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Carbon and important macroelements of *Terric Histosol* after 12 years renaturalization

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Abstract

The aim of this study was to determine the chemical properties of peat soil depending on changes in land-use. The *Terric Histosol* (HSs) was investigated in this research, and the treatments of former different land-use in Radviliškis site. Chemical analyses were carried out at the Chemical Research Laboratory of LRCAF. After 12 years since the end of field experiment the differences in soil chemical composition remained still between treatments of differently used peat soil. Due to mineralization, the content of soil organic matter (SOM) and SOC respectively decreased, the largest amounts of SOC are stored in the upper soil layer of perennial grasses fertilized with NPK (NPK), there was the highest yield of biomass; and accordingly, the lowest content of SOC – in soil of un-used peat (UU). The distribution of total N and P in profile of *Terric Histosol* is directly related to the vertical gradient of mineralization intensity; higher amounts of N and P have been accumulated where mineralization was more intense. The distribution of total K is related to land-use of *Terric Histosol*, whereas the biggest quantity of total K was established in arable land which has been fertilized with mineral fertilisers.

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Introduction

On a global scale wetland and peatland soils (*Histosol*) are an important reservoir of organic carbon and their use contributes to carbon emissions or accumulation processes (Rabenhorst and Swanson, 2000). Organic carbon in these soils is stored in the form of plant residues in various stages of decomposition as well as in the form of heterogeneous humic compounds, which can be described as a complex mixture of macromolecules of variable chemical composition, shape and size (Zavarzina et al., 2002). The processes of peat formation and organic carbon accumulation are replaced by processes of peat degradation, mineralization and settling of peat layer after the peat was drained**.** Significant impact on intensity of organic matter mineralization and changes in the structure of soil profile has the degree of peat drainage, soil tillage and fertilization (Szajdak et al., 2002). Rarely found experimental data and publications about changes in chemical composition of peat soils under renaturalization are relevant in environmental point of view. Considerable attention is given to anthropogenic transformation and renaturalization of these soils, which leads to changes of their chemical and physical properties. Due to negative human activity impact on the

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environment the studies of global carbon cycle and quantitative evaluations has become particularly relevant.

The management and enhancement of soil organic carbon (SOC) is important for sustainable agriculture. SOC is also the source and sink of atmospheric CO_2 and plays a key role in global C cycling. Total soil organic C (SOC) content can be easily measured by conventional methods. The changes in SOC due to management practices are difficult to detect since these changes occur slowly and are relatively small compared to the vast background of SOC, which varies both spatially and temporally (Purakayastha et al., 2008). The identification of some more sensitive labile SOC factions, such as water soluble organic carbon (WSC), readily mineralizable carbon (RMC) contributes to the elucidation of changes in SOC at early stages of alterations in management practices (Gong et al., 2009; Purakayastha et al., 2008). Soil C and nitrogen (N) contents and storage are influenced by soil-forming and anthropogenic factors. Human activities such as fertilizer practices and cropping systems play a key role in the regulation of C and N contents in agricultural soils and emissions of greenhouse gases (Gal et al., 2007; Jagadamma et al., 2007).

On a global scale, organic soils (*Histosols*) are an important reservoir of organic carbon (Rabenhorst and Swanson, 2000). Carbon in these soils is stored in the form of plant remnants in various stages of decomposition, as well as in the form of heterogeneous organic (humic) compounds, which can be described as a complex mixture of polyelectrolyte-like macromolecules of variable chemical composition, shape, and size (Zavarzina et al., 2002). As a result of humification, the humic substances content in organic soils increases. They participate in sorption processes in the soil, and form soluble and insoluble complexes with metallic ions (Stevenson, 1994). Humic substances are the main constituents of the adsorptive complex that affects soil properties.

Perennial grasses are believed to be able to reduce organic matter (OM) decomposition, since they partly restore OM by leaving a great content of root and stubble. Some researchers recommended establishing long-term grasslands, which, if properly managed, could produce a high herbage yield; however, OM transformation depends on the composition of individual swards and their management. Natural and agricultural ecosystems not only play an important role in the conversion of atmospheric CO_2 into SOM, but also in the sequestration of SOC.

The less is known about the dynamics of SOC after agricultural abandonment or renaturalization (La Mantia et al., 2007; Alberti et al., 2011); this process is connected to the development of the natural vegetation through secondary succession processes (Kosmas et al., 2000; Van Rompaey et al., 2001). Peat soils used for agriculture have been limited study in Lithuania (Šlepetienė et al., 2010; Amalevičiūtė et al., 2013, 2014). One of the few experiments has been carried out in Radviliškis Experimental Station of Lithuanian Institute of Agriculture in a peat bog with removed and non-removed peat layer during 1995–2001(Petraitytė et al., 2002). Evident changes in soil properties were determined after ending of soil-use after 3–4 years (Šlepetienė et al., 2006). The effect of renaturalization on soil agrochemical properties has been investigated in Vokė Branch of LIA in *Haplic Luvisol* (Marcinkonis, 2007) and in Perloja Experimental Station of LIA in *Haplic Arenosol* (Armolaitis et al., 2011). Till now a little has been investigated the changes in soil profile structure, quantity and quality of organic matter affected by drainage of low moor peat soil and its renaturalization. As indicated in literature the changes in soil chemical composition including organic matter in peat bog soil take place much more intensively than in mineral soils.

The main task of this research was to study the chemical composition of the former differently used peat soil, to identify the differences in the soil organic carbon (SOC), water extractable organic carbon (WEOC) and other importan macroelemens of *Terric Histosol*.

Material and Methods

Experimental site and conditions

Field experiments were conducted at the former Radviliškis Experimental Station of the Lithuanian Institute of Agriculture on a peat bog (*Terric Histosol, HSs*) at an altitude of 120 m above sea level (55°45´N. 23°30´E). Radviliškis district's shallow peat soil of the low-lying bog according to the LTDK-99 classification (Lietuvos dirvožemių klasifikacija, 2001) is referred to as *Pachiterric Histosol (HSs-ph)*. According to WRB2014 (World reference base for soil resources, 2014), this soil is referred to as eutrophic (saturaded), ground water-fed, drained soil, with a preserved peat structure (HS-fi.dr.rh.eu, *Eutric Rheic Drainic Fibric Histosol*). The Radviliškis peat bog eastern edge borders the Radviliškis town and covers an area of 1203 ha. The Radviliškis bog has formed at the source of the Beržė River. The treatments investigated in the soil with a non-removed peat layer were as follows: 1) un-used peat soil, 2) earlier unfertilized perennial grasses, 3) former crop rotation (potatoes, winter rye, red clover) field, 4) former red clover (*Trifolium pratense L.)* and timothy (*Phleum pratense L.*) mixture, 5) former perennial grasses applied with commercial NPK fertilisers.

Table 1. The scheme of former consecutive crop rotation, used in peat bog

Treatments				
UU	UF	CF	M	NPK
-	Sowing of perennial grasses	Potatoes	Sowing of red clover and timothey mixture	Sowing of perennial grasses
-	Perennial grasses 1st year of use	Winter rye	Mixture 1st year of use	Perennial grasses 1st year of use
-	Perennial grasses 2nd year of use	Sowing (Red clover and timothey mixture)	Mixture 2nd year of use	Perennial grasses 2nd year of use
-	Perennial grasses 3rd year of use	Mixture 1st year of use	Mixture 3rd year of use	Perennial grasses 3rd year of use
-	Perennial grasses 4th year of use	Mixture 2nd year of use	Mixture 4th year of use	Perennial grasses 4th year of use
-	Perennial grasses 5th year of use	Ryegrass annual	Mixture 5th year of use	Perennial grasses 5th year of use
-	Winter rye	Winter rye	Winter rye	Winter rye

Note: UU – un-used peat soil; UF – unfertilized perennial grasses; CF – crop rotation field; M – red clover and timothy mixture; NPK – perennial grasses fertilized with NPK.

Methods of analyses.

Chemical analyses were carried out at the Chemical Research Laboratory of Institute of Agriculture (LRCAF). The soil samples were air-dried, crushed and sieved through a 2-mm sieve and homogeneously mixed. Soil pH was determined in 1M KCl (soil–solution ratio 1:2.5) using potentiometric method. For the other soil analyses an aliquot of the soil samples was passed through a 0.25-mm sieve. Soil organic carbon (SOC) content was determined by the Tyurin method modified by Nikitin (1999) with spectrophotometric measure procedure at the wavelength of 590nm and glucose as a standard. Soil organic matter (SOM) content was calculated by multiplying SOC content by 1.724. Soil total nitrogen (N) was determined by the Kjeldhal method with photometric measure procedure at the wavelength of 655 nm. Soil total phosphorus (P) content was determined by photometric procedure at the wavelength of 430 nm, and soil total potassium (K) – by atomo - absorciometric procedure after wet digestion with sulphuric acid (Šlepetienė et al., 2010). Mobile humic acids were extracted using 0.1M NaOH solution and determined according Ponomariova and Plotnikova (1980). Labile water extractable organic carbon (WEOC) was determined in water extract (soil–water ratio 1:5), and measured by IR-detection method after UV-catalysed persulphate oxidation.

Statistical analyses

Significance of the differences between the means was determined according to the least significant difference (LSD) at 0.05 probability level. The experimental data were analysed by a one-factor analysis of variance method recommended in agronomy science using *ANOVA* for *Excel* version 6.0 (Tarakanovas and Raudonius, 2003).

Results and Discussion

The data presented in Figure 1 show that grass yield was different in peat used for agricultural purposes and non-used. The differences in plant yield as well as plant species determined transformation of organic matter and at the same time C transformation in peat. After 12 years of the field experiment completion it's interesting what are the main factors influencing soil organic carbon (SOC) accumulation. During the period when the experiment was continued, the yield of the above-ground plant mass was estimated for 7 consecutive years. The highest yield of plant above-ground mass (on average 7.1 t ha^{-1}) was in the treatment where grasses were fertilised with mineral fertilizers (NPK), and it was 1.7 times higher compared to un-used peat (UU). In the unfertilized grasses treatment (UF) the yield average was 6.7 t ha^{-1}, and the former red clover and timothy mixture (M) produced a comparable yield of above-ground mass (6.6 t ha^{-1}).

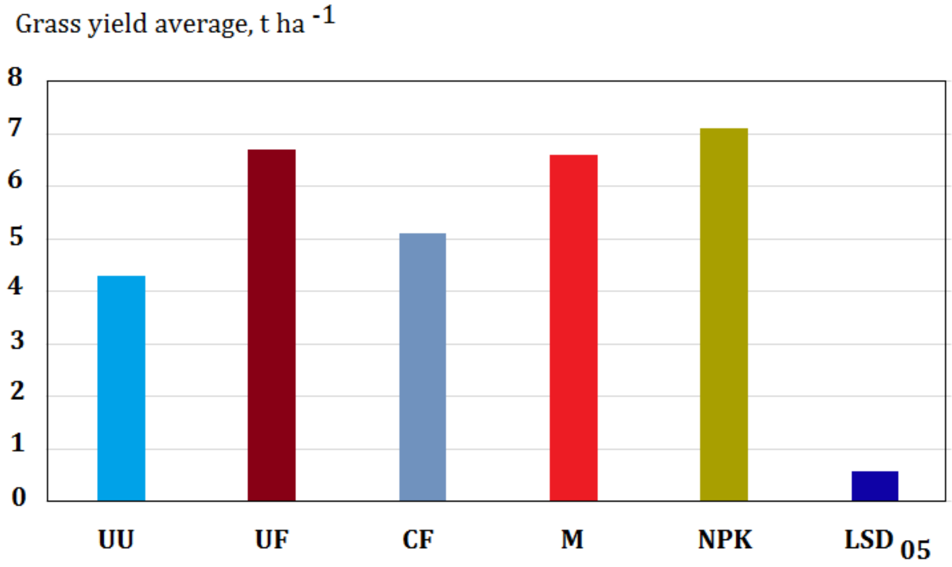

Figure 1. The average of grass yield in former used Terric Histosol, t ha^{-1}

Note: UU – un-used peat soil; UF – unfertilized perennial grasses; CF – crop rotation field; M – red clover and timothy mixture; NPK – perennial grasses fertilized with NPK.

The data in table 2 presented the *Terric Histosol* pH changes with depth. The pH of the soil ranged from 5.67 to 6.05. Due to mineralization, the content of soil organic matter (SOM) and SOC respectively decreased, the largest amounts of SOC are stored in the upper soil layer of perennial grasses fertilized with NPK (NPK), there was the highest yield of biomass; and accordingly, the lowest content of SOC – in soil of un-used peat (UU) (Table 2).

Table 2. The pH, SOC, SOM and WEOC in different land-use of Terric Histosol, 2012

Treatment	pH			SOC, g kg^{-1}			SOM, g kg^{-1}			WEOC, g kg^{-1}		
	Soil depth, cm											
	0–10	10–20	20–30	0–10	10–20	20–30	0–10	10–20	20–30	0–10	10–20	20–30
UU	5.97	6.03	5.99	405.6	393.9	417.2	699.2	679.1	719.3	1.11	1.00	0.91
UF	5.83	5.80	5.84	406.4	408.1	402.9	700.7	703.5	694.5	0.83	0.85	0.87
CF	6.01	6.00	5.96	424.0	417.9	400.4	731.0	720.5	690.3	0.87	0.89	0.85
M	5.81	5.85	5.82	449.2	426.5	462.5	774.5	735.2	797.3	0.79	0.80	0.75
NPK	6.05	5.98	5.67	481.3	477.3	468.2	829.7	822.8	807.2	0.72	0.70	0.72
LSD$_{05}$	0.243	0.222	0.444	53.89	34.26	39.38	92.90	59.06	67.89	0.274	0.185	0.263

Note. UU – un-used peat soil; UF – unfertilized perennial grasses; CF – crop rotation field; M – red clover and timothy mixture; NPK – perennial grasses fertilized with NPK.

The intensive mineralization in the 0–30 cm layer leads to such distribution of SOC in the soil. The SOC content in the *Terric Histosol* is unequal due to different land-use.

Labile carbon (WEOC) is the fraction of soil organic carbon with most rapid turnover times and its oxidation drives the flux of CO_2 between soils and atmosphere (Zou et al., 2005). The compounds that are part of the labile SOC fraction are biochemical active, they are related to material and energy transformations in the soil, as well as appreciably affect soil fertility (Popov et al., 2004).

Labile water extractable organic carbon (WEOC) content in peat soil was 0.70–1.11 g kg^{-1} (Table 2). The upper layer (0–10 cm) in UU, CF treatments had more labile carbon than deeper layer (20–30 cm). This was affected by the intense mineralization of the upper layer. Due to peat soil cultivation and mineralization, organic acids can form organic-mineral compounds and reduce their mobility and solubility, which in turn, decreases dissolved organic carbon content in the soil.

The largest accumulation of mobile humic acids (MHA) in peat soil was determined in the former agricultural land compared with UU peat soil (Figure 2).

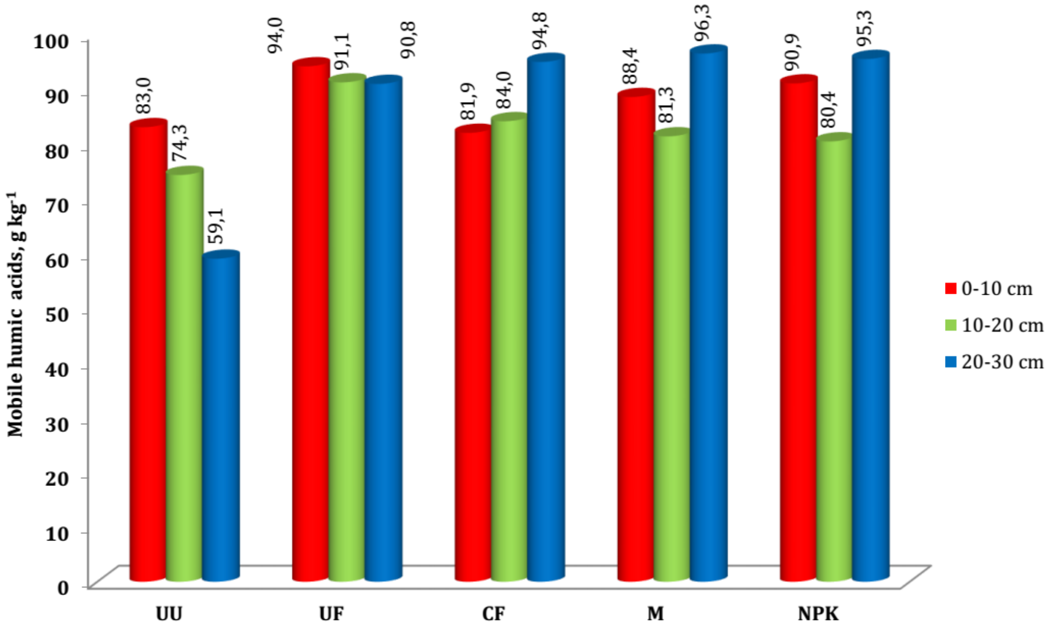

Figure 2. The content of mobile humic acids in different land-use of Terric Histosol, 2012

Note. UU – un-used peat soil; UF – unfertilized perennial grasses; CF – crop rotation field; M – red clover and timothy mixture; NPK – perennial grasses fertilized with NPK.

The largest MHA content was established in the treatment of former mixture of red clover and timothy (M) (96.3 g kg^{-1}). The range and importance of the diverse functions, services and resources provided by peat lands are changing dramatically with the increases in human demand for the use of peat ecosystems and their natural resources. Peat-forming ecosystems are important sinks for atmospheric carbon, nevertheless generally underestimated in global climatic change studies. Our research and data presented in this paper partly fill this gap. Using these and similar experimental findings one can predict the changes in peat and choose conservation measures.

After investigation of content of soil macroelements in *Terric Histosol* it was found that the lowest total nitrogen (N) content was in crop rotation field. Significant differences were determined in the crop rotation field (CF) and perennial grasses fertilized with NPK at P<0.05 level of probability, while remaining differences are influenced by the fertilization applied previously (Table 3).

Table 3. The content of total soil N, P and K in different land-use of Terric Histosol, 2012

Treatment	Soil total N, g kg^{-1}			Soil total P, g kg^{-1}			Soil total K, g kg^{-1}		
	Soil depth, cm								
	0–10	10–20	20–30	0–10	10–20	20–30	0–10	10–20	20–30
UU	33.0	29.9	29.9	1.72	1.45	1.48	0.71	0.62	0.26
UF	28.8	30.7	26.5	1.72	1.64	1.48	0.61	0.35	0.42
CF	27.4	21.9	26.8	1.79	1.72	1.48	1.04	0.38	0.56
M	22.5	27.0	30.6	1.57	1.51	1.35	0.56	0.50	0.48
NPK	37.1	37.2	34.6	1.48	1.40	1.29	1.35	1.08	1.01
LSD 0.05	9.252	6.771	10.698	0.269	0.455	0.23	1.118	0.759	0.372

Note. UU – un-used peat soil; UF – unfertilized perennial grasses; CF – crop rotation field; M – red clover and timothy mixture; NPK – perennial grasses fertilized with NPK.

The quantity of total phosphorus in *Terric Histosol* decreased with depth and this corresponding to the data of other researchers, who found a negative correlation between content of total P and humic acids in peat bogs (Satrio et al., 2009).

The higher C and N content in peat soil increase the productivity of swards cultivated there. The presence high content of potassium K in the investigated peat soil relates with use of mineral fertilizers in agriculture, so the highest amounts of total K were found in perennial grasses fertilized with NPK soil (1.35, 1.08 and 1.01 g kg^{-1}), and the lowest amount of total K was determined in treatment of unfertilized perennial grasses

(0.61, 0.35 and 0.42 g kg^{-1}) in 0–10, 10–20 and 20–30 cm layers respectively. Total K is predominantly accumulated in the upper 0–10 cm layer of *Terric Histosols*, and its concentration gradually decreases with depth.

Conclusion

Renaturalization is still observed after the usage of the peat soil and there are variations in their chemical compositions. After 12 years since the end of field experiment the differences in soil chemical composition remained still between treatments of differently used peat soil.

Irrespective to the land-use of peat the mineralization results decrease of SOC and increase of labile water extractable organic carbon content in the soil, which leads to carbon emission into the atmosphere. Labile water extractable organic carbon (WEOC) content in peat soil was 0.70–1.11 g kg^{-1}. The upper layer (0–10 cm) in UU, CF treatments had more labile carbon than deeper layer (20–30 cm). This was affected by the intense mineralization of the upper layer.

The distribution of total N and P in profile of *Terric Histosol* is directly related to the vertical gradient of mineralization intensity; higher amounts of N and P have been accumulated where mineralization was more intense. The distribution of K is related with land-use of *Terric Histosol* as its biggest quantity is established in arable land - crop rotation field, which has been associated with commercial fertilisers. The highest amounts of total K were found in perennial grasses formerly fertilized with NPK.

In order to conserve organic matter on *Terric Histosol* long-lived sown grasses should be grown with moderate fertilization.

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