a	±0.01	10.0a	±0.02	10.1a
	20–30	±0.02	8.7b	±0.11	8.2b	±0.03	11.3a
C_{frac2} g kg^{-1}	0–10	±0.01	0.4b	±0.01	0.1b	±0.03	1.5a
	10–20	±0.01	1.1a	±0.01	0.3a	±0.01	0.5a
	20–30	±0.11	2.8a	±0.01	0.4b	±0.01	0.3b
C_{frac3} g kg^{-1}	0–10	±0.17	8.0a	±0.05	7.4a	±0.07	7.8a
	10–20	±0.01	7.5a	±0.05	7.5a	±0.08	6.9a
	20–30	±0.01	6.1b	±0.01	7.6a	±0.03	6.4ab
C_{frac4} g kg^{-1}	0–10	±0.02	15.6a	±0.17	14.8ab	±0.11	13.8b
	10–20	±0.08	13.3a	±0.11	13.1a	±0.13	12.7a
	20–30	±0.04	11.0b	±0.08	12.2a	±0.04	11.2b
TOC g kg^{-1}	0–10	±0.01	37.0a	±0.25	35.1ab	±0.23	32.8b
	10–20	±0.01	31.7a	±0.01	31.4a	±0.21	30.2a
	20–30	±0.07	28.7a	±0.13	28.5a	±0.16	29.1a
LI	0–10	±0.05	13.0a	±0.02	13.2a	±0.11	12.2b
	10–20	±0.01	12.3a	±0.07	12.5a	±0.14	12.7a
	20–30	±0.01	11.2a	±0.08	11.6a	±0.04	12.0a
CMI	0–10	±0.05	48.0a	±0.09	46.3b	±0.01	100
	10–20	±0.04	39.0a	±0.04	39.3a	±0.01	100
	20–30	±0.02	32.1a	±0.07	32.9a	±0.01	100

$Cfrac_1$, very-labile C fraction; $Cfrac_2$, labile C fraction; $Cfrac_3$ less-labile C fraction; $Cfrac_4$ non-labile C fraction; LI, lability index; CMI, carbon management index. The data represents means ± SD. Different lower case letters in the same layer indicate significant differences between different tillage systems at the 0.05 probability level.

commonly determined by wet sieving based on early work of Kemper and Koch (1966) and Kemper and Rosenau (1986).

Soil bulk density was determined on an oven-dry basis by the core method (Blake and Hartge, 1986).

2.4.3. Soil chemical analysis

The soil samples were analyzed for total-N (Kjeldahl method), available K (extracted with neutral 1 N NH_4OAc) and available P (Olsen extractant) following the standard methods according to Soil Studies Development Methodology delivered by the National Institute of Research and Development in Soil Science, Agrochemistry and Environment – ICPA, Bucharest (INCD – APM – ICPA et al., 1987). The DTPA extractable -Zn, Cu, Fe, Mn were determined using an Atomic Absorption Spectrometer (ContrAA 700, Analytik Jena, Germany) (Lindsay and Norvell, 1978). Soil pH was determined in water using an electronic pH meter with a grass electrode (WTW pH 3320, Germany).

2.5. Statistical analysis

The analysis of variance (ANOVA), appropriate for randomized complete block design, was the procedure used to analyze the obtained data. Significant differences between treatments were calculated by Duncan's test. Statistical analyses were performed using SPSS 22.0 for Windows (SPSS Inc., Chicago, 2007).

3. Results and discussion

3.1. Carbon fraction and C-stabilization

Tillage and cropping system significantly influenced TOC content and C-fractions, C-pools and C-management indices in the 0–10 cm depth soil layer (Table 3 and Fig. 2). The concentration of TOC ($p < 0.05$) in the surface soil 0–10 cm was maximum (37.0 g kg^{-1}) in no-tillage variant with similar values at the sub-surface depth 10–20 cm (31.4–31.6 g kg^{-1}) in both the conservative treatments. The increase of TOC under reduced tillage was more in surface soil 0–10 cm than of 10–20 cm and 20–30 cm soil depth, due to surface retention of crop residues.

Notably, in this study, the $Cfrac_4$ (42% of TOC) was the dominant C-fraction, followed by $Cfrac_2$ (29–36%), $Cfrac_3$ (20–23%) and $Cfrac_1$ (0.2–4.6%). Based on a long-term study, Hazra et al. (2018) reported that the higher labile C-fraction is attributed to crop residue which is easily mineralizable and releases plant nutrients that favors higher microbial activity. Plots under no till and chisel treatment had 7–13%, 34–35% and 9–15% higher ($p < 0.05$) $Cfrac_4$, $Cfrac_1$ and TOC, respectively compared to that of conventional ones. Under chisel and no tillage treatment the non-labile fraction $Cfrac_4$, in 0–10 cm depth was higher when compared with conventional tillage and the scale of improvement was higher in no till variant over chisel. However, tillage system had no effect on $Cfrac_4$ in 10–20 cm soil depth, while in 20–30 cm depth the improvement was higher at conservative tillage. A significant increase in less-labile $Cfrac_3$ was noticed in no till over chisel, but not in 10–20 cm soil depth. The possible reason is the slow mineralization rate of C substrates resulted in cumulative accumulation of resistant and less oxidizable C compounds. Majumder et al. (2008) and Benbi et al. (2012) reported that $Cfrac_3$ and $Cfrac_4$ together constituted the major share of TOC in rice soil.

The addition of easily decomposable lignin and cellulose through crop residue, induce higher labile C- fractions $Cfrac_1$, $Cfrac_2$ and $Cfrac_3$ which facilitated C-build-up (Hazra et al., 2018). In support as these findings, Nandan et al. (2019) suggest that elimination of tillage could increase recalcitrant C-pool as the higher content of less-labile C-fraction ($Cfrac_3$) and non-labile C-fraction ($Cfrac_4$) was observed in zero till crop establishment treatments.

Crop residue retention, minimum mechanical disturbance of soil and restricted soil carbon oxidation directly influenced C-pools in surface soil 0–10 cm (Fig. 2). This way, conservation tillage associated with higher C-input may have a strong positive impact on soil health and particularly on TOC level (Luo et al., 2010, Parihar et al., 2018) (Table 3).

The no tillage system had a higher passive carbon pool and carbon management index than with the conventional system. However, no tillage and chisel system had the same values of active carbon pool but higher than of the conventional one. Passive and active C -pools are recognized as essential markers of soil quality which influence plant nutrient supply and crop productivity (Benbi et al., 2012). Due to anaerobic decomposition of C-input, the less labile $Cfrac_3$ is intensely settle, which store afterwards higher passive C-pool. Therefore, higher share of passive C-pool is vital for longer persistence of soil organic C. Based on the research of Singh et al. (2005) slow mineralization rate of soil carbon resulted in progressive accumulation of resistant and less oxidizable C compounds like lignins. Our results are in accordance with the findings of Majumder et al. (2008) Nandan et al. (2018) and Benbi et al. (2012) who found that non-labile and less-labile C fractions represent the substantial portion of TOC in rice soil of hot humid tropics. In this study, conservation tillage treatments (no tillage and chisel) increased the C stabilization in passive pool ($Cfrac_3$ and $Cfrac_4$) which indicates that retention of crop residues with conservation tillage practice could increase passive C-pool. The higher content of less oxidizable polysaccharide and lignin in straw residue is effective for improving recalcitrant C-pool that persists longer in soil. Our results suggest that conservative tillage could maintain higher passive C-pool over conventional tillage and thus upgrade the quality of organic carbon, which persist longer in the soil.

The state and rate of soil organic carbon changes is established as a sensitive measurement based on carbon management index. The values of CMI under conservative treatments increased in 0–10 cm soil depth, while in 10–20 cm and 20–30 cm depth remained relatively stable (Table 2). Significant variation ($p < 0.05$) of CMI with depth might be the results of surface placement of crop residues and lack of soil disturbance that kept residues isolated from the lower depth (Gupta Choudhury et al., 2014). Based on a study, Blair et al. (2006) reported

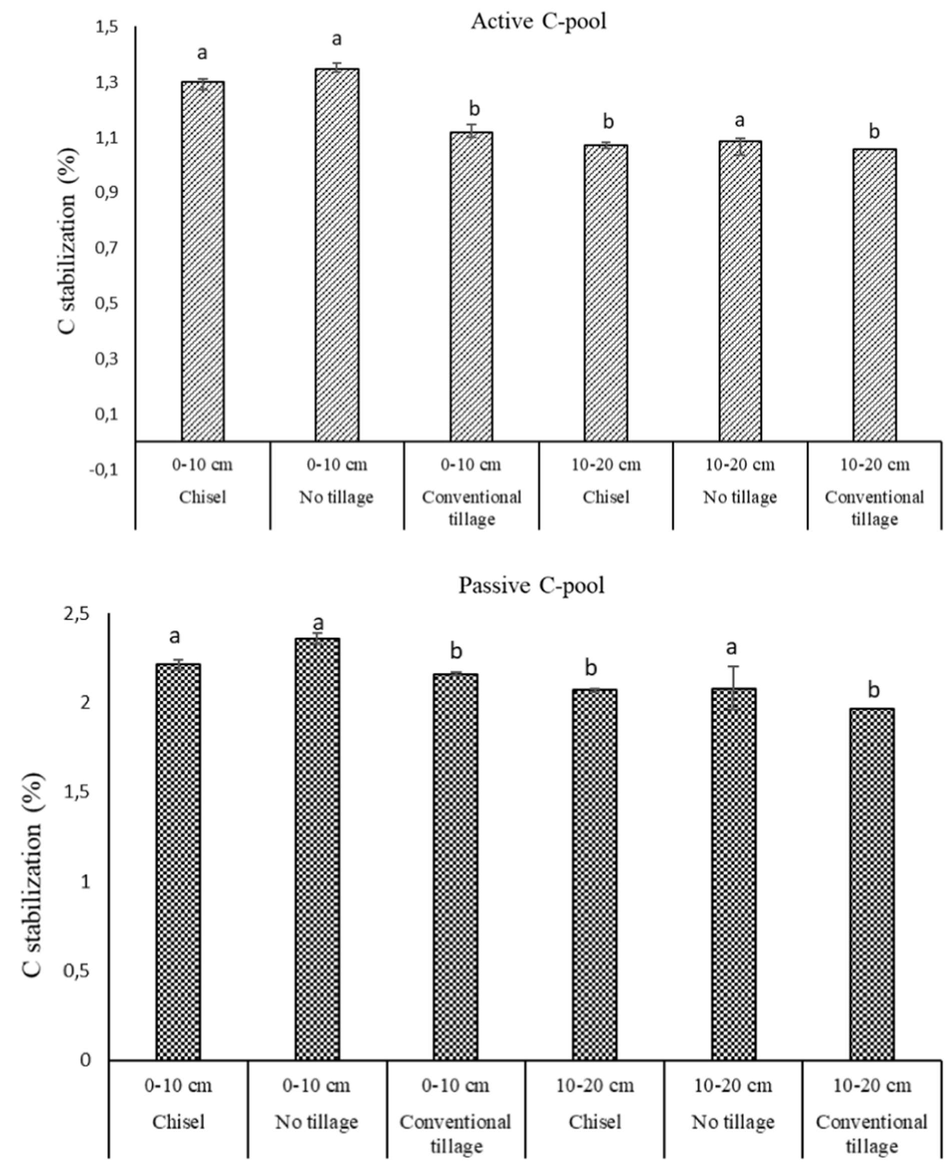

Fig. 2. Effect of tillage systems on active and passive C-pools. Vertical error bars represent the corresponding standard error of mean values. Different lower case letters in the same layer indicate significant differences between different tillage systems at the 0.05 probability level.

Table 4
Effect of crop rotation and tillage on soil chemical properties and available nutrients after 10 years crop rotation.

Parameter	Depth (cm)	Tillage system					
		No tillage		Chisel		Conventional tillage	
pH	0–10	±0.02	6.22b	±0.01	6.32b	±0.02	6.44a
	10–20	±0.01	6.24b	±0.02	6.30ab	±0.01	6.40a
	20–30	±0.01	6.37b	±0.02	6.35b	±0.02	6.42a
N_t (%)	0–10	±0.03	0.18a	±0.01	0.17ab	±0.01	0.15b
	10–20	±0.01	0.17a	±0.02	0.16a	±0.01	0.14b
	20–30	±0.03	0.15a	±0.01	0.15a	±0.05	0.15a
Available P (mg kg^{-1})	0–10	±0.04	73.4a	±0.05	59.4b	±0.02	53.1c
	10–20	±0.04	45.2a	±0.01	44.3a	±0.03	49.4a
	20–30	±0.06	38.4a	±0.03	36.9a	±0.01	37.3a
Available K (mg kg^{-1})	0–10	±0.04	320a	±0.02	265b	±0.02	228c
	10–20	±0.15	240a	±0.01	240a	±0.02	231a
	20–30	±0.07	210ab	±0.05	223a	±0.03	190b
Extractable Zn (mg kg^{-1})	0–10	±0.01	1.25a	±0.01	1.23b	±0.03	1.22b
	10–20	±0.01	1.15a	±0.01	1.13a	±0.01	1.13a
	20–30	±0.03	1.10a	±0.02	1.07a	±0.01	1.05a

The data represents means ± SD. Different lower case letters in the same layer indicate significant differences between different tillage systems at the 0.05 probability level.

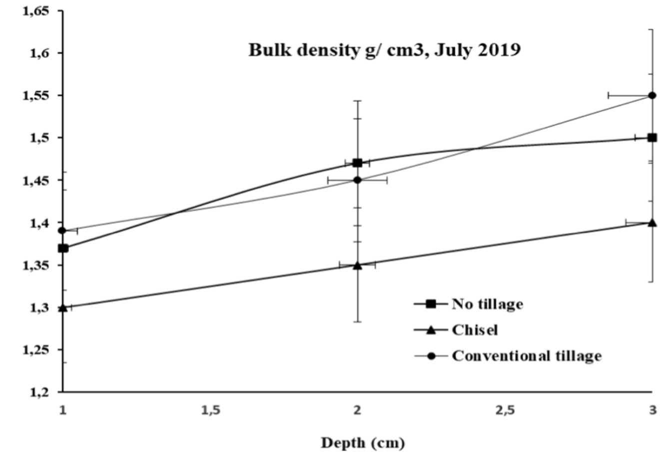

Fig. 3. Comparison of depth-incremental bulk densities for the no-till, chisel and conventional tillage. Vertical error bars represent the corresponding standard error of mean values.

that organic inputs improve CMI compared to mineral fertilization.

A durable integrated effect of conservation tillage (no tillage and chisel) with crop residue retention over conventional tillage was observed on soil quality parameters. In the present study, intensive tillage practices accelerate soil organic matter mineralization and faster soil organic carbon decomposition (Nandan et al., 2018, Elder and Lal, 2008). Our results were consistent with Gao et al. (2019); they found that higher soil organic carbon in the 0–20 cm depth under conservation tillage was attributed to the absence of disturbance, which promotes root development and increase crop residue accumulation at the soil surface.

3.2. Soil chemical properties

The response of soil available N, P, K and extractable Zn, Cu, Fe to tillage and cropping system varied with soil depth. After 10 years of different tillage system an increase ($p < 0.05$) of available N, P and K in the 0–10 cm depth was obtained, with the highest values in no-tillage system (Table 4). Similar values (45–49 mg kg^{-1}) of available P in the 10–20 cm depth were obtained in all the tillage systems. The increased soil available nutrients in no tillage could be attributed to the supplemental nutrient input through residue crop left on soil surface, in addition to the recommended mineral fertilizers dose (Zhang et al., 2013, Nandan et al., 2019). Indirectly, soil organic carbon may promote microbial activity, which influences the availability of P in soil. Competitive sorption between humic and fulvic acids and low molecular weight aliphatic acids and P, for soil sorption sites, resulted in increased concentration of P in soil solution (Guppy et al., 2005). Likewise, higher K source from lignin and polysaccharides cereal crop residues, suggest increased K content in soil.

On soil extractable - Zn, Cu, Fe, Mn, no specific trend was observed.

The soil N_t content varied significantly ($p < 0.05$) among different tillage systems and crop rotation treatments. In surface 0–10 cm soil layer, higher quantities of N_t were obtained in both the conservative treatments (Table 4). The N_t content varied from 0.162% to 0.173% in conservative system to 0.141–0.149% in conventional tillage. As reported by numerous researcher crop residue present a considerable impact in enhancing soil quality by improving soil organic and N content, aggregate and Carbon stability, as they are the direct sources of N and C for microorganisms (Tonitto et al., 2006, Yadav et al., 2017). Addition of crop residues on soil surface, promotes for short periods immobilization of N, while for long terms, increase mineralization and nutrient availability (Yadvinder-Singh et al., 2004). The potential explanation is the reduced soil disturbance in conservative tillage, which ensure macronutrients accumulation on surface soil. In general, the values of available N, P and K decreased with depth within the soil profiles as the soil become compacted.

No tillage practices significantly decreased soil pH by 3.2% and 1.8% as compared to conventional tillage. As reported by many previous studies (Limousin and Tessier, 2007, Li et al., 2019) an increase in surface soil acidity with no-tillage and chisel compared with conventional was obtained. This may be due to the higher initial organic matter content or soil organic matter decomposition leading to greater hydrogen ion accumulation over time. The increased root exudation and nitrification and the reduced surface soil disturbance, enhance soil acidification of surface soil (Sithole et al., 2016, Malik et al., 2018). In contrast, conventional tillage directly distributes fertilizers uniformly throughout plowed areas, leading to (pH = 6.44) less acidified surface soil layer (Blevins et al., 1984).

Table 5
Means for bulk density under different tillage treatments in all depth.

	Layer (cm)	Tillage system					
		No tillage		Chisel		Conventional tillage	
Bulk density ($g\ cm^{-3}$)	**0–10**	±0.01	1.37b	±0.01	1.30c	±0.01	1.39a
	10–20	±0.02	1.47a	±0.02	1.35b	±0.05	1.45a
	20–30	±0.05	1.50a	±0.02	1.40b	±0.03	1.55a

The data represents means ± SD. Different lower case letters in the same layer indicate significant differences between different tillage systems at the 0.05 probability level.

3.3. Bulk density

Conservative tillage practices predict a soil structure improvement due to the reduced soil disturbance and residue retention. (Li et al., 2019). In general, soil bulk density can reflect soil compaction with different degrees based on tillage practices types. Fig. 3 shows the effect of different tillage systems on bulk densities values. Among all tillage treatments the values of bulk density increased with depth within the soil profiles as the soil gradually turn to be settle under the influence of rainfall, particle resettlement and cycles of wetting and drying (Blanco-Canqui and Ruis, 2018) (Table 5).

After ten years of rotation, the traffic treatments affected significantly the soil bulk density in the 0–10 cm layer with mean bulk densities of 1.30, 1.37 and 1.39 g cm^{-3}, for chisel, no-tillage, and conventional tillage, respectively. These results are in accordance with results of Gao et al. (2019) that reported significant higher bulk density value, in the 0–10 cm layer in conventional than that of no tillage.

The lowest bulk density value (1.30 g cm^{-3}) was registered on chisel variant, that conservative tillage practices which intensify the soil loosening. Analyzing the 10–20 cm layers we observed that the lowest values 1.35 g.cm^{-3} have been provided also by chisel treatment (Table 5). Blanco-Canqui and Ruis (2018), reported a decrease of soil bulk density values after a long term no tillage practice due to residue retention. Bai et al. (2009) found higher bulk density values in conventional compared with no-tillage in the 10–20 cm depth, with no statistically significant differences between these two treatments. However, a recent review paper synthesizing results from 62 studies indicated that no tillage can either increase or decrease soil bulk density, depending on the length under no tillage management (Blanco-Canqui and Ruis, 2018).

Significantly higher ($p < 0.05$) bulk densities for the conventional treatment were found at 30 cm depth indicating a compacted layer. However, the higher bulk density value (1.55 g cm^{-3}) obtained in conventional treatment, was below the critical values that could compromise or limit plant/crop growth.

Table 6
Effect of tillage system on water stable aggregates after ten years of crop rotation.

Treatment	Depth (cm)	V_1 %	V_2 %	V_3 %	V_4 %	V_5 %	V_6 %	V_7 %	V_8 %	V_9 %
No-tillage	0–10	74.50	94.17	92.33	89.83	50.17	58.00	70.37	93.07	42.00
	10–20	85.00	94.83	94.50	88.50	66.67	74.33	81.13	95.63	52.17
	20–30	91.67	92.33	96.00	93.00	81.67	76.67	83.17	92.72	51.83
	Mean	**83.72a**	**93.78a**	**94.28a**	**90.44a**	**66.17b**	**69.67a**	**78.22a**	**93.81a**	**48.67a**
Chisel	0–10	81.25	86.67	94.00	84.25	66.83	57.67	77.98	94.37	46.17
	10–20	95.50	93.33	96.83	92.50	84.67	69.50	80.38	94.78	57.50
	20–30	95.17	91.67	92.17	90.50	82.00	72.17	78.17	93.93	49.33
	Mean	**90.64a**	**90.56a**	**94.33a**	**89.08a**	**77.83a**	**66.44a**	**78.84a**	**94.36a**	**51.00a**
Conventional tillage	0–10	94.00	92.17	90.83	85.67	68.83	75.75	73.65	91.10	42.83
	10–20	85.67	90.33	88.17	86.00	63.83	70.50	66.05	91.85	49.17
	20–30	93.00	92.33	93.42	92.17	64.83	65.50	68.43	86.25	59.33
	Mean	**90.89a**	**91.61a**	**90.81b**	**87.94a**	**65.83b**	**70.58a**	**69.38b**	**89.73b**	**50.44a**

$V_{1,}$ soil dried at 85 °C, in oven; $V_{2,}$ soil dried 15 days at room temperature; $V_{3,}$ soil dried at room temperature and stored 7 days at 5 °C in refrigerator; $V_{4,}$ soil dried 15 days at room temperature; $V_{5,}$ soil dried 15 days at room temperature; $V_{6,}$ soil dried at room temperature and stored 7 days at −18 °C; $V_{7,}$ soil dried 6 weeks at room temperature; $V_{8,}$ soil dried 6 weeks at room temperature. $V_{9,}$ soil dried 15 days at room temperature. Means within the same column followed by the same letter are not significantly different ($P < 0.05$).

3.4. Soil aggregate stability

The resulting water stable aggregates within soil tillage system, depth and methods of pre-wetting and storage are shown in Table 6. The stability of soil aggregates was greater for all procedures of conservative tillage (48.67–94.36%) than conventional tillage (50.44–90.81%). The methods (V_3, V_7, V_8) of slow wetting and storage at room temperature increased the percent of water stable aggregate in no tillage compared to conventional practice. The increased aggregate stability is a consequence of residue retention that enhance organic matter accumulation and facilitates soil aggregation through microbial activity (Schmidt et al., 2018, Tagar et al., 2017).

The ability of nine procedures to discern differences in aggregate stability was found in V_3, V_7 and V_8. There were differences also in V_5 but the direct immersion in water causes slaking of soil aggregates, results from the compression of air trapped inside aggregates during rapid wetting, as occurs when dry aggregates are rapidly immersed in a liquid. Pre-wetting aggregates to field capacity increased their stability relative to that of air-dried aggregates. The results obtained in the other 5 Aggregates Drying Methods and Treatments before wet sieving (Table 2) did not show any significant differences, as it can be seen in Table 6. In conclusion, no single method of measuring aggregate stability is suitable for all soils and conditions. In order to point differences between treatments and plots, researchers should consider to use varied methods and slow wetting pretreatments with adjustment of test sequence duration in order to reach 50–70% aggregate stability.

4. Conclusions

The results obtained maintain the assumption that conservation tillage can improve soil physico-chemical properties, especially by reducing bulk density and increasing stability of aggregates and soil total organic carbon. The addition of crop residues in chisel and no-tillage treatments, increased non labile C fraction C*frac4* in 0–20 cm depth. The effect of tillage practices on total organic carbon and soil available nutrients was notable after ten-year rotation. The effect was intense for total N, followed by available -P and K. No tillage and chisel increased the stability of aggregate due to the reduced soil disturbance and residue retention on soil surface as compared to conventional tillage. The highest values of aggregate stability occurred for soil dried at room temperature and slow wetting before wet sieving. Significantly higher total organic carbon stocks in no tillage could enhance the soil aggregate stability. On the contrary, conventional tillage practice increased soil bulk density, with values that persist below the critical values that may compromise the crop growth.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Authors acknowledge the logistic support from Competitiveness Operational Programme (COP) 2014 – 2020, under the project number 4/AXA1/1.2.3. G/05.06.2018, SMIS2014+ code 119611, with the title "*Establishing and implementing knowledge transfer partnerships between the Institute of Research for Agriculture and Environment - IAȘI and agricultural economic environment*".

References

Amezketa, E., 1999. Soil aggregate stability: a review. J. Sustain. Agric. 14, 83–151.

Angers, D., Eriksen-Hamel, N., 2008. Full inversion tillage and organic carbon distribution in soil profiles: a meta-analysis. Soil Sci. Soc. Am. J. 72, 1370–1374. https://doi.org/10.2136/sssaj2007.0342.

Bai, Y., He, J., Li, H., Wang, Q., Chen, H., Kuhn, N.J., Hikel, H., Chen, F., Gong, Y., 2009. Soil structure and crop performance after 10 years of controlled traffic and traditional tillage cropping in the dryland Loess Plateau in China. Soil Sci. 174, 113–119. http://edoc.unibas.ch/dok/A6083563.

Benbi, D.K., Toor, A.S., Kumar, S., 2012. Management of organic amendments in rice-wheat cropping system determines the pool where carbon is sequestered. Plant Soil 360, 145–162. https://doi.org%2F10.1007%2Fs11104-012-1226-3.

Blair, G.J., Lefroy, R.D.B., Lisle, L., 1995. Soil carbon fractions based on their degree of oxidation and development of a carbon management index for agricultural systems. Aust. J. Agri. Res. 46, 1459–1466. https://doi.org/10.1071/AR9951459.

Blair, N., Faulkner, R.D., Till, A.R., Korschens, M., Schulz, E., 2006. Long-term management impacts on soil C, N and physical fertility-part II: Bad Lauchstadt static and extreme Fym experiments. Soil Tillage Res. 91, 39–47. https://doi.org/10.1016/j.still.2005.11.001.

Blake, G.R., Hartge. K.H., 1986. Bulk density In Klute A. Am. Soc. Agron. 363–375.

Blanco-Canqui, H., Ruis, S.J., 2018. No-tillage and soil physical environment. Geoderma 326, 164–200. https://doi.org/10.1016/j.geoderma.2018.03.011.

Blevins, R.L., Smith, M.S., Thomas, G.W., 1984. Changes in soil properties under no-tillage. In: Phillips, R.E., Phillips, s.H., (Eds), No Tillage Agriculture: Principles and Practices. Springer US, Boston, MA, 190-230. https://doi.org/10.1007/978-1-4684-1467-7_9.

Blevins, R.L., Lal, R., Doran, J.W., Langdale, G.W., Frye, W.W., 1998. Conservation tillage for erosion control and soil quality. Adv. Soil Water Conserv. 51–68.

Borges, J.A.R., Piresa, L.F., Cássaroa, F.A.M., Waldir, L.R., Heckc, R.J., Rosad, J.A., Wolfe, F.G., 2018. X-ray microtomography analysis of representative elementary volume (REV) of soil morphological and geometrical properties. Soil Tillage Res. 182, 112–122. https://doi.org/10.1016/j.still.2018.05.004.

Bronick, C.J., Lal, R., 2005. Soil structure and management: a review. Geoderma 124, 3–22.

Chan, K.Y., Bowman, A., Oates, A., 2001. Oxidizable organic carbon fractions and soil quality changes in oxicpaleustalf under different pasture leys. Soil Sci. 166, 61–67.

Elder, J.W., Lal, R., 2008. Tillage effects on gaseous emissions from an intensively farmed organic soil in north Central Ohio. Soil Tillage Res. 98, 45–55. https://doi.org/10.1016/j.still.2007.12.002.

Gao, L., Wang, B., Li, S., Wu, H., Wu, X., Liang, G., Gong, D., Zhang, X., Cai, D., Degre, A., 2019. Soil wet aggregate distribution and pore size distribution under different tillage systems after 16 years in the Loess plateau of China. Catena 173, 38–47. https://doi.org/10.1016/j.catena.2018.09.043.

Guppy, C.N., Menzies, N.W., Moody, P.W., Blamey, F.P., 2005. Competitive sorption reaction between phosphorous and organic matter in soil: a review. Soil Res. 43 (2), 189–202. https://doi.org/10.1071/SR04049.

Gupta Choudhury, S., Srivastava, S., Singh, R., Chaudhari, S.K., Sharma, D.K., Singh, S. K., Sarkar, D., 2014. Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice-wheat cropping system under reclaimed sodic soil. Soil Till. Res. 136, 76–83.

Hazra, K.K., Ghosh, P.K., Venkatesh, M.S., Nath, C.P., Kumar, N., Singh, M., Singh, J., Nadarajan, N., 2018. Improving soil organic carbon pools through inclusion of summer mungbean in cereal-cereal cropping system in Indo-Gangeticplain. Arch Agron. Soil. Sci. 64, 1690-1704. https://1080/03650340.2018.1451638.

Hellner, Q., Koestel, J., Ulén, B., Larsbo, M., 2018. Effects of tillage and liming on macropore networks derived from X-ray tomography images of a silty clay soil. Soil Use Manage. 34, 197–205. https://doi.org/10.1111/sum.12418.

Hernanz, J.L., Peixoto, H., Cerisola, C., Sánchez-Girón, V., 2000. An empirical model to predict soil bulk density profiles in field conditions using penetration resistance, moisture content and soil depth. J. Terramechanics 37, 167–184. https://doi.org/10.1016/S0022-4898(99)00020-8.

INCDPAPM-ICPA, Florea, N., Balaceanu, V., Rauta, C., Canarache, A., (Eds.), 1987. Soil Studies Development Methodology (SSDM). Ins. Cercet. Pedologie Agrochimie, Min. Agr., Metode Rapoarte Indrumari, Bucuresti.

Jat, S.L., Parihara, C.M., Singha, A.K., Nayak, H.S., Meena, B.R., Kumara, B., Pariharc, M. D., Jat, M.L., 2019. Differential response from nitrogen sources with and without residue management under conservation agriculture on crop yields, water-use and economics in maize-based rotations. Field Crop Res. 236, 96–110. https://doi.org/10.1016/j.fcr.2019.03.017.

Kan, Z.R., Ma, S.T., Liu, Q.Y., Liu, B.Y., Virk, A.L., Qi, J.Y., Zhao, X., Lal, R., Zhang, H.L., 2020. Carbon sequestration and mineralization in soil aggregates under long-term conservation tillage in the North China Plain. Catena 188, 104428.

Kemper, W.D., Rosenau, R.C., 1986. Aggregate stability and size distribution. Soc. Agron./Soil Sci. Soc. Am. 9, 425–442.

Kemper, W.D., Koch, E.J.,1966. Aggregate Stability of Soils from the Western Portions of the United States and Canada, Tech. B. 1355, 52.

Lampurlanes, J., Plaza-Bonilla, D., Alvaro -Fuentes, J., Cantero- Martinez, C., 2016. Long-term analysis of soil water conservation and crop yield under different tillage systems in Mediterranean rainfed conditions. Field Crop Res. 189, 59-67. https://doi.org/10.1016/j.fcr.2016.02.010.

Lehmann, A., Zheng, W., Rillig, M.C., 2017. Soil biota contributions to soil aggregation. Nat. Ecol. Evol. 12, 1828. https://doi.org/10.1038/s41559-017-0344-y.

Li, Y., Chang, S.X., Tian, L., Zhang, Q., 2018. Conservation agriculture practice increase soil microbial biomass carbon and nitrogen in agricultural soils: a global meta-analysis. Soil Biol. Biochem. 121, 50–58. https://doi.org/10.1016/j.soilbio.2018.02.024.

Li, Y., Li, Z., Cui, S., Jagadamma, S., Zhang, Q., 2019. Residue retention and minimum tillage improve physical environment of the soil in croplands: A global meta -analysis. Soil Tillage Res. 194, 104292 https://doi.org/10.1016/j.still.2019.06.009.

Limousin, G., Tessier, D., 2007. Effects of no-tillage on chemical gradients and topsoil acidification. Soil Tillage Res. 92, 167–174. https://doi.org/10.1016/j.still.2006.02.003.

Lindsay, W.L., Norvell, W.A., 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. Am J. 42, 421–428. https://doi.org/10.2136/sssaj1978.03615995004200030009x.

Luo, Z., Wang, E., Sun, O., 2010. Can no-tillage stimulate carbon sequestration in agricultural soils? Ameta-analysis of paired experiments. Agri. Eco. Environ. 139, 224–231. https://doi.org/10.1016/j.agee.2010.08.006.

Majumder, B., Mandal, B., Bandyopadhyay, P.K., Gangopadhyay, A., Mani, P.P., Kundu, A.L., Majumder, D., 2008. Organic amendments influence soil organic carbon pools and crop productivity in 19 years old rice-wheat agroecosystems. Soil Sci. Soc. Am. J. 72, 775–785. https://doi.org/10.2136/sssaj2006.0378.

Malik, A.A., Puissant, J., Buckeridge, K.M., Goodall, T., Jehmlich, N., Chowdhury, S., Gweon, H.S., Peyton, J.M., Mason, K.E., van Agtmaal, M., Blaud, A., Clark, I.M., Whitaker, J., Pywell, R.F., Ostle, N., Gleixner, G., Griffiths, R.I., 2018. Land use driven change in soil pH affects microbial carbon cycling processes. Nat. Commun. 9, 3591.

Martin, J.A.R., Fuentes, J.A., Gabriel, J.L., Gutierrez, C., Nanos, N., Escuer, M., Ramos-Miras, J.J., Martin-Lammerding, C.G.D., Boluda, R., 2019. Soil organic stock on the Majorca Island: Temporal change in agricultural soil over the last 10 years. Catena 181, 104087. https://doi.org/10.1016/j.catena.2019.104087.

Modak, K., Ghosh, A., Bhattacharyya, R., Biswas, D.R., Das, T.K., Das, S., Singh, G., 2019. Response of oxidative stability of aggregate-associated soil carbon and deep soil carbon sequestration to zero tillage in subtropical India. Soil Till. Res. 195, 104370.

Nandan, R., Singh, S.S., Kumar, V., Singh, V., Hazra, K.K., Nath, C.P., Malik, R.K., Poonia, S.P., Solanki, C.H., 2018. Crop establishment with conservation tillage and crop residue retention in rice-based cropping system of eastern India: yield advantage and economic benefit. Paddy Water Environ. 16 (3), 477–492. https://doi.org/10.1007/s10333-018-0641-3.

Nandan, R., Singh, V., Singh, S.S., Kumar, V., Hazra, K.K., Nath, C.P., Poonia, S., Malik, R.K., Bhattacharyya, R., Andrew Mcdonald, A., 2019. Impact of conservation tillage in rice -based cropping systems on soil aggregation, carbon pools and nutrients. Geoderma 340, 104–114. https://doi.org/10.1016/j.geoderma.2019.01.001.

Pagliai, M., Vignozzi, N., Pellegrini, S., 2004. Soil structure and the effect of management practices. Soil Till. Res 79, 131–143. https://doi.org/10.1016/j.still.2004.07.002.

Parihar, C.M., Parihar, M.D., Tek, B., Sapkota, R.K., Nanwal, A.K., Singh, S.L., Jat, H.S., Nayak, D.M., Mahala, L.K., Singh, S.K., Kakraliya, Clare Stirlingn M., Jat, M., 2018 Long-term impact of conservation agriculture and diversified maize rotation on carbon pools and stocks, mineral nitrogen fractions and nitrous oxide fluxes in inceptisol of India. Sci. Total Environ. 640-641 1382-1392. https://doi.org/10.1016/j.scitotenv.2018.05.405.

Pittelkow, C.M., Liang, X., Linquist, B.A., van Groenigen, K.J., Lee, J., Lundy, M.E., van gestel, N., Six, J., Venterea, R.T., van Kessel C., 2015. Productivity limits and potentials of the principles of conservation agriculture. Nature 517, 365–368. https://doi:10.1038/nature13809.

Raus, L., Jităreanu, G., Ailincăi, C., Pârvan, L., Ţopa, D., 2016. Impact of different soil tillage systems and organo-mineral fertilization on physical properties of the soil and on crops yield in pedoclimatical conditions of Moldavian Plateau. Romanian Agric. Res. 33.

Schmidt, E.S., Villamil, M.B., Amiotti, N.M., 2018. Soil quality under conservation practices on farm operations of the southern semiarid pampas region of Argentina. Soil Tillage Res. 176, 85–94. https://doi.org/10.1016/j.still.2017.11.001.

Singh, Y., Singh, B., Timsina, J., 2005. Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping system in the tropics. Adv. Agron. 85, 269–407. https://doi.org/10.1016/S0065-2113(04)85006-5.

Six, J., Feller, C., Denef, K., Ogle, S.M., Moraes, J.C.S.A., Albrecht, A., 2002. Soil organic matter, biota and aggregation in temperate and tropical soils – effects of no-tillage. Agronomie 22, 755–775. https://doi.org%2F10.1051%2Fagro%3A2002043.

Sithole, N.J., Magwaza, L.S., Mafongoya, P.L., 2016. Conservation Agriculture and its impact on soil quality and maize yield: A South African perspective. Soil Tillage Res. 162, 55–67. https://doi.org/10.1016/j.still.2016.04.014.

Tagar, A.A., Gujjar, M.A., Adamowski, J., Leghari, N., Soomro, A., 2017. Assessment of implement efficiency and soil structure under different conventional tillage implements and soil moisture contents in a silty loam soil. Catena 158, 413–420. https://doi.org/10.1016/j.catena.2017.07.017.

Tonitto, C., David, M.B., Drinkwater, L.E., 2006. Replacing bare fallows with covercrops in fertilizers-intensive cropping system: a meta-analysis of crop yield and N dynamics. Agric. Ecosyst. Environ. 112, 58–72. https://doi.org/10.1016/j.agee.2005.07.003.

Vazquez, E., Benito, M., Espejo, R., Teutscherova, N., 2019. Effects of no-tillage and liming amendment combination on soil carbon and nitrogen mineralization. Eur. J. Soil Biol. 93, 103090 https://doi.org/10.1016/j.ejsobi.2019.103090.

Vereecken, H., Schnepf, A., Hopmans, J.W., Javaux, M., Or, D., Roose, T., Vanderborght, J., Young, M.H., Amelung, W., Aitkenhead, M., Allison, S.D., 2016. Modeling soil processes: review, key challenges, and new perspectives. Vadose Zone J. 15 (5), 1–57. https://doi.org/10.2136/vzj2015.09.0131.

Yadav, R.K., Purakayastha, T.J., Khan, M.A., Kaushik, S.C., 2017. Long term impact of manuring and fertilization on enrichment, stability and quality of organic carbon in Inceptisol under two potato-based cropping systems. Sci. Total. Environ. 609, 1535–1543. https://doi.org/10.1016/j.scitotenv.2017.07.128.

Yadvinder-Singh, B.S., Ladha, J.K., Khind, C.S., Khera, T.S., Bueno, C.S., 2004. Effect of residue decomposition on productivity and soil fertility in rice-wheat rotation. Soil Sci. Soc. Am. J. 68, 854–864. https://doi.org/10.2136/sssaj2004.8540.

Zhang, C., Liu, G., Xue, S., Sun, C.L., 2013. Soil organic carbon and total nitrogen storage as affected by land use in a small watershed of the Loess Plateau, China. Eur. J. Soil Biol. 54, 16–24. https://doi.org/10.1016/j.ejsobi.2012.10.007.

Zhang, H., Wu, P., Fan, M., Zheng, S., Wu, J., Yang, X., Zhang, M., Yin, A., Gao, C., 2018. Dynamics and driving factors of the organic carbon fractions in agricultural land reclaimed from coastal wetlands in eastern China. Ecol. Indic. 89, 639–647. https://doi.org/10.1016/j.ecolind.2018.01.039.

Zuber, S.M., Villamil, M.B., 2016. Meta-analysis approach to assess effect of tillage on microbial biomass and enzyme activities. Soil Biol. Biochem. 97, 176–187. https://doi.org/10.1016/j.soilbio.2016.03.011.