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Long-term contrasting tillage in Cambisol: effect on water-stable aggregates, macropore network and soil chemical properties**

Mykola Kochiieru[1]*, *Virginijus Feiza*[1], *Dalia Feizienė*[1], *Krzysztof Lamorski*[2], *Irena Deveikytė*[1], *Vytautas Seibutis*[1], *and Simona Pranaitienė*[1]

[1]Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Instituto ave. 1, Akademija, Kėdainiai distr., Lithuania
[2]Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, 20-290 Lublin, Poland

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A b s t r a c t. The aggregate stability of the soil is subject to the influence of anthropogenic factors and is of great interest all over the world. The research aimed to quantify the correlations between soil organic carbon, total nitrogen, total phosphorus, and total potassium, soil macropore parameters and water-stable aggregates under no-tillage and conventional tillage in Cambisol. The content of water-stable aggregates and macroporosity tended to increase in the following order: conventional tillage (returned residues) < conventional tillage (removed residues) < no-tillage (removed residues) < no-tillage (returned residues) in both fertilizations. The relationships between total nitrogen and various soil factors were investigated: soil organic carbon ($r=0.65$, $p<0.05$), total phosphorus ($r=0.65$, $p<0.05$), were statistically significant. Soil organic carbon and total nitrogen were positively correlated with water-stable aggregates ($r=0.81$, $p<0.01$ and $r=0.68$, $p<0.05$, respectively), whereas the relationship between total potassium and water-stable aggregates was negative. The relationship between total phosphorus and water-stable aggregates ($r=0.62$, $p<0.05$) was positive. The soil chemical properties, macropores and water-stable aggregates that were averaged across the residues and fertilizations were higher in no-tillage than in conventional tillage. Soil organic carbon, total nitrogen and total phosphorus all had a positive direct influence on the formation of water-stable aggregates under different tillage conditions. Since our results are largely based on correlations, the mechanisms of interaction between the soil chemical properties, water-stable aggregates and the formation of pores in the soil need to be explored further in future investigations.

K e y w o r d s: Cambisol, conventional tillage, no-tillage, X-ray computed tomography, soil organic carbon

INTRODUCTION

The influence of anthropogenic factors on the formation of the structure of the soil is of great importance in terms of both agronomy and climate. Brevil *et al.* (2015) wrote that different management practices often lead to a change in the soil's biological, physical, and chemical properties, which in turn leads to changes in the functions of the soil. Management practices to sustain crop yields are also necessary in order to conserve or enhance crop yields and their quality. Soil nutrient concentrations (N, P, K, and organic C) are accurate indicators of soil quality and productivity due to their beneficial effects on the physical and chemical properties of the soil. Soil organic carbon (SOC) is increasingly viewed as the main indicator of soil quality (Feizienė *et al.*, 2018). Soil organic carbon content is essential to the

*Corresponding author e-mail: mykola.kochiieru@lammc.lt
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formation of aggregates. Soil organic content and quality have been reported to be affected by soil management practices (Simon *et al.*, 2009). Kochiieru *et al.* (2020a) wrote that one of the main factors for water-stable aggregates in various types of land use in Cambisol and Retisol was the SOC content. Soil aggregation is an important component of the soil that indirectly affects aeration and mechanical resistance (Haydu-Houdeshell *et al.*, 2018). The aggregation of the soil and soil chemical properties are important indicators of the dynamics of soil fertility because they represent changes in soil management (Kochiieru *et al.*, 2020a). Kochiieru *et al.* (2020a) found that the content of water-stable aggregates in reduced tillage was higher than that in conventional tillage in the Cambisol and Retisol.

By using a quantitative assessment of soil porosity, it may be understood how substances move in the soil. Currently, X-ray computed tomography is widely used to study soil macroporosity (Gackiewicz *et al.*, 2022). With the help of this modern method, soil porosity, as well as the shape, size and other characteristics of soil pores are determined, visualizations of the pores in 3D are also available (Hu *et al.*, 2016). Many studies have been aimed at evaluating the response of soil pore properties to changes in the structure of the soil (Yang *et al.*, 2018), the division of macropores into different macropore types (Fukumasu *et al.*, 2022), the influence of soil wetting and drying cycles on pore structure (Pires *et al.*, 2020), and the change in macropore networks in soil chronology (Musso *et al.*, 2019). Meng *et al.* (2017) quantified the macropore network of the soil in different highland forest communities. The evaluation of macropore networks and the visualization of them in 3D may be used to develop an understanding of the parameters of macropores and their physical functions, as well as to predict their dynamics in different land uses and soil types (Kochiieru *et al.*, 2020a). Wang *et al.* (2019) used X-ray computed tomography to evaluate the impact of land use transition from rice to vegetables on the quality of the soil structure and found a significant relationship between the degradation of soil structure and a decrease in soil organic matter. Hu *et al.* (2016) wrote about the importance of macropores as ways to transfer air and substances in the soil. Different types of macropores have various functions which are related in different ways to the physical (Singh *et al.*, 2021) and chemical properties of the soil. Xu *et al.* (2019) found that soil organic matter increased the total soil porosity, and the volume of both the small and medium size pores. Hu *et al.* (2016) wrote that the variability in the transfer of soluble substances affects soil voids and cracks between the soil aggregates, which increases the volume of soil porosity. Several studies have been published to characterize the macropore structure parameters using X-ray computed tomography, such as macropore volumes and the size distribution of macropores (Hu *et al.*, 2015) for different land uses and soil types (Kochiieru *et al.*, 2020b; 2022). The main factors influencing the parameters of the soil macropores are the types of soil and land use (Luo *et al.*, 2010; Kochiieru *et al.*, 2020b). Hu *et al.* (2015) found that anthropogenic impacts have greatly affected the soil pores in the pastures of Northern China.

The research aimed to quantify the relationships between the soil chemical properties (soil organic carbon, total nitrogen, total phosphorus, and total potassium), macropore parameters, and water-stable aggregates in the topsoil under contrasting tillage applications conventional tillage (CT) and no-tillage (NT) in different fertilization and plant residue management systems. Our investigations were focused on the Cambisol, the Central Lithuania Lowland as the most productive soil area for agriculture production is located there.

MATERIALS AND METHODS

The study was conducted in Central Lithuania with an average annual temperature of 6.2° and an average annual rainfall of 700 mm. In the experimental field of the Institute of Agriculture, the Lithuanian Research Centre for Agriculture and Forestry (LAMMC), the soil type was determined to be Cambisol (loam, drained, Endocalcaric, Endogleyic) using WRB soil classification system (2015).

The experimental treatments consisted of two soil tillage systems (Factor A: – conventional tillage (CT), no-tillage (NT), two fertilization levels (Factor B: 1 – not fertilized, 2 – fertilized with mineral NPK fertilizers), and two plant residue management systems (Factor C: 1 – plant residues removed, 2 – plant residues returned). The crop grown in the investigation field was spring triticale (× *Triticosecale* Wittm.) in 2019. The tillage systems were investigated in a long-term field trial that was established in 1999. Conventional tillage consists of stubble cultivation and deep ploughing. Also, a day before sowing, pre-sowing tillage using CT was carried out. Direct drilling into NT and CT was performed using a flat double-disc seed drill. Fertilizers were applied during pre-sowing tillage. The basic properties of the soil are shown in Table 1.

Soil samples were taken using plastic cylinders and steel cylinders from a 5-10 cm soil depth in August 2019. Plastic cylinders with a diameter of 50 mm were used to scan the soil. Steel cylinders with a diameter of 53 mm were intended to transport the soil samples. One soil column with a 46 mm diameter and a height of 50 mm was selected for scanning using computed tomography. Soil macropores were studied using a GE Nanotom 180S device at the Institute of Agrophysics of the Polish Academy of Sciences. VG Studio Max 2.0, software Avizo 9, and Fiji (Schindelin *et al.*, 2012) were used for the image analysis. The research results included the macropore volumes, surface area, and the diameter of the macropores. A more detailed description of the computed tomography analysis may be found in the study by Kochiieru *et al.* (2022). The classification of the macropores was determined: coarse >5 mm, medium 2-5 mm, fine 1-2 mm, and very fine 0.075-1 mm according to Brewer (1964).

Table 1. Soil texture composition at study site (n = 3)

Tillage (Factor A)	Fertilization (Factor B)	Residues (Factor C)	Soil texture composition (%)			Texture
			Sand >0.05 mm	Silt 0.002-0.05 mm	Clay <0.002 mm	
Conventional tillage	Not fertilized	Removed	50.50 ± 0.4	38.30 ± 2.5	11.20 ± 2.1	Loam
		Returned	47.10 ± 0.2	39.53 ± 0.9	13.37 ± 0.9	Loam
	Fertilized	Removed	51.07 ± 0.5	35.27 ± 1.5	13.66 ± 1.5	Loam
		Returned	48.97 ± 0.4	37.53 ± 1.6	13.50 ± 1.9	Loam
No-tillage	Not fertilized	Removed	51.73 ± 1.6	38.07 ± 1.7	10.20 ± 0.2	Loam
		Returned	49.87 ± 0.7	38.37 ± 0.2	11.76 ± 0.7	Loam
	Fertilized	Removed	50.80 ± 1.9	37.50 ± 1.0	11.70 ± 1.9	Loam
		Returned	48.20 ± 1.7	38.73 ± 1.9	13.07 ± 0.7	Loam

± Standard error of soil texture composition.

Soil samples for water-stable aggregates (WSA) analysis were collected for different treatments from a 0-10 cm soil depth in April 2019. The Retsch AS200 sieve shaker sieved air-dried soil to obtain soil aggregates of 1-2 mm. Water-stable aggregates were determined using a wet sieving apparatus (Eijkelkamp Agrisearch Equipment, the Netherlands). Four replications of WSA analysis were performed in the laboratory at LAMMC (Kochiieru *et al.*, 2020a).

Disturbed soil samples were taken from a 0-10 cm soil depth in April 2019. The soil organic carbon content was investigated by applying photometric carbon determination using Tyurin's method. The total nitrogen (N_{total}) content of the soil was determined using the Kjeldahl method. The total potassium (K_{total}) was quantified using a Perkin Elmer Analyst atomic absorption spectrometer. The total phosphorus (P_{total}) content was determined spectrophotometrically at a wavelength of 430 nm using a Cary 50 UV-Vis spectrophotometer. Three replications of chemical analyses were performed in the laboratory at LAMMC.

A 3-factorial ANOVA (tillage x fertilization x residues) was used. A data evaluation was carried out using the statistical software package SAS 7.1 (SAS Inc., USA). For data comparison, Duncan's multiple range tests with probability levels $p < 0.05$ and $p < 0.01$ were used. Also, in this study, Pearson correlation analyses of the relationship between the different parameters were carried out.

RESULTS AND DISCUSSION

The aggregation of the soil is considered to be the most important factor in the sustainability of soil aggregates, and it also indicates the quality of the soil (Sarker *et al.*, 2018). The effect of tillage on WSA was statistically significant at $p < 0.001$, with the exception of residues ($p < 0.984$) and fertilization ($p < 0.422$) which did not have a significant effect (Table 2). The water-stable aggregate content, averaged across different residues and fertilizations, was 48% lower for the conventional tillage than for the no-tillage system. The WSA content averaged across different tillage systems and residues was 9.8% lower in treatments with fertilizers than without fertilization.

The effect of tillage under different residue methods for water-stable aggregate changes was statistically significant at $p < 0.001$ in both types of fertilization (Table 3).

It was found that water-stable aggregate content tended to decrease in the following order: no-tillage (returned residues) > no-tillage (removed residues) > conventional tillage (removed residues) > conventional tillage (returned residues) for both fertilizations (Table 3). This shows that residues and tillage had a different effect on water-stable aggregates. Intensive anthropogenic activity causes a decrease in the water stability of aggregates in the 0-10 cm soil layer. Our results are consistent with those of An *et al.* (2010) which state that intensive soil tillage reduced sustainable soil aggregates which in turn affected soil quality.

3D visualizations of soil macropores at a 5-10 cm depth under different soil management regimes with and without fertilizer are shown in Figs 1 and 2. Hu *et al.* (2015) wrote that the soil type, land use, and anthropogenic activity all influence the soil pore parameters. The small and continuously distributed macropore network probably consists of inter-aggregate macropores such as those formed by freeze-thaw or wet-dry conditions (Luo *et al.*, 2010) and during the formation of pores and canals by the roots of plants and soil fauna. The macropores in conventional tillage were less abundant as compared to the macropore network in arable land under the no-tillage system (Figs 1-2).

The characteristics of the macropores varied with different treatments (Table 4).

The content of coarse macropores within the tillage system ranged from zero to 0.11% in conventional tillage, and from zero to 0.79% in no-tillage. The coarse macropores averaged across residues and fertilizations were 91% higher for NT than in the arable land under CT (Table 4).

Table 2. Average content ± standard error of water-stable aggregates in relation to the different type of tillage, residues, and fertilization (n = 12)

Tillage (Factor A)	Fertilization (Factor B)	Residues (Factor C)	Water-stable aggregates (%)	Actions		
				A	B	C
Conventional tillage			31.29b ± 1.81	**		
No-tillage			60.41a ± 1.50			
	Not fertilized		48.13a ± 3.85		ns	
	Fertilized		43.42a ± 4.24			
		Removed	45.68a ± 2.70			ns
		Returned	45.81a ± 5.13			
Interactions:						
A x B			**			
A x C			**			
B x C			ns			
A x B x C			**			

Data followed by the same letters are not significantly different at $p < 0.05$. The least significant difference at: *$p < 0.05$ and **$p < 0.01$, ns – not significant.

Table 3. Effect of tillage on water-stable aggregates under different modes of fertilization (n = 4)

Tillage	Residues	Water-stable aggregates (%)	
		Not fertilized	Fertilized
Conventional tillage	Removed	42.18c ± 1.74	30.67c ± 1.46
	Returned	27.51d ± 0.42	24.73d ± 0.97
No-tillage	Removed	55.69b ± 1.24	54.21b ± 1.56
	Returned	67.02a ± 1.01	64.19a ± 0.78
F		203.5	232.4
Pr > F		0.001	0.001

± Standard error of water-stable aggregates.

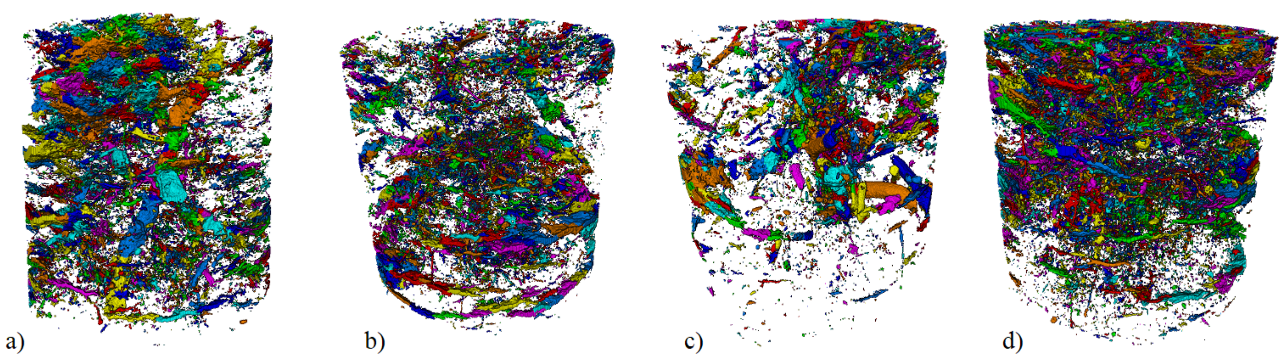

Fig. 1. 3D visualization of soil macropores at 5-10 cm depth under different soil management regimes without mineral NPK fertilizer application: a – conventional tillage, residues removed; b – conventional tillage, residues returned; c – no-tillage, residues removed; d – no-tillage, residues returned. Different colours are used to distinguish between the individual macropores detected using a labelling procedure.

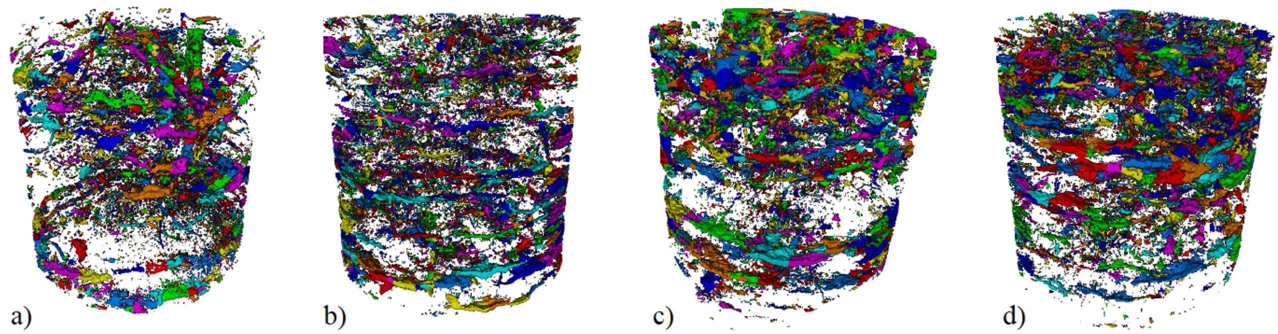

Fig. 2. 3D visualization of soil macropores at a 5-10 cm depth for different soil management regimes with mineral NPK fertilizer application: a – conventional tillage, residues removed; b – conventional tillage, residues returned; c – no-tillage, residues removed; d – no-tillage, residues returned. Different colours are used to distinguish between the individual macropores detected using a labelling procedure.

Table 4. Volume of different class-size of macropores under different soil tillage fertilization and residues management (n = 1)

Tillage (Factor A)	Fertilization (Factor B)	Residues (Factor C)	Volume of different size-class of macropores (%)			
			Coarse	Medium	Fine	Very fine
Conventional tillage	Not fertilized	Removed	0.11	1.26	0.86	0.46
		Returned	0.00	0.83	0.68	0.46
	Fertilized	Removed	0.00	0.64	0.82	0.48
		Returned	0.00	0.48	0.65	0.47
	Average		0.03	0.80	0.75	0.47
No-tillage	Not fertilized	Removed	0.00	1.33	0.77	0.25
		Returned	0.00	0.91	1.77	0.84
	Fertilized	Removed	0.79	1.07	1.17	0.34
		Returned	0.45	1.52	1.29	0.46
	Average		0.31	1.21	1.25	0.47

The volume of the medium macropores within the tillage system amounted to values ranging from 0.48 to 1.26% in conventional tillage, and 0.91-1.52% in no-tillage. The average volume of the medium macropores was 34% lower under the CT system than in the arable land under NT (Table 4).

The volume of fine macropores within the tillage system ranged from 0.65 to 0.86% under conventional tillage, while it ranged from 0.77-1.77% under no-tillage. The fine macropores averaged across residues and fertilizations were 40% higher under NT than in arable land under CT (Table 4). The content of very fine macropores within the tillage system ranged from 0.46 to 0.48% in conventional tillage, and 0.25-0.84% in no-tillage. The average volume of the medium macropores was 0.47% in both arable lands.

The average content of the macropores tended to decrease in the following order: medium > fine > very fine > coarse macropores in the arable land under conventional tillage (Table 4). Similar results were obtained under conventional tillage in the Retisol (Kochiieru *et al.*, 2020b).

The macropore characteristics under different soil management systems with different fertilization regimes and residues are listed in Table 5. The soil samples in the arable land under no-tillage had the largest total macropore surface area within the tillage system (12 513-3 1247 mm^2) and their volume of macropores lay within quite a narrow range (2.35-3.73%). However, the lowest surface area (15 142-19 127 mm^2) and macroporosity (1.60-2.69%) were determined in conventional tillage. While the average total pore length was higher in conventional tillage than in no-tillage.

The macroporosity content tended to increase in the following order: conventional tillage (returned residues) < conventional tillage (removed residues) < no-tillage (removed residues) < no-tillage (returned residues) in both fertilizations (Table 5, Figs 1-2). This shows that the residues had an effect on the volume of the macropore that varied between the different tillage regimes. Intensive anthropogenic activity causes changes that reduced the stability of the aggregates and thereby reduced the volume of macropores.

Table 5. Macropore characteristics under different soil tillage, fertilization and residues management (n = 1)

Tillage (Factor A)	Fertilization (Factor B)	Residues (Factor C)	Macroporosity (%)	Total pore length (mm)	Total surface area (mm^2)	Mean pore size (mm)
Conventional tillage	Not fertilized	Removed	2.69	12082	19127	0.17
		Returned	1.97	10911	15621	0.18
	Fertilized	Removed	1.94	11442	15142	0.18
		Returned	1.60	11974	15413	0.17
	Average		2.05	11602	16326	0.18
No-tillage	Not fertilized	Removed	2.35	6143	12513	0.19
		Returned	3.52	19355	31247	0.19
	Fertilized	Removed	3.37	8238	18251	0.20
		Returned	3.73	11571	23253	0.19
	Average		3.24	11327	21316	0.19

Table 6. Soil chemical properties ± standard error in relation to different soil tillage, fertilization modes and residues management strategies (n = 9)

Tillage (Factor A)	Fertilization (Factor B)	Residues (Factor C)	SOC	N_{total}	P_{total}	K_{total}
			($g\ kg^{-1}$)			
Conventional tillage			8.33b ±0.14	0.78b ±0.02	0.39b ±0.01	4.60a ±0.09
No-tillage			9.29a ±0.10	0.93a ±0.02	0.48a ±0.02	4.53a ±0.08
	Not fertilized		8.68a ±0.22	0.84a ±0.03	0.40b ±0.01	4.70a ±0.07
	Fertilized		8.93a ±0.15	0.88a ±0.03	0.48a ±0.02	4.43b ±0.08
		Removed	8.88a ±0.14	0.80b ±0.02	0.45a ±0.02	4.67a ±0.06
		Returned	8.73a ±0.23	0.91a ±0.03	0.43a ±0.02	4.46a ±0.09
Actions and interactions:						
A			**	**	**	ns
B			ns	ns	**	*
C			ns	**	ns	ns
A x B			**	**	**	**
A x C			**	**	**	ns
B x C			ns	*	*	**
A x B x C			**	**	**	**

Data followed by the same letters are not significantly different at $p < 0.05$. * and ** – the least significant difference at $p < 0.05$ and $p < 0.01$, respectively; ns – not significant. SOC – soil organic carbon, N_{total} – soil total nitrogen, P_{total} – soil total phosphorus, K_{total} – soil total potassium.

Soil management causes changes in the organic matter of the soil. The chemical composition is usually determined in the organic material within the soil aggregates. An *et al.* (2010) documented that intensive soil tillage reduces the stability of aggregates, soil organic carbon, and the basic nutrients affecting soil quality. The content of SOC within the tillage system ranged from 7.55 to 8.72 g kg^{-1} in conventional tillage, and from 9.04 to 9.46 g kg^{-1} in no-tillage. Averaged across residues and fertilizations, SOC was 10% higher in no-tillage than in conventional tillage (Table 6). Feizienė *et al.* (2018) found that no-tillage in the Cambisol loam was superior to conventional tillage in terms of SOC sequestration in the topsoil. Jiao *et al.* (2020) wrote that intensive anthropogenic activity leads to a decrease in the content of SOC in the arable layer. The impact of anthropogenic activity on the topsoil may be characterized as that of soil with a disturbed structure due to the level of SOC as compared to natural soil such as that found in a forest (Kochiieru *et al.,* 2020a).

The soil total nitrogen (N_{total}) content within the tillage system was in the range of 0.73-0.88 g kg^{-1} in conventional tillage and 0.82-1.00 g kg^{-1} in the arable land of no-tillage. The N_{total} averaged across residues and fertilizations was 15% lower in conventional tillage than in no-tillage (Table 6).

The total phosphorus (P_{total}) content of the soil within the tillage system was within the range of 0.35-0.42 g kg^{-1} in conventional tillage and 0.41-0.56 g kg^{-1} in the arable land of no-tillage. The soil P_{total} in no-tillage was 19% higher than in the arable land of conventional tillage. Plants absorb significant amounts of soil phosphorus, but they can also be sources of various phosphorus losses after exposure to freeze-thaw cycles in wintertime (Kochiieru *et al.*, 2020a) under conditions of uneven land use. Soil total potassium (K_{total}) content within the tillage system was within the range of 4.25-4.87 g kg^{-1} in conventional tillage and 4.25-4.79 g kg^{-1} in arable land with no-tillage. The K_{total} value, averaged across residues and fertilizations was 2% lower in the arable land of no-tillage than it was for conventional tillage.

The number of chemical elements has an impact on aggregate formation and soil stability. The pore characteristics are affected by the properties of the soil, primarily the organic matter content (Guo *et al.*, 2018). Kalhoro *et al.* (2017) suggested that WSA stability is related to soil organic matter as one of the important factors in the aggregation process.

Soil organic carbon was positively correlated with N_{total} ($r=0.65$, $p<0.05$) and P_{total} ($r=0.77$, $p<0.01$), while the relationship with K_{total} was insignificant. The greatest effect of an increase in SOC was demonstrated with fine size macropores ($r=0.70$, $p<0.05$) and total macroporosity ($r= 0.73$, $p<0.01$, Table 7). The same results were obtained by Kochiieru *et al.* (2022) in a different type of soil. Xu *et al.* (2020) established a relationship between soil organic carbon and total macroporosity ($r=0.81$, $p<0.01$). The total nitrogen content was positively correlated with many of the researched factors (soil organic carbon content ($r=0.65$, $p<0.05$), P_{total} ($r=0.65$, $p<0.05$), fine size macropores ($r=0.75$, $p<0.01$) and total macroporosity ($r=0.71$, $p<0.05$), whereas the influence of K_{total} was negative for SOC. In this study, increasing the number of small macropores revealed the greatest potential for increasing N_{total}. The enlargement of any class of macropores showed no positive effect of increasing K_{total}. Within the 0-10 cm layer, the SOC and N_{total} positively correlated with WSA ($r=0.81$, $p<0.01$ and $r=0.68$, $p<0.05$, respectively). The correlation between WSA and SOC ($r=0.81$; Table 7) showed the dominant effect of the contribution of soil organic carbon to the formation of aggregate stability. The same results were obtained by Kochiieru *et al.* (2020a). Haydu-Houdeshell *et al.* (2018) found a relationship between aggregate stability and organic carbon ($r^2=0.67$). Mahmoodabadi and Ahmadbeigi (2013) indicated that the stability of the aggregate is influenced to a high degree by the effect of the system of tillage on organic carbon. The total phosphorus accumulation in Cambisol reacted positively to a significant extent to the increase in the volume of fine size macropores ($r=0.58$, $p<0.05$), and the total volume of macropores ($r=0.74$, $p<0.01$). P_{total} was positively correlated with WSA ($r=0.62$, $p<0.05$). The total potassium content (K_{total}) correlations with other indices that were researched were non-significant. K_{total} correlated negatively with water-stable aggregates (Kochiieru *et al.*, 2020a). There were significant relationships between the water-stable aggregates and medium-size macropores ($r=0.72$, $p<0.05$), fine-size macropores ($r=0.83$, $p<0.01$), and total volume macroporosity ($r=0.91$, $p<0.01$), while the relationships with the coarse and very fine size macropores were insignificant (Table 7).

Soils are important components in the cycling of many global nutrients. Anthropogenic activities greatly influence the porous network of the soil, its physical properties, and

Table 7. Matrix of correlations among various soil chemical properties, volume of macropores, and water-stable aggregates

Index	SOC	N_{total}	P_{total}	K_{total}	Volume of macropores				
					Coarse	Medium	Fine	Very fine	Macro
SOC (g kg^{-1})	1.00								
N_{total} (g kg^{-1})	0.65*	1.00							
P_{total} (g kg^{-1})	0.77**	0.65*	1.00						
K_{total} (g kg^{-1})	-0.32	-0.44	-0.22	1.00					
Coarse (%)	0.50*	0.44	0.89**	0.14	1.00				
Medium (%)	0.42	0.26	0.36	0.18	0.43	1.00			
Fine (%)	0.70*	0.75**	0.58*	-0.21	0.31	0.30	1.00		
Very fine (%)	0.14	0.39	-0.06	-0.26	-0.30	-0.29	0.68*	1.00	
Macro (%)	0.73**	0.71*	0.74**	-0.02	0.64*	0.68*	0.86**	0.30	1.00
WSA (%)	0.81**	0.68*	0.62*	-0.11	0.42	0.72*	0.83**	0.22	0.91**

The least significant difference at: $*p < 0.05$ and $**p < 0.01$. SOC – soil organic carbon, N_{total} – soil total nitrogen, P_{total} – soil total phosphorus, K_{total} – soil total potassium, WSA – water-stable aggregates, Macro – volume of macropores.

nutrient distribution. In addition, climate change affects the condition and functions of the soil. The most significant impact of climate change is manifested in the depth of soil freezing. For example, in the Nemoral environmental zone, soil freezing in winter has been unusually shallow and often short-lived. The maximum depth of soil freezing in recent years in different regions of Lithuania has ranged from 0 to 15 cm and was short-lived. This indicates that climate change determines new features of the structure and functions of soils. Soil macroporosity is known to influence water cycle processes such as nutrient transport and infiltration. Macropores are large pores that freely drain water under the action of gravity. This means that the relationship between the network of macropores, nutrients, and soil organic carbon in different land uses can cause different soil behaviour.

Many years of anthropogenic activity have dramatically changed the structure of the soil as compared to the naturally developed soil in the forest.

CONCLUSIONS

1. Soil chemical properties, the soil macropore network, and water-stable aggregates averaged across residues and fertilizations were higher in no-tillage conditions than under conventional tillage.

2. The content of water-stable aggregates and macroporosity tended to decrease in the following order: no-tillage (returned residues) > no-tillage (removed residues) > conventional tillage (removed residues) > conventional tillage (returned residues) in both fertilizations.

3. Soil organic carbon, total nitrogen, and total phosphorus had a positive direct effect on the formation of water-stable aggregates.

4. Since our results were largely based on correlations, the mechanisms of interaction between the chemical properties of the soil, water-stable aggregates and the formation of pores in the soil should be explored further in future investigations.

Conflict of interest: The authors declare that there is no conflict of interest regarding the publication of this paper.

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