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The distribution of organic carbon, its forms and macroelements in agricultural soils

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Abstract

The objective of the present study was to estimate the distribution of soil organic carbon (SOC) and its forms (protected and labile organic carbon) and total nitrogen (N_{tot}), plant available phosphorus (P_2O_5) and pottassium (K_2O) within 0–30 cm layer of a ploughed horizon in agricultural soils as influenced by tillage and fertilisation. Research was carried out in two regions of Lithuania: in Central (sites I and II) and Northern (site III) parts of Middle Lithuanian Lowland. Tillage systems, including conventional tillage (CT) and no-tillage (NT), straw management methods and mineral fertilisation were investigated on a loam and sandy loam top layer of glacial morain *Eutric Endocalcaric Endostagnic Cambisol* in site I. Five fertilisation treatments were tested in a grassland with a sandy loam top layer of glacial morain *Endocalcaric Albic Brunic Endogleyic Arenosol* in site II: without fertilisation and fertilisation with separated liquid and separated solid digestates at rates of 85 and 170 kg ha^{-1} N. The field experiment on a glaciolacustrine *Eutric Endocalcaric Amphistagnic Endogleyic Cambisol* with clay loam in site III involved the following tillage systems: conventional tillage (CT), ploughless tillage (PT), ploughless tillage with lime sludge incorporation (PT + LS) and no-tillage with a cover crop for winter mulch (NT + WM). Long-term NT caused pronounced stratification of N_{tot}, available K_2O and SOC within the arable layer of *Eutric Endocalcaric Endostagnic Cambisol*. The highest accumulation of SOC and chemically protected-humified carbon in the grassland on an *Endocalcaric Albic Brunic Endogleyic Arenosol* was determined at the highest digestate rate of 170 kg ha^{-1} N. High SOC accumulation potential was shown by PT + LS in a *Eutric Endocalcaric Amphistagnic Endogleyic Cambisol*. This significantly increased the share of humified carbon fraction bound with calcium in 0–10 and 10–20 cm soil layers. Reduction of tillage intensity by applying PT and NT + WM increased the concentration of labile organic carbon in the soil, especially in the upper 0–10 cm layer. The lime sludge application reduced the amount of labile organic carbon by its incorporation with calcium in this amendment, while increasing the stability of carbon compounds. In *Eutric Endocalcaric Endostagnic Cambisol,* the mean results of 0–30 cm layer revealed that the share of F4 carbon fraction, resistant to degradation, in the SOC was significantly higher under NT than under CT.

Key words: digestate, fertilisation, labile and protected carbon, lime sludge, soil, tillage.

Introduction

Studies on the organic part of the soil were started more than 200 years ago, since it was already clear that soil organic matter (SOM) influenced plant growth, the vital physical and chemical properties of the soil, on which crop yields depend. SOM, whose main constituent is soil organic carbon (SOC), has been increasingly considered as an indicator of soil quality, one of the components of biosphere sustainability and stability (O'Rourke et al., 2015; Lal, 2018). The main functions of soil: biomass production, biodiversity stock, source of raw materials, storage, filtration and transformation of nutrients, materials and water, physical and cultural environment for humans, are directly dependent on the carbon stock. Forms of carbon (C) in the Earth's crust in the widest understanding can be divided into three groups: elemental C found in geological materials (graphite, coal) and as a product of incomplete combustion of organic matter (charcoal, graphite, soot); inorganic C – geological or soil parent materials, usually as carbonates: calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) and siderite

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($FeCO_3$), organic C – compounds of plant and animal origin at various stages of decomposition, ranging from 2 mm or more as crop residues, also plant debris referred to as particulate SOC with a size between 0.05 and 2 mm, and humus – highly decomposed materials less than 0.05 mm that are dominated by molecules attached to soil minerals (Jakhar et al., 2017; Ondrasek et al., 2019). SOC research has become particularly relevant because of the necessity to look for ways to reduce CO_2 emissions to the atmosphere by storing in the soil. Soils are known to have the unique and specific property to store large C quantities. They are estimated to contain about two to three times the amount of C stored in the atmosphere and vegetation in the total amount.

An increase in the global temperature because of radiative forcing of greenhouse gases (GHGs) in the atmosphere has been estimated at 0.6°C temperature during the 20th century and is projected to be 1.4 to 5.8°C by 2100 relative to 1990 (IPCC, 2001). An increase in the atmospheric concentration of CO_2 from 280 ppm in 1750 to 367 ppm in 1999 is attributed to emissions from fossil fuel combustion estimated at 270 ± 30 Pg C and land use change at 136 ± 55 Pg C. Due to intensive management, soil has lost 78 ± 12 Pg C, which is estimated from depletion of SOC pool. Most agricultural soils have lost from 50% to 70% of their original SOC resources, and the depletion is extended by further soil degradation and desertification. The restoration of degraded soils, conversion of agriculturally marginal lands to appropriate land use and the adoption of recommended management practices on agricultural soils can reverse degradative trends and lead to SOC sequestration (Stockmann et al., 2013).

The capacity of soils to store organic C represents a key function of soils that is not only decisive for climate regulation but also affects other soil functions (Ondrasek et al., 2019; Wiesmeier et al., 2019). Concentrations and stocks of SOC depend on the genetic properties of the soil and its use as well as other factors. Soil C assessment in different parts of the world requires methods that are appropriate to the circumstances. The variety of methods that have been developed and tested for use in different countries raises concerns about their comparability. Ensuring this comparability warrants serious international priority. In the case of C projects, credible and cost-effective techniques of monitoring changes in soil C still need to be developed. The speed and accuracy of analytical methods are mostly dependent on the technical facilities available. Based on the results of laboratory studies, C models are developed to predict ways to preserve and maximize C accumulation, realize C accumulation and sequestration potential. In terms these processes, it is very important to monitor soil changes, even though, the implementation of soil monitoring networks poses several scientific, technical and operational challenges (Smith et al., 2020).

SOC accumulation in the soil has not been given enough attention in Lithuania. Episodic investigations of SOM were done in Lithuania more than three decades ago and were limited to the 0–20 cm layer. Currently, at the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry SOC and soil quality parameters were comprehensively studied in the soil of agricultural systems differing in intensity (Feiziene et al., 2011; 2016; 2018; Slepetiene et al., 2011; Bogužas et al., 2015; Volungevicius et al., 2018). Humus, like other key agrochemical indicators, was also investigated in the Lithuania (Mažvila et al., 2010). In addition, more detailed quantitative and qualitative humus investigations in long-term experiments are being conducted (Liaudanskiene et al., 2013; Amalevičiūtė et al., 2014; Jokubauskaite et al., 2015; Staugaitis et al., 2016; Feiziene et al., 2018). Some agronomic studies were carried out on the changes in C in the deeper soil layers and throughout the profile, but in most cases, they were episodic, small-scale, without establishing the relationship with C sequestration and emission. In collaboration with UK researchers, in the context of international research, it was also a great opportunity to compare the scientific achievements in SOC and SOM research worldwide with the achievements in Lithuania (Jankauskas et al., 2006 a; b).

In agricultural soils, SOC changes are intensive due to the constant changes in soil use, tillage, fertilisation, especially with intensive technologies (Leifeld et al., 2005; Paustian et al., 2016). Therefore, it is very important to assess the alterations in SOC accumulation in the soil (0–30 cm layer) occurring due to the changes in land use, e.g., conversion of grassland or pasture to arable land and vice versa. It has been established how much SOC is stored in different soil groups, i.e. on arable land, grasslands, pastures or forest. However, there is a lack of data about C stock changes in specific soil groups due to land use conversion.

The objective of the present study was to estimate the distribution of soil organic carbon (SOC) and its forms (protected and labile organic carbon) and total N (N_{tot}), plant available phosphorus (P_2O_5) and potassium (K_2O) within 0–30 cm layer of a ploughed horizon in agricultural soils as influenced by tillage and fertilisation.

Materials and methods

Experimental sites, treatments and design. Research was carried out on agricultural soils in two regions: Central and Northern parts of Middle Lithuanian Lowland and three experimental sites of Lithuania.

Experimental site I: Akademija, Kėdainiai district. The research area was situated in the Central part of Middle Lithuanian Lowland (55°23′21.55″ N 23°52′09.50″ E). The data presented in this paper were collected from two long-term experiments on a glacial morain *Eutric Endocalcaric Endostagnic Cambisol* (Loamic, Aric, Drainic) according to WRB (2014). The investigations were carried out at Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry in two three-factorial field experiments established in 1999 according to the same trial design. One of them was set up on a loam soil, and the other was established on a sandy loam textured ploughed Ap horizon. Both field experiments had a split-split-plot design with four replications. Straw management methods were the main plots, tillage systems – conventional tillage (CT) and no-tillage (NT) – were as sub-plots, and fertilisation according to soil properties and target yield was as split-split-plots. Fertilisation was the same for all tillage and straw management treatments. Moreover, in phosphorous-rich loam, P fertilisers were not used.

Experimental site II: Surviliškis (55°26′03.07″ N 24°02′12.26″ E)*, Kėdainiai district* (Central part of Middle Lithuanian Lowland)*,* perennial grassland on a glacial morain *Endocalcaric Albic Brunic Endogleyic Arenosol* (Dystric) according to WRB (2014). The experiment including five fertilisation treatments was conducted in 2018: without fertilisation; fertilisation with separated liquid digestate 85 and 170 kg ha^{-1} N and with separated solid digestate 85 and 170 kg ha^{-1} N, based on the results of the chemical analysis of the digestate. A randomised experimental design with three field replicates was used. A plot size was 6 m^2. Dry and liquid digestate was spread on the grassland manually.

The experiment was laid out on a semi-natural grassland, established 10 years ago.

Experimental site III: Joniškėlis, Pasvalys district. The soil of the research area is a glaciolacustrine *Eutric Endocalcaric Amphistagnic Endogleyic Cambisol* (Clayic, Aric, Drainic) according to WRB (2014) with a clay loam Ap horizon. Research was carried out in the field experiment, established in 2006 at the Joniškėlis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry situated in the Northern part of Middle Lithuanian Lowland (56°02′19.23″ N 24°09′59.30″ E). This paper presents experimental data for the 2015–2017 period. Research design involved the following tillage systems: conventional (ploughing) tillage (CT), ploughless tillage (PT), ploughless tillage with lime sludge incorporation (PT + LS) and no-tillage with a cover crop for winter mulch (NT + WM). The experiment was conducted in the crop rotation: field pea → winter wheat → spring oilseed rape → spring barley. Cover crops were as follows: before field pea growing – a mixture of white mustard and oilseed radish, before spring oilseed rape – a mixture of field pea and common vetch and before spring barley growing – oats. Lime sludge (Ca-amendment) 7 t ha^{-1} was incorporated three times per rotation for spring crops during the 1st stage of the experiment (2007–2010), once per rotation for spring barley during the 2nd stage of the experiment (2011–2014), and during the 3rd stage of the experiment (2015–2018) lime sludge was not incorporated, but the effect of its previous incorporation was monitored. Straw of all crops was incorporated into the soil during tillage operations. The field experiment was arranged in a randomized single row design with four replicates.

Soil sampling. The soil samples in all experimental sites were collected annually from 0–10, 10–20 and 20–30 cm depths of ploughed Ap horizon after the main crop harvesting. Six to eight sub-samples per plot were taken randomly with a steel auger. For each treatment and for each soil depth, soil samples were prepared in three replicates. The samples were air-dried, visible roots and plant residues were removed manually. Then the samples were crushed and sieved through a 2-mm sieve and homogeneously mixed.

Laboratory analyses were performed at the Chemical Research Laboratory of the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry. For the analysis of soil organic carbon (SOC), humic substances C and labile water extractable organic carbon an aliquot of the samples was passed through a 0.25-mm sieve. The SOC content was determined by a spectrophotometric measurement at 590 nm after dichromatic oxidation and using glucose as a standard (Nikitin, 1999). The labile C content was determined by IR-detection after UV-catalysed persulfate oxidation. Soil clay fraction (particles <2 μm size) was isolated by the granulometric fractionation method of Schulz (2004) after sonication of soil aggregates. The C content in the clay fraction was determined by the Dumas method; the C content of the humus fractions was determined according to Ponomareva and Plotnikova (1980) modified Tyurin method. Chemodestructive fractionation for determination of easily oxidizable F1, F2, relatively stable F3 and resistant to degradation F4 fractions was performed according to the Popov and Tcyplenkov (1994) method, the procedure described in detail in Liaudanskienė et al. (2013). Total nitrogen (N_{tot}) content was determined by Kjeldahl method. The contents of plant available phosphorus (P_2O_5) and potassium (K_2O) were measured by extraction according to Egner-Riehm-Domingo (A-L) method. The acidity (pH) of the soil was determined by the potentiometric method in 1 M KCl (1:2.5, w/v) extract. Soil bulk density was determined for estimating nutrient and SOC amount within different soil layers. Bulk density was assessed during implementation of complex sandbox method procedures (Klute, 1986). P_2O_5 (*a*) and K_2O stocks (kg ha^{-1}) were calculated as follows: concentration (mg kg^{-1}) × bulk density (t m^{-3}) × 0.1 m.

Statistical analysis. The data were analysed using the software *SAS Enterprice*, version 7.1 (SAS Institute Inc., USA). The analysis of variance (*ANOVA*) was performed to determine the effects of management practices on soil chemical parameters, SOC content and its qualitative indices. The data were compared using Fisher's least significant difference (LSD) test at the probability levels of $P < 0.05$ and $P < 0.01$.

Results and discussion

Effect of soil management on SOC in morainic loam and sandy loam top layer. In loam, in the conventional tillage (CT) system straw removal caused 30% higher SOC stock within 0–30 cm soil layer than straw return. In no-tillage (NT) system this difference reached 24%. Application of mineral fertilisers reduced this difference due to tillage and residue interactions (Table 1). However, NT had the advantage over CT. On average, NT superiority over CT for SOC sequestration in loam reached 8% on the background without residues and 13% on the background with residues.

In contrast to loam, in sandy loam, in the CT system straw removal caused 7% lower SOC content within 0–30 cm soil layer than straw return. Conversely, in the NT system SOC content on the background with residues decreased by 10%, compared to residue removal (Table 1). NT had the advantage over CT only under residue removal. On average, NT superiority over CT for SOC sequestration on this background reached 4%. However, under residue return, SOC sequestration was 16% higher in CT than NT.

Influence of tillage, fertilisation and straw management on soil chemical properties. Nutrient stratification is a typical feature under long-term NT management. On loam, long-term NT practice without fertilisation under straw removal caused pronounced stratification of N_{tot}, available K_2O and SOC within the arable layer. The ratios of each index between 0–10 and 10–20 cm soil layers varied in the range of 1.08–1.39. Furthermore, mineral fertiliser application in NT system under straw removal reduced these ratios by 4–12%. Conversely, CT without fertilisation under residue removal resulted in higher content of N_{tot}, available P_2O_5 and K_2O and SOC in 10–20 cm than in 0–10 cm soil layer (Table 1). Crop fertilisation in the CT system under residue removal determined decrease of available P_2O_5 and K_2O and SOC content within all arable layers, compared to unfertilised treatments, while stratification ratio changed fractionally.

Long-term NT practice under straw returning, irrespective of fertilisation, substantially increased only available P_2O_5 and K_2O and SOC ratios between 0–10 and 10–20 cm soil layers. However, CT practice without fertilisation under straw returning did not change noticeably the ratios of all indices between 0–10 and 10–20 cm soil layers, compared to the data on the background without residues. However, CT practice with fertilisation under straw returning significantly reduced the values of all indices in all soil layers (Table 1).

On sandy loam, after residue removal, CT without fertilisation resulted in higher concentration of N_{tot}, available P_2O_5 and K_2O in 10–20 cm than in 0–10 cm

Table 1. Soil chemical parameters as influenced by long-term tillage, fertilisation and residue management in morainic loam and sandy loam *Eutric Endocalcianc Endostagnic Cambisol* (site I, 2016)

Treatment	Soil layer cm	Loam					Sandy loam				
		pH_{KCl}	N_{tot}	SOC	P_2O_5	K_2O	pH_{KCl}	N_{tot}	SOC	P_2O_5	K_2O
			t ha^{-1}		kg ha^{-1}			t ha^{-1}		kg ha^{-1}	
Straw removed											
CT without fertilisers	0–10	7.03	1.88	17.2	465	291	5.90	1.60	13.2	161	153
	10–20	7.10	1.93	18.0	481	302	5.97	1.62	12.2	153	152
	20–30	7.10	1.67	16.6	482	299	5.93	1.33	12.4	155	166
	Mean 0–30	*7.08*	*1.83*	*17.3*	*476*	*297*	*5.93*	*1.52*	*12.6*	*156*	*157*
	Σ 0–30		*5.48 c*	*51.8 b*	*1427 b*	*892 b*		*4.55 c*	*37.8 d*	*469 d*	*471 d*
	0–10:10–20	*0.99*	*0.97*	*0.96*	*0.97*	*0.96*	*0.99*	*0.99*	*1.08*	*1.05*	*1.01*
CT + NK fertilisers	0–10	6.97	1.92	15.9	388	265	5.47	1.67	14.2	188	175
	10–20	7.10	1.90	17.1	372	278	5.47	1.75	13.0	194	181
	20–30	7.07	1.70	16.6	360	273	5.27	1.33	13.5	192	176
	Mean 0–30	*7.04*	*1.84*	*16.5*	*373*	*272*	*5.40*	*1.58*	*13.6*	*191*	*177*
	Σ 0–30		*5.52 b*	*49.6 c*	*1120 c*	*817 c*		*4.75 b*	*40.7 b*	*574 c*	*532 c*
	0–10:10–20	*0.98*	*1.01*	*0.93*	*1.04*	*0.95*	*1.00*	*0.95*	*1.09*	*0.97*	*0.97*
NT without fertilisers	0–10	7.20	2.10	20.0	526	357	5.80	1.89	14.2	142	141
	10–20	7.23	1.86	18.5	641	289	5.83	1.73	15.2	135	135
	20–30	7.30	1.35	17.1	573	271	5.77	1.30	13.1	135	138
	Mean 0–30	*7.24*	*1.77*	*18.5*	*580*	*306*	*5.80*	*1.64*	*14.2*	*137*	*138*
	Σ 0–30		*5.31 d*	*55.6 a*	*1739 a*	*917 b*		*4.92 a*	*42.6 a*	*412 d*	*414 e*
	0–10:10–20	*1.00*	*1.13*	*1.08*	*0.82*	*1.24*	*0.99*	*1.09*	*0.93*	*1.05*	*1.04*
NT + NK fertilisers	0–10	7.33	2.19	18.3	524	426	5.37	1.87	13.6	236	196
	10–20	7.33	2.03	19.1	571	306	5.57	1.74	14.2	239	174
	20–30	7.40	1.52	16.0	565	255	5.73	1.28	11.3	182	170
	Mean 0–30	7.35	1.91	17.8	553	329	5.56	1.63	13.0	219	180
	Σ 0–30		*5.74 a*	*53.6 b*	*1660 a*	*987 a*		*4.89 a*	*39.1 c*	*657 b*	*539 c*
	0-10:10–20	*1.00*	*1.08*	*0.96*	*0.92*	*1.39*	*0.96*	*1.07*	*0.96*	*0.99*	*1.13*
Straw returned											
CT without fertilisers	0–10	6.70	1.86	13.4	324	224	6.20	1.51	14.3	174	180
	10–20	6.73	1.85	13.3	343	235	6.17	1.70	15.8	177	207
	20–30	6.70	1.51	11.3	380	280	6.27	1.33	13.1	195	196
	Mean 0–30	*6.71*	*1.74*	*12.7*	*349*	*246*	*6.21*	*1.51*	*14.4*	*182*	*195*
	Σ 0–30		*5.23 d*	*38.0 e*	*1048 c*	*738 d*		*4.54 c*	*43.2 a*	*546 c*	*584 b*
	0–10:10–20	*1.00*	*1.01*	*1.01*	*0.94*	*0.95*	*1.00*	*0.89*	*0.90*	*0.98*	*0.87*
CT + NPK fertilisers	0–10	6.53	1.79	12.8	250	238	6.17	1.65	13.7	245	212
	10–20	6.60	1.91	15.1	277	239	6.20	1.64	15.6	251	221
	20–30	6.57	1.45	12.1	258	249	6.27	1.30	12.1	220	195
	Mean 0–30	*6.57*	*1.72*	*13.3*	*262*	*242*	*6.21*	*1.53*	*13.8*	*238*	*209*
	Σ 0–30		*5.15 e*	*40.0 d*	*786 d*	*726 d*		*4.58 c*	*41.4 b*	*715 a*	*628 b*
	0–10:10–20	*0.99*	*0.94*	*0.85*	*0.90*	*1.00*	*1.00*	*1.01*	*0.88*	*0.98*	*0.96*
NT without fertilisers	0–10	6.83	2.03	15.2	329	246	5.87	1.72	12.3	152	164
	10–20	6.93	1.85	12.4	353	214	5.97	1.55	13.1	160	166
	20–30	6.83	1.57	13.1	398	204	6.03	1.10	9.8	195	155
	Mean 0–30	*6.86*	*1.82*	*13.6*	*360*	*221*	*5.96*	*1.46*	*11.8*	*169*	*162*
	Σ 0–30		*5.45 c*	*40.8 d*	*1079 c*	*664 e*		*4.37 d*	*35.3 e*	*506 d*	*486 d*
	0–10:10–20	*0.99*	*1.10*	*1.23*	*0.93*	*1.15*	*0.98*	*1.11*	*0.94*	*0.95*	*0.99*
NT + NPK fertilisers	0–10	6.60	2.11	17.4	297	281	5.13	1.84	13.2	205	240
	10–20	6.73	1.95	15.2	274	192	5.10	1.68	13.3	218	264
	20–30	6.77	1.53	14.8	282	190	5.47	1.29	11.4	160	220
	Mean 0–30	6.69	1.86	15.8	284	221	5.23	1.60	12.6	194	242
	Σ 0–30		*5.59 b*	*47.4 c*	*853 d*	*663 e*		*4.81 a*	*37.8 d*	*583 c*	*725 a*
	0–10:10–20	*0.98*	*1.08*	*1.14*	*1.08*	*1.46*	*1.01*	*1.10*	*0.99*	*0.94*	*0.91*

Note. CT – conventional tillage, NT – no-tillage, SOC – soil organic carbon; summarized data of each index, followed by the same letters are not significantly different at $p < 0.05$.

soil layer (Table 1), while SOC content was higher in 0–10 cm than in 10–20 cm layer. Long-term NT caused pronounced stratification of N_{tot} and available K_2O within arable layer, but SOC content was lower in 0–10 cm than in 10–20 cm soil layer. The SOC stratification ratio between the 0–10 and 10–20 cm layers was 0.93. Crop fertilisation with mineral NPK fertilisers in the CT system determined decrease of N_{tot}, available P_2O_5 and K_2O stratification ratio, compared to unfertilised treatments, while this ratio for SOC did not change. The analogous fertilisation in the NT system resulted in a decrease in N_{tot} and available P_2O_5 but had minor effect on other parameters within 0–20 cm soil layer.

After straw incorporation, under CT management, the stratification ratio of N_{tot}, available P_2O_5 and K_2O did not change noticeably, but stratification ratio of SOC significantly decreased, compared to the ratio on the background without residues. Under NT, this ratio significantly increased for N_{tot} and SOC, compared to the ratio on the background without crop residues.

Effect of soil management on SOC and agrochemical properties in glaciolacustrine clay loam. Soil pH in 0–10 and 10–20 cm layers remained almost unchanged with CT and PT, but in 20–30 cm layer increased significantly to 6.04 with CT (Table 2). The effect of the former Ca-amendment with PT in the third rotation was strongly significantly increased in all three layers, and in the whole 0–30 cm layer (pH = 6.69). In this soil management combination, also the greatest potential for C accumulation was observed: SOC increase in 0–10 cm layer was the highest and amounted to 26.13 t ha^{-1}. Significant increase in available P_2O_5 was determined in PT, PT + LS and NT + WM in 0–10 cm soil layer.

SOC stability. More stable C compounds are less degradable and decompose more slowly. The degradation of SOC determines which SOC compounds remain in the soil and what interactions take place between them. An increase in SOC stock can partly offset the anthropogenic greenhouse gas (GHG) emissions (Lal, 2003; Paustian

Table 2. Soil chemical parameters as influenced by tillage, Ca-amendment and cover crop in glaciolacustrine clay loam *Eutric Endocalcaric Amphistagnic Endogleyic Cambisol* (site III, 2017)

Treatment	Soil layer cm	pH_{KCl}	N_{tot}	SOC	P_2O_5	K_2O
			t ha^{-1}		kg ha^{-1}	
CT	0–10	5.80	2.30	22.21	190.5	563.6
	10–20	5.80	2.30	22.28	213.0	545.4
	20–30	6.04	1.88	16.49	204.0	489.9
	Mean 0–30	5.87	2.16	20.33	202.5	533.0
	0-10:10-20	1.00	1.00	1.00	0.89	1.03
PT	0–10	5.92	2.42	25.38	286.5	595.8
	10–20	6.04	2.66	22.46	195.0	426.8
	20–30	6.12	1.73	15.75	126.0	371.6
	Mean 0–30	6.02	2.27	21.20	202.5	464.7
	0–10:10–20	0.98	0.91	1.13	1.47	1.40
PT + LS	0–10	6.79	2.72	26.13	313.5	639.9
	10–20	6.84	2.27	21.98	198.0	498.8
	20–30	6.44	1.87	15.42	154.5	393.2
	Mean 0–30	6.65	2.28	21.17	222.0	510.6
	0–10:10–20	0.99	1.20	1.19	1.58	1.28
NT + WM	0–10	5.83	2.73	25.75	231.0	661.8
	10–20	5.98	2.30	21.14	153.0	456.3
	20–30	6.14	1.75	13.65	144.0	394.4
	Mean 0–30	5.97	2.26	20.18	175.5	504.2
	0–10:10–20	0.97	1.19	1.22	1.51	1.45
$LSD_{0.05}$	0–10	**0.28**	**0.16**	**1.64**	**21.33**	**67.72**
	10–20	**0.18**	**0.82**	**0.94**	**43.76**	**66.56**
	20–30	**0.22**	**0.15**	**1.00**	**45.07**	**57.43**
	Mean 0–30	**0.22**	**0.25**	**0.75**	**41.56**	**63.90**

Note. CT – conventional tillage, PT – ploughless tillage, PT + LS – ploughless tillage with lime sludge incorporation, NT + WM – no-tillage with cover crop for winter mulch; SOC – soil organic carbon.

et al., 2016). But the questions addressed in a variety of scientific debates are about how much C stocks can be raised and what determines it? Feng (2012) suggested that further studies of the driving factors (e.g., chemical composition of organic C inputs, mineralogy, and organo-mineral binding types and strength) are needed to determine maximal C loadings and estimate the maximal soil C storage potential. The "4 per 1,000" initiative was launched at the COP21 Paris climate summit in 2015. It aims to boost C storage in agricultural soils by 0.4% each year to help mitigate climate change and increase food security (https://www.4p1000.org/). Despite the global importance of these societal imperatives, soil C sequestration is still not on the political agenda and was not formally discussed at the COP23 Bonn meeting in 2017. Crucially, the "4 per 1,000" initiative will help governments to implement sustainable intensification of food production (Chabbi et al., 2017). Increased organic C sequestration in soil underpins several Sustainable Development Goals (SDGs) and directly contributes to SDG2 "Zero Hunger", SDG13 "Climate Action" and SDG15 "Life on Land" (https://www.nature.com).

The Earth's soil cover is one of the main reservoirs of organic C in the biosphere. The physical protection of SOC occurs in aggregates: SOC in most mineral soils is protected in aggregate interiors or through adsorption to mineral surfaces (Lehmann, Kleber, 2015), when relatively shallow-rooted agricultural ecosystems are converted to deep-rooted forests, root C inputs are introduced to deeper soil layers and can enhance or promote the decomposition of older SOC that was formerly protected under the agricultural ecosystem (Dijkstra, Cheng, 2007; Mobley et al., 2015).

In morainic loam, the mean results of F1, F2 and F3 fractions within the whole 0–30 cm soil layer were very similar in both CT and NT tillage systems, while percent of F4 fraction was higher under NT than under CT (Table 3). However, the distribution of chemodestructive fractions of SOC among different soil layers was unequal under tillage systems. NT caused slightly higher content of F2 (moderately labile C) within 0–10 cm layer and F4 (resistant C) within 10–20 cm layer, compared to CT. Consequently, loam response to different soil management for SOC stability was very similar.

Soil C distribution in chemodestructive fractions was more evident in sandy loam. In this soil, the mean results of the whole 0–30 cm layer revealed that C content in F1, F2 and F3 fractions was lower under NT, while percent of F4 fraction was significantly higher under NT than under CT (Table 3). Consequently, long-term no-tillage management did not change C distribution in chemodestructive fractions within 0–10 cm layer apparently, compared to CT. However, it resulted in significantly higher SOC stability within 10–20 and 20–30 cm layers.

With the increase of SOC in the upper 0–10 cm glaciolacustrine clay loam layer due to the application of ploughless tillage and additional improving measures (Ca-amendment with lime sludge and cover crop for mulch), the proportion of easily oxidizable labile fractions (F1 and F2) in the SOC also increased, compared to the CT (Table 4). Labile SOM compounds are biochemically most active, related to the transformation of matter and energy in the soil, thus affecting crop yield (Popov et al., 2004).

Chemically protected-humified carbon. Soil, which is a complex and continuously developing part of many ecosystems, plays an especially important role in the protection of natural environment and use of its resources for centuries (Six et al., 2002). The content of total SOC is not always a useful indicator for monitoring purposes, where the changes in land use are not drastic. In the last decades, more attention has been paid to the SOC of various lability (Schulz, 2004; Kolář et al., 2009), which has been acknowledged as a good indicator of soil quality and environmental health (Strosser, 2010). Carbon distribution in different fractions was reported by Six et al. (2002) and Sleutel et al. (2006). The results of our experiment show the distribution of C

Table 3. Soil organic carbon (SOC) distribution in chemodestructive fractions in morainic loam and sandy loam *Eutric Endocalcaric Endostagnic Cambisol* (site I, 2017)

Tillage system	Soil depth	C of chemodestructive fractions, in % of SOC			
	cm	F1	F2	F3	F4
		Loam			
Conventional tillage (CT)	0–10	46.45	12.40	15.27	25.88
	10–20	48.02	14.31	17.22	20.45
	20–30	44.77	14.44	19.77	21.03
	Mean 0–30	**46.41**	**13.72**	**17.42**	**22.45**
No-tillage (NT)	0–10	46.82	13.83	14.53	24.83
	10–20	45.76	11.99	16.10	26.14
	20–30	45.99	13.56	19.35	21.09
	Mean 0–30	**46.19**	**13.13**	**16.66**	**24.02**
		Sandy loam			
CT	0–10	44.69	10.03	15.43	29.85
	10–20	43.47	12.72	15.20	28.61
	20–30	40.65	10.98	16.16	32.22
	Mean 0–30	**42.94**	**11.24**	**15.60**	**30.23**
NT	0–10	41.91	11.47	10.88	35.74
	10–20	38.10	9.092	15.10	37.71
	20–30	35.55	11.91	14.13	38.41
	Mean 0–30	**38.52**	**10.82**	**13.37**	**37.29**

F1 – labile, F2 – moderately labile, F3 – stable, F4 – resistant fractions

Table 4. Soil organic carbon (SOC) distribution in chemodestructive fractions in glaciolacustrine clay loam *Eutric Endocalcaric Amphistagnic Endogleyic Cambisol* (site III, 2016)

Tillage system	Soil depth	C of chemodestructive fractions, in % of SOC			
	cm	F1	F2	F3	F4
CT	0–10	48.64	12.75	26.72	11.89
	10–20	52.01	15.87	18.33	13.79
	20–30	65.73	13.87	10.73	17.92
	Mean 0–30	**55.46**	**14.16**	**18.59**	**14.53**
PT	0–10	52.23	12.73	18.96	16.08
	10–20	47.50	14.97	18.48	19.04
	20–30	45.91	14.03	22.29	17.76
	Mean 0–30	**48.55**	**13.91**	**19.91**	**17.63**
PT + LS	0–10	49.45	13.28	23.08	14.18
	10–20	50.59	14.03	20.02	15.37
	20–30	48.59	12.96	23.57	14.87
	Mean 0–30	**49.54**	**13.42**	**22.22**	**14.81**
NT + WM	0–10	50.65	12.28	18.62	18.45
	10–20	48.12	13.85	22.77	15.25
	20–30	49.74	13.23	25.31	11.73
	Mean 0–30	**49.50**	**13.12**	**22.23**	**15.14**

CT – conventional tillage, PT – ploughless tillage, PT + LS – ploughless tillage with lime sludge incorporation, NT + WM – no-tillage with cover crop for winter mulch; F1 – labile, F2 – moderately labile, F3 – stable, F4 – resistant fractions

in humified fractions using different tillage systems and soil amendments in clay loam soil (Table 5). The best combination of soil management for SOC accumulation potential was PT + LS, which significantly increased the fraction of humified C bound with Ca in 0–10 and 10–20 cm layers, compared to CT.

Mobile fulvic acids usually dominate in loam and sandy loam soil. They are less valuable than humic acids, and their content was 2.29 g kg^{-1} in no fertilised treatment in the soil having cambic properties – *Endocalcaric Albic Brunic Endogleyic Arenosol* (Table 6). The amount of mobile humic acids (MHA) tended to increase to 2.32–2.46 g kg^{-1} in 0–10 cm layer after fertilisation with the highest rate (170 kg ha^{-1} N) of solid and liquid digestate. When using all types and rates of digestate as a biofertiliser, this increase was 36–45% higher in 20–30 cm layer, compared to CT.

Labile organic carbon. Water extractable organic C is one of the labile, most rapidly changing forms of active C. Many studies (Geraei et al., 2016; Jokubauskaite et al., 2016; Awale et al., 2017; Slepetiene et al., 2017; Volungevičius et al., 2019) have used labile organic C to assess the impact of agricultural management and land use change on soil quality. The data presented in Figures 1 and 2 show that the C contents of the labile fraction were relatively small in *Cambisols* – 0.205–0.307 g kg^{-1} in 0–10 cm, and in the deeper soil layers they were even smaller. The greater part of SOC is present in insoluble forms in most soils, except for a small fraction, and labile C, which is determined by measuring the C content of aqueous extracts using sensitive laboratory equipment. Labile organic C constitutes a small part of the total SOC; however, it is the most mobile and reactive soil C pool that influences the physical, chemical and biological processes occurring in the soil.

On loamy textured *Cambisol*, on background without straw, C content in labile fractions within 0–10 cm layer varied from 0.345 g kg^{-1} under NT management to 0.379 g kg^{-1} under CT. In 10–20 cm layer, in the CT system, labile organic C content did not change, compared to the top-soil layer, while in NT system it decreased by 11%. In 20–30 cm layer, labile organic C content became 15% lower, compared to the top-soil layer under both tillage systems.

Straw returning reduced labile organic C by 16% in the NT system and by 35% in the CT system within the whole 0–30 cm layer. On the background with straw, C content in labile fractions within 0–10 cm layer varied from 0.252 g kg^{-1} under CT to 0.304 g kg^{-1} under NT. In 10–20 cm layer, in CT, labile organic C content did not change noticeably, compared to the top-soil layer, while in NT system it decreased by 16%. In 20–30 cm layer, labile organic C content decreased by 19% in CT and by 24% in NT, compared to the top-soil layer.

Table 5. Soil organic carbon (SOC) distribution in humified fractions in glaciolacustrine clay loam *Eutric Endocalcaric Amphistagnic Endogleyic Cambisol* (site III, average of 2015–2016)

Tillage system	Soil layer cm	Share of humified carbon, in % of SOC		
		mobile	stabilized by Ca	stabilized by clay minerals
CT	0–10	13.07	15.86	31.22
	10–20	13.03	16.78	31.17
	20–30	12.88	17.70	31.16
	Mean 0–30	12.99	16.78	31.18
PT	0–10	12.85	16.11	30.94
	10–20	12.59	16.55	30.76
	20–30	12.05	17.20	30.60
	Mean 0–30	12.50	16.62	30.77
PT + LS	0–10	11.50	16.98	31.79
	10–20	11.59	17.97	31.42
	20–30	11.82	18.46	30.97
	Mean 0–30	11.64	17.80	31.39
NT + WM	0–10	13.36	15.42	30.98
	10–20	13.16	16.41	30.73
	20–30	12.96	17.83	30.55
	Mean 0–30	13.16	16.55	30.77
LSD_{05}	0–10	0.868	0.961	1.230
	10–20	0.873	0.934	1.394
	20–30	0.890	0.942	1.295
	Mean 0–30	0.877	0.945	1.306

CT – conventional tillage, PT – ploughless tillage, PT + LS – ploughless tillage with lime sludge incorporation, NT + WM – no-tillage with cover crop for winter mulch

Table 6. Soil organic carbon (SOC) and humified C content as influenced by fertilisation with digestate in glacial morain *Endocalcaric Albic Brunic Endogleyic Arenosol* (site II, 2018)

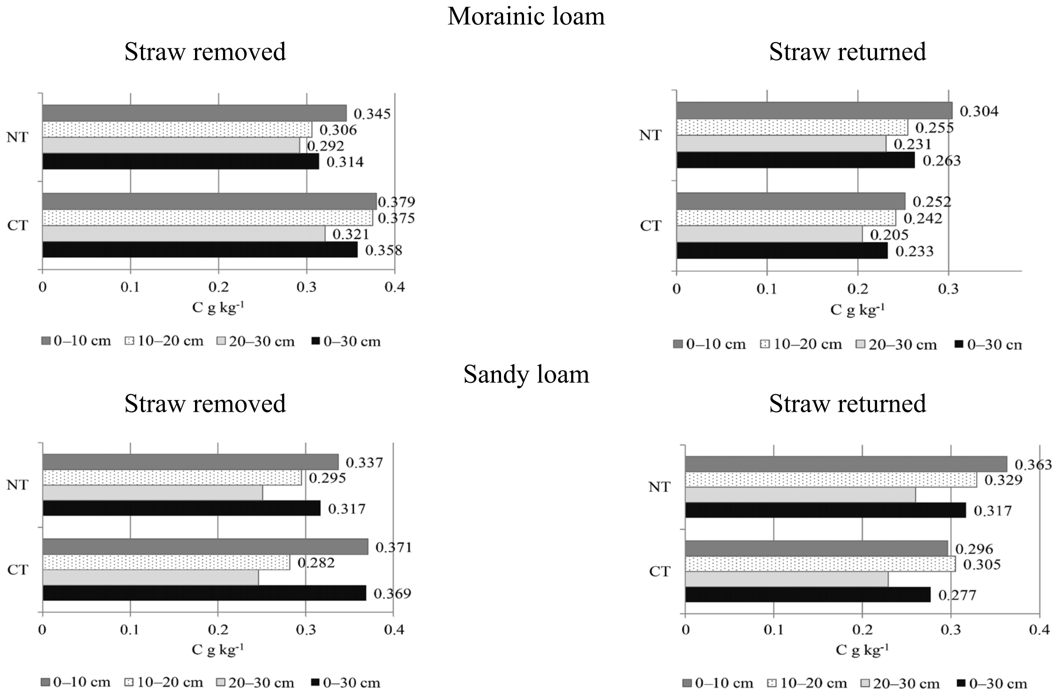
Treatment	Soil layer	SOC	C-MHS	C-MHA	C-MHS	C-MHA
	cm	g kg^{-1}			% to control	
Control (no fertiliser)	0–10	11.77	3.94	2.29	100	100
	10–20	8.40	2.71	2.30	100	100
	20–30	4.00	1.05	0.53	100	100
	Mean 0–30	8.06	2.57	1.71	100	100
Liquid digestate 85 kg ha^{-1} N	0–10	13.07	4.01	2.31	102	101
	10–20	8.70	2.92	1.29	108	56
	20–30	4.70	1.50	0.72	143	136
	Mean 0–30	8.82	2.81	1.44	109	84
Liquid digestate 170 kg ha^{-1} N	0–10	13.37	4.02	2.46	102	107
	10–20	9.80	3.06	2.46	113	107
	20–30	4.30	1.36	0.73	130	138
	Mean 0–30	9.16	2.81	1.88	109	110
Solid digestate 85 kg ha^{-1} N	0–10	12.83	4.22	2.28	107	100
	10–20	9.33	3.24	1.82	120	79
	20–30	4.57	1.50	0.77	143	145
	Mean 0–30	8.91	2.99	1.62	116	95
Solid digestate 170 kg ha^{-1} N	0–10	13.53	4.21	2.32	107	101
	10–20	8.83	3.15	1.74	116	76
	20–30	4.23	1.51	0.73	177	138
	Mean 0–30	8.86	2.96	1.60	115	94
LSD_{05}	0–10	2.91	0.822	0.411		
	10–20	3.20	0.897	0.460		
	20–30	2.93	0.921	0.460		
	Mean 0–30	3.01	0.880	0.444		

C-MHS – carbon of mobile humic substances, C-MHA – carbon of mobile humic acids

On sandy loamy *Cambisol*, on the background without straw, C content in labile fractions within 0–10 cm layer varied from 0.337 g kg^{-1} under NT to 0.371 g kg^{-1} under CT. In 10–20 cm layer, in CT, labile organic C content decreased by 24%, in NT by 12%, compared to the top-soil layer. In 20–30 cm layer, labile organic C content decreased by 34% in CT and by 26% in NT, compared to the top-soil layer.

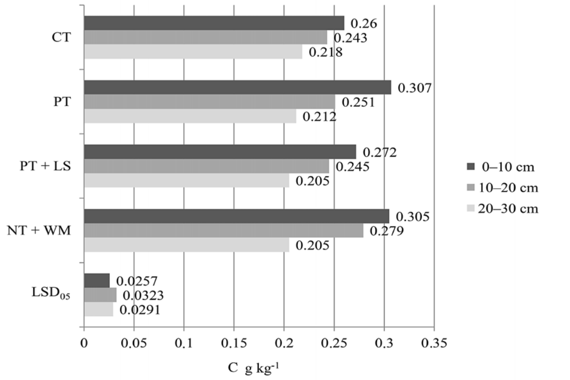
In contrast to loam, straw returning did not change labile organic C under NT but reduced its content by 25% in CT within the whole 0–30 cm layer. On the background with straw, C content in labile fractions within 0–10 cm layer varied from 0.296 g kg^{-1} under CT to 0.363 g kg^{-1} under NT. In 10–20 cm layer, in CT, labile organic C content slightly increased (by 3%), compared to the top-soil layer, while in NT it decreased by 9%. In 20–30 cm layer, labile organic C content decreased by 23% in CT and by 28% in NT, compared to the top-soil layer.

Labile organic C fractions are more sensitive to changes in soil management. The results of our experiment showed that with decreasing tillage intensity in clay loam *Cambisol* the concentration of labile organic C in the soil, especially in the upper 0–10 cm layer, increased by 0.307 g kg^{-1} in the ploughless tillage treatment and by 0.305 g kg^{-1} in the no-tillage with a cover crop for winter mulch treatment (Fig. 2). Concentrations of labile organic C decreased with increasing soil depth. Lime sludge increased the stability of carbon by decreasing the amount of labile organic C.



NT – no-tillage, CT – conventional tillage

Figure 1. The influence of soil management on labile organic carbon content in morainic loam and sandy loam *Eutric Endocalcianc Endostagnic Cambisol* (site I, 2017)



CT – conventional tillage, PT – ploughless tillage, PT + LS – ploughless tillage with lime sludge incorporation, NT + WM – no-tillage with cover crop for winter mulch

Figure 2. The influenced of the tillage systems on labile organic carbon content in glaciolacustrine clay loam *Eutric Endocalcaric Amphistagnic Endogleyic Cambisol* (site III, 2017)

Conclusions

1. Long-term no-tillage (NT) resulted in pronounced soil organic carbon (SOC) and macronutrients stratification, increasing of SOC, total nitrogen (N_{tot}), available K_2O within 0–30 cm top layer in morain *Eutric Endocalcaric Endostagnic Cambisol* (site I). NT superiority over conventional tillage (CT) for SOC sequestration in loam reached 8% on the background without straw and 13% on the background with straw. However, in sandy loam top layer, NT had the advantage over CT only under straw removal – its superiority over CT for SOC sequestration reached 4%. Meanwhile, under straw return, SOC sequestration was 16% higher in CT than NT.

2. Ploughless tillage with lime sludge (Ca-amendment) incorporation (PT + LS) had the highest potential for SOC accumulation in clay loam top layer of glaciolacustrine *Eutric Endocalcaric Amphistagnic Endogleyic Cambisol* (site III). It significantly increased the fraction of humified Ca-bound C in 0–10 and 10–20 cm layers, compared to CT. Due to the application of ploughless tillage (PT), the soil stratified into layers according to the concentration of labile organic C.

3. Soil C distribution in chemodestructive fractions was more evident in sandy loam top layer *Eutric Endocalcaric Endostagnic Cambisol* (site I) – the mean results of 0–30 cm layer revealed that C content in easily oxidizable F1, F2 and relatively stable F3 fractions was lower under NT, while percent of resistant F4 fraction was significantly higher under NT than under CT. However, the distribution of C in fractions of different stability was most influenced by soil genesis. The results of our study showed that C transformation in the soil and chemical composition of the soil reflect this transformation, depending on soil management applied and the inherent properties of the soil itself.

4. The highest accumulation of SOC as well as chemically protected-humified C in a sandy loam top layer of glacial morain *Endocalcaric Albic Brunic Endogleyic Arenosol* (site II) used as grassland was determined at the highest digestate rate of 170 kg ha^{-1} N, which showed that it was not only important as a biofertiliser for plants, but also as a potential soil improver promoting accumulation of SOC and C of mobile humic acids.

5. The results of our study suggest that with decreasing tillage intensity in a clay loam top layer *Eutric Endocalcaric Amphistagnic Endogleyic Cambisol* (site III) the concentration of labile organic C in the soil, especially in the upper 0–10 cm layer increased by 0.307 g kg^{-1} under PT and 0.305 g kg^{-1} under NT with a cover crop for winter mulch (NT + WM). The lime sludge application reduced the amount of labile organic C, while increasing the stability of C compounds. The concentrations of labile organic C decreased with increasing soil depth.

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References

1. Amalevičiūtė K., Šlepetienė A., Liaudanskienė I., Šlepetys J. 2014. Chemical composition of peat bog soil and its influencing factors. Žemės ūkio mokslai / Agricultural Sciences, 21 (1): 1–8 (in Lithuanian). https://doi.org/10.6001/zemesukiomokslai.v21i1.2850
2. Awale R., Emeson M. A., Machado S. 2017. Soil organic carbon pools as early indicators for soil organic matter stock changes under different tillage practices in Inland Pacific Northwest. Frontiers in Ecology and Evolution, 5: 96. https://doi.org/10.3389/fevo.2017.00096
3. Bogužas V., Mikučionienė R., Šlepetienė A., Sinkevičienė A., Feiza V., Steponavičienė V., Adamavičienė A. 2015. Long-term effect of tillage systems, straw and green manure combinations on soil organic matter. Zemdirbyste-Agriculture, 102 (3): 243–250. https://doi.org/10.13080/z-a.2015.102.031
4. Chabbi A., Lehmann J., Ciais P., Loescher H. W., Cotrufo M. F., Don A., SanClements M., Schipper L., Six J., Smith P., Rumpel C. 2017. Aligning agriculture and climate policy. Nature Climate Change, 7: 307–309. https://doi.org/10.1038/nclimate3286
5. Dijkstra F. A., Cheng W. 2007. Interactions between soil and tree roots accelerate long-term soil carbon decomposition. Ecology Letters, 10: 1046–1053. https://doi.org/10.1111/j.1461-0248.2007.01095.x
6. Feiziene D., Feiza V., Slepetiene A., Liaudanskiene I., Kadziene G., Deveikyte I., Vaideliene A. 2011. Long-term influence of tillage and fertilization on net carbon dioxide exchange rate on two soils with different textures. Journal of Environmental Quality, 40 (6): 1787–1796. https://doi.org/10.2134/jeq2011.0180
7. Feiziene D., Feiza V., Povilaitis V., Putramentaite A., Janusauskaite Daiva, Seibutis V., Slepetys J. 2016. Soil sustainability changes in organic crop rotations with diverse crop species and the share of legumes. Acta Agriculturae Scandinavica, Section B: Soil and Plant Science, 66 (1): 36–51. https://doi.org/10.1080/09064710.2015.1063683
8. Feiziene D., Feiza V., Karklins A., Versuliene A., Janusauskaite D., Antanaitis S. 2018. After-effects of long-term tillage and residue management on topsoil state in Boreal conditions. European Journal of Agronomy, 94: 12–24. https://doi.org/10.1016/j.eja.2018.01.003
9. Feng W. 2012. Testing the soil carbon saturation theory: maximal carbon stabilization and soil organic matter stability as a function of organic carbon inputs: doctor dissertation. University of Pennsylvania, USA, 173 p.
10. Geraei D.S., Hojati S., Landi A., Cano A. F. 2016. Total and labile forms of soil organic carbon as affected by land use change in southwestern Iran. Geoderma Regional, 7: 29–37. https://doi.org/10.1016/j.geodrs.2016.01.001
11. IPCC. 2001. Climate Change 2001. Contribution of Working Group 1 to the 3rd Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, 881 p.
12. Jakhar R. R., Yadav S. R., Jakhar R. K., Devra P., Ram H., Kumar R. 2017. Potential and importance of carbon sequestrations in agricultural soils. International Journal of Current Microbiology and Applied Sciences, 6 (2): 1776–1788. https://doi.org/10.20546/ijcmas.2017.602.199
13. Jankauskas B., Jankauskiene G., Slepetiene A., Fullen M. A., Booth C. A. 2006 (a). International comparison of analytical methods of determining the soil organic matter content of Lithuanian *Eutric Albeluvisols*. Communications in Soil Science and Plant Analysis, 37: 707–720. https://doi.org/10.1080/00103620600563499
14. Jankauskas B., Slepetiene A., Jankauskiene G. Fullen M. A., Booth C. A. 2006 (b). A comparative study of analytical methodologies to determine the soil organic matter content of Lithuanian *Eutric Albeluvisols*. Geoderma, 136 (3–4): 763–773. https://doi.org/10.1016/j.geoderma.2006.05.015
15. Jokubauskaite I., Amaleviciute K., Lepane V., Slepetiene A., Slepetys J., Liaudanskiene I., Karcauskiene D., Booth C. A. 2015. High-performance liquid chromatography (HPLC)-size exclusion chromatography (SEC) for qualitative detection of humic substances and dissolved organic matter in mineral soils and peats in Lithuania. International Journal of Environmental Analytical Chemistry, 95 (6): 508–519. https://doi.org/10.1080/03067319.2015.1048435
16. Jokubauskaite I., Karčauskienė D., Slepetiene A., Repsiene R., Amaleviciute K. 2016. Effect of different fertilization modes on soil organic carbon sequestration in acid soils. Acta Agriculturae Scandinavica, Section B: Soil and Plant Science, 66 (8): 647–652. https://doi.org/10.1080/09064710.2016.1181200
17. Klute A. 1986. Methods of soil analysis. Part 1. Physical and Mineralogical Methods (2nd ed.). American Society of Agronomy. https://doi.org/10.2136/sssabookser5.1.2ed
18. Kolář L., Kužel S., Horáček J., Čechová V., Borová-Batt J., Peterka J. 2009. Labile fractions of soil organic matter, their quantity and quality. Plant, Soil and Environment, 55 (6): 245–251. https://doi.org/10.17221/87/2009-PSE
19. Lal R. 2003. Global potential of soil carbon sequestration to mitigate the greenhouse effect. Critical Reviews in Plant Sciences, 22 (2): 151–184. https://doi.org/10.1080/713610854
20. Lal R. 2018. Digging deeper: a holistic perspective of factors affecting soil organic carbon sequestration in agroecosystems. Global Change Biology, 24 (8): 3285–3301. https://doi.org/10.1111/gcb.14054
21. Lehmann J., Kleber M. 2015. The contentious nature of soil organic matter. Nature, 528: 60–68. https://doi.org/10.1038/nature16069
22. Leifeld J., Bassin S., Fuhrer J. 2005. Carbon stocks in Swiss agricultural soils predicted by land-use, soil characteristics, and altitude. Agriculture, Ecosystems and Environment, 105 (1–2): 255–266. https://doi.org/10.1016/j.agee.2004.03.006
23. Liaudanskiene I., Slepetiene A., Velykis A., Satkus A. 2013. Distribution of organic carbon in humic and granulodensimetric fractions of soil as influenced by tillage and crop rotation. Estonian Journal of Ecology, 62 (1): 53–69. https://doi.org/10.3176/eco.2013.1.05
24. Liaudanskienė I., Šlepetienė A., Šlepetys J., Stukonis V. 2013. Evaluation of soil organic carbon stability in grasslands of protected areas and arable lands applying chemo-destructive fractionation. Zemdirbyste-Agriculture, 100 (4): 339–348. https://doi.org/10.13080/z-a.2013.100.043
25. Mažvila J., Staugaitis G., Kutra G. J., Jankauskas B. 2010. Application of empirical models for assessing the erodibility of Lithuanian soils. Žemės ūkio mokslai, 17 (3–4): 69–78 (in Lithuanian).
26. Mobley M. L., Lajtha K., Kramer M. G., Bacon A. R., Heine P. R., Richter D. D. 2015. Surficial gains and subsoil losses of soil carbon and nitrogen during secondary forest development. Global Change Biology, 21: 986–996. https://doi.org/10.1111/gcb.12715
27. Nikitin B. A. 1999. Methods for soil humus determination. Agro Chemistry, 3 (2): 156–158 (in Russian).
28. Ondrasek G., Bakić Begić H., Zovko M., Filipović L., Meriño-Gergichevich C., Savić R., Rengel Z. 2019. Biogeochemistry of soil organic matter in agroecosystems & environmental implications. Science of the Total Environment, 658: 1559–1573. https://doi.org/10.1016/j.scitotenv.2018.12.243
29. O'Rourke S. M., Angers D. A., Holden N. M., McBratney A. B. 2015. Soil organic carbon across scales. Global Change Biology, 21 (10): 3561–3574. https://doi.org/10.1111/gcb.12959
30. Paustian K., Lehmann J., Ogle S., Reay D., Robertson G. P., Smith P. 2016. Climate-smart soils. Nature, 532: 49–57. https://doi.org/10.1038/nature17174
31. Ponomareva V. V., Plotnikova T. A. 1980. Humus and soil formation. Leningrad, 198 p. (in Russian).
32. Popov A. I., Tcyplenkov V. P. 1994. Sankt-Peterburg State University. Method of determination of humus forms. Patent of Russian Federation No. 2020481 (in Russian).
33. Popov A. I., Rusakov A. V., Nadporozhskaja M. A., Yakovleva V. V. 2004. The use of the chemodestruction fractionating for the estimation of quantitative–qualitative composition of soil organic matter. Humus and soil-forming: collection of scientific works of St. Petersburg State Agrarian University, p. 63–72 (in Russian).
34. Schulz E. 2004. Influence of site conditions and management on different soil organic matter (SOM) pools. Archives of Agronomy and Soil Science, 50: 33–47. https://doi.org/10.1080/03650340310001627577
35. Six J., Callewaert P., Lenders S., De Gryze S., Morris S. J., Gregorich E. G., Paul E. A., Paustian K. 2002. Measuring and understanding carbon storage in afforested soils by physical fractionation. Soil Science Society of America Journal, 66: 1981–1987. https://doi.org/10.2136/sssaj2002.1981

36. Slepetiene A., Slepetys J., Liaudanskiene I., Kadziuliene Z., Velykis A., Adamovics A. 2011. Changes of soil organic carbon and mobile humic acids in response to different agricultural management. Agraarteadus. Journal of Agricultural Science, 22 (2): 64–70.
37. Slepetiene A., Staugaitis Z., Tilvikiene V., Slepetys J., Kadziuliene Z. 2017. The effect of mineral fertilizers and biogas digestate used for cocksfoot fertilization on the soil nitrogen changes. Fresenius Environmental Bulletin, 26 (4): 2604–2608.
38. Sleutel S., De Neve S., Nemeth T., Toth T., Hofman G. 2006. Effect of manure and fertilizer application on the distribution of organic carbon in different soil fractions in long-term field experiment. European Journal of Agronomy, 25: 280–288. https://doi.org/10.1016/j.eja.2006.06.005
39. Smith P., Soussana J.-F., Angers D., Schipper L., Chenu C., Rasse D. P., Batjes N.H., van Egmond F., McNeill S., Kuhnert M., Arias-Navarro C., Olesen J. E., Chirinda N., Fornara D., Wollenberg E., Álvaro-Fuentes J., Sanz-Cobena A., Klumpp K. 2020. How to measure, report and verify soil carbon change to realize the potential of soil carbon sequestration for atmospheric greenhouse gas removal. Global Change Biology, 26 (1): 219–241. https://doi.org/10.1111/gcb.14815
40. Staugaitis Ž., Slepetiene A., Tilvikienė V., Kadžiulienė Ž. 2016. The influence of cocksfoot fertilization with mineral fertilizers and digestate on total and labile carbon in the soil. Žemės ūkio mokslai /Agricultural Sciences, 23 (3): 123–129 (in Lithuanian). https://doi.org/10.6001/zemesukiomokslai.v23i3.3359
41. Stockmann U., Adams M. A., Crawford J. W., Field D. J., Henakaarchchi N., Jenkins M., Minasny B., McBratney A. B., de Remy de Courcelles V., Singh K., Wheeler I., Abbott L., Angers D. A., Baldock J., Bird M., Brookes P. C., Chenu C., Jastrow J. D., Zimmermann M. 2013. The knowns, known unknowns and unknowns of sequestration of soil organic carbon. Agriculture, Ecosystems and Environment, 164: 80–99. https://doi.org/10.1016/j.agee.2012.10.001
42. Strosser E. 2010. Methods for determination of labile soil organic matter: an overview. Journal of Agrobiology, 27 (2): 49–60. https://doi.org/10.2478/s10146-009-0008-x
43. Volungevicius J., Amaleviciute-Volunge K., Versuliene A., Feiziene D., Feiza V., Slepetiene A., Liaudanskiene I., Vaisvalavicius R. 2018. The effects of agrogenic transformation on soil profile morphology, organic carbon and physico-chemical properties in *Retisols* of Western Lithuania. Archives of Agronomy and Soil Sciences, 64 (13): 1910–1923. https://doi.org/10.1080/03650340.2018.1467006
44. Volungevičius J., Fęiza V., Amalevičiūtė-Volungė K., Liaudanskienė I., Šlepetienė A., Kuncevičius A., Vengalis R., Vėlius G., Prapiestienė R., Poškienė J. 2019. Transformations of different soil under natural and anthropogenized land management. Zemdirbyste-Agriculture, 106 (1): 3–14. https://doi.org/10.13080/z-a.2019.106.001
45. Wiesmeier M., Urbanski L., Hobley E., Langc B., von Lützow M., Marin-Spiotta E., van Wesemaele B., Rabot E., Ließ M., Garcia-Franco N., Wollschläger U., Vogel H-J., Kögel-Knabner I. 2019. Soil organic carbon storage as a key function of soils – a review of drivers and indicators at various scales. Geoderma, 333: 149–162. https://doi.org/10.1016/j.geoderma.2018.07.026
46. WRB. 2014. World reference base for soil resources. World Soil Resources Reports No. 106. FAO, p. 187–189.

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Dirvožemio organinės anglies, jos formų ir makroelementų pasiskirstymas žemės ūkio paskirties dirvožemiuose

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Santrauka

Tyrimo tikslas – įvertinti dirvožemio organinės anglies bei jos formų (apsaugotos ir labilios) ir suminio azoto (N_{tot}), judriųjų P_2O_5 bei K_2O pasiskirstymą dirvožemio 0–30 cm sluoksnyje priklausomai nuo naudojimo – žemės dirbimo ir tręšimo. Tyrimas atliktas dviejuose šalies regionuose – centrinėje (I ir II vietovės) ir šiaurinėje (III vietovė) Vidurio Lietuvos žemumos dalyse. I vietovėje moreniniame vidutinio sunkumo priemolyje ir smėlingame lengvame priemolyje *Eutric Endocalcaric Endostagnic Cambisol* (Loamic, Aric, Drainic)) tirta tradicinis (skutimas + arimas) žemės dirbimas ir tiesioginė sėja, šiaudų panaudojimo būdai ir tręšimas mineralinėmis trąšomis. II vietovėje tirta tręšimo įtaka moreniniam smėlžemiui (*Endocalcaric Albic Brunic Endogleyic Arenosol* (Dystric)) penkių variantų bandyme: be trąšų, tręšiant separuotu skystu digestatu 85 ir 170 kg ha^{-1} N, tręšiant separuotu sausu digestatu 85 ir 170 kg ha^{-1} N. III vietovėje limnoglacialiniame sunkaus priemolio rudžemyje (*Eutric Endocalcaric Amphistagnic Endogleyic Cambisol* (Clayic, Aric, Drainic)) tirtos žemės dirbimo sistemos: tradicinė, neariminė, neariminė įterpus kalkių purvą ir be žemės dirbimo, tarpinius pasėlius palikus mulčiui per žiemą.

Ilgalaikis tradicinio žemės dirbimo atsisakymas priemolio dirvožemyje nulėmė suminio azoto, judriojo K_2O ir dirvožemio organinės anglies stratifikaciją dirvožemio viršutiniuose sluoksniuose. Daugiausia organinės anglies ir chemiškai apsaugotos humifikuotos anglies žolyno dirvožemyje nustatyta patręšus didžiausia norma digestato (anaerobinio raugo) – 170 kg ha^{-1} N. Didelis organinės anglies sekvestravimo potencialas nustatytas sunkaus priemolio rudžemyje neariminį žemės dirbimą derinant su įterptu kalkių purvu. Tai esmingai padidino su kalciu sujungtos humifikuotos anglies frakciją dirvožemio 0–10 ir 10–20 cm sluoksniuose, palyginus su tradiciniu arimu. Sunkaus priemolio rudžemyje žemės dirbimo intensyvumo sumažinimas, taikant neariminį dirbimą ir be žemės dirbimo, tarpinius pasėlius palikus mulčiui, padidino labilios anglies koncentraciją, ypač 0–10 cm sluoksnyje. Kalkių purvo panaudojimas sumažino labilios anglies kiekį ir kartu padidino dirvožemio organinės anglies stabilumą, jai susijungus su kalkių purve esančiu kalciu. Smėlingame lengvame priemolyje neariant 0–30 cm sluoksnyje chemodestrukciniam skaidymui atsparios F4 frakcijos anglies dalis buvo esmingai didesnė, palyginus su tradicinio dirbimo taikymu.

Reikšminiai žodžiai: digestatas (anaerobinis raugas), kalkių purvas, labili ir apsaugota anglis, tręšimas, žemės dirbimas, dirvožemis.