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Chemical composition of differently used *Terric Histosol*

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Abstract

The main objective of this study was to identify the differences in the soil organic matter (SOM) and organic carbon (SOC) and hot water soluble carbon (HW-C) contents, as well as accumulation of elements associated with SOM of *Terric Histosol* (*HSs*) with removed or non-removed peat layer as affected by land use – arable land, meadow and forest. Soil samples for chemical analysis were taken from the 0–30 cm layer of peat bog soil in 3 replicates at the former Radviliškis Experimental Station in Lithuania. C, N, S contents, C:N, C:S and N:S ratios were measured by a dry combustion method using a fully automated analyzer Vario EL III ("Elementar", Germany). Soil organic matter (SOM) content was calculated by multiplying Corg content by 1.724. Hot water extractable carbon (HW-C) was extracted by soil-water solution ratio 1:5 according to the VDLUFA standard method. The differently used *Terric Histosol* had different SOM, carbon, nitrogen and sulphur contents. The highest concentrations of hot water extractable carbon (HW-C) were established in the forest (1.42%) and in the meadow of peat bog soil (1.13%) with a non-removed peat layer. This demonstrates the intensive SOM transformation processes here. Significant correlations between most of the parameters were determined in this study. A strong correlation between SOM and N (r = 0.670**) was determined. Also, strong correlations were established between soil components such as soil carbon and ratios C:N, C:S and N:S as well as HW-C and HW-N. For the assessment of changes in peat soil it is necessary to study not only total contents of SOM and SOC but also hot-water soluble carbon (HW-C), which can be considered as a sensitive indicator of the land use impact.

Key words: peat bog soil, land use, meadow, forest, arable land, SOC, SOM.

Introduction

Soil organic matter (SOM) is considered as one of the main indicators of soil fertility, cultivation level and soil resistance to the negative anthropogenous and natural factors; it serves in providing soil with nutrients, adds to their conservation, and determines the soil potential properties. There are numerous findings on the dynamics of SOM status in mineral soils; however, there are not enough data on the status of organic matter in peat bog soils, i.e. in sensitive and rapidly changing ecosystems (Glatzel et al., 2003; Janušienė, Šleinys, 2003).

Radviliškis bog corresponds to boggy soils prevalent in the country (Эрингис, 1964; Bilevičius, Puodžiukynas, 1969; Pelkinių dirvožemių naudojimas, 1996). A judicious management of soils under completing and diverse land uses is the key to increasing SOM (Blanco-Canqui, Lal, 2004). Botanical composition, physical and agrochemical properties of drained and cultivated peat bogs make it possible to grow various agricultural crops under relatively favourable conditions (Lietuvos dirvožemių…, 1998).

In order to develop predictive models that work over time-scales, we need a better understanding of feedback mechanisms between hydrology, community composition, and organic matter accumulation in peatlands (Bauer, 2004). Grassland re-cultivation research in Germany has shown that when the use of abandoned grasslands is resumed and 3 cuts are taken annually one can expect to have quite a satisfactory sward in the grassland where 90% of the area is occupied by nettle after three years. The number of plant species increased from 17 to 36, and the nutritive value of the sward improved (Briemle, 2001).

Forests favor the soil organic carbon sequestration because of their increased woody biomass, extensive roots, and abundant litter (Sharrow, Ismail, 2004). Extensive roots of forest plants influence the microbial biomass in the soil by controlling the C cycle between the atmosphere and the soil (Brown, 2000). Conversion of forests to croplands also decreases SOC concentration and degrades soil structural properties (Lal, 1997). Dissolved organic nutrients are present in significant concentrations in most ecosystems but particularly within forest ecosystems (Michalzik et al., 2001). Significant inputs of dissolved organic carbon (DOC) into forest ecosystems occur from both above ground (e.g. throughfall, litter-fall) and below ground (e.g. microbial / root exudation and turnover) (Lajtha et al., 2005).

Ecosystems of peat bogs are one of the larger organic carbon reserves. Perennial grasses are believed to be able to reduce OM decomposition, since they partly restore OM by leaving a great root content and stubble. Some researchers recommend establishing long-term grasslands, which, if properly managed, could produce a high herbage yield (Bilevičius, Puodžiukynas, 1969; Барсуков, 1998; Szabo et al., 1999; De Visser et al., 2001), however, OM transformation depends on the composition of individual swards and their management. Natural and agricultural ecosystems play an important role in the conversion of atmospheric CO_2 into SOM pool to sequester SOC. Conversion of natural ecosystems into agricultural lands for intensive cultivation severely depletes SOC pools. SOC is the main component of soil organic matter. Numerous researchers have investigated the effects of different management practices on SOM, composition using chemical, spectroscopic and other methods. Less is known on the impact of different land use systems on accumulation of soluble organic carbon.

For research tasks it is necessary to divide SOC into discrete, measurable and biologically significant entities, so-called "pools". Typically, SOC is divided into fractions having different properties and rates of turnover (Krull et al., 2004). Haynes (2000) noted that water-soluble carbon was an important fraction as it was considered the main energy source for microbes, the primary source for soil nutrients nitrogen (N), phosphorus (P), sulphur (S) and reacted quickly to changes in the soil quality status. Water extractable organic matter (WEOM) consists of a heterogeneous mixture of hydro-soluble structures either freely circulating in soil or physically trapped within or loosely adsorbed onto soil minerals (Zsolnay, 2003). WEOM comprises structures involved in various processes in soil including pedogenesis, carbon distribution and stabilization (Kaiser, Guggenberger, 2000). WEOM also affects the speciation and transfer of organic and mineral contaminants (Dudal et al., 2005), and may represent a serious risk of contamination in ground and adjacent surface waters. WEOM in natural and agro-ecosystems is the net output of multiple simultaneously-acting biotic and abiotic processes involving formation, degradation, and transferring mechanisms (Kalbitz et al., 2000). Compared to total SOM the concentrations of water extractable organic matter are very small. Nevertheless, it is linked to many important soil functions. Numerous factors affect WEOM dynamics, most of them interacting in the same or in different directions (Embacher et al., 2007). The HW-C being a component of the labile SOM and also being closely related to soil microbial biomass and micro aggregation could therefore be used as one of the soil quality indicators in soil-plant ecosystems. There is very little information in the literature of any attempt to explore the potential of this pool of C as a soil quality indicator (Ghani et al., 2003).

The main objective of this study was to identify the differences in the organic matter (SOM) and organic carbon (SOC) also hot water soluble carbon (HW-C) and nitrogen (HW-N) contents, as well as accumulation of other elements associated with SOM, of *Terric Histosol* with removed or non-removed peat layer as affected by land use – arable land, meadow and forest.

Materials and methods

Soil sampling and site description. Soil sampling was done at the former Radviliškis Experimental Station in Lithuania in a peat bog (*Terric Histosols*, *HSs*) lying 120 meters above the sea level (55° 45′N, 23° 30′E) with removed and non-removed peat layer (Эрингис, 1964). Soil samples for chemical analysis were taken in 2007 from the 0–30 cm layer of peat bog soil in 3 replicates. Land use systems were investigated as follows: meadow, in peat bog with non-removed peat layer; meadow, in peat bog with removed peat layer; intensively used arable land in peat bog with non-removed peat layer; forest in peat bog with non-removed peat layer; forest in peat bog with removed peat layer. The investigated peat bog, whose eastern edge borders

Radviliškis town, covers an area of 1203 ha. The Radviliškis bog formed at the source of the Beržė river. Drainage of the bog was started in 1905 after digging a bank channel, which was deepened several times in the course of time. Peat digging for fuel was begun in 1938. The peat was dug especially intensively during the 1954–1966 period, during which 85% of peat was removed. The peat bog was drained by a closed drainage. Sand lies under peat layer. After removal of the peat layer the bog was drained by a closed drainage and part of land was sown with perennial grasses or used intensively as arable soil (Эрингис, 1964; Bilevičius, Puodžiukynas, 1969). The peat in the peat bog with non-removed layer was well decomposed (40%), and in that with removed layer, the peat was medium decomposed (27–30%). The thickness of the peat layer of investigated peat bog soil with non-removed peat layer was 2.2 m; with removed peat layer – 0.3–0.5 m. The main agrochemical properties of the peat bog soil with removed and with non-removed peat layer were: pH_{KCl} value 5.5–5.6 and 6.2–6.5, mobile P_2O_5 – 89–140 and 79–138 mg kg^{-1} and K_2O – 90–120 and 101–112 mg kg^{-1} soil, respectively (Petraitytė et al., 2003).

Chemical analyses. The soil samples for chemical analyses were air-dried, then dried at 60°C and finally milled with ultracentrifugal mill ZM 200 fitted with 0.2 mm sieve. C, N, S contents and C:N, C:S, N:S ratios were measured by a dry combustion method using a fully automated analyzer Vario EL III (“Elementar”, Germany). For analyses, 30–35 mg of the sample were mixed (1:1) with WO_3 catalyst, pressed into special tin boats and burned automatically in the O_2 enriched atmosphere at +1150°C. SOM content was calculated by multiplying SOC content by 1.724. Hot water extractable carbon was extracted by soil-water solution ratio 1:5 analysed according to VDLUFA standard method (Schulz, 2004).

The resultant data were processed using *Stat-Eng* for *Excel*, *vers.1.55* (Tarakanovas, Raudonius, 2003).

Results and discussion

The lowest carbon content (278.2 g kg^{-1}) was determined in the peat bog soil with removed peat layer in the forest and conversely, the highest content (468.6 g kg^{-1}) was in the meadow with non-removed peat layer (Fig. 1).

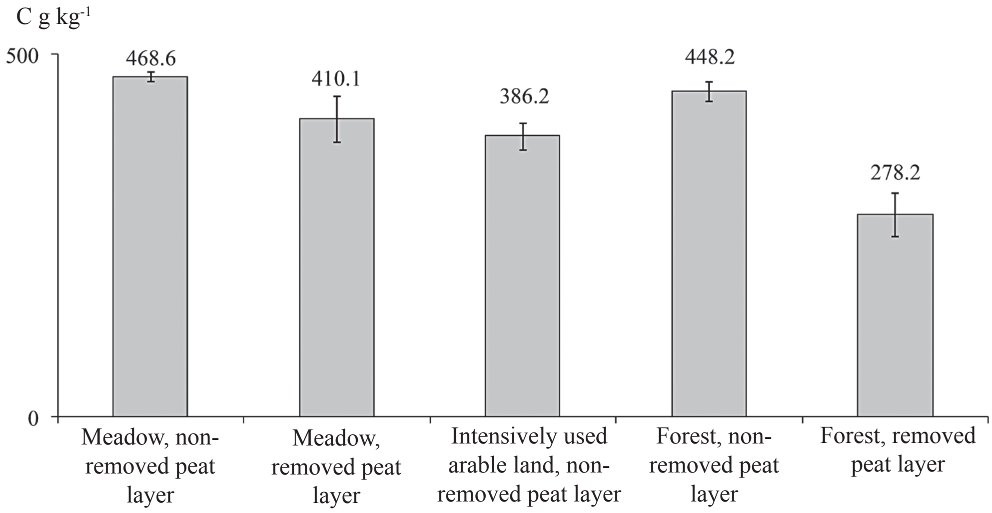

Figure 1. The influence of land use on the soil organic carbon content in *Terric Histosol* (0–30 cm) Radviliškis Experimental Station, 2007

Minimum N content was established in the forest soil with removed and non-removed peat layer 18.8 and 23.0 g kg^{-1} (Fig. 2). The peat removal decreased significantly ($p < 0.05$) the carbon content (Fig. 1) as well as nitrogen (Fig. 2) content of peat bog soil. Higher carbon and nitrogen contents in peat soil increase the productivity of swards cultivated there. Herbage dry matter yields produced in grasslands established on the peat bog soil with non-removed peat layer were significantly higher than those produced on the peat bog soil with removed peat layer (Bilevičius, Puodžiukynas, 1969; Pelikinių dirvožemių naudojimas, 1996). On peat bog with non-removed peat layer the aftermath tends to grow more rapidly and herbage yields distribute more evenly throughout the growing season (Эрингис, 1964; Petraitytė et al., 2003).

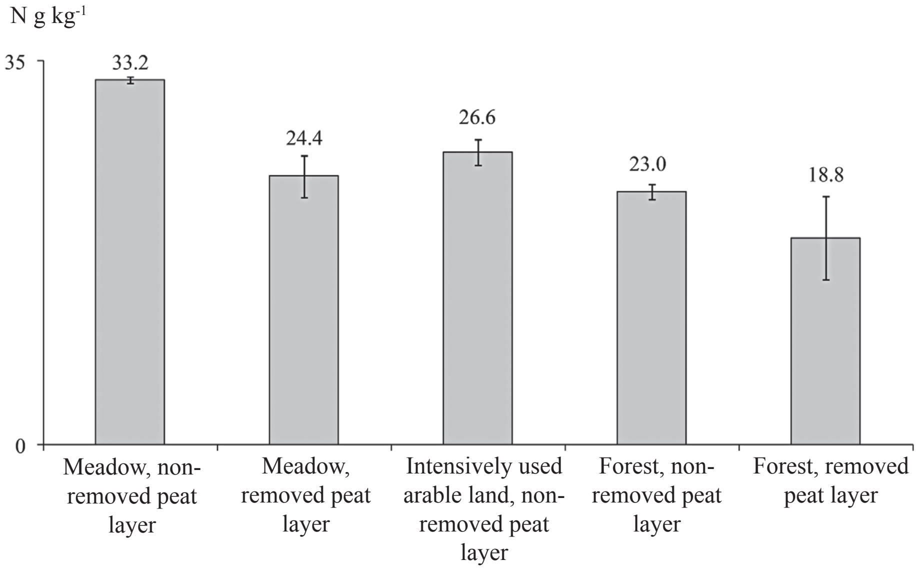

Figure 2. Influence of the land use on the nitrogen content in *Terric Histosol* (0–30 cm)
Radviliškis Experimental Station, 2007

Different use of the peat bog exerted a marked effect on other soil chemical indicators. Table 1 shows that SOM content in the *Terric Histosol* depended significantly on land use. The highest content of SOM (705 g kg^{-1}) accumulated in the peat bog meadow with non-removed peat layer.

Table 1. The chemical composition of differently used peat bog soil (0–30 cm)
Radviliškis Experimental Station, 2007

Land use	SOM	HW-C	HW-N	P	S	pH
	g kg^{-1} of soil					
Meadow, in peat bog with non-removed peat layer	705 ± 15.6	11.3 ± 0.3	0.112 ± 0.009	1.39 ± 0.12	4.95 ± 0.07	5.73 ± 0.10
Meadow, in peat bog with removed peat layer	637 ± 57.4	7.3 ± 0.1	0.088 ± 0.023	4.7 ± 0.08	6.03 ± 0.71	6.61 ± 0.17
Intensively used arable land in peat bog with non-removed peat layer	586 ± 24.8	9.4 ± 0.4	0.096 ± 0.002	1.27 ± 0.10	3.63 ± 0.18	6.13 ± 0.08
Forest in peat bog with non-removed peat layer	540 ± 16.0	5.5 ± 1.3	0.062 ± 0.011	0.38 ± 0.02	8.59 ± 0.44	6.48 ± 0.31
Forest in peat bog with removed peat layer	443 ± 67.4	14.2 ± 1.5	0.103 ± 0.003	0.64 ± 0.08	2.45 ± 0.42	4.99 ± 0.12

In the meadow peat removal resulted in SOM reduction from 705 to 637 g kg^{-1}. Both types of peat under the forest had smaller contents of SOM – 443–540 g kg^{-1}. The S content of peat soil was relatively high (3.63–8.59 g kg^{-1}) compared to phosphorus content (0.38–4.7 g kg^{-1}). In forest soil HW-C ranged from 5.5 g kg^{-1} with non-removed peat layer to 14.2 g kg^{-1} – with removed peat layer (Table 1). It was found that the HW-C depended on the land use and therefore can be used as a sensitive indicator of organic matter transformations. Table 1 shows that pH ranged from 4.99 to 6.61 and the lowest values of pH were recorded for forest soil with removed peat layer.

The C:N ratio in peat bog soil except for the forest with removed peat layer was close to the same indicator usually established in cultivated mineral soils of the country (Table 2). The C:S ratio was significantly higher than that of C:N, and was the highest (113.4) in the forest of peat bog with removed peat layer. The N:S ratio was the lowest under forest in the peat bog with non-removed peat layer (2.3).

Strong positive correlations between some parameters were determined in this study (Table 3). Strong correlation of the same trend was found between C:S and N:S (r = 0.991**). A strong correlation between SOM and N (r = 0.670**) was established. The opposite trend of the relationship between pH and HW-C (r = −0.902**) indicates that a decrease in pH, which means the increase in peat soil acidity, increases soil organic matter mobility and transformation processes.

Table 2. Proportions of carbon, nitrogen and sulphur contents in differently used peat bog soil (0–30 cm)

Land use	C:N	Relative values %	C:S	Relative values %	N:S	Relative values %
Meadow, in peat bog with non-removed peat layer	114.1 ± 0.21	100	28.2 ± 2.6	100	6.7 ± 0.06	100
Meadow, in peat bog with removed peat layer	16.8 ± 0.27	119	68.6 ± 2,91	243	4.1 ± 0.20	61
Intensively used arable land in peat bog with non-removed peat layer	14.5 ± 0.07	103	106.3 ± 0.64	377	7.3 ± 0.07	109
Forest in peat bog with non-removed peat layer	19.5 ± 0.01	138	54.4 ± 2.37	193	2.3 ± 0.37	34
Forest in peat bog with removed peat layer	15.0 ± 0.33	106	113.4 ± 0.90	402	7.6 ± 0.20	113

Table 3. Linear correlation (r) determined between investigated parameters

	C	N	S	P	C:N	C:S	N:S	HW-C	HW-N
HW-C			−0.748**						
HW-N			−0.674**					0.597*	
pH			0.639*		0.572*			−0.902**	
SOM		0.670**			−0.727**				
C									
N	0.818**								
S	0.721**								
P		0.693**							
C:N				−0.794**		−0.886**		−0.749**	−0.671**
C:S	−0.542*		−0.950**				0.991**	0.821**	0.614*
N:S			−0.919**	0.666**	−0.706**		−0.931**	0.818**	0.628*

Note. r – correlation coefficient; * – $P < 0.05$ level of probability, ** – $P < 0.01$ level of probability.

In natural ecosystems the balance usually settles between organic matter mineralization and humification, while in disturbed ecosystems mineralization and peat degradation processes start to prevail (Szabo et al., 1999). This can lead to complete degradation of peat bogs, which is conditioned by many reasons, one of which is incorrect land use. It was stated that the global area of peatlands in the world had been reduced significantly (estimated to be at least 10 to 20%) in the last 200 years through climate change and human activities, particularly by drainage for agriculture and forestry (http://www.mirewiseuse.com/statement.html). Human pressures on peatlands are both direct through land conversion, drainage, excavation, and indirect, as a result of air pollution, water contamination, and contraction through water removal.

The range and importance of the diverse functions, services and resources provided by peatlands are changing dramatically with the increases in human demand for 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. It is well known that the changes in SOM content during land use may be difficult to detect in a short term. Soluble compounds are much more sensitive indicators of soil changes. Therefore, the effects of land use in peat bog on the total content and soluble forms of SOM are poorly known. Our research and data provided in this paper partly fill in this gap. Using these and similar experimental data one can predict the changes in peat and choose conservation measures. Therefore, for the assessment of the changes in peat soil it is necessary to study not only the total contents of SOM and carbon or sulphur and nitrogen but also hot-water soluble carbon, as well as ratios C:N, C:S, which can be useful for the future research on land use impact.

Conclusions

1. The differently used *Terric Histosol* had a different carbon, nitrogen, and sulphur contents. The highest contents of carbon and nitrogen were identified in peat soil with non-removed peat layer used as a meadow.

2. The highest concentrations of hot water extractable carbon (HW-C) were established in the forest with removed peat layer (14.2 g kg^{-1}) and in the meadow of peat bog soil (11.3 g kg^{-1}) with non-removed peat layer. This demonstrates the intensive SOM transformation processes.

3. Significant correlations between most of the parameters were determined in this study. A strong correlation between SOM and N (r = 0.670**) was established. Strong correlations between soil components such as soil carbon and ratios C:N, C:S and N:S as well as HW-C and HW-N were also determined.

4. For the assessment of changes in peat soil (*Terric Histosol*) it is necessary to study not only the total contents of SOM and SOC but also hot-water soluble carbon (HW-C), which can be considered as a sensitive indicator of the land use impact.

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Skirtingai naudojamo *Terric Histosol* cheminė sudėtis

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Santrauka

Dirvožemio ėminiai paimti buvusios Radviliškio bandymų stoties eksperimentinėje bazėje iš divožemio 0–30 cm sluoksnio trimis pakartojimais. Tyrimų tikslas – nustatyti skirtingai naudojamo durpinio dirvožemio (*Terric Histosol*, *HSs*) pagrindinius cheminius komponentus ir jų tarpusavio ryšius. Cheminėms analizėms dirvožemio bandiniai sumalti ultracentrifuginiu malūnu ZM 200 su 0,2 mm sietu. Anglies (C), azoto (N), sieros (S) kiekis ir C:N, C:S bei N:S santykis nustatyti naudojant automatinį analizatorių „Vario EL III“ („Elementar“, Vokietija). Dirvožemio organinė medžiaga perskaičiuota iš organinės anglies, nustatytos cheminiu būdu, naudojant vidutinį perskaičiavimo koeficientą 1,724. Fosforas (P) nustatytas cheminiu būdu po suardymo sieros rūgštimi spektrofotometru „Cary 50“ („Varian“, Vokietija). Karštame vandenyje tirpi anglis (HW-C) nustatyta VDLUFA metodu – ekstrahuojant (dirvožemio ir vandens santykis 1:5). Skirtingai naudojamas *Terric Histosol* turėjo nevienodą kiekį organinės medžiagos, anglies, azoto ir sieros. Didžiausia karštu vadeniu ekstrahuotos anglies koncentracija nustatyta nenukastoje žemapelkėje miške (1.42 %) ir pievoje (1.13 %). Tai parodė joje vykstančius intensyvius dirvožemio organinės medžiagos transformacijos procesus. Esminiai koreliaciniai ryšiai nustatyti tarp daugumos šių tyrimų metu nustatytų rodiklių. Nustatyta koreliacija tarp dirvožemio organinės medžiagos ir azoto kiekio ($r = 0.670^{**}$). Taip pat nustatyta stipri koreliacija tarp dirvožemio cheminių komponentų – C, C:N, C:S bei N:S ir karštame vandenyje tirpios anglies bei azoto. Kaip jautrų pokyčių durpiniame dirvožemyje indikatorių siūloma taikyti karštu vadeniu ekstrahuotos anglies kiekį.

Reikšminiai žodžiai: durpinis dirvožemis, žemėnauda, pieva, miškas, ariama žemė, dirvožemio organinė medžiaga, dirvožemio organinė anglis.