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The Effect of Reduced and Conventional Tillage Systems on Soil Aggregates and Organic Carbon Parameters of Different Soil Types

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Abstract: Tillage is a significant type of soil intervention and should be conducted based on the specific soil type. The aim of this study was to determine the influence of different tillage intensities (RT: reduced tillage; CT: conventional tillage), which are correlated with carbon sequestration, on soil properties. The study areas included fields on real farms in Eutric Fluvisol (EF), Mollic Fluvisol (MF), Haplic Chernozem (HC), Haplic Luvisol (HL), Eutric Regosol (ER), Eutric Gleysol (EG), and Stagnic Planosol (SP). The effects of tillage systems depended on the soil type and were more evident in soil aggregates of more productive soils. Agronomically, the most valuable fractions of aggregates were dominant in more productive soils (EF, MF, HC) in the CT system and less dominant in less productive soils (HL, ER, EG, SP) in the RT system. Smaller aggregates (<0.5 mm), which indicate deterioration of soil properties, were negatively correlated with clay ($r = -0.364$, $p < 0.01$), total organic carbon ($r = -0.245$, $p < 0.05$), and stabile carbon fractions ($r = -0.250$, $p < 0.05$). In the case of soil organic carbon, tillage system was mainly correlated with soil texture. Tillage had no influence on soils with lower proportions of silt. On the whole, the suitability of the tillage system for a specific soil type depended on soil productivity and soil texture; however, EG was an exception and showed no differences in response to the tillage system used. The results of this study show that the main factors influencing the choice of tillage system are soil type and genesis, soil texture, and soil production ability.

Keywords: soil aggregates; soil organic carbon; soil texture; soil type; tillage intensity

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1. Introduction

The intensity of tillage significantly influences soil properties, meaning that its suitability differs based on soil type. Basic tillage systems depend on the intensity of the disturbance and include conventional (usually mouldboard ploughing) and conservation (reduced, usually chiselling/disking or no-till management) systems [1]. Reduced tillage (RT) is a non-inversive tillage method associated with fewer tillage operations per year [2]. No-till technology (NT) is the best when it comes to emissions. It positively influences the decrease in carbon mineralization [3] and supports soil aggregation [4]; however, it is associated with increased risk of soil compaction [5], lower yields [6,7], and poor water infiltration [8]. Ploughing has a positive impact on these parameters [9]. Each mechanical disturbance of the soil affects the soil structure, resp. soil aggregates. Farmers usually alternate between these tillage systems. Alternating tillage improves aggregate size and stability, although NT is limited to the topsoil [4]. At the 0.0–0.1 m and the 0.1–0.2 m soil depths, NT and subsoiling (SS) contribute to higher proportions of wet-sieved macroaggregates (WSA) compared with CT. Deeper tillage increases the proportion and stability of macroaggregates, as well as soil organic carbon (SOC) content at a depth of 0.1–0.3 m [10]. SOC content increases as the aggregate size increases [11]. NT supports the stabilization of carbon in aggregates [12,13]. The content of smaller dry-sieved aggregates (DSA) increases with tillage intensity [14]. DSA stability is an important factor that is closely associated with clay content. NT appears to be the best for forming aggregates that are more resistant to erosion and degradation [15]. However, RT increases SOC sequestration and the stability of agricultural soil aggregates [16]. Overall, tillage influences the aggregate dynamics [17]. Tillage is one of the key elements that determine the carbon stock in agricultural soils [18]. Tillage also has different effects, depending on the conditions. Mouldboard ploughing had a negative effect on soil organic fractions in Mediterranean dryland areas [8], but a positive effect on carbon sources in deeper sections of the soil [19]. SS and ploughing increase SOC storage [20]. Moreover, the turning of straw by deep ploughing increases SOC content and root length density [7]. The incorporation of organic carbon into soil aggregates is one of the main mechanisms of carbon sequestration in arable land [21]. Changes in the aggregates are observed after changes in the chemical structure of soil organic matter (SOM) [22]. Soil properties influence SOM in the aggregates more substantially than land use management [23], and even they depend on specific aggregate sizes [24]. The stability of organic substances is influenced by the intensity of oxidation, which changes in relation to the level of soil disruption. Carbon can also be sequestered by the incorporation of plant residues into deeper layers of the soil, mainly through ploughing or SS [20]. However, tillage systems have different effects, depending on the soil type. Tillage systems have been presented as more appropriate, although the conditions under which they are used differ. In some cases, their economic effects may be preferred, while in others, their ecological effects may be preferred. However, it is not possible to generalize the influence of tillage on all soils, because each soil has its own specific profile based on its genesis [25], region [26], and soil management [27]. Each tillage system has advantages in relation to specific soils, and their use can therefore not be generalized. The suitability of each method should be reviewed in relation to the soil type due to its specific genesis.

The aim of this study was to determine the differences in the influences of two different tillage systems based on soil type properties—fractional composition of soil aggregates, labile organic carbon fractions, and stabile organic carbon fractions—associated with carbon sequestration.

2. Materials and Methods

Studied fields are located in the Podunajska (Nové Zámky, Šaľa, Vráble, Piešťany) and Eastern Slovak (Trebišov, Michalovce, Sobrance) lowlands. These fields are on real farms that use tillage systems. Each locality included 3 areas with similar soil types. Geological substrates in the lowlands are Neogene clay, sand, and gravel that are covered with loess and loess loam in some areas. Fluvial sediments are found along the rivers Vah and Laborec. The region is monotonous, mostly wavy, and covered with loess and loess loam. In some places, Neogene rafts of clay, sand, and gravel are found. The localities are situated in slightly warm to warm climatic regions (Table 1) [28]. The samples represent high and very high productive soils (80–83 points; HC, MF, EF) and productive and medium productive soils (63–78 points; HL, ER, EG, SP) based on the values of soil production potential (http://www.podnemapy.sk/portal/verejnost/bh_pp/bh.aspx (accessed on 17 December 2019)).

The study consisted of 7 types of soil (EF: Eutric Fluvisol; MF: Mollic Fluvisol; HC: Haplic Chernozem; HL: Haplic Luvisol; ER: Eutric Regosol; EG: Eutric Gleysol; and SP: Stagnic Planosol [29]) from three agricultural areas in Slovakia. Two tillage systems: reduced tillage (RT, disking to a depth of 0.10–0.12 m) and conventional tillage (CT, mouldboard deep ploughing), representing non-invasive (shallow) and invasive (deep) tillage, respectively, were used. Each system was used in three fields of arable land with different crop residue management systems, resp. carbon balance in all 21 areas. Cereals were the dominant crops in all 126 fields. The organic carbon balance in the last 10 years was

8.083–20.013 t ha^{-1}. The average basic properties of soils from fields included in the study are presented in Table 2.

Table 1. Soil sampling locations.

Soil Type	Locality	A (m)	T (°C)	P (mm)
Eutric Fluvisol	Trebišov (Milhostov, Kráľovský Chlmec, Streda n.Bodrogom)	104	9.0	564
Mollic Fluvisol	Nové Zámky (Nové Zámky, Komoča, Šurany)	110	10.4	566
Haplic Chernozem	Piešťany (Piešťany, Trebatice, Krakovany)	163	9.4	611
Haplic Luvisol	Vráble (Vráble, Nová Ves n./Žitavou, Horný Ohaj)	144	9.1	605
Eutric Regosol	Šaľa (Šaľa, Močenok, Horná Králová)	130	9.8	568
Eutric Gleysol	Michalovce (Hažín, Petrikovce, Lúčky)	100	9.1	593
Stagnic Planosol	Sobrance (Blatné Revištia, Blatná Polianka, Bežovce)	120	9.1	652

A: Average altitude; T: Average annual temperature; P: Average rainfall per year.

Table 2. Average values of basic pedological characteristics of the soil types.

Soil Type	TOC ($g{\cdot}kg^{-1}$)	pH/KCl	Clay (%)	Processes in Soil Genesis
EF	21.33 ± 2.91^{b}	6.44 ± 0.49^{d}	34.28 ± 3.05^{a}	alluvial accumulation of C
MF	32.25 ± 7.21^{a}	6.73 ± 0.95^{a}	32.31 ± 5.94^{a}	humification
HC	18.09 ± 4.46^{bc}	6.59 ± 1.11^{bcd}	25.60 ± 1.60^{b}	humification
HL	16.87 ± 3.18^{bcd}	6.37 ± 0.83^{bc}	22.95 ± 4.48^{b}	illimerization
ER	10.50 ± 2.48^{d}	6.16 ± 1.06^{ab}	13.59 ± 3.88^{c}	oxidation, degradation
EG	22.29 ± 4.92^{b}	6.01 ± 0.92^{cd}	32.46 ± 5.34^{a}	gleyzation
SP	16.77 ± 3.41^{bcd}	5.97 ± 0.98^{cd}	21.55 ± 4.49^{b}	pseudogleyzation, ferrolysis

EF: Eutric Fluvisol; MF: Mollic Fluvisol; HC: Haplic Chernozem; HL: Haplic Luvisol; ER: Eutric Regosol; EG: Eutric Gleysol; SP: Stagnic Planosol; TOC: total organic carbon. The different letters (a, b, c, and d) represent statistically significant differences ($p < 0.05$) based on the LSD test.

Soil sampling was conducted at two depths (0.0–0.1 m and 0.0–0.3 m), resulting in 252 samples (7 soil types × 3 fields × 3 different carbon inputs × 2 tillage systems × 2 depths).

Soil Samples and Analytical Methods Used

The fields in the agroecosystems were located in different farms under real production conditions. Three sample replicates were collected from a depth of 0.10 m and 0.30 m each and used for soil aggregate determination. These homogeneous soil samples represent the entire soil profile. This was not the average value of soil samples from three depths, but actual sampling at both depths. The samples were dried at 25 ± 2 °C.

To determine the fractions of soil aggregates, the soils were separated using a sieve [30]. The fractions of dry-sieved macroaggregates were >7, 5–7, 3–5, 1–3, 0.5–1, and 0.25–0.5 mm, while the fractions of wet-sieved macroaggregates were >5, 3–5, 2–3, 1–2, 0.5–1, and

0.25–0.5 mm. These represent the different soil size fractions in the net aggregate with different potentials for sequestration. The distribution of particle sizes was determined after dissolution of $CaCO_3$ in 2 mol. $HCl \cdot dm^{-3}$ and oxidation of the organic matter with 30% H_2O_2. Following repeated washing, samples were dispersed in $Na(PO_3)_6$. Silt, sand, and clay fractions were determined using the pipette method [31].

To determine the chemical properties, the soil samples were sieved (2 mm, resp. 0.25 mm). The total organic carbon (TOC) content was determined through wet combustion using $K_2Cr_2O_7$ oxidation [32] and labile carbon (C_L) was determined through $KMnO_4$ oxidation [33]. The non-labile carbon (C_{NL}), lability of carbon (L_C), the index of carbon lability (LI_C), carbon pool index (CPI), and carbon management index (CMI) [34] were calculated. Next, labile fractions of carbon, cold water extractable organic carbon (CWEOC), and hot water extractable organic carbon (HWEOC) were determined according to the method by Ghani et al. [35], with final organic carbon being determined using wet combustion [32].

The obtained data were analysed using Statgraphic Plus statistical software. A multifactor ANOVA model was used to compare individual treatments. Statistical significance was set at $p < 0.05$, with separation of the means by LSD and multiple-range test (two files with n = 252 and n = 126). Correlation analysis was used to determine the relationships between macroaggregate fractions, particle size distribution, and organic carbon and its parameters. Significance of Pearson correlation coefficients were tested at $p < 0.05$ and $p < 0.01$.

3. Results and Discussion

3.1. Soil Macroaggregates

The most significant effect of the tillage systems was observed in the SP (Table 3), and was present in almost all the DSA and WSA fractions. In SP, the contents of smaller aggregate fractions (0.25–1 mm) were higher in the case of RT, where the cyclic oxidation and reduction support the acidification that contributes to leaching of exchangeable cations and the destruction of clay minerals [36] that leads to the disintegration of larger aggregates. Moreover, Fe and Al oxides were more involved in the formation of the smaller aggregates [21], but their higher proportions characterize the deterioration of the soil structure [37]. In the case of CT, the larger aggregate fractions (>1 mm) were present in greater quantities due to the incorporation of organic sources, which are also rich in carbon, that contribute to the stability of the aggregates [38].

In the case of more (high and very) productive soils (HC, MF, EF), the larger fractions (>3 mm) and smaller fractions (<3 mm) of DSA were present in higher proportions in RT and CT, respectively. However, in the case of less (low and medium) productive soils (EG, ER, HL), smaller DSA fractions were present in higher proportions in RT only. The tillage system had a stronger effect on DSA than WSA and was more markedly visible in more productive soils. The carbon in DSA is less stabilized than that in WSA, therefore they are more easily disturbed [39]. Similar high proportions of smaller DSA fractions in CT of more productive soils and in RT of less productive soils are mainly due to organic sources. More productive soils are richer in organic carbon, but after increased tillage, this content decreases due to increased oxidation, leading to the disintegration of the aggregates, resulting in higher content of smaller aggregates. Less productive soils are low in organic carbon and are naturally dominated by smaller aggregates. Sesquioxides can act as the main aggregating agent [17].

In the case of WSA, the influence of tillage was more significant in more productive soils (with the exception of SP). Agronomically, the contents of the most valuable fractions of macroaggregates (0.5–2 mm, WSA; 0.5–3 mm, DSA) were found in more productive soils subjected to CT and in less productive soils subjected to RT. Each mechanical soil intervention increases the oxidation process [40,41], which leads to the mineralization of organic carbon substances. Therefore, the tillage system had a greater effect on soils with a higher content of organic carbon, which participates in the formation of DSA and WSA. Larger fractions of WSA (>2 mm) were positively correlated with clay content and

TOC, especially the stabile fractions. Conversely, smaller fractions of WSA (<2 mm) were negatively correlated with clay content and TOC (Table 4). This points to the importance of organic substances in the mechanism of soil aggregation. Since more productive soils are richer in organic carbon, the influence of the tillage method was more pronounced in these soils.

Table 3. Differences in the fractions of soil macroaggregates of different soils and tillage.

		DSA (%)					
		>7 mm	**5–7 mm**	**3–5 mm**	**1–3 mm**	**0.5–1 mm**	**0.25–0.5 mm**
EF	RT	39.10 ^{a}	39.10 ^{a}	**10.63 ^{a}**	13.15 ^{a}	**17.70 ^{b}**	**10.13 ^{b}**
	CT	29.71 ^{a}	29.71 ^{a}	**8.02 ^{b}**	12.7$^{4\,a}$	**26.53 ^{a}**	**14.35 ^{a}**
MF	RT	**41.16 ^{a}**	**14.62 ^{a}**	**15.44 ^{a}**	**15.50 ^{b}**	**6.34 ^{b}**	**2.65 ^{b}**
	CT	**24.47 ^{b}**	**6.74 ^{b}**	**11.29 ^{b}**	**27.41 ^{a}**	**18.58 ^{a}**	**6.72 ^{a}**
HC	RT	28.34 ^{a}	**12.05 ^{a}**	**15.61 ^{a}**	**18.46 ^{b}**	**10.18 ^{b}**	4.66 ^{a}
	CT	25.69 ^{a}	**10.14 ^{b}**	**13.39 ^{b}**	**21.84 ^{a}**	**14.21 ^{a}**	5.48 ^{a}
HL	RT	**22.97 ^{b}**	8.96 ^{a}	12.44 ^{a}	18.31 ^{a}	**11.96 ^{a}**	**7.28 ^{a}**
	CT	**39.14 ^{a}**	10.00 ^{a}	13.70 ^{a}	19.39 ^{a}	**8.83 ^{b}**	**3.18 ^{b}**
ER	RT	32.38 ^{a}	11.28 ^{a}	13.79 ^{a}	**19.01 ^{b}**	10.16 ^{a}	4.22 ^{a}
	CT	28.50 ^{a}	9.17 ^{a}	13.48 ^{a}	**23.03 ^{a}**	13.14 ^{a}	4.4$^{9\,a}$
EG	RT	40.22 ^{a}	9.31 ^{a}	11.78 ^{a}	18.18 ^{a}	**11.29 ^{a}**	4.31 ^{a}
	CT	42.91 ^{a}	10.69 ^{a}	13.18 ^{a}	16.77 ^{a}	**8.22 ^{b}**	3.58 ^{a}
SP	RT	**31.56 ^{b}**	**8.75 ^{b}**	**11.86 ^{b}**	**17.57 ^{b}**	**11.47 ^{a}**	**6.30 ^{a}**
	CT	**38.28 ^{a}**	**10.60 ^{a}**	**14.04 ^{a}**	**19.15 ^{a}**	**9.51 ^{b}**	**3.85 ^{b}**
		WSA (%)					
		>5 mm	**3–5 mm**	**2–3 mm**	**1–2 mm**	**0.5–1 mm**	**0.25–0.5 mm**
EF	RT	**24.68 ^{a}**	23.05 ^{a}	**20.02 ^{b}**	**11.26 ^{b}**	9.46 ^{a}	4.20 ^{a}
	CT	**10.82 ^{b}**	18.58 ^{a}	**28.61 ^{a}**	**18.00 ^{a}**	11.64 ^{a}	4.77 ^{a}
MF	RT	**32.57 ^{a}**	18.10 ^{a}	**18.69 ^{b}**	**8.82 ^{b}**	9.45 ^{a}	5.02 ^{a}
	CT	**8.88 ^{b}**	17.46 ^{a}	**25.06 ^{a}**	**17.72 ^{a}**	15.81 ^{a}	7.16 ^{a}
HC	RT	**5.73 ^{a}**	**9.84 ^{a}**	**16.51 ^{a}**	12.22 ^{a}	**20.99 ^{b}**	14.33 ^{a}
	CT	**1.91 ^{b}**	**3.49 ^{b}**	**7.33 ^{b}**	9.08 ^{a}	**40.36 ^{a}**	15.30 ^{a}
HL	RT	6.2$^{6\,a}$	8.22 ^{a}	18.34 ^{a}	16.51 ^{a}	23.48 ^{a}	13.01 ^{a}
	CT	8.02 ^{a}	11.78 ^{a}	21.82 ^{a}	17.39 ^{a}	20.04 ^{a}	9.00 ^{a}
ER	RT	9.19 ^{a}	10.12 ^{a}	15.36 ^{a}	15.81 ^{a}	22.51 ^{a}	12.67 ^{a}
	CT	5.81 ^{a}	9.39 ^{a}	20.49 ^{a}	17.58 ^{a}	20.79 ^{a}	11.41 ^{a}
EG	RT	24.76 ^{a}	19.80 ^{a}	21.49 ^{a}	12.10 ^{a}	9.64 ^{a}	4.48 ^{a}
	CT	23.08 ^{a}	21.5 ^{8a}	22.40 ^{a}	14.96 ^{a}	9.11 ^{a}	3.12 ^{a}
SP	RT	**15.12 ^{b}**	**16.02 ^{b}**	21.30 ^{a}	**17.50 ^{a}**	**13.48 ^{a}**	**6.68 ^{a}**
	CT	**28.73 ^{a}**	**23.49 ^{a}**	19.21 ^{a}	**12.47 ^{b}**	**6.54 ^{b}**	**3.40 ^{b}**

EF: Eutric Fluvisol; MF: Mollic Fluvisol; HC: Haplic Chernozem; HL: Haplic Luvisol; ER: Eutric Regosol; EG: Eutric Gleysol; SP: Stagnic Planosol; RT: reduced tillage; CT: conventional tillage; DSA: dry-sieved macroaggregates; WSA: water-resistant macroaggregates. The different letters (a and b, bold) show statistically significant differences ($p < 0.05$) based on the LSD test.

Plant residues incorporated in the soil come from labile sources and are stabilized by mixing with minerals. This is reflected in a higher proportion of agronomically valuable aggregates during CT. On the contrary, root exudates are an important source of labile carbon in mechanically undisturbed soils; however, the mechanism of the stabilization is restricted to alternating dry and wet periods [42], which dominate in the rhizosphere in

RT. Moreover, the fine roots, mucilage, and exudates stimulate microbial activity [43] as an additional source of labile carbon. In more productive soils, the most agronomically valuable aggregates are formed by disrupting larger aggregates through ploughing (CT), while in less productive soils, they are formed by aggregating smaller aggregates as a result of their non-disruption (RT). This can result in similar proportions of aggregates in both tillage systems. The stabilization of SOM is mainly controlled by organo-mineral complexes [44].

Table 4. Correlations between the clay and organic carbon contents and the fractions of water-resistant macroaggregates.

WSA Fractions	**Clay**	**TOC**	**C_{NL}**
>5 mm	0.323 **	0.210 *	0.201 *
3–5 mm	0.377 **	0.310 **	0.325 **
2–3 mm	0.197 *	0.237 *	0.252 *
1–2 mm	−0.186 *	ns	ns
0.5–1 mm	−0.285 **	−0.311 **	−0.317 **
0.25–0.5 mm	−0.364 **	−0.245 *	−0.250 *

WSA: water-resistant macroaggregates; TOC: total organic carbon; C_{NL}: non-labile carbon. ** $p < 0.01$; * $p < 0.05$; ns: nonsignificant.

3.2. Soil Organic Carbon

Analysis of EF showed statistically significant differences across all parameters (Table 5). In the case of RT, the contents of both labile (CWEOC, HWEOC, C_L) and stabile (C_{NL}) organic carbons were higher. The lability of organic carbon was also higher. EF is a soil characterised by a fluctuation of underground water level, alluvial accumulation of organic carbon [45], and high substrate heterogeneity [46]. However, these effects are largely negated by conversion to arable land. After a change in the hydromorphic regime of this soil, its natural properties are mainly a reflection of actual agronomic interventions [47]. Although the content of organic carbon was higher in RT, its lability was also higher, which in the long-term leads to its decrease [48]. The exception again was SP, which had a significantly higher content of organic carbon—mainly the labile form—in the CT system.

Table 5. Differences in the parameters of different soils and tillage.

		TOC	**CWEOC**	**HWEOC**	**C_L**	**C_{NL}**	**L_C**	**LI_C**	**CPI**	**CMI**
				(g·kg^{-1})						
EF	RT	**23.20** ^{a}	0.61 ^{a}	**1.19** ^{a}	**2.06** ^{a}	**21.15** ^{a}	**0.097** ^{a}	**0.904** ^{a}	**0.956** ^{a}	**86.47** ^{a}
	CT	**19.45** ^{b}	0.56 ^{a}	**1.02** ^{b}	**1.48** ^{b}	**17.97** ^{b}	**0.082** ^{b}	**0.761** ^{b}	**0.803** ^{b}	**61.23** ^{b}
MF	RT	26.96 ^{a}	0.65 ^{a}	1.40 ^{a}	2.45 ^{a}	27.52 ^{a}	0.102 ^{a}	1.002 ^{a}	0.520 ^{a}	88.81 ^{a}
	CT	38.01 ^{a}	0.54 ^{a}	1.42 ^{a}	3.49 ^{a}	3.452 ^{a}	0.103 ^{a}	1.751 ^{a}	0.700 ^{a}	134.08 ^{a}
HC	RT	**21.47** ^{a}	**0.67** ^{a}	1.27 ^{a}	**2.26** ^{a}	**19.21** ^{a}	0.117 ^{a}	1.177 ^{a}	0.993 ^{a}	121.76 ^{a}
	CT	**14.70** ^{b}	**0.59** ^{b}	1.18 ^{a}	**1.67** ^{b}	**13.03** ^{b}	0.129 ^{a}	1.286 ^{a}	0.712 ^{a}	93.79 ^{a}
HL	RT	17.59 ^{a}	0.59 ^{a}	1.16 ^{a}	1.76 ^{a}	15.83 ^{a}	0.110 ^{a}	0.767 ^{a}	0.376 ^{a}	29.18 ^{a}
	CT	16.15 ^{a}	0.52 ^{a}	1.13 ^{a}	1.67 ^{a}	14.48 ^{a}	0.115 ^{a}	0.806 ^{a}	0.346 ^{a}	27.90 ^{a}
ER	RT	**19.93** ^{a}	**0.67** ^{a}	1.16 ^{a}	2.08 ^{a}	**17.85** ^{a}	0.116 ^{a}	0.842 ^{a}	**0.505** ^{a}	43.86 ^{a}
	CT	**17.07** ^{b}	**0.57** ^{b}	1.10 ^{a}	2.10 ^{a}	**14.97** ^{b}	0.147 ^{a}	1.048 ^{a}	**0.445** ^{b}	45.29 ^{a}
EG	RT	23.40 ^{a}	0.56 ^{a}	1.04 ^{a}	2.01 ^{a}	21.39 ^{a}	0.095 ^{a}	0.660 ^{a}	0.564 ^{a}	37.31 ^{a}
	CT	21.16 ^{a}	0.47 ^{a}	0.94 ^{a}	2.69 ^{a}	18.48 ^{a}	0.145 ^{a}	1.100 ^{a}	0.505 ^{a}	60.61 ^{a}
SP	RT	**14.43** ^{b}	**0.42** ^{b}	0.94 ^{a}	**1.27** ^{b}	13.16 ^{a}	0.098 ^{a}	0.780 ^{a}	0.578 ^{a}	**44.92** ^{b}
	CT	**19.10** ^{a}	**0.52** ^{a}	0.97 ^{a}	**1.86** ^{a}	17.25 ^{a}	0.107 ^{a}	0.844 ^{a}	0.770 ^{a}	**64.72** ^{a}

EF: Eutric Fluvisol; MF: Mollic Fluvisol; HC: Haplic Chernozem; HL: Haplic Luvisol; ER: Eutric Regosol; EG: Eutric Gleysol; SP: Stagnic Planosol; RT: reduced tillage; CT: conventional tillage; TOC: total organic carbon; C_L: labile carbon; C_{NL}: non-labile carbon; L_C: lability of carbon; LI_C: index of carbon lability; CPI: carbon pool index; CMI: carbon management index; CWEOC: cold water extractable organic carbon; HWEOC: hot water extractable organic carbon. The different letters (a and b, bold) show statistically significant differences ($p < 0.05$) based on the LSD test.

With regard to SOM, the tillage system affects the textural composition, which is one of the factors that characterises the transformation of organic substances. Overall, tillage did not influence soils with a lower proportion of silt (MF < HL < EG) (Figure 1). On the other hand, statistically significant differences in TOC (Figure 2) were observed in soils with a higher proportion of silt (SP > ER > HC > EF) (Figure 1), which bound a significant amount of carbon [49]. Soil texture is one of the parameters [50] that influences quantity and quality.

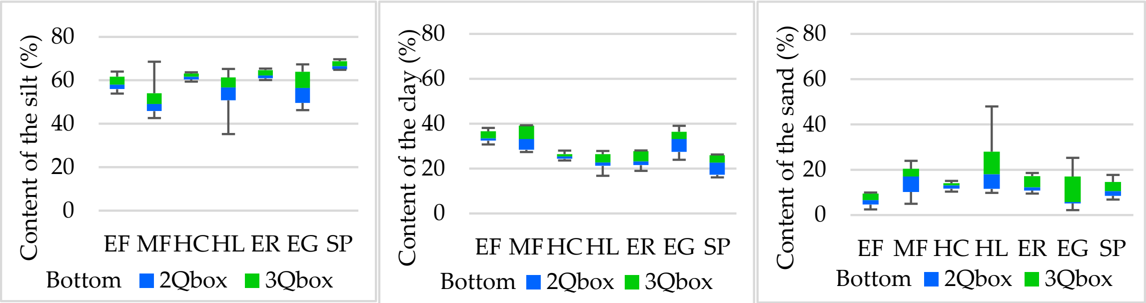

Figure 1. Differences in particle size fractions; EF: Eutric Fluvisol; MF: Mollic Fluvisol; HC: Haplic Chernozem; HL: Haplic Luvisol; ER: Eutric Regosol; EG: Eutric Gleysol; SP: Stagnic Planosol. Error bars represent maximum and minimum values.

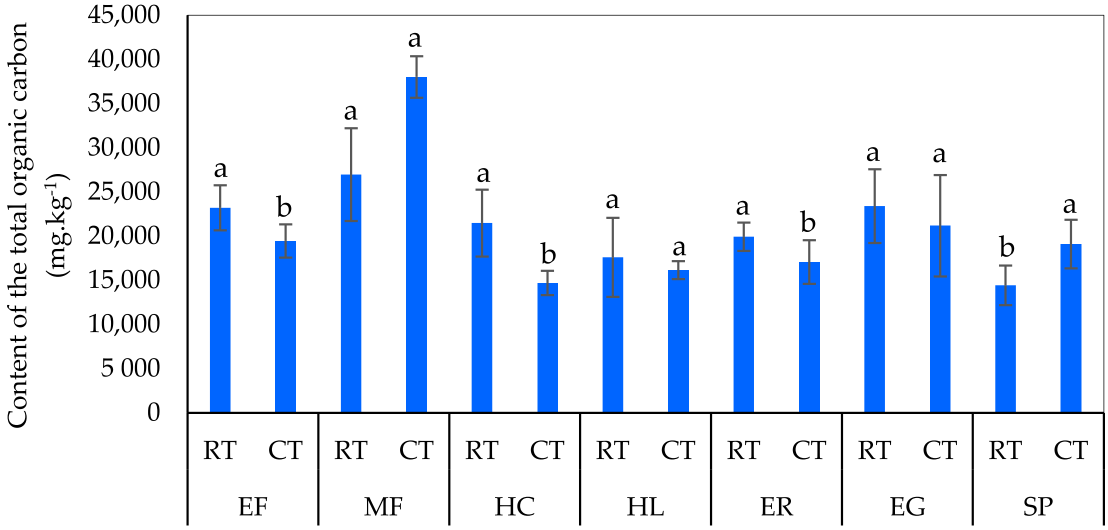

Figure 2. Differences in total organic carbon in the soils. EF: Eutric Fluvisol; MF: Mollic Fluvisol; HC: Haplic Chernozem; HL: Haplic Luvisol; ER: Eutric Regosol; EG: Eutric Gleysol; SP: Stagnic Planosol; RT: reduced tillage; CT: conventional tillage. The different letters (a and b) represent statistically significant differences ($p < 0.05$) based on the LSD test.

The influence of clay on carbon content has been determined [51,52]. EF contained the finest—grained soil, which had not only the highest proportion of clay (Figure 1), but also the lowest proportion of sand (Figure 1). In the RT system, MF was followed by EG > EF > HC > ER > HL > SP (Figure 3a), while in the CT system, the order was EG > EF > SP > ER > HL > HC (Figure 3b). Moreover, the differences observed in RT were significantly higher than those observed in CT. EF, MF, and EG contained the highest clay content (Figure 1). Tillage system was most pronounced in EF, whereas it had no effect on MF and EG. The TOC contents of RT and CT were highest in MF > EG> EF, which are soils from floodplains and are characterized by higher organic matter content [53,54]. The same positions and orders of ER and HL were maintained in both CT and RT. However, the position of SP and HC differed significantly depending on tillage system. In the case of RT (Figure 3a), TOC content was lowest in SP, while in the case of CT (Figure 3b), it was lowest in HC. TOC content was intermediate in HC in RT and in SP in CT. It can therefore be concluded that CT is more suitable for SP. In this soil, the ploughing acts on the organic carbon, stabilizing it through alternating oxidation and reduction conditions. This can also contribute to the development of the root system [3,55], leading to an increase in the activity and diversity of the microbial community that subsequently supports the growth of new carbon sources. In the case of HC, ploughing causes higher aeration, which leads to a decrease in the carbon content [56] and a disturbance of the originally diverse microbial community and the potentially existing substrates. Conservation tillage (reduced, minimum), which retains more precipitation, seems to be more suitable in semi-arid areas of HL [57]. However, without ploughing, compaction can occur in soils with higher clay content [58].

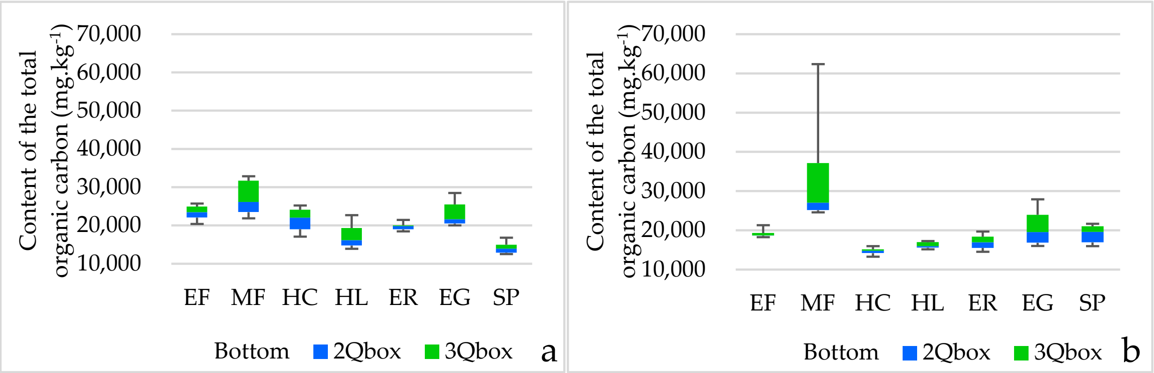

Figure 3. Differences (mg·kg^{-1}) in total organic carbon content of soils in (**a**) reduced tillage and (**b**) conventional tillage systems; EF: Eutric Fluvisol; MF: Mollic Fluvisol; HC: Haplic Chernozem; HL: Haplic Luvisol; ER: Eutric Regosol; EG: Eutric Gleysol; SP: Stagnic Planosol. Error bars represent maximum and minimum values.

No differences in TOC content were recorded for soil samples taken at a depth of 0.1 m (Figure 4a), apart from in MF. However, significant differences were recorded for soil samples taken at a depth of 0.3 (Figure 4b). The tillage system did not affect the carbon parameters of soil samples taken at depths of 0.1 m or 0.3 m. The influence of the tillage system on the carbon content is often observed only to a depth of 0.1 m, and its distribution in deeper parts of the soil is negligible [19]. However, it is inaccurate to make comparisons at such a depth, because during ploughing, organic sources are incorporated to a greater depth (>0.1 m) and thus the TOC content in ploughed soils can be higher than in unploughed soils because the organic input in RT is limited. Although RT produces lower emissions compared with CT, it indirectly decreases the biomass of microorganisms through the lower input of carbon into the soil [59] as well as the microbial diversity, which is bound to these sources. This ultimately inhibits the sequestration of carbon from the atmosphere into the soil. The properties of the layer 0.1 m deep are regulated by agronomic measures, thus the differences between the soils in this layer can decrease over time and it can ultimately reach a state called "natural hydroponics". It is therefore difficult to make any assessments of the influence of tillage systems and the associated carbon sequestration in this soil layer. Koch a Stockfisch [60] reported that, after ploughing, organic carbon, particularly the labile components at the 0.30–0.45 m depth, increased [61], while greater stabilization of organic carbon occurred in deeper layers of the soil [62]. Moreover, the rhizosphere zone is not limited to this layer, thus nutrient uptake and other processes also take place at depths below 0.1 m. It is therefore important to monitor the influence of whichever soil management system is in use at a greater soil depth. Several studies in Brazil and the Midwestern part of North America showed a redistribution, but not a decrease, of carbon in the soil after reduction in tillage [63].

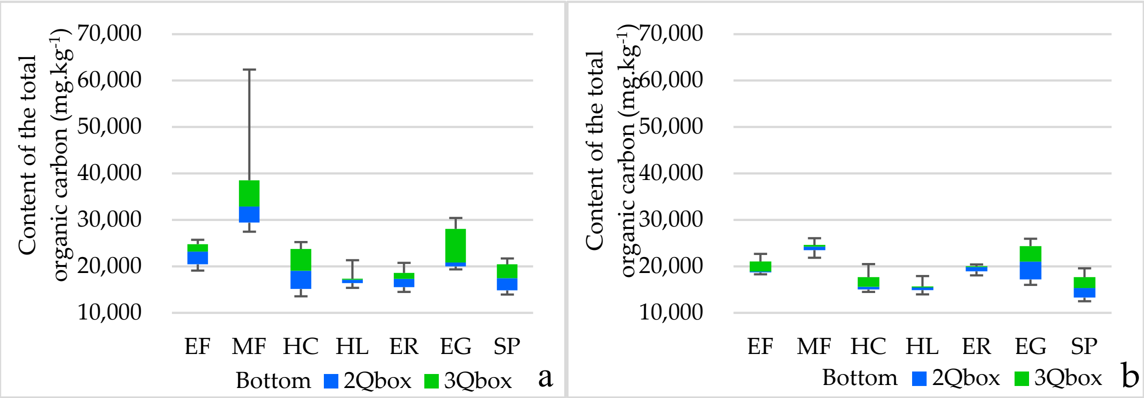

Figure 4. Differences (mg·kg^{-1}) in total organic carbon of soils from a depth of (**a**) 0.0–0.1 m and (**b**) 0.0–0.3 m. EF: Eutric Fluvisol; MF: Mollic Fluvisol; HC: Haplic Chernozem; HL: Haplic Luvisol; ER: Eutric Regosol; EG: Eutric Gleysol; SP: Stagnic Planosol. Error bars represent maximum and minimum values.

4. Conclusions

The effect of the tillage system cannot be generalized to all soils, but its suitability is determined by the soil type. The potential for carbon sequestration in arable land is closely associated with soil aggregation and the stability of organic carbon. There are no rules for determining the suitability of the tillage system. The favourable effect of tillage on soil aggregates depended on soil productivity and, in the case of soil organic carbon, on soil texture. Based on this, due to better conditions for aggregation, the CT system was more suitable for more productive soils (HC, MF, EF), while the RT system was more suitable for less productive soils (HL, ER, EG), with the exception of SP. RT was associated with several carbon parameters (except SP). Since carbon sequestration is controlled by physical (soil aggregation) and chemical (organic carbon stability) factors, the suitability of tillage systems based on soil types is as follows: CT is better for EF, MF, HC, and SP; and RT is better for HL and ER. Tillage had no significant effect on EG. These results show that the choice of tillage system depends on a combination of soil type and actual soil conditions.

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References

1. Azimi-Nejadian, H.; Hossein Karparvarfard, S.; Naderi-Boldaji, M. Weed seed burial as affected by mouldboard design parameters, ploughing depth and speed: DEM. simulations and experimental validation. *Biosyst. Eng.* **2022**, *216*, 79–92. [CrossRef]
2. Van Balen, D.; Cuperus, F.; Haagsma, W.; De Haan, J.; Van den Berg, W.; Sukkel, W. Crop yield response to long-term reduced tillage in a conventional and organic farming system on a sandy loam soil. *Soil Tillage Res.* **2023**, *225*, 105553. [CrossRef]
3. Liu, X.; Li, Q.; Tan, S.; Wu, X.; Song, X.; Gao, H.; Han, Z.; Jia, A.; Liang, G.; Li, S. Evaluation of carbon mineralization and its temperature sensitivity in different soil aggregates and moisture regimes: A 21-year tillage experiment. *Sci. Total Environ.* **2022**, *837*, 155566. [CrossRef] [PubMed]
4. Weidhuner, A.; Hanauer, A.; Krausz, R.; Crittenden, S.J.; Gage, K.; Sadeghpour, A. Tillage impacts on soil aggregation and aggregate-associated carbon and nitrogen after 49 years. *Soil Till. Res.* **2021**, *208*, 104878. [CrossRef]

5. Arachchi, L.P.V. Effect of deep ploughing on the water status of highly and less compacted soils for coconut (*Cocos nucifera* L.) production in Sri Lanka. *Soil Till. Res.* **2009**, *103*, 350–355. [CrossRef]
6. Hofbauer, M.; Bloch, R.; Bachinger, J.; Gerke, H.H. Effects of shallow non-inversion tillage on sandy loam soil properties and winter rye yield in organic farming. *Soil Till. Res.* **2022**, *222*, 105435. [CrossRef]
7. Chen, J.; Pang, D.-w.; Jin, M.; Luo, Y.-l.; Li, H.-y.; Li, Y.; Wang, Z.-l. Improved soil characteristics in the deeper plough layer can increase grain yield of winter wheat. *J. Integr. Agr.* **2020**, *19*, 1215–1226. [CrossRef]
8. Melero, S.; Panettieri, M.; Madejó, E.; Macpherson, H.G.; Moreno, F.; Murillo, J.M. Implementation of chiselling and mouldboard ploughing in soil after 8 years of no-till management in SW, Spain: Effect on soil quality. *Soil Till. Res.* **2011**, *112*, 107–113. [CrossRef]
9. Ucgul, M.; Saunders, C. Simulation of tillage forces and furrow profile during soil-mouldboard plough interaction using discrete element modelling. *Biosyst. Eng.* **2020**, *190*, 58–70. [CrossRef]
10. Hu, R.; Liu, Y.; Chen, T.; Zheng, Z.; Peng, G.; Zou, Y.; Tang, C.; Shan, X.; Zhou, Q.; Li, J. Responses of soil aggregates, organic carbon, and crop yield to short-term intermittent deep tillage in Southern China. *J. Clean. Prod.* **2021**, *298*, 126767. [CrossRef]
11. Gao, L.; Wang, B.; Li, S.; Wu, H.; Wu, X.; Liang, G.; Gong, D.; Zhang, X.; Cai, D.; Degré, A. Soil wet aggregate distribution and pore size distribution under different tillage systems after 16 years in the Loess Plateau of China. *Catena* **2019**, *173*, 38–47. [CrossRef]
12. Modak, K.; Biswas, D.R.; Ghosh, A.; Pramanik, P.; Das, T.K.; Das, S.; Kumar, S.; Krishnan, P.; Bhattacharyya, R. Zero tillage and residue retention impact on soil aggregation and carbon stabilization within aggregates in subtropical India. *Soil Till. Res.* **2020**, *202*, 104649. [CrossRef]
13. Ndzelu, B.S.; Dou, S.; Zhang, X.; Zhang, Y.; Ma, R.; Liu, X. Tillage effects on humus composition and humic acstructural characteristics in soil aggregate-size fractions. *Soil Till. Res.* **2021**, *213*, 105090. [CrossRef]
14. Jin, V.L.; Wienhold, B.J.; Mikha, M.M.; Schmer, M.R. Cropping system partially offsets tillage-related degradation of soil organic carbon and aggregate properties in a 30-yr rainfed agroecosystem. *Soil Till. Res.* **2021**, *209*, 104968. [CrossRef]
15. Pi, H.; Huggins, D.R.; Sharratt, B. Dry aggregate stability of soils influenced by crop rotation, soil amendment, and tillage in the Columbia Plateau. *Aeolian Res.* **2019**, *40*, 65–73. [CrossRef]
16. Sae-Tun, O.; Bodner, G.; Rosinger, C.; Zechmeister-Boltenstern, S.; Mentler, A.; Keiblinger, K. Fungal biomass and microbial necromass facilitate soil carbon sequestration and aggregate stability under different soil tillage intensities. *Appl. Soil Ecol.* **2022**, *179*, 104599. [CrossRef]
17. Xue, B.; Huang, L.; Huang, Y.; Yin, Z.; Li, X.; Lu, J. Effects of organic carbon and iron oxides on soil aggregate stability under different tillage systems in a rice–rape cropping system. *Catena* **2019**, *177*, 1–12. [CrossRef]
18. Qiu, S.; Yang, H.; Zhang, S.; Huang, S.; Zhao, S.; Xu, X.; He, P.; Zhou, W.; Zhao, Y.; Yan, N.; et al. Carbon storage in an arable soil combining field measurements, aggregate turnover modeling and climate scenarios. *Catena* **2023**, *220*, 106708. [CrossRef]
19. Gál, A.; Vyn, T.J.; Michéli, E.; Kladivko, E.J.; McFee, W.W. Soil carbon and nitrogen accumulation with long-term no-till versus moldboard plowing overestimated with tilled-zone sampling depths. *Soil Till. Res.* **2007**, *96*, 42–51. [CrossRef]
20. Guo, X.; Wang, H.; Yu, Q.; Ahmad, N.; Li, J.; Wang, R. Xiaoli Wang All rights reserved. Subsoiling and plowing rotation increase soil C and N storage and crop yield on a semiarLoess Plateau. *Soil Till. Res.* **2022**, *221*, 105413. [CrossRef]
21. Six, J.; Elliott, E.T.; Paustian, K. Soil macroaggregate turnover and microaggregate formation: A mechanism for C sequestration under no-tillage agriculture. *Soil Biol. Biochem.* **2000**, *32*, 2099–2103. [CrossRef]
22. Kogut, B.M.; Artemyeva, Z.S.; Kirillova, N.P.; Yashin, M.A.; Soshnikova, E.I. Organic Matter of the Air-Dry ad Water-Stable Macroaggregates (2–1 mm) of Haplic Chernozem in Contrasting Variants of Land Use. *Eurasian Soil Sci.* **2019**, *52*, 141–149. [CrossRef]
23. Kpemoua, T.P.I.; Barré, P.; Chevallier, T.; Houot, S.; Chenu, C. Drivers of the amount of organic carbon protected inside soil aggregates estimated by crushing: A meta-analysis. *Geoderma* **2022**, *427*, 116089. [CrossRef]
24. Almajmaie, A.; Hardie, M.; Acuna, T.; Birch, C. Evaluation of methods for determining soil aggregate stability. *Soil Till. Res.* **2017**, *167*, 39–45. [CrossRef]
25. Kochiieru, M.; Feiziene, D.; Feiza, V.; Volungevicius, J.; Velykis, A.; Slepetiene, A.; Deveikyte, I.; Seibutis, V. Freezing-thawing impact on aggregate stability as affected by land management, soil genesis and soil chemical and physical quality. *Soil Till. Res.* **2020**, *203*, 104705. [CrossRef]
26. Renton, M.; Flower, K.C. Occasional mouldboard ploughing slows evolution of resistance and reduces long-term weed populations in no-till systems. *Agric. Syst.* **2015**, *139*, 66–75. [CrossRef]
27. Skaalsveen, K.; Ingram, J.; Clarke, L.E. The effect of no-till farming on the soil functions of water purification and retention in north-western Europe: A literature review. *Soil Till. Res.* **2019**, *189*, 98–109. [CrossRef]
28. Korec, P.; Lauko, V.; Tolmáči, L.; Zubrický, G.; Mičietová, E. *Region and Districts of Slovakia. A New Administrative Structure*; Q111: Bratislava, Slovakia, 1997; 391p.
29. WRB. *World Reference Base for Soil Resources 2015: International Soil Classification System for Naming Soils and Creating Legends for Soil Maps World Soil Resources Reports No. 198*; FAO: Rome, Italy, 2015.
30. Sarkar, D.; Haldar, A. *Physical and Chemical Methods in Soil Analysis*; New Age International (P) Ltd.: Delhi, India, 2005; 228p.
31. Van Reeuwijk, L.P. *Procedures for Soil Analysis*; International Soil Reference and Information Centre: Wageningen, The Netherlands, 2002.
32. Orlov, D.S.; Grišina, L.A. *Chemical Analysis of Humus*; IMU: Moskva, Russia, 1981; 272p.

33. Loginov, W.; Wisniewski, W.; Gonet, S.S.; Ciescinska, B. Fractionation of organic carbon based on susceptibility to oxidation. *Pol. J. Soil Sci.* **1987**, *20*, 47–52.
34. Blair, G.J.; Lefroy, R.D.B.; Lisle, L. Soil carbon fractions, based on their degree of oxidation, and the development of a Carbon Management Index for agricultural systems. *Austr. J. Agric. Res.* **1995**, *46*, 1459–1466. [CrossRef]
35. Ghani, A.; Dexter, M.; Perrott, K.W. Hot-water extractable carbon in soils: A sensitive measurement for determining impacts of fertilisation, grazing and cultivation. *Soil Biol. Biochem.* **2003**, *35*, 1231–1243. [CrossRef]
36. Ranst, E.V.; Dumon, M.; Tolossa, A.R.; Cornelis, J.-T.; Stoops, G.; Vandenberghe, R.E.; Deckers, J. Revisiting ferrolysis processes in the formation of Planosols for rationalizing the soils with stagnic properties in WRB. *Geoderma* **2011**, *163*, 265–274. [CrossRef]
37. Whalen, J.K.; Chang, C. Macroaggregate characteristics in cultivated soils after 25 annual manure applications. *Soil Sci. Soc. Am. J.* **2002**, *66*, 1637–1647. [CrossRef]
38. An, S.; Mentler, A.; Mayer, H.; Blum, W.E.H. Soil aggregation, aggregate stability, organic carbon and nitrogen in different soil aggregate fractions under forest and shrub vegetation on the Loess Plateau, China. *Catena* **2010**, *81*, 226–233. [CrossRef]
39. Wei, X.; Shao, M.; Gale, W.J.; Zhang, X.; Li, L. Dynamics of aggregate-associated organic carbon following conversion of forest to cropland. *Soil Biol. Biochem.* **2013**, *57*, 876–883. [CrossRef]
40. Grandy, A.S.; Robertson, G.P. Initial cultivation of a temperate-region soil immediately accelerates aggregate turnover and CO_2 and N_2O fluxes. *Glob. Chang. Biol.* **2006**, *12*, 1507–1520. [CrossRef]
41. Six, J.; Paustian, K. Aggregate-associated soil organic matter as an ecosystem property and a measurement tool. *Soil Biol. Biochem.* **2014**, *68*, A4–A9. [CrossRef]
42. Ariani, M.; Hanudin, E.; Haryono, E. The effect of contrasting soil textures on the efficiency of alternate wetting-drying to reduce water use and global warming potential. *Agr. Water Manag.* **2022**, *274*, 107970. [CrossRef]
43. Brax, M.; Buchmann, C.; Kenngott, K.; Schaumann, G.E.; Diehl, D. Influence of the physico-chemical properties of root mucilage and model substances on the microstructural stability of sand. *Biogeochemistry* **2020**, *147*, 35–52. [CrossRef]
44. Cai, A.; Feng, W.; Zhang, W.; Xu, M. Climate, soil texture, and soil types affect the contributions of finefraction-stabilized carbon to total soil organic carbon in different land uses across China. *J. Environ. Manag.* **2016**, *172*, 2–9. [CrossRef]
45. Luster, J.; Kalbitz, K.; Lennartz, B.; Rinklebe, J. Properties, processes and ecological functions of floodplain, peatland, and paddy soils. *Geoderma* **2014**, *228–229*, 1–4. [CrossRef]
46. Rychtecká, P.; Samec, P.; Rosíková, J. Floodplain forest soil series along the naturally wandering gravel-bed river in temperate submontane altitudes. *Catena* **2023**, *222*, 106830. [CrossRef]
47. Vásconez Navas, L.K.; Becker, J.N.; Heger, A.; Gröngröft, A.; Eschenbach, A. Are active and former floodplain soils of the lower middle Elbe similar? A study of soil characteristics and possible implications for forest restoration. *Catena* **2023**, *222*, 106814. [CrossRef]
48. Mayer, M.; Krause, H.-M.; Fliessbach, A.; Mäder, P.; Steffens, M. Fertilizer quality and labile soil organic matter fractions are vital for organic carbon sequestration in temperate arable soils within a long-term trial in Switzerland. *Geoderma* **2022**, *426*, 116080. [CrossRef]
49. Christensen, B.T.; Sörensen, L.H. The distribution of native and labelled carbon between soil particle size fractions isolated from long-term incubation experiments. *J. Soil Sci.* **1985**, *36*, 219–229. [CrossRef]
50. Laborde, J.P.; Wortmann, C.S.; Blanco-Canqui, H.; Lindquist, J.L. Modeling soil texture and residue management effects on conservation agriculture productivity in Nepal. *Soil Till. Res.* **2021**, *213*, 105113. [CrossRef]
51. Ndzana, G.M.; Zhang, Y.; Yao, S.; Hamer, U.; Zhang, B. The adsorption capacity of root exudate organic carbon onto clay mineral surface changes depending on clay mineral types and organic carbon composition. *Rhizosphere* **2022**, *23*, 100545. [CrossRef]
52. Oades, J.M. The retention of organic matter in soils. *Biogeochem* **1988**, *5*, 35–70. [CrossRef]
53. Du Laing, G.; Rinklebe, J.; Vandecasteele, B.; Meers, E.; Tack, F.M.G. Trace metal behavior in estuarine and riverine floodplain soils and sediments: A review. *Sci. Total Environ.* **2009**, *407*, 3972–3985. [CrossRef]
54. Rinklebe, J.; Shaheen, S.M. Assessing the mobilization of cadmium, lead, and nickel using a seven-step sequential extraction technique in contaminated floodplain soil profiles along the central Elbe River, Germany. *Water Air Soil Poll.* **2014**, *225*, 2039. [CrossRef]
55. McDonald, G.K.; Taylor, J.; Verbyla, A.; Kuchel, H. Assessing the importance of subsoil constraints to yield of wheat and its implications for yield improvement. *Crop Pasture Sci.* **2013**, *63*, 1043–1065. [CrossRef]
56. Willems, A.B.; Augustenborg, C.A.; Hepp, S.; Lanigan, G.; Hochstrasser, T.; Kammann, C.; Müller, C. Carbon dioxide emissions from spring ploughing of grassland in Ireland. *Agr. Ecosys. Environ.* **2011**, *144*, 347–351. [CrossRef]
57. Cantero-Martínez, C.; Angás, P.; Lampurlanés, J. Long-term yield and water use efficiency under various tillage systems in Mediterranean rainfed conditions. *Ann. Appl. Biol.* **2007**, *150*, 293–305. [CrossRef]
58. López-Garrido, R.; Madejón, E.; Murillo, J.M.; Moreno, F. Soil quality alteration by mouldboard ploughing in a commercial farm devoted to no-tillage under Mediterranean conditions. *Agr. Ecosys. Environ.* **2011**, *140*, 182–190. [CrossRef]
59. Dalal, R.C.; Henderson, P.A.; Glasby, J.M. Organic matter and microbial biomass in a vertisol after 20 yr of zero-tillage. *Soil Biol. Biochem.* **1991**, *23*, 435–441. [CrossRef]
60. Koch, H.J.; Stockfisch, N. Loss of soil organic matter upon ploughing under a loess soil after several years of conservation tillage. *Soil Till. Res.* **2006**, *86*, 73–83. [CrossRef]

61. Paustian, K.; Collins, H.P.; Paul, E.A. Management controls on soil carbon. In *Soil Organic Matter in Temperate Agroecosystems*; Paul, E.A., Paustian, K., Elliott, E.T., Cole, C.V., Eds.; CRC Press: Boca Raton, FL, USA, 1997; pp. 15–49.
62. Sisti, C.P.J.; Santos, H.P.; Kohhann, R.; Alves, B.J.R.; Urquiaga, S.; Boddey, R.M. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. *Soil Till. Res.* **2004**, *76*, 39–58. [CrossRef]
63. Jantalia, C.P.; Resck, D.V.S.; Alves, B.J.R.; Zotarelli, L.; Urquiaga, S.; Boddey, R.M. Tillage effect on C stocks of a clayey Oxisol under a soybean-based crop rotation in the Brazilian Cerrado region. *Soil Till. Res.* **2007**, *95*, 97–109. [CrossRef]