Chapter 4

The Status of Pachiterric Histosol Properties as Influenced by Different Land Use

Alvyra Slepetiene, Kristina Amaleviciute-Volunge,
Jonas Slepetys, Inga Liaudanskiene and
Jonas Volungevicius

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Abstract

Soil drainage as well as soil cultivation and fertilization has considerable influence on the organic matter mineralization rate and changes in the profile structure. Our research suggested that quantitative and qualitative characteristics of peat soil are changing in response to the renaturalization processes and different management. The study set out to estimate chemical and physical properties of Pachiterric Histosol, qualitative and quantitative changes in carbon resulting from different management and renaturalization processes. Wetland and peatland soils are among the largest organic carbon stocks, and their use contributes to carbon emissions or accumulation processes. The focus of our work is research into the peculiarities of organic carbon accumulation and transformation as influenced by different land use of peat soil. Results on the chemical properties of Pachiterric Histosol showed the influence of management and renaturalization on mobile and by pyrophosphate solution extractable humic and fulvic acids and humification degree. We are also exploring the specificities of organic carbon variation in the context of peat renaturalization and are seeking to answer the question as how to optimize the use of peat soils and how to match up this with the renaturalization processes in order to reduce greenhouse gas emissions and contribute to organic carbon accumulation and conservation in the soil.

Keywords: Pachiterric Histosol, land use, soil profile, carbon, humification, humic acids

1. Introduction

Peat soils in the world: Soils are the largest pool of carbon in terrestrial ecosystems, globally containing more than two-thirds of the ecosystem's total carbon [1]. Organic soils (histosols) are an important reservoir of organic carbon (OC) [2]. Peatlands are an integral part of the global climate system. They occupy a relatively small fraction (approximately 3%) of the Earth's land area, but store about 30% of the world's soil carbon [3, 4]. Heightened attention is being devoted to their anthropogenic transformation changes in the physical and chemical properties caused by those processes [3, 5, 6]. Anthropogenic disturbance, primarily agriculture and forestry as well as drainage can disrupt the cycle of carbon and result in the changes in atmospheric gas emissions [3, 7]. Increasingly, more research is being carried out on the properties of peat soils worldwide [8–10]. **Figure 1** shows territories of peat in the world.

Peat soils in the Nordic-Baltic region: Relatively large territories of the Nordic-Baltic countries are covered by peat soil layers [13]. The Nordic and Baltic countries contain a large extent of peatland, which is characterized by a great diversity of peat accumulating ecosystems. Approximately, 45% of this peatland has been drained and emits about 25% of the total CO_2 emissions. The CO_2 emissions from the peatland in Iceland and Latvia are twice as large as those from all other sources combined, except land use; in Estonia, Lithuania and Finland 50%, in Sweden 25% and in Norway 15%. Just in Denmark and Greenland, the emissions from peat soils are below 10% of the total other CO_2 emissions [14]. Peatlands may thus play a vital role in national climate change mitigation policies.

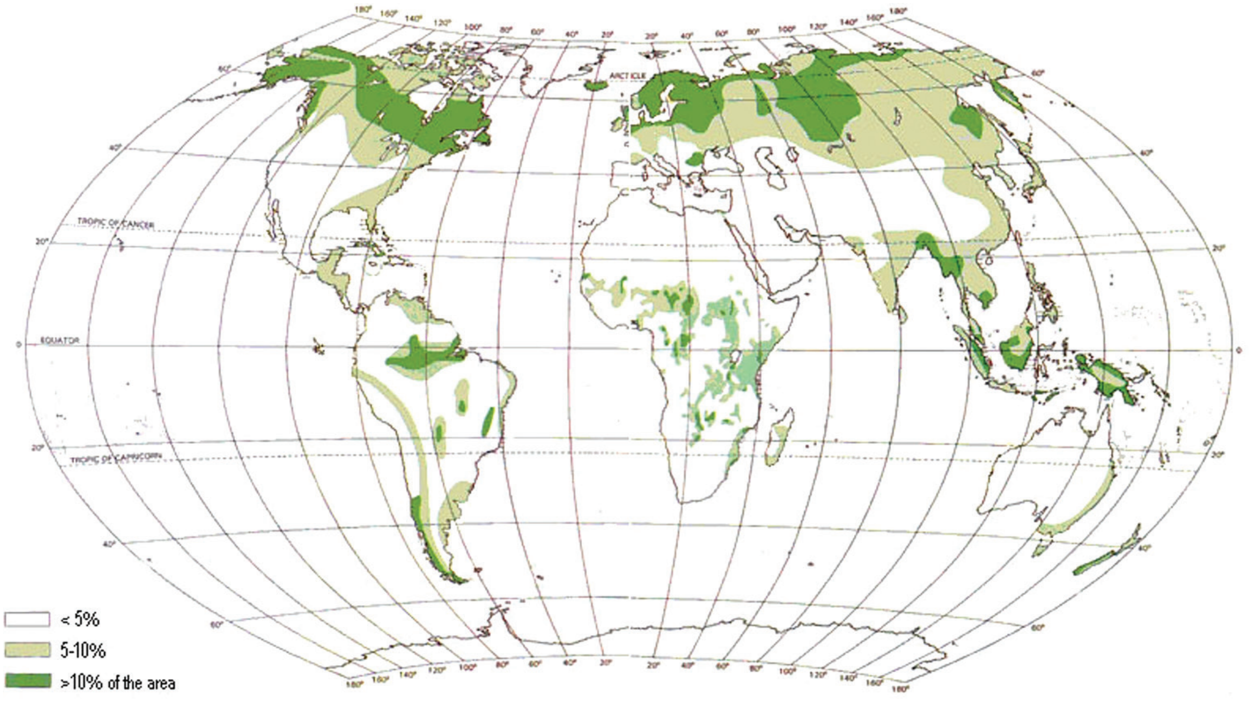


Figure 1. Peats in the world [11, 12].

Peat soils in Lithuania: Peat soils occupy approximately 9.5% of the Lithuanian soil cover [15]. Of these, about 44% is made up of marshes, 13%—high bogs, about 2%—intermediate type peat, and even 34%—other peaty mineral soils, and about 90% of all peatlands are drained or removed and are used for agriculture. There are approx. 40,000 bogs varying in size in Lithuania; low-lying bogs constitute nearly two-thirds of the peat soils [16]. According to various sources, their area totals 414,000–578,000 ha. Histosols occupy nearly 8% of the total area of Lithuania. Terric Histosol accounts for 44%, Fibric Histosol for 13%, Terric-Fibric Histosol for 2% and other Umbric mineral soils for 34% of the total Histosols. About 7% of Lithuania's Histosols have been little investigated so far, their types have not been identified. Specimens of the most common and typical Histosols occurring in Lithuania are provided in **Figures 2** and **3**.

Histosols with a peat layer depth of not less than 100 cm are attributed to deep peat soils, and those with a peat layer thickness not exceed 100 cm are attributed to shallow peat soils. The peat layer thickness of Histosols with a removed peat layer generally does not exceed 40–50 cm. The peat layer thickness of Umbric mineral soils does not exceed 40 cm. In drained Histosols, due to the mineralization of the upper peat layer, the peat layer thickness may decrease to 20 cm. The various types of Histosols differ in morphological and chemical properties.

Peat soils, especially those used for agricultural purposes, have been insufficiently studied so far. The soil drainage methods, soil cultivation, fertilization and crops exert considerable influence on the organic matter mineralization rate and changes in the soil profile structure. There is very little research evidence on the morphology of the peat soil profile, changes in organic matter forms, humification and carbon as influenced by drainage, agricultural use and renaturalization.

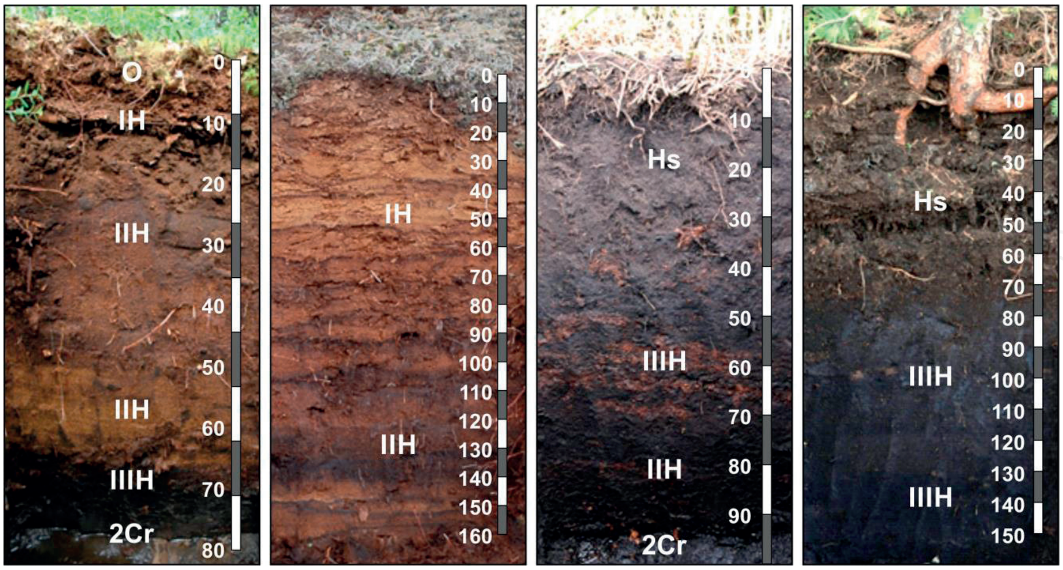


Figure 2. Profiles of Lithuanian Histosols: from left to right, 1 – Pachifibric Histosol (high moor shallow peat soil) – Siluva high bog, 55°32′22.27″N 23°17′50.48″E, 2 – Bathifibric Histosol (high moor deep peat soil) – Rekyva high bog, 55°50′27.54″N 23°18′13.67″E, 3 – Pachiterric-Fibric Histosol (transitional moor shallow peat soil) – Siluva peatland, 55°32′36.51″N 23°13′49.50″E, 4 – Bathiterric – Fibric Histosol (transitional moor deep peat soil) – Tytuvenai intermediate bog, 55°34′16.76″N 23°17′27.90″E (pictures by Dr J. Volungevičius).

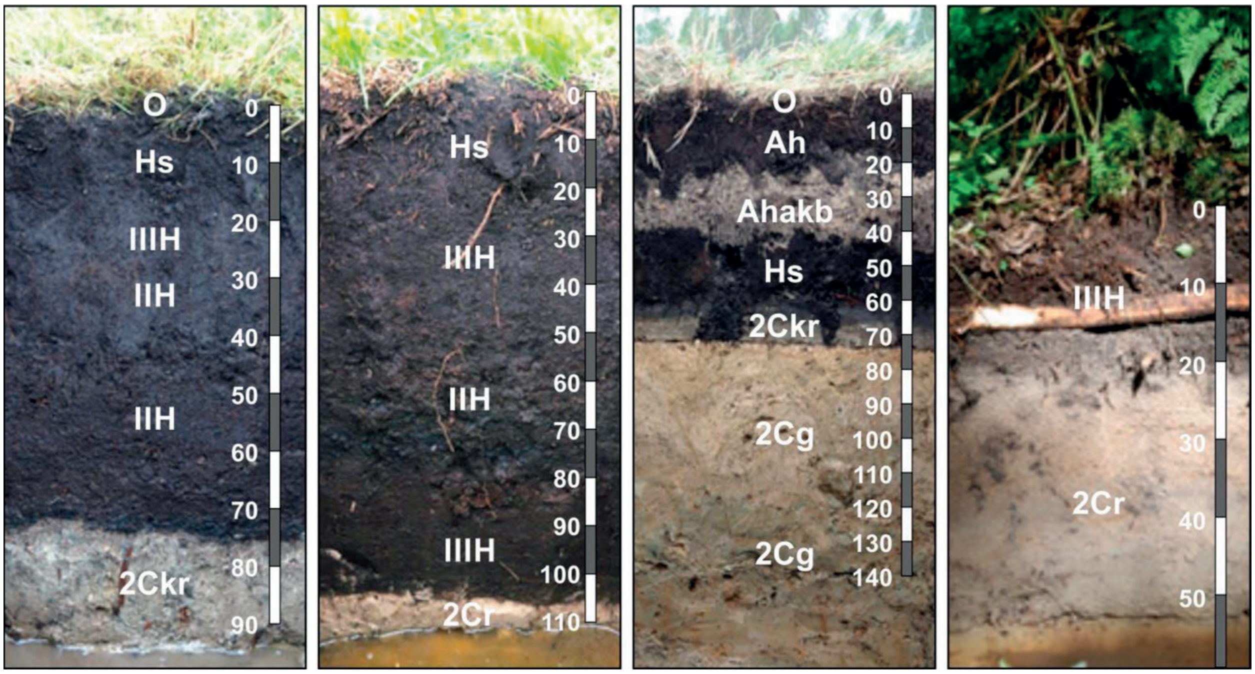


Figure 3. Profiles of Lithuanian Histosols: from left to right, 1 – Pachiterric Histosol (low moor shallow peat soil) – Radviliskis low bog, 55°49′43.15″N 23°28′36.03″E, 2 – Bathiterric Histosol (low moor deep peat soil) – Kabeliai peatland, 53°57′11.59″N 24°19′01.31″E, 3 – Removed Drainic Bathiterric Histosol – Radviliskis low bog, 55°48′51.15″N 23°29′22.43″E, 4 – Areni – Umbric Gleysol – the Curonian spit, 55°31′04.73″N 21°06′50.94″E. Pictures by J. Volungevičius.

Vegetation and peat soils: There is research evidence on the positive role of grasslands in the organic matter buildup. Perennial grasses can decrease organic matter decomposition, since they partly restore organic matter by leaving a large amount of plant debris such as roots and stubble. It is recommended establishing long-term grasslands, which, if appropriately managed, could produce an abundant biomass yield; however, organic matter transformation is influenced by the sward composition and management, as well as by soil conditions.

Plants are known to influence peatland carbon fluxes both (i) directly through respiration and (ii) by the production of litter and root exudates, which are then broken down by microbes within the peat matrix [17]. It has been documented that plant identity can influence the diversity of low molecular weight soil organic compounds and that plant species richness increases the richness of soil organic compounds, at least for low molecular weight organic compounds [18]. The fresh organic matter should be introduced in the soil, which would promote humus formation. Crops grown in a crop rotation determine the quantitative and qualitative composition of plant residues getting into the soil and significantly regulate soil microflora complex. Grasses and legumes are an important source of soil humic substances. They leave a large amount of roots in the soil, during the breakdown process of which soil humus substances are formed, of which the most valuable are humic acids. It was determined that about 49–50 dt of non-decomposed roots are left in 1 ha of the soil under clover [19].

Peat soil and land use: In order to elucidate which factors cause an increase or decrease in soil organic carbon after agricultural abandonment, it is necessary to integrate the data on the temporal dynamics of the plant community and soil organic carbon. According to the data of the Lithuanian Geological Survey (https://www.lgt.lt/epaslaugos/pages/trees/geolis.xhtml), about 90% of the wetlands are drained in Lithuania. Nearly 94% of the soils in low moor peat and peaty declensions were drained in Lithuania in the second half of the twentieth century. Draining of peat soils was conducted in order to adapt them for agricultural purposes [20]. However, there is very little published data on the changes in peat soils in response to different land use and renaturalization process. To date, there are few studies that have investigated peat soils, especially their use for agricultural purposes.

Peat soil organic carbon: Strack and Zuback [10] have documented that peatlands have a significant role in the global carbon cycle by storing from 469 to 486 Gt of carbon, emitting around 10% of the total global methane emissions and acting as great sources of organic carbon (particulate and dissolved) to downstream ecosystems. The change of land use and accompanying disturbance of peat soil can be the main cause of soil carbon loss, e.g. deforestation [21–23], cultivation [24] and cropping [25]. Labile soil organic matter is characterized by fast decomposition rates and short turnover times. It accounts for approximately 5% of soil organic matter, but is highly active because it is made up of readily decomposable compounds [25]. In sustainable agriculture, the management and enhancement of soil organic carbon are highly relevant. Soil organic matter is the source and sink of the atmospheric carbon dioxide and plays a major role in the global cycling of carbon. Soil organic carbon content can be measured by conventional techniques. The contents and storage of soil carbon and nitrogen are impacted by soil-forming and anthropogenic factors.

Anthropogenic activities such as fertilization and cropping systems play a significant role in the regulation of carbon and nitrogen amounts in agricultural soils and greenhouse gas emissions [26, 27]. Due to the human activities, the atmospheric carbon dioxide concentration is rapidly increasing, while the long-term storage capacity of terrestrial and ocean ecosystems is decreasing [28]. In order to understand the role of the soil in the global carbon dynamics, it is necessary to estimate soil carbon stocks. Recently, elevated attention has been paid to the role of soils in the global carbon cycle, where the world’s soils contain roughly three times the carbon contained in the total world’s vegetation and twice the amount of carbon as carbon dioxide in the earth’s atmosphere [29], and thus the alterations in soil carbon content can influence the atmospheric composition [9].

Peat soil humic substances: The quantity and quality of SOM and its major component — humus — are influenced by management practices. From the agricultural point of view, the understanding of the behavior and the function of soil organic matter pools are important to the environmental sustainability [30, 31]. Humification of organic substrates is a complex biochemical process occurring with a direct participation of micro-organisms. Generally, only a small part, about 10–20% of organic matter present in the soil is subject to humification. The major part of organic residues (80–90%) mineralizes to simple compounds or forms less readily decomposed organic compounds (lignin type), that make up almost non-hydrolysable part of soil organic matter [19]. The remaining part of plant organic matter turns into humic substances. Plant biological properties have a great effect on humus formation. Organic matter composing plant residues take part in the biochemical transformation process. The final result of this is products of full mineralization CO2, H2O, low molecular weight organic compounds and high molecular weight compounds. Since the soil contains various enzymes, different reactions can take place simultaneously. Carbohydrates and amino acids are fully mineralized. Organic compounds more resistant to biological oxidation (oligosaccharides, polysaccharides and lignin) break down much more slowly.

In these soils, organic carbon is stored in the form of plant residues in various stages of decomposition, as well as in the form of humic compounds, which can be defined as a mixture of macromolecules of variable chemical composition, size and shape [32]. Humification processes result in an increase in the content of humic substances in organic soils. They are involved in sorption processes and form soluble and insoluble complexes with metallic ions in the soil [33]. Soil humic substances are the key constituents of the adsorptive complex that affects various soil characteristics.

Dissolved organic carbon concentrations of peat soil: A few studies have attempted to understand the dissolved organic carbon cycling in peatlands. It was found that the concentrations of dissolved organic carbon are controlled by the total carbon content of the peat soil [34], by availability of oxygen, by water table depth [35] and by the peat degradation status [36]. The concentrations of dissolved organic carbon responded to the environmental conditions, but only after a lag period of a few weeks [37]. Dissolved organic carbon concentrations vary with season and land use — this has been proved by investigations from two fens in Northeastern Germany over 2 years [38]. The alterations in soil organic carbon resulting from the management practices are difficult to identify because these changes are slow and relatively small compared to the extensive background of soil organic carbon, which vary both spatially and temporally [39]. The identification of some sensitive labile soil organic carbon fractions, such as water soluble organic carbon and readily mineralizable carbon contributes to clarification of soil organic carbon changes at early stages as affected by management.

Organic matter humification degree of peat: Although mires and peatlands form one of the largest reservoirs of refractory organic matter, few studies on the humification process for peat have been conducted [40, 41]. In scientific literature, there is little information about the degree of humification of soil organic matter in peat soils. Different methods and approaches are used for the assessment and determination of humification. For example, the ratio of the area under fluorescence emission per total C content was defined as the SOM humification index [42]. According to Bejger et al. [43], humification is understood as the transformation of macromorphologically identifiable organic matter into amorphous compounds, as a rule involving the changes that occur in vegetal residues or soil organic matter during the humification process. Also, the ratio among extractable carbon, humic acids carbon, fulvic acids carbon and total organic carbon is used to determine the degree of humification [44]. It is clear that the relative increase in the share of humic acids with respect to other humic substances is valuable from the agronomic and ecological viewpoint. In our work, we used the definition of Orlov [45], stating that the relative share of carbon of humic acids in the total organic carbon in the soil, expressed in %, is understood as the degree of humification.

The main task of this research was to study the chemical composition of Histosol, to identify the differences in the soil total carbon, dissolved organic carbon, humic substances, humification of organic matter of differently used peat soil a with removed and non-removed peat layer.

2. Experimental site and conditions

History: The wetlands are surface areas of excess moisture, overgrown with specific vegetation, and covered with a layer of peat that is thicker than 30 cm; land areas where the peat layer is thinner are called waterlogged soils. There are about 40,000 wetlands of various sizes in Lithuania [16]. Their total area is 414,000–578,000 ha, and they represent 6–7% of the country's territory. The low moor peat lands are predominant, and they account for about 66% of all wetlands. The Radviliškis Experimental Station was established in 1936 with a view to investigating whether low moor peat soils could be used for agricultural purposes. The studies from other countries indicate that the most valuable plants in the low moor peat soils are perennial grasses. However, it was also necessary to study annual plants to select the right plant change in the crop rotation in the low moor peat soil. The Radviliškis low moor peat land was formed at the source of the Beržė River, the eastern edge of peat land borders the Radviliškis town (**Figure 4**), and covers an area of 1203 ha. Field experiments were conducted at the former Radviliškis Experimental Station of the Lithuanian Institute of Agriculture on a low moor peat (Pachiteric Histosol) with the removed and non-removed peat layer at an altitude of 120 m above the sea level (55°45′N, 23°30′E).

The general characteristics of peat soil profiles (I, II, III) are presented in **Table 1**.

Stages of the long-term investigations: Peat soils in the former Radviliškis Experimental Station were studied using different approaches. The study period was divided into four stages. In each of these stages, we focused on specific problems.

Stage I: In 1995, an experiment involving field and grassland plants was set up on a low-lying bog with a removed and non-removed peat layer at Lithuanian Institute of Agriculture's Radviliškis Experimental Station. In 1995–2001, the study involved the following treatments: unused peat soil; unfertilized perennial grasses; crop rotation field; red clover and timothy mixture; perennial grasses fertilized with NPK (**Table 2**).

In this experiment, the effects of different use of peat soil on its properties were compared.

Treatments of the experiment

Stage II: In 2001, the use of Histosol for agricultural purposes was discontinued. Stage I was completed. However, it was noticed that within 3–4 years after the discontinuation of grassland use, marked changes occurred in it: unsown forbes and various types of willows appeared, alterations occurred in the soil properties as well. The process of renaturalization started. Therefore, research was resumed in order to study the processes of renaturalization.

Stage III: In 2007, while conducting research within the framework of the project funded by the Lithuanian Science and Studies Board, the first marked changes were identified in the unused peat soil. The published data suggest, as well as our observations in the current study, that the changes in organic matter in peat soils are much more evident than those occurring in mineral soils. Therefore it was important to continue to monitor and evaluate the ongoing renaturalization processes, in particular in terms of the quantity and quality of organic matter, and to determine the quality indicators that had not been studied before.

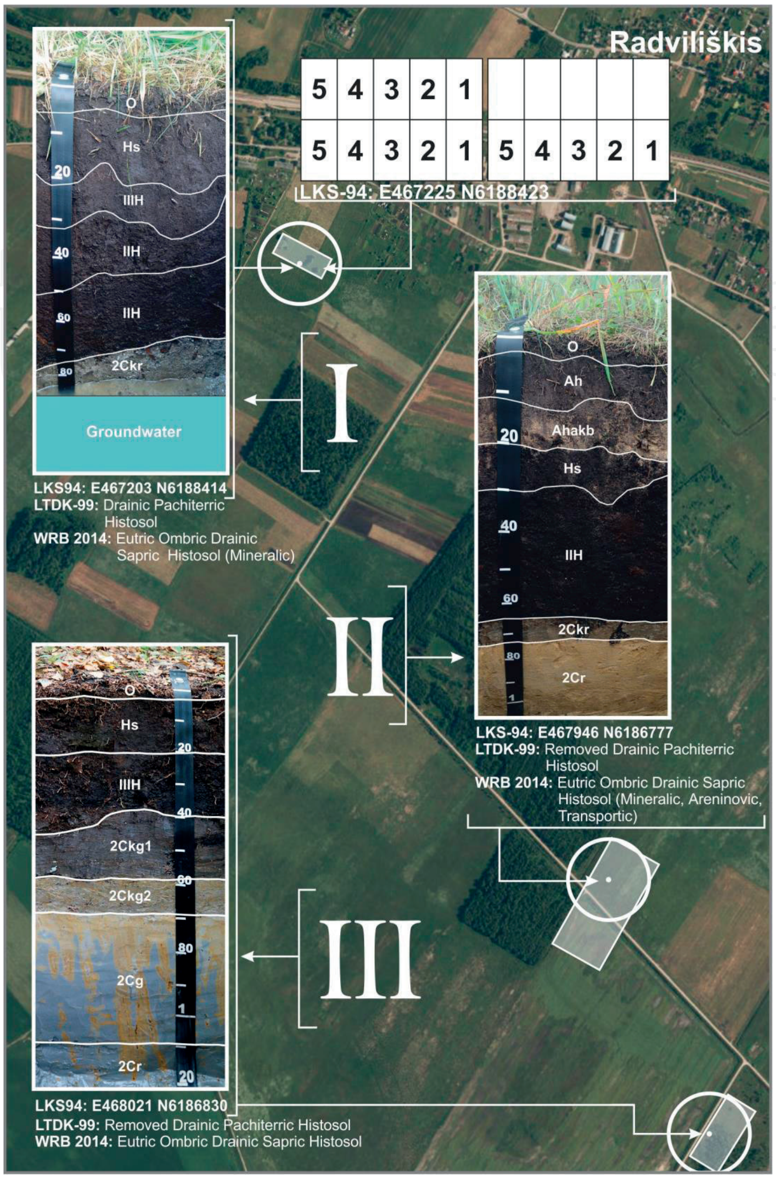


Figure 4. The scheme of the experimental site and sampling places: I – Drainic Pachiterric Histosol with a non-removed peat layer under renaturalization; II – Differently used removed Drainic Pachiterric Histosol; III – Differently used removed Drainic Pachiterric Histosol (source from information system of Lithuanian geological survey: Swamp and peat bogs of Lithuania; https://www.lgt.lt/epaslaugos/pages/trees/geolis.xhtml).

Stage IV: Since 2012 up to now. At this stage, we have accumulated the largest body of evidence from peat soil research, analyzed and summarized the data on the soil chemical composition from the renaturalization viewpoint and compared different land uses.

The treatments investigated at this stage of the long-term experiments in the soil with a non-removed peat layer were as follows: (i) unused peat soil; (ii) former unfertilized perennial grasses; (iii) former crop rotation (potatoes; winter rye and red clover) field; (iv) former red clover (Trifolium pratense L.) and timothy (*Phleum pratense* L.) mixture; (v) former perennial grasses fertilized with commercial NPK fertilizers. The treatments of peat soil with a removed peat layer were: (i) natural forest; (ii) arable crop rotation field and (iii) meadow.

Soil name according to LTDK-99	**I – Drainic Pachiterric Histosol with non-removed peat layer**	**II – Drainic Pachiterric Histosol with removed peat layer**	**III – Drainic Pachiterric Histosol with removed peat layer**
Soil name according to WRB 2014	Rheic Drainic Fibric Histosol (Eutric)	Drainic Fibric Histosol (Areninovic, Eutric, Transportic)	Drainic Fibric Histosol (Eutric, Transportic)
Coordinates: Longitude	E467203 E20°28′34.651″	E467946 E20°29′18.058″	E04968302 E23°29′39.02″
Latitude	N6188414 N55°50′24.572″	N6186777 N55°49′31.803″	N06186032 N55°48′26.37″
Altitude	119 m	117 m	116 m
Climate: Precipitation	560 mm		
Average annual air temp.	+7.4°C		
Average annual soil temp.	+7.8°C		
Relief: Genetic group	Almost equal	Little wavy	
Genetic subgroup	Organogenic plain	Organogenic upland	
Land use	Perennial meadows		Forest
Natural vegetation (trees)	—	—	*Betula pendula (Roth),* *Salix viminalis (L.),* *Salix cinerea (L.),* *Frangula alnus (Mill.),* *Sorbus aucuparia (L.),* *Padus avium (Mill.)*
Natural vegetation (herbaceous)	*Elytrigia repens* (L.) Gould, *Cirsium arvense* (L.) Scop, *Urtica urens* (L.), *Taraxacum officinale* (L.) Weber ex F.H. Wigg, *Rumex crispus* (L.), *Aegopodium podagraria* (L.), *Stellaria palustris* (L.)	*Sinapis arvensis* (L.), *Elytrigia repens* (L.) Gould, *Taraxacum officinale* (L.) Weber ex F.H. Wigg, *Euphorbia cyparissias* (L.), *Hieracium pilosella* (L.), *Achillea millefolium* (L.), *Polygonum persicaria* S.F.Gray, *Equisetum arvense* (L.), *Viola arvensis* Murray.	*Phragmites communis (Trin.), Carex nigra (Reichard), Calamagrostis arundinaceae (Roth), Festuca gigantea (Vill.),* *Urtica dioica (L.), Glechoma hederacea (L.)* *Aegopodium podagraria (L.)*
Soil surface coating	100%	70–80%	70–80%
Soil-forming material	Low moor peat on the ground moraine	Low moor peat on sapropel and limnoglacial sand	
The beginning of carbonate occurring:	75 cm	65–74 cm, sapropel interlayer foams	40–70 cm, sapropel interlayer foams
Depth of groundwater:	Min – 50 cm; max – 75 cm	−120 cm	−115 cm
Effective soil depth	75 cm	65 cm	40 cm
Anthropogenic effects:	Drained	Drained, removed peat layer	
Soil moisture:	Moist 0–50 cm; wet 50–120 cm	Dry 0–60 cm; moist 65–74 cm; wet 74–120 cm	Dry 0–40 cm; moist 40–110 cm; wet 110–120 cm

Table 1. The general characteristics of three peat soil profiles.

Treatments				
UU	**UF**	**CF**	**M**	**NPK**
—	Sowing of perennial grasses	Potatoes	Sowing of red clover and timothy 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 of red clover and timothy 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	Mixture 5th year of use	Perennial grasses 5th year of use
—	Winter rye	Winter rye	Winter rye	Winter rye

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

Table 2. The experimental design of differently used Histosol.

Thus, in the long-term research (1995–2017) we have attempted to study and build up a complete picture of the various changes that have occurred in the properties of Histosol over the period of more than two decades. Research done in other countries suggests that perennial grasses are the most profitable plants on low-lying bogs. However, our research was aimed to verify whether it is possible to grow various other plants, including annuals, and choose the right crop sequence in the rotation without damage to soil properties.

Methods of analyses: Soil samples for chemical analyses at stage I of the experiment were taken from 0 to 20 cm peat layer in 3 replicates. Prior to the chemical analyses, the samples were crushed and sieved through a 2-mm sieve, visible roots and plant residues were manually removed, and the samples were air-dried. For the analyses of humic substances aliquot of soil samples were further crushed and passed through a 0.25 mm sieve. Analyses were carried out at the Chemical Research Laboratory of Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry.

Soil pH was determined in 1 M KCl according to the standard ISO 10390:2005. Soil total nitrogen (Ntotal) was determined by the Kjeldahl method, and plant-available phosphorus (P_2O_5) and potassium (K_2O) were determined by the Egner-Riehm-Domingo method. The total content of potassium (K) was determined using an atomic absorptiometer AAnalyst 200 (Perken Elmer, USA) after the mineralization with sulfuric acid. Soil organic carbon content was determined by the Tyurin method modified by Nikitin in 1999 [46] using a photometric procedure at the wavelength of 590 nm and glucose as a standard after wet combustion, using the UV-VIS spectrophotometer Cary 50 (Varian, Netherlands) equipped with a computer program.

Mobile humic substances and humic acids were determined according to the method of Ponomareva and Plotnikova [47] using a soil: 0.1 M NaOH solution ratio of 1:5 for the extraction of mobile humic substances (**Figure 5**).

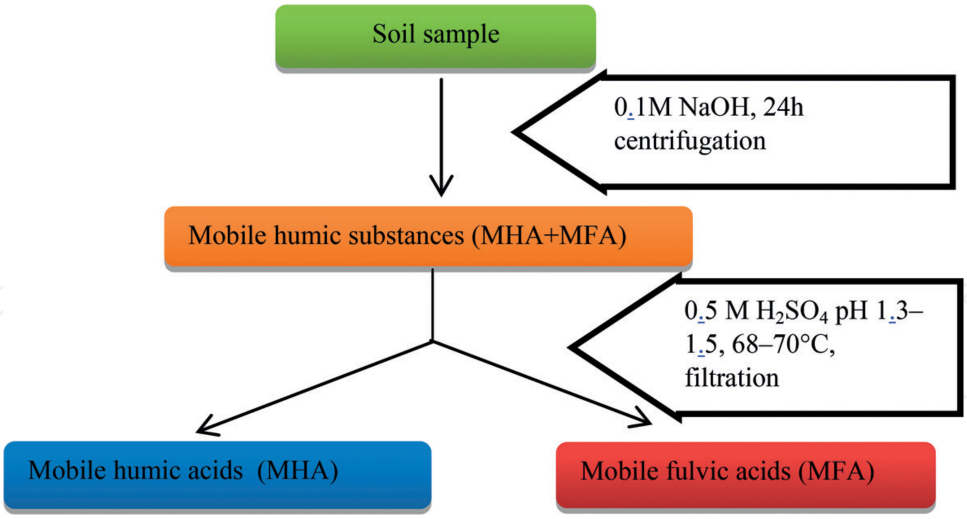


Figure 5. Determination of mobile humic substances according to the Ponomariova-Plotnikova-modified Tyurin method.

During stage I of the long-term soil investigations, humic substances were additionally extracted from the Histosol (0–20 cm) by the NaOH and sodium pyrophosphate +NaOH solution [46].

Water extractable organic carbon (WEOC) was determined using an ion chromatograph SKALAR (Skalar Analytical B.V., Netherlands). The soil samples were shaken with cold distilled water at soil: water ratio of 1:5 for 1 hour using a multi-functional orbital shaker PSU-20i (BioSan, Latvia). The extract was obtained after filtration through 0.45 μm cellulose filters. The automatic ion chromatographic measurement procedure is based on the following reactions: the sample is acidified under nitrogen using sulfuric acid solution. Labile organic carbon is released in the sample thanks to this reaction. In this process, organic carbon is oxidized to carbon dioxide. The amount of carbon dioxide is measured by infrared detection at 2–100 mg C L^{-1} range. The obtained results (mg C L^{-1}) are recalculated in g kg^{-1} soil.

For the determination of hot water extractable carbon (HWEOC), a suspension of soil:water (1:20) was prepared and boiled for 2 hours under reflux. Brown-yellow color extract was filtered through 0.45 μm cellulose filter. Carbon content in the extract was determined with an analyzer TOC 5050A (Shimadzu, Japan).

Soil particle size distribution was determined in the liquid dispersion using the light-scattering technique Mastersizer 2000 (Malvern Instruments, UK) which measures particles in a wide range from 2000 to 2.0 μm.

Statistical analyses: Experimental data were analyzed by the one-factor analysis of variance (SAS) and ANOVA.

3. Results and discussion

Profile I of Drainic Pachiterric Histosol (with non-removed peat layer) (**Figure 6**).

We determined that the most notable changes in soil characteristics are taking place in the upper layer of the peat soil profile. Organic matter transformation is taking place in this soil layer.

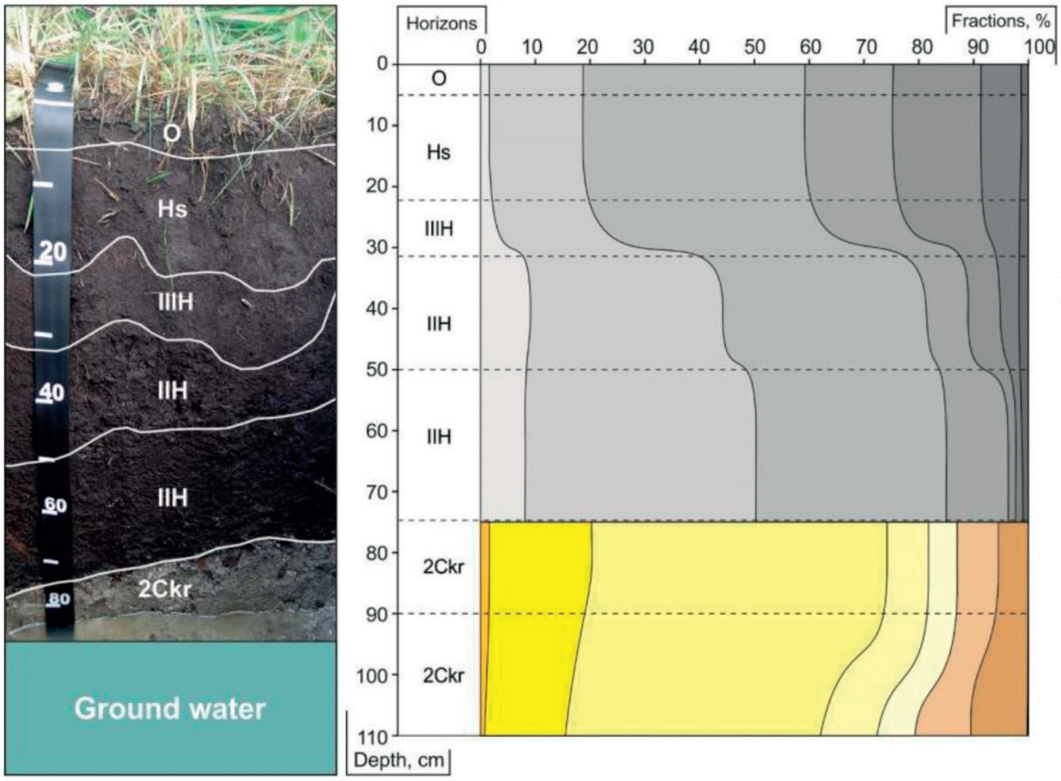


Figure 6. The textural composition of Drainic Pachiterric Histosol with a non-removed peat layer (according to WRB2014: Rheic Drainic Fibric Histosol (Eutric)).

The peat soil, the profile of which is given in **Figure 6**, was formed on Central Lithuanian ground moraine loam formations, which are found at a depth of 75 cm (2Ckr horizon), and they consist of carbonated skeleton moraine loam enriched with rocky stones. This horizon is waterlogged, and forms the basis for the formation of peat. The upper peat layer is drained, mineralized and, therefore, settled (up to 20 cm). Surface strongly mineralized Hs horizon formed after soil drainage and plowing, and the total thickness of the peat does not exceed 100 cm. This peat soil was not arable recently, therefore, the sod horizon enriched with organic matter began to form on its surface, and this is typical of soils that have long been present under the natural vegetation cover.

Profile II of Drainic Pachiterric Histosol (with non-removed peat layer, grassland) (**Figure 7**).

If the effect of human activity on the morphological and chemical characteristics of the peat soil profile is inherent only in the upper horizons (0–25, and partially 25–35 cm), meanwhile the peat soil, which profile is presented, is partly man-made due to intense anthropogenic activity. The basis of this peat soil is limnoglacial sand, whose fraction composition changes in depth. The amount of medium (500–250 μm) and small (250–100 μm) sand fraction is decreasing, and content of silt particles (53–2 μm) are increasing. The limnoglacial sand, covered with watertight sapropel at depths of 65–75 cm, creates favorable conditions for the formation of peat.

The upper layer of this peat soil was removed, and the naturally occurring medium mineralized peat remained only at 35–65 cm depth (horizon IIH). The horizon Hs formed after

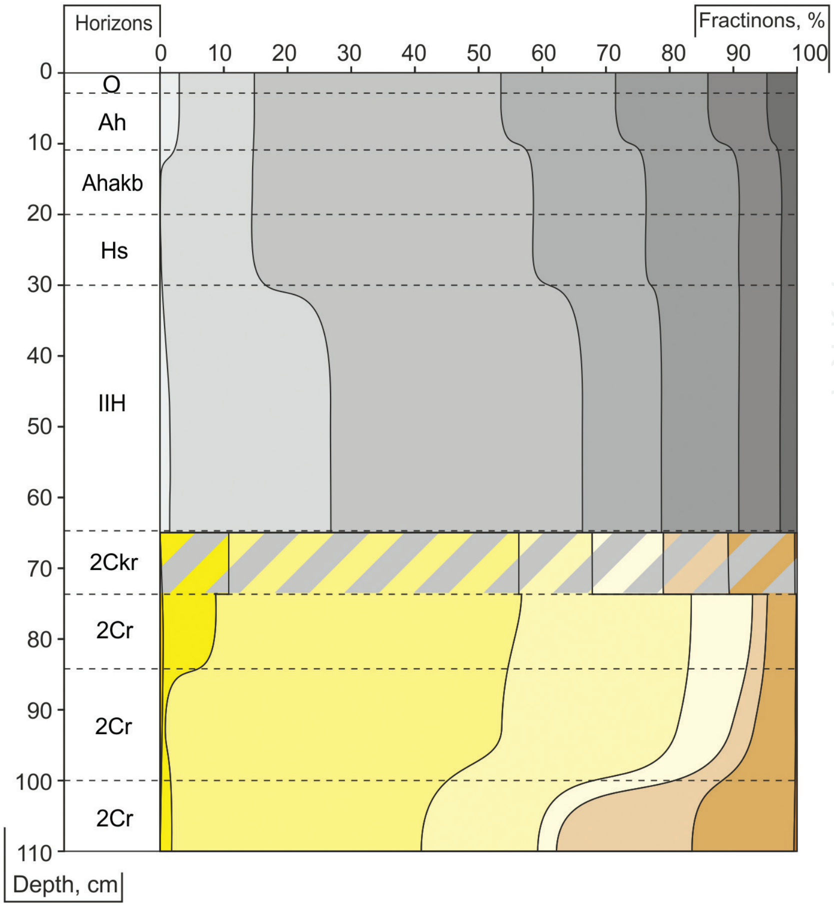
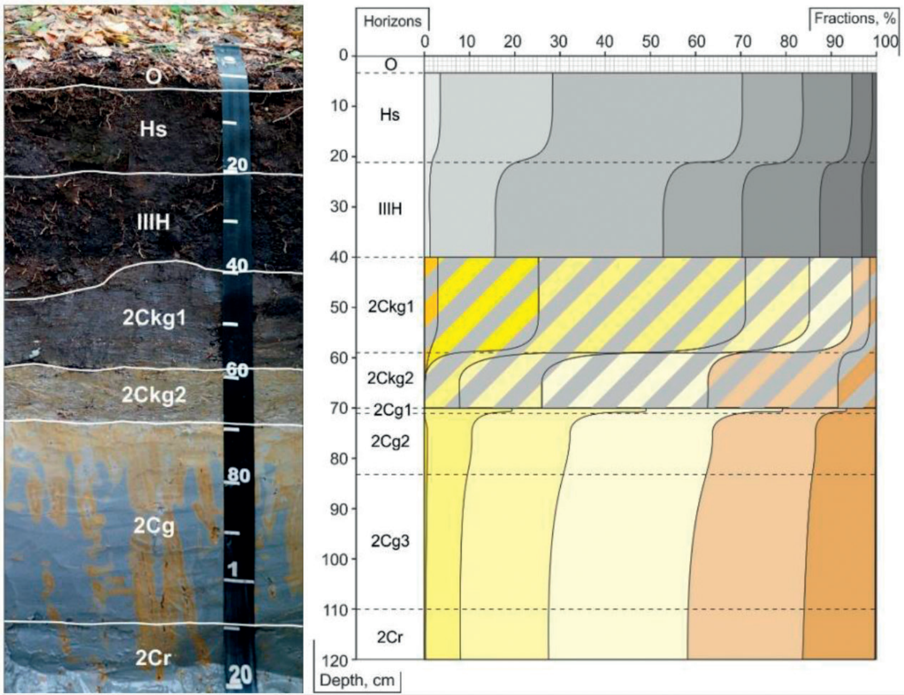


Figure 7. The textural composition of Drainic Pachiterric Histosol with a removed peat layer (according to WRB 2014: Removed Drainic Fibric Histosol (Areninovic, Eutric, Transportic)).

the drainage and exploitation of peat as a relic of the exhausted horizon. The anthropogenic Ahakb horizon was pushed/poured from the mixed mineral and organic soil when the surface and drainage system of the maintained peat bog were treated. Mineral humic Ah horizon was formed in the upper part of the removed peat profile after re-cultivation. The O horizon that formed above Ah horizon indicates that this anthropogenic peat does not undergo intense economic activity, and therefore the surface may be characterized by a weak sod formation process.

Profile III of Drainic Pachiterric Histosol (forest) (**Figure 8**).This Histosol has formed in the central part of the limnoglacial basin. Its ground surface is composed of limnoglacial sand, whose texture varies with depth. The content of medium (500–250 μm) and fine (250–100 μm) sand fractions is decreasing and the content of silt particles (53–2 μm) is negligibly increasing. Limnoglacial sand at the 40–70 cm depth is underlain by carbonated sapropel. This sapropel forms aquifuge, which creates conducive conditions to peat formation. As peat layer is removed in this Histosol, and according to the rules of peat bog exploitation, there has to be left about 50 cm peat, currently only 37 cm of the peat layer remains (in the 7–40 cm depth) and it consists of strongly decomposed peat (IIIH) and mineralized peat (Hs). Soil-forming ground surface texture of this Histosol is heterogeneous. This ground surface contains two



Fractions of soil forming materials	Particle sizes, µm (by FAO)							
	Sand					Silt		Clay
	Very coarse	Coarse	Medium	Fine	Very Fine	Coarse	Fine	
Mineral	2000-1000	1000-500	500-250	250-106	106-53	53-38	38-2	<2
Organomineral	2000-1000	1000-500	500-250	250-106	106-53	53-38	38-2	<2

Figure 8. The textural composition of Drainic Pachiterric Histosol with a removed peat layer (according to WRB 2014: Removed Drainic Fibric Histosol (Eutric, Transportic)).

horizons differing in genesis and four horizons differing in texture. The sand layer present at 84–120 cm depth (2Cg3–2Cr horizons) formed at a deeper place of the limnoglacial basin under the effect of less intensive movement of water mass. This is evidenced by an increase in silt (53–2 μm) content. With decreasing water mass, its movement exerted marked effect on the newly forming deposits: silt (53–2 μm) content decreased, while sand (500–53 μm) content increased. This effect is particularly evident at 70–72 cm depth of the profile. Sapropel started to form from the decomposed organic residues after the basin had drained. Silt particles (106–38 μm) and more decomposed organic matter predominate in sapropel present at 60–70 cm depth. Fine sand (250–106 μm) and higher decomposed organic matter content predominate in sapropel at the 40–60 cm. With increasing mineralization of peat horizons, the content of 1000–250 μm particles increases. Peat mineralization decreases with depth.

3.1. Chemical composition of Pachiterric Histosol

At stage I of the experiment, Pachiterric Histosol with non-removed peat layer had the higher N content (26.0–27.1 g kg-1), compared to peat with removed peat layer (16.1–18.7 g kg^{-1}), as well as P (**Tables 3** and **4**). In opposite, the highest ash content was determined in peat soil with removed peat layer (26.6–34.4%). Also, results of SOC and pH indicated different carbon amounts then peat soil layer was previously removed or non-removed (**Tables 3** and **4**).

Pachiterric Histosol with non-removed peat layer	pH_{KCl}	Ash %	SOC $g\ kg^{-1}$	N	P	K	P_2O_5	K_2O
				Total			Mobile (A-L)	
				$g\ kg^{-1}$			$mg\ kg^{-1}$	
Unused peat soil	5.6	19.2	343.8	26.8	12.0	0.95	89	531
Former unfertilized perennial grasses	5.6	18.6	343.7	26.0	11.8	0.74	57	136
Former crop rotation field	5.5	18.3	338.8	26.4	12.9	0.81	129	525
Former red clover and timothy mixture	5.5	17.9	341.4	27.1	12.3	0.69	137	360
Former perennial grasses fertilized with commercial NPK	5.6	18.4	342.0	26.7	13.0	0.77	180	390

Table 3. Content of macroelements (0–20 cm) of Pachiterric Histosol with a non-removed peat layer. Stage I of the experiment. 1998–2001.

Pachiterric Histosol with a removed peat layer	pH_{KCl}	Ash %	SOC $g\ kg^{-1}$	N	P	K	P_2O_5	K_2O
				Total			Mobile (A-L)	
				$g\ kg^{-1}$			$mg\ kg^{-1}$	
Unused peat soil	6.3	28.6	330.2	16.6	0.83	0.90	110	314
Former unfertilized perennial grasses	6.5	34.4	324.3	16.1	0.51	0.79	79	225
Former crop rotation field	6.4	32.8	321.5	16.1	0.50	1.00	230	446
Former red clover and timothy mixture	6.2	30.9	328.8	16.8	0.45	0.88	188	331
Former perennial grasses fertilized with commercial NPK	6.2	26.6	332.3	18.7	0.47	0.85	165	338

Table 4. Content of macroelements (0–20 cm) of Pachiterric Histosol with a removed peat layer. Stage **I** of the experiment. 1998–2001.

Different factors cause an increase or decrease in SOC and humic substances. Soil organic carbon (SOC) stocks are expected to increase after conversion of cropland into grassland [48]. Shallow and conventional tillage, past cultivation affected peat properties [38, 49, 50]. The composition of humic substances of Pachiterric Histosol with a non-removed peat layer is presented in **Table 5**. Humic substances (humic acids and fulvic acids) are organic compounds of mineral soils and peats. Humic acids are more valuable. They are formed during chemical and physical transformations in soils and peats. The differently used peat soil had different contents of 0.1 M NaOH and pyrophosphate solution extractable humic acids (**Table 5**).The content of humic acids extracted by pyrophosphate solution was much higher than that extracted by 0.1 M NaOH solution. The soil of the crop rotation field had lower humic acids contents compared to the soil under grasses.

Peat humification degree is an indicator of processes of decomposition and humification of peat. Peat humification can be estimated in the field or in the laboratory conditions using a range of the methods including determination of chemical properties [40]. Humification degree (HD) by mobile humic acids (HA1) of Pachiterric Histosol with non-removed peat layer was higher (12.1–12.9) compared to peat with non-removed peat layer (7.8–8.7) (**Figures 9** and **10**).

Treatment	HA1 g kg^{-1}	MHS	HA$_{pyr}$	HS$_{pyr}$
Unused peat soil	47.1	89.3	47.1	132.4
Unfertilized perennial grasses	48.9	91.9	49.3	136.5
Crop rotation field	48.3	92.0	44.7	136.0
Red clover and timothy mixture	49.6	93.3	51.8	136.4
Perennial grasses fertilized with NPK	48.3	92.1	50.6	133.5

Note: HA1, mobile humic acids, extracted by 0.1 M NaOH; HA$_{pyr}$, humic acids in pyrophosphate solution; HS$_{pyr}$, humic substances extracted by pyrophosphate solution.

Table 5. Composition of humic substances in differently used Pachiterric Histosol (0–20 cm) with non-removed peat layer. Stage I of the experiment. 1998–2001.

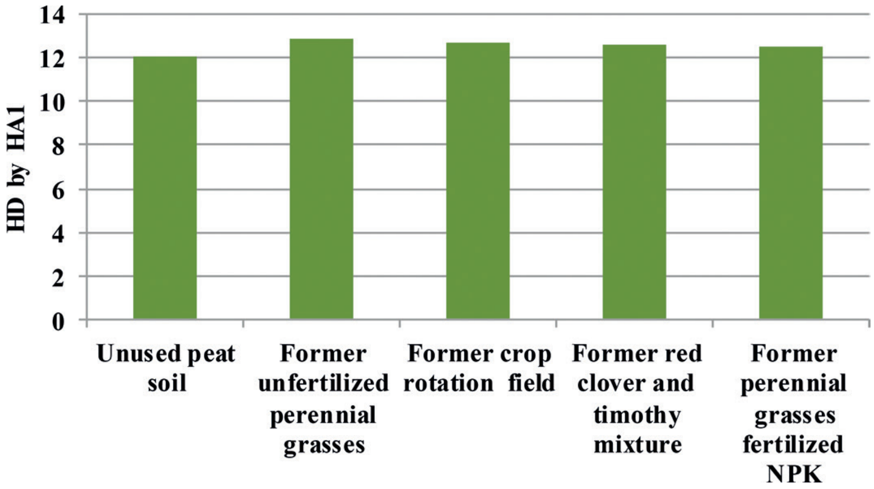


Figure 9. HD (%) according HA1 in differently used Pachiterric Histosol with non-removed peat layer (0–20 cm). Stage I of the experiments. 1998–2001.

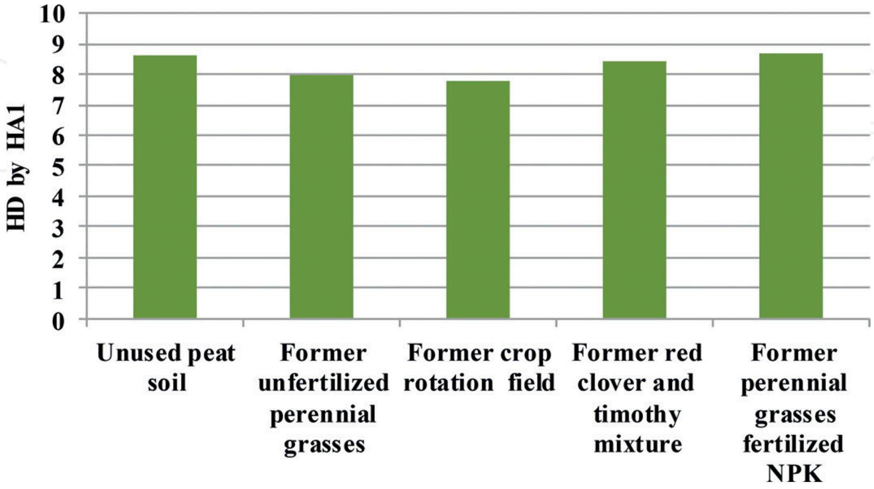


Figure 10. HD (%) according HA1 in differently used Pachiterric Histosol with removed peat layer (0–20 cm). Stage I of the experiments. 1998–2001.

HD (%) according to HA1 in differently used Pachiterric Histosol with a non-removed peat layer was higher, compared to the soil with a removed peat layer. In the unused peat soil, particularly in Pachiterric Histosol with a removed peat layer, under the effects of renaturalization, there was determined a markedly lower HD compared with that in the Pachiterric Histosol formerly used for agricultural purposes (**Figures 11** and **12**).

Humification degree (HD) by HA1 of Pachiterric Histosol with non-removed peat layer at stage IV of the experiments was higher (20.0–20.4) in peat soil under former grasses and legumes (**Figure 12**). HD in crop rotation field of peat with removed peat layer was similar to HD in peat soil with non-removed peat layer (**Figures 13** and **14**). In the long-time, semi-natural sward of peat soil with removed peat layer humification processes were more intensive: HD reached 76.3% (**Figure 14**).

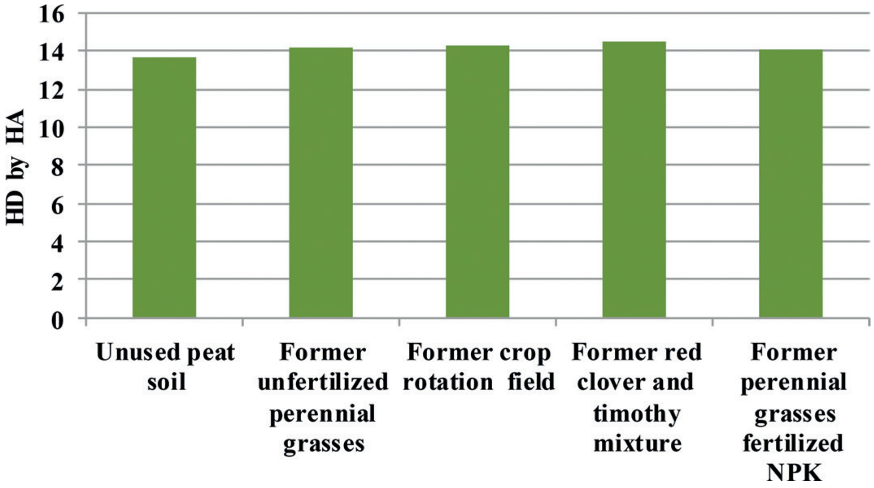


Figure 11. HD (%) according HApyr in differently used Pachiterric Histosol with non-removed peat layer (0–20 cm). Stage I of the experiments. 1998–2001.

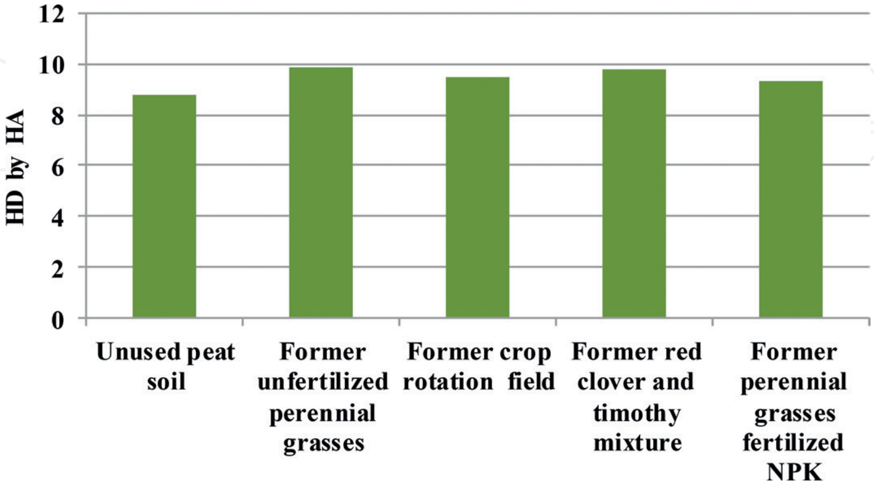


Figure 12. HD (%) according HApyr in differently used Pachiterric Histosol with removed peat layer (0–20 cm). Stage I of the experiments. 1998–2001.

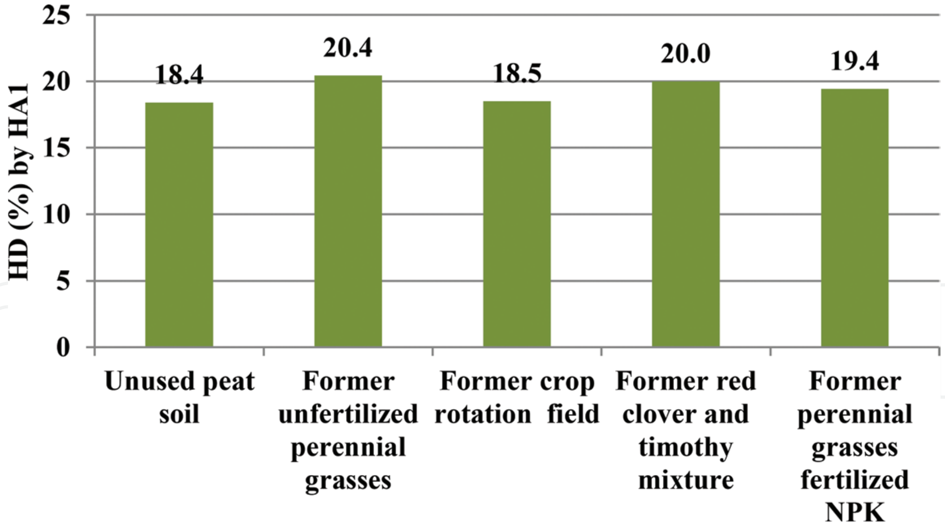


Figure 13. HD (%) by HA1 in differently used Pachiterric Histosol with non-removed peat layer (0–20 cm). Stage IV of the experiments. 2012–2014.

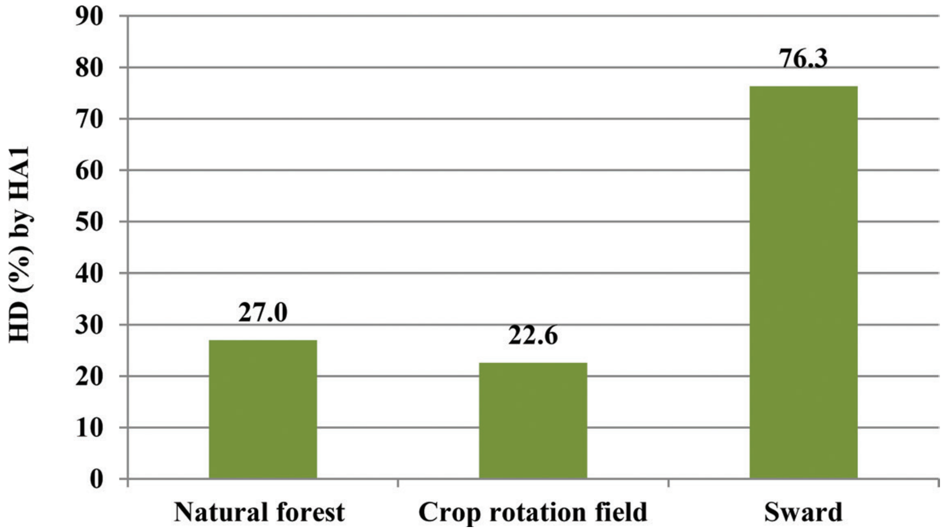


Figure 14. HD (%) by HA1 in differently used Pachiterric Histosol with removed peat layer (0–20 cm). Stage IV of the experiments. 2012–2014.

3.2. Macroelements of differently used Pachiterric Histosol

After more than 12 years, the soil under unfertilized grasses had the same content of N (26.0 g kg^{-1}), the content of N in other treatments decreased during this period. The peat soil under perennial grasses fertilized with mineral fertilizers had a higher mobile potassium (K_2O) content 495.7 mg kg^{-1}. The total potassium content was related to former fertilization (**Table 6**).

Labile carbon (WEOC and HWEOC amounts): According to data presented it the **Figure 13**, when organic carbon compounds reduce their solubility, mobility, decreasing WEOC content of Pachiteric Histosol, thus increases carbon stability of organic soil. Marked differences in WEOC contents in the 0–20 cm layer were determined between the Histosols with a removed and non-removed peat layer (**Figures 15** and **16**).The amount of labile WEOC ranged from

Pachiterric Histosol with non-removed peat layer	**pH_{KCl}**	**Ash %**	**SOC g kg^{-1}**	**N**	**P**	**K**	**P_2O_5**	**K_2O**
				Total			**Mobile (A-L)**	
				g kg^{-1}			**mg kg^{-1}**	
Unused peat soil	6.05	15.9	406	25.8	1.39	1.07	79.04	351.6
Former unfertilized perennial grasses	6.00	15.5	416	26.0	1.46	1.04	61.55	364.4
Former crop rotation field	6.09	15.4	423	24.1	1.46	1.33	106.42	420.1
Former red clover and timothy mixture	6.02	15.6	415	18.8	1.12	1.15	83.21	387.8
Former perennial grasses fertilized with commercial NPK	6.08	16.0	435	24.2	1.11	1.22	75.01	495.7
$LSD_{0.05}$	0.072	0.38	12.3	2.49	0.173	0.242	9.973	80.32

Table 6. Content of macroelements (0–20 cm) of Pachiterric Histosol with a non-removed peat layer. Stage IV of the experiment. Average data of 2012–2014.

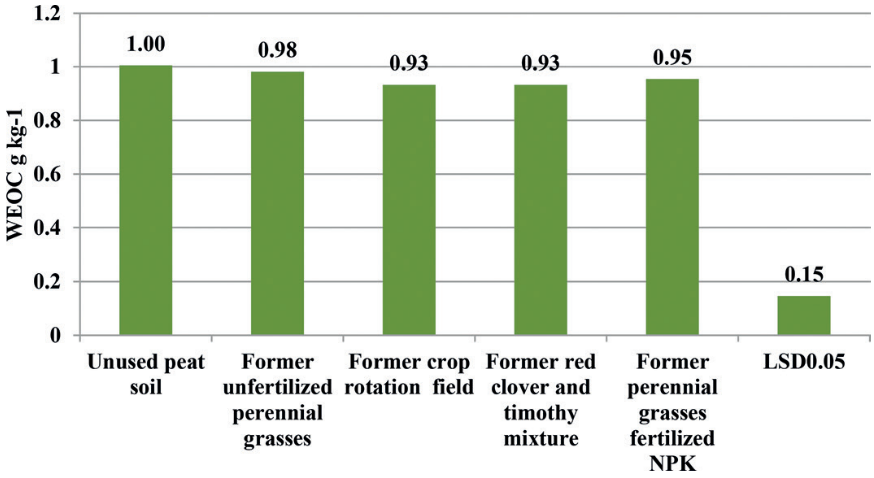


Figure 15. WEOC (g kg^{-1}) in differently used Pachiterric Histosol with non-removed peat layer, of the long-term experiment (IV stage of the experiment).

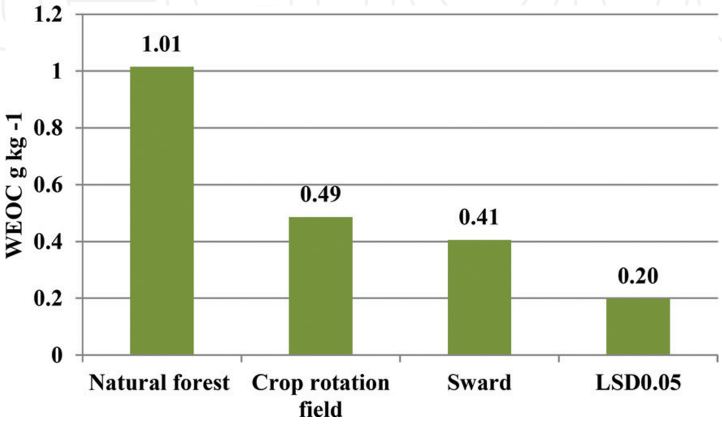


Figure 16. WEOC (g kg^{-1}) in differently used Pachiterric Histosol with removed peat layer, of the long-term experiment (IV stage of the experiments).

0.93 to 1.0 g kg^{-1} in peat soil with non-removed peat layer and from 0.41 to 1.01 g kg^{-1} in this soil with removed peat layer. In the soil of former perennial grasses and crop rotation, field significantly less WEOC was found compared to at all unused soil (1.00 g kg^{-1}).

Due to peat soil cultivation and mineralization, organic acids form organo-mineral compounds and reduce their mobility and solubility, which in turn, decreases soil WEOC content. In natural forest, there were established higher (1.01 g kg^{-1}) amounts of labile carbon compared with other land use. It is related both to the organic matter as well as total carbon accumulation in the forest floor.

The amount of labile carbon (HWEOC) was higher compared to WEOC and ranged from 13.9 to 14.8 g kg^{-1} in Pachiteric Histosol with non-removed peat layer (**Figure 17**). The higher (14.8 g kg^{-1}) amount of HWEOC was found in unused peat soil and former red clover and timothy mixture field. The soil of former perennial grasses was found significantly less of HWEOC (13.9 g kg^{-1}).

The soil of unused peat with the greatest share of dissolved organic carbon had the highest lability and the lowest stability of carbon compounds. The highest accumulation of soil organic carbon but the lowest relative share of WEOC was in the peat of former red clover and timothy mixture former perennial grasses fertilized with commercial NPK respectively, which shows that the most favorable processes for carbon stabilization and conservation are taking place there.

In summary: Peat soils, particularly those used for agricultural purposes, have been insufficiently studied so far. There is especially little research on the morphology of peat soil profile and organic matter changes after drainage and during the renaturalization process. Soil drainage as well as soil cultivation and fertilization has considerable influence on the organic matter

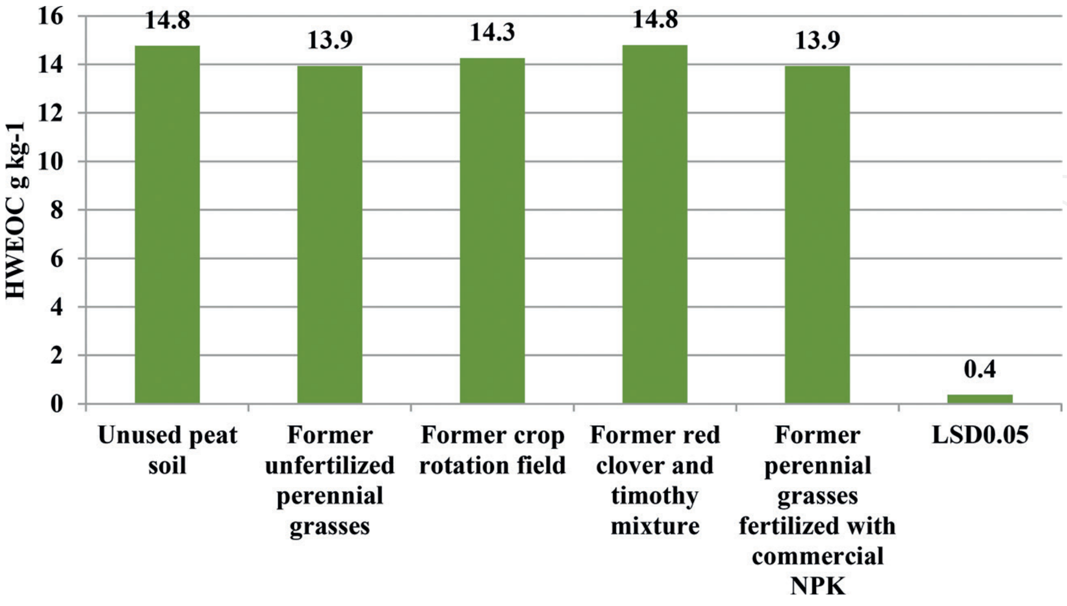


Figure 17. HWEOC (g kg^{-1}) in differently used Pachiterric Histosol with non-removed peat layer, of the long-term experiment (IV stage of the experiment).

mineralization rate and changes in the profile structure. Our research suggested that quantitative and qualitative characteristics of peat soil are changing in response to the renaturalization processes and different management. The study set out to estimate chemical and physical properties of Pachiterric Histosol, qualitative and quantitative changes in carbon resulting from different management and renaturalization processes. Wetland and peatland soils are among the largest organic carbon stocks, and their use contributes to carbon emissions or accumulation processes. The focus of our work is research into the peculiarities of organic carbon accumulation and transformation as influenced by different land use of peat soil. Results on the chemical properties of Pachiterric Histosol showed the influence of management and renaturalization on mobile and by pyrophosphate solution extractable humic and fulvic acids and humification degree. We are also exploring the specificities of organic carbon variation in the context of peat renaturalization and are seeking to answer the question as how to optimize the use of peat soils and how to match up this with the renaturalization processes in order to reduce greenhouse gas emissions and contribute to organic carbon accumulation and conservation in the soil.

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Conflict of interest

No conflict of interest is declared.

Author details

Alvyra Slepetiene*, Kristina Amaleviciute-Volunge, Jonas Slepetys, Inga Liaudanskiene and Jonas Volungevicius

*Address all correspondence to: alvyra@lzi.lt

Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Kedainiai, Lithuania

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