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PHYSICAL, CHEMICAL AND BIOCHEMICAL PROPERTIES OF WESTERN SIBERIA *SPHAGNUM* AND *CAREX* PEAT SOILS

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Comparative study of physical, chemical and biochemical properties has been carried out in acrotelm and catotelm of Sphagnum and Carex dominated peat soils in Western Siberia. Concentration of total nitrogen is directly proportional to ammonium and nitrates ions, activity of urease, bulk density and inversely proportional to C/N, porosity and moisture in both peat soils. The data received indicate lower rate of nitrogen transformation and decrease processes of organic matter decomposition in Sphagnum than in Carex dominated peat soils. The studies showed that organic matter from Sphagnum dominated peat soils has undergone the most significant biochemical and chemical transformation (oxidation, hydrolysis, polymerization) with the accumulation of resistant compounds compared to the organic matter from Carex dominated peat soils.

Key words: *Sphagnum* and *Carex* peats soils, enzymatic activity, physical, chemical and biochemical properties.

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INTRODUCTION

A great majority of present-day peatlands originated in the last 15,000 years. It is estimated that 4 million km^2 on Earth (some 3% of the land area) is covered with peatlands [Joosten and Clarke, 2002]. Over 90% of peatlands are in the temperate and cold belt in the Northern Hemisphere (Western Siberia, Canada and Alaska, and Northern Europe). The remaining area is located in tropical and sub-tropical latitudes, much of it under forest (Southeast Asia, and parts of the Amazon basin) [Lappalainen, 1996].

West Siberian Lowland is the largest wetland area of the world. The total area of 0.6-1.0 x 10^6 km^2 of the West Siberian peatlands contains a carbon pool of 51-70 Pg C (Pg=10^{15} g). These values represent 18-30% of the area and 11-15% of the peat carbon pool of all boreal and subarctic peatlands [Repo et al., 2007].

However, low rate of peat mineralization, the relative humidity and cool climate accompanied by poor drainage across the flat terrain has maintained accumulation of organic matter and development of an important carbon pool [Dobrovol'skaya et al., 2014]. Peat accumulation generally takes place as a result of limited decomposition of plant material. An important factor for peat accumulation is the chemical and structural composition of the organic material, which determines its “ability to decay”. However, water seems to be the most important external factor limiting decay. The ability to decay varies with species, plant part, chemical and biochemical compounds. This means that some plant species, organs, and compounds are more inclined to accumulate peat than others. A large number of plant species occurring in mires can contribute to peat formation, such as S*phagnum* and some other mosses, sedges, grasses and woody plants. Consequently, a wide variety of “botanical” peat types exists. Thus, botanical composition, relative amounts of the main plant species or species groups is the fundamental property for determining the nature of peat and the physical, chemical and biochemical properties of the peat.

Sphagnum (moss) and *Carex* (sedge) are typical peat forming plant species. They form peat in different ways. *Sphagnum* moss grows from the apical bud and respectively lower layers die and form peat [Mäkilä, 2011a]. The *Sphagnum* litter decomposes more slowly than leaves of most other plants in their natural habitats. However, low concentration of nitrogen, acid conditions which are produced by the *Sphagnum* itself and wet environment are the most common reasons for above processes. *Sphagnum* mosses produce nutrient poor, recalcitrant litter that is enriched in organic compounds (e.g. uronic acids) and polyphenols, thus inhibiting microbial activity and depressing vascular plant growth, fundamentally

influencing bog biogeochemistry [van Breemen, 1995; Clymo and Hayward, 1982]. In *Sphagnum* primary production ranged from 10 to 500 g m^{-2} yr^{-1} depending of the plant species and localization [Mäkilä and Goslar, 2008].

In *Carex* peat soils (and also in the formation of other high plants), the most important constituents are roots [Mäkilä, 2011a]. Certain proportion of roots dies and regenerates, so besides living roots, there are roots of different ages in the same peat volume. Finally, all roots die and form peat [Mäkilä, 2011a]. Williams et al. [2000] demonstrated that in *Carex* lack condensed tannins, which are typical inhibitors. In *Carex* dominated boreal peatlands the primary production may exceed 1000 g m^{-2} yr^{-1} [Mäkilä and Goslar, 2008].

Peatlands are characterised biophysically by two horizons, the surface acrotelm and the deeper catotelm. The acrotelm layer is located 10-50 cm from the base of the euphotic layer [Clymo, 1992]. The acrotelm has a high hydraulic conductivity, variable water content and consists of living and undecomposed dead plant material. Upper layer is rich in peat-forming aerobic bacteria and other microorganisms and has a live matrix of growing plant material. As litter and new peat in the acrotelm are exposed to oxygen and varying water levels, they are subject to a relatively high decay rate. However, in comparison with acrotelm the catotelm has water content invariable with time, a small hydraulic conductivity, is not subject to air entry and is devoid of peat-forming aerobic microorganisms. In the deeper layer, the decay rate declines sharply and becomes less dependent on surface environmental conditions over time [Nungesser, 2003; Holden and Burt, 2003].

Enzymes in soil play an important role in catalyzing reactions indispensable in life processes of soil microorganisms, decomposition of organic residues, forming organic matter and soil structure as well as circulation of nutrients [Sinsabaugh et al., 2008]. Savicheva and Inisheva [2008] postulated that organic matter transformations in peat soils are performed by enzymes from the classes of hydrolases and oxidoreductases. In peat soils waterlogged conditions might limit enzyme activity by changes in the microbial community and increased concentrations of inhibitors such as Fe(II) [Kang and Freeman, 1999].

There is a lot of data focused on the differences between *Sphagnum* and *Carex* dominated peat soils in the literature. However, a lot of research currently refers to botanical composition, accumulation of organic matter and the release of CO_2, CH_4 of West Siberia peatlands. Limited information concerning physical, chemical and biochemical properties between *Sphagnum* and *Carex* dominated peat soils in Western Siberia is available in the literature. Furthermore, the knowledge about physical, chemical parameters and enzymes in *Sphagnum* and *Carex* dominated peat soil of Western Siberia is still poorly documented and understood. Thus, the study was conducted to show the impact of two typical peat forming plant species – *Sphagnum* and *Carex* on physical, chemical and biochemical properties of peat soils in Western Siberia at two different depths (0-50 cm and 50-100 cm). Therefore, the study should increase the knowledge about these processes and mechanisms in *Sphagnum* and *Carex* dominated peat soils.

MATERIALS AND METHODS

Nine peatland sites differing in type of peat and botanical composition situated in West Siberia (Russia) near Mukhrino Field Station have been investigated. GPS parameters and location of all investigated peatlands are included in fig. 1, Appendix, table 1. Mukhrino Field Station is located at the west bank of the Irtysh River near the confluence with the Ob River in the central taiga subzone of West Siberian, 26 km west of the town of Khanty-Mansiysk. This area is owned and run by the UNESCO Chair on Environmental Dynamics and Climate Change at the Yugra State University, Khanty-Mansiysk, Russia.

Due to severe continental climate, the environmental conditions in the region are comparable with the sub-arctic zone of Northern Europe (fig. 1; table 1). Thickness of peat deposit ranges from 1.0 to 4.0 m. The vegetation of Mukhrino mire is presented in table 1. The investigated materials were peat samples collected from eleven of *Sphagnum*, and *Carex* dominated peat soils. In the research area the total annual precipitation equals to 530.6 mm and the average annual air temperature is -1.12°C. On average of the vegetation season lasts about 120 days.

The peat samples were taken in 2012 from above-mentioned investigated points. Samples were collected with the Instorf sampler (container length 50 cm) from 0 to 50 cm (acrotelm) and from 50 to 100 cm (catotelm) depths in the stratigraphic profile of each peat deposit. The peat soil samples were wrapped in aluminum foil and transported to the laboratory at ca. 4°C and stored at -20°C. The samples were dried at 20°C, sieved through 1 mm mesh in order to remove large particles and undecomposed plant debris, and stored prior to analysis.

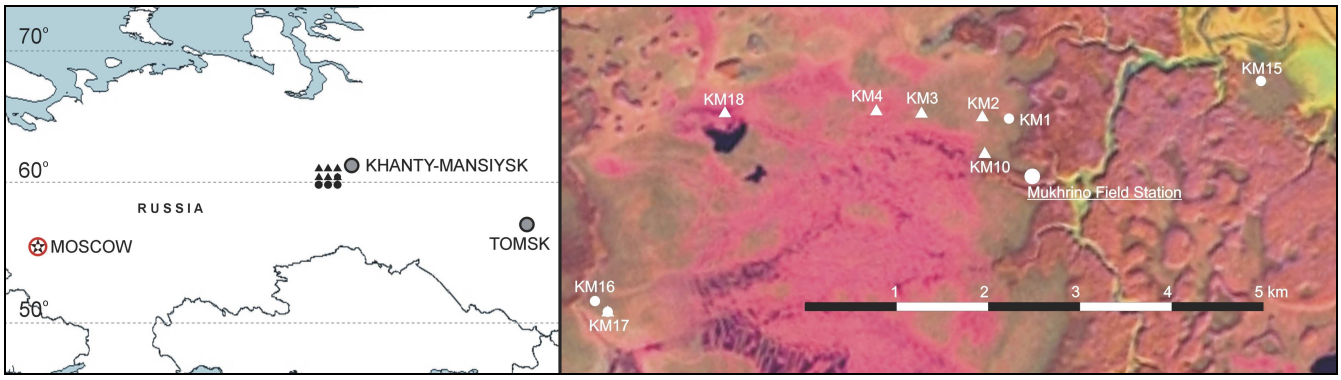

Fig. 1. Setting of the study site (Landsat image - band 453) ▲ ***Sphagnum* dominated peat soils:** Mukhrino Field Station: KM2, KM3, KM4, KM10, KM17 (0-50 cm), KM18 ● ***Carex* dominated peat soils:** Mukhrino Field Station: KM1, KM15, KM16, KM17 (50-100 cm)

The degree of decomposition or humification of the peat is assessed by measuring its fiber or humus content. In practice, peat decomposition is determined by a field method (von Post pressing method) [von Post, 1922; Szajdak et al., 2011c]. The method identifies ten classes of decomposition, with H1 being undecomposed peat and H10 completely decomposed peat.

pH was measured in 1N KCl and in water (1:20 v/v) suspensions by potentiometric method. Soil bulk density was estimated from the soil organic matter concentration. The soil samples were dried at 105°C and ashed at 550°C using a muffle furnace. Bulk density was determined in soils mass per unit volume of soil [Okruszko and Piaścik, 1990]. Porosity was calculated from the bulk density ratio of the soil to the density of solids. Density of solids was calculated from equation [Okruszko and Piaścik, 1990]

$$DS = 0.011\ A + 1.451 \quad (1)$$

where: DS – density of solids, A – ash content.

The total organic carbon (TOC) was analyzed on Total Organic Carbon Analyzer (TOC 5050A) with Solid Sample Module (SSM-5000A) produced by Shimadzu (Japan). Dissolved organic carbon (DOC) was evaluated on TOC 5050A equipment produced by Shimadzu (Japan). For the investigation of DOC soil samples were heated in deionized water at 100°C for two hours under a reflux condenser. Extracts were filtered through 0.45 μm pore-size filters and analyzed on TOC 5050A facilities [Smolander and Kitunen, 2002]. Total nitrogen was evaluated by the Kjeldahl methods.

Ammonium ions were measured on ion chromatograph Waters 1515 (USA) equipped with a 1515 Isocratic HPLC pump, conductivity detector Waters 432, a rotary valve fitted with 20 μL sample loop and column PRP-X200 (150 x 4.1 mm I.D.) from Hamilton, protected with a guard column of the same material (25 x 2.3 mm I.D.). Nitrate ions were determined on ion chromatograph HIC-6A Shimadzu (Japan) equipped with a LP-6A Isocratic HPLC pump, conductivity detector CDD-6A, a rotary valve fitted with 20 μL sample loop and column PRP-X100 (150 x 4.1 mm I.D.) column from Hamilton, protected with a guard column of the same material (25 x 2.3 mm I.D.). Nitrate and ammonium ions as nitrogen were assayed in the same water extracts with an ion chromatograph [Szajdak and Gaca, 2010].

The ferrous ions in soils were determined by phenanthroline method [Minczewski and Marczenko, 1976; Szajdak et al., 2011a; Szajdak et al., 2011b]. The concentrations of ferrous ions were estimated colorimetrically at λ_{max}=512 nm on UV-VIS spectrophotometer Beckman DU®-68 USA. Deionized water was used as blank. The ferric ions were measured by thiocyanate technique [Minczewski and Marczenko, 1976; Szajdak et al., 2011a; Szajdak et al., 2011b]. The content of ferric ions was determined colorimetrically at λ_{max}=480 nm on UV-VIS spectrophotometer Beckman DU®-68 USA. Deionized water was used as blank.

Urease [EC 3.5.1.5] activity was evaluated by Hoffmann and Teicher method [Szajdak et al., 2002; Szajdak et al., 2011a; Szajdak et al., 2011b]. This method involves determination of the ammonium released by urease when soil is incubated with buffered (pH = 6.7) urea solution and toluene at 37°C for 3 h. The absorbance of the solution was measured colorimetrically at λ_{max}=630 nm using a UV-VIS spectrophotometer Beckman DU®-68 USA.

Xanthine oxidase [EC 1.17.3.2] activity was measured by Krawczyński method [Krawczyński, 1972; Szajdak et al., 2011a; Szajdak et al., 2011b]. Xanthine is used as a substrate for measurement of activity of the xanthine oxidase in fresh soil samples. The absorbance of the solution was measured colorimetrically at λ_{max}=290 nm using a UV-VIS spectrophotometer Beckman DU®-68 USA.

Phenol oxidase [EC 1.14.18.1] activity was determined by Perucci method [Perucci et al., 2000; Szajdak et al., 2011a; Szajdak et al., 2011b]. Catechol is used as a substrate for measurements of phenol oxidase activity in fresh soil samples. The absorbance of the solution was measured colorimerically at λ_{max}=525 nm using a UV-VIS spectrophotometer Beckman DU®-68 USA.

Peroxidase [EC 1.11.1.7] activity in soils was assayed by Bartha and Bordeleau method [Bartha and Bordeleau, 1969; Szajdak et al., 2011a; Szajdak et al., 2011b]. Peroxidase activity was estimated by following the H_2O_2-mediated oxidation of *o*-dianisidine. The absorbance of the solution was measured colorimetrically at λ_{max}=460 nm using a UV-VIS spectrophotometer Beckman DU®-68 USA.

Nitrate reductase [EC 1.7.99.4] activity was determined using potassium nitrate as a substrate and 2,4-dinitrophenol as inhibitor of nitrite reductase according to Kandeler [1996]. The field-moist soil samples were incubated for 24 h at 25ºC under waterlogged conditions in test tubes. Nitrite released as a result of incubation was extracted with potassium chloride solution and determined colorimetrically at λ_{max}=520 nm [Szajdak and Gaca, 2010; Szajdak and Gaca, 2011; Szajdak et al., 2011a].

All chemical and biochemical analyzes were run in triplicate, and the results were averaged. The confidence intervals were calculated using the following formula: $\bar{x} \pm t_{\alpha \cdot (n-1)}$ SE, where: $\bar{x}$ – mean; $t_{\alpha \cdot (n-1)}$ – value of the Student test for $\alpha = 0.05$; n-1 – degree of freedom, SE – standard error. All the chemicals used in this study were of analytical grade of purity.

RESULTS AND DISCUSSION

Acidic conditions and moisture

Both peat soils revealed acidic conditions (Appendix, table 2). Values of pH_{KCl} ranged from 2.40 to 3.28 in *Sphagnum* dominated peat soils, whereas in *Carex* dominated peat soils were slightly higher between 3.72 and 4.43 (table 2). However, pH measured in H_2O was from 3.14 to 4.02 in *Sphagnum* dominated peat soils and from 4.15 to 5.32 in *Carex* dominated peat soils. However, Golovchenko et al. (2007) demonstrated the pH of the saline exratct varied between 2 and 4 in ombrotrophic peatlands (shrubby-sedge-sphagnum) and Błońska (2010) indicated lowest pH_{KCl} (2.74) in *Sphagnum*.

The moisture of *Sphagnum* was statistically significant higher than in *Carex* dominated peat soils of acrotelm and catotelm (table 2). The moisture content of the moss is directly related to its thermal conductivity which changes ten-fold between dry and saturated conditions.

Bulk density and porosity

Our studies revealed that the bulk density increases with the depth in *Sphagnum*, but decreases with the depth in *Carex* dominated peat soils (table 2). Bulk densities were statistically significant lower in *Sphagnum* (98.17-105.80 kg$\cdot$m^{-3}) than in *Carex* (114.00-157.67 kg$\cdot$m^{-3}) dominated peat soils of acrotelm and catotelm (table 2). Moreover, it was observed the impact of the kind of peats on the differences in porosity. The values of porosity for *Sphagnum* dominated peat in both depth of sampling were statistically significant higher (92.57-93.00%) than in *Carex* dominated peat soils (88.88-91.90%) (table 2). These data suggest lower decomposition degree in *Sphagnum* than in *Carex* dominated peat soils, because decay can also result in an increase of the dry bulk density. According to Bozkurt et al. [2001] the bulk density at first decreases with the depth because of decomposition without compression, and later increases, as compression becomes the dominant factor. Paavilainen and Päivänen [1995] showed in *Sphagnum* peat a positive and approximately linear regression between bulk density and the von Post humification scale value. In addition, Borren et al. [2004] postulated lower dry bulk density in ombrotrophic *Sphagnum fuscum* deposit of the bog than in the minerotrophic herb-moss deposits. Moreover, Mäkilä [2011b] demonstrated lower bulk density in coastal *Sphagnum* bogs than in *Carex* appa mire.

Carbon content

Data presented in table 2 showed no statistically significant differences of the TOC concentrations between *Sphagnum* and *Carex* dominated peat soils in both layers. The amount of TOC in acrotelm was 413.68±8.45 g kg^{-1} and in catotelm was 437.54±9.00 g kg^{-1} in *Sphagnum* dominated peat soils. In Carex dominated peat soils the content of TOC in acrotelm was 416.93±16.65 g kg^{-1} and in catotelm was 447.45±13.73 g kg^{-1}. Our data are in line with the results of Bejger et al. [2011]. These authors reported no significant differences of organic carbon concentration between *Sphagnum* and *Carex* peat soils.

Inisheva et al. [2011], Mäkilä [2011b], Savelyeva and Yudina [2003] and Arkhipov and Maslov [1998] proved that the content of organic carbon in *Sphagnum* was lower than in *Carex* dominated peat soils.

However, these authors have not shown statistically significant differences in carbon values between *Sphagnum* and *Carex* peat soils.

Koerselman et al. [1993] detected higher concentration of organic matter in *Sphagnum* than in *Carex* soils, and between these data no statistically significant differences were observed.

Moreover, Beilman et al. [2009] and Robinson and Moore [1999] evaluated statistically significant lower amounts of organic carbon in *Sphagnum* than in sedge peat.

In addition, our previous study in Polish peat soils confirmed higher concentrations of TOC in raised bog (from 606.26 to 636.75 $g \cdot kg^{-1}$) than in fen (from 509.95 to 607.85 $g \cdot kg^{-1}$) [Szajdak et al. 2012a; Szajdak et al. 2012b].

The content of DOC in our samples of *Sphagnum* (14.67 $g \cdot kg^{-1}$) was statistically significant higher than in *Carex* dominated peat soils (10.12 $g \cdot kg^{-1}$) in catotelm (table 2). These outcomes are in line with Ulanowski and Branfireun [2013], who confirmed that *Carex* dominated surface pore-waters had statistically significant lower DOC concentrations than *Sphagnum* dominated peat soils. Also, higher results of DOC found Chanton et al. [2008] in bog sites dominated by *Sphagnum* and woody plants than in fen sites dominated by sedges, further indicating lower reactivity of DOC at the *Sphagnum* and woody plant sites. Furthermore, Szajdak et al. [2012a and 2012b] indicated the increase of the concentration of DOC in raised bog (from 11.38 to 15.60 $g \cdot kg^{-1}$) in comparison with fen (from 4.87 to 11.24 $g \cdot kg^{-1}$) in Polish peatlands.

Nitrogen

Our results showed statistically significant lower total nitrogen in *Sphagnum* (from 11.16 to 12.10 $g \cdot kg^{-1}$) than in *Carex* (from 13.66 to 16.13 $g \cdot kg^{-1}$) dominated peat soils in acrotelm and catotelm (table 2). These data are in line with Scheffer et al. [2001], who indicated lower concentration of total nitrogen in *Sphagnum squarrosum* than *Carex diandra*. In addition, Glenn et al. [2006] proved that total nitrogen in *Sphagnum* spp. at the poor fen was lower than half in relation to *Carex lasiocarpa* at the extreme-rich fen. Moreover, in Polish peatlands was observed higher content of total nitrogen in fen (from 18.48 to 22.96 $g \cdot kg^{-1}$) than in raised bog (from 8.96 to 13.16 $g \cdot kg^{-1}$) [Szajdak et al., 2012a and 2012b]. Total nitrogen deposition is usually divided into a wet and a dry component, and includes deposition of inorganic inputs of NO_x and NH_y as well as organic inputs, such as the nitrogen in pollen, amino acids, and organic nitrates [Limpens et al., 2006]. According to Malmer and Wallén [2005] low availability of N and P in *Sphagnum*-mires results partly from low mineralization rates and partly from the losses associated with the formation of peat. Furthermore, Aerts et al. [1999] found that low-N concentrations are responsible for the slow decomposition of *Sphagnum* tissue. In addition, Savicheva and Inisheva [2008] suggested that the processes of biochemical degradation are significantly affected by nitrogen-containing compounds. Westbrook et al. [2006] showed that the total nitrogen content varies from 1.17 to 2.80% in peat soils. This author revealed that dynamic of peatland nitrogen is driven by their hydrological condition and thus tend to exhibit high spatial variation in nitrogen cycling processes. High soil moisture and degree of soil anoxia has been shown to increase soil nitrogen availability of post-harvest in peatland. Additionally, altered soil microclimate and peat disturbance lead to higher nitrogen cycling rates in peatlands following harvest.

Our investigations showed statistically significant higher amounts of ammonium at the depth of 0-50 cm (37.86 $mg \cdot kg^{-1}$) and 50-100 cm (28.94 $mg \cdot kg^{-1}$) in *Carex*, than in *Sphagnum* (acrotelm 25.30 $mg \cdot kg^{-1}$, catotelm 18.64 $mg \cdot kg^{-1}$) dominated peat soils (table 2). However, nitrate ions were from 22.78 to 32.14 $mg \cdot kg^{-1}$ in *Carex* and from 15.96 to 26.53 $mg \cdot kg^{-1}$ in *Sphagnum* dominated peat soils for both layers. The previous study of Szajdak et al. [2012a and 2012b] demonstrated higher content of ammonium and nitrate ions in raised bog than in fen in Polish peatlands. Nitrate export following harvest results from increased ammonification (degradation of organic nitrogen compounds with the formation of ammonium) and nitrification (NH_4^+ oxygenation to NO_3^-) in conjunction with drastically reduced vegetative nitrogen uptake [Spoelstra et al., 2010]. NH_4^+ is likely to be immobilized by the microbial biomass because of high C/N ratio of *Sphagnum* whereas NO_3^- can also be denitrified thus raising N released to the atmosphere as either N_2O or N_2, modifying the N sink capacity of *Sphagnum*-mires [Francez et al., 2011].

The C/N ratio was statistically significant higher in *Sphagnum* (34.19 and 39.20) than in *Carex* dominated peat soils (27.74 and 30.52) (table 2) in acrotelm and catotelm. These values of C/N suggest a lower decomposition degree of organic residues in *Sphagnum* than in *Carex* dominated peat soils. Scheffer et al. [2001] showed slower degradation of litter in *Sphagnum* than in *Carex,* which was caused by intrinsic differences in litter quality and not by the environment.

Iron content

In addition, the results of our study showed no statistically significant differences for Fe(II) and Fe_{total} concentrations between *Sphagnum* and *Carex* dominated peat soils in both layers (table 2). Whereas, Fe(III) content was statistically significantly higher in *Sphagnum* (37.98 $mg \cdot kg^{-1}$) than in *Carex* (26.18 $mg \cdot kg^{-1}$) in catotelm. Higher concentrations of Fe(III) in *Sphagnum* than in *Carex* dominated peat soils suggest higher oxygenic properties in *Sphagnum* dominated peat soils. Steinmann and Shotyk [1997] observed the increase of the amount of Fe(II) and Fe(III) with the depth in *Sphagnum* dominated peat. One possible explanation for the relatively high concentrations of Fe(III) in catotelm is the complexation of Fe(III) by organic ligands such as humic substances. According to Lovley and Anderson [2000] dissimilatory iron (III) reduction significantly influence the fate of both organic and inorganic compounds in pristine and contaminated subsurface environments. In deep pristine aquifers iron (III) reduction can be an important processes for oxidation of organic matter, increasing the concentrations of dissolved inorganic carbon and dissolved iron (II) while at the same time preventing the accumulation of sulfide. The major differences between *Sphagnum* and *Carex* peat were found to derive from the habitat conditions at the time of peat formation. *Carex* peats are formed exclusively in fen and most often in nutrient-rich peatlands with high pH and a high microbial activity [Ringqvist and Öborn, 2002]. Decomposition of organic matter without removal of an element will lead to a gradual increase in the concentration with time. If such conditions exist in a peat profile the element will increase with depth. In contrast, a decrease in the concentration with depth or the presence of an accumulation horizon indicates on the translocation of the element [Bozkurt et al., 2001].

Enzymes

Soil enzymes play key biochemical functions in the overall process of organic matter humification and decomposition in the soil system. The rate of decomposition is mainly determined by the degradability of the litter and enzymes as biotic factors and pH, humidity, temperature, oxygen availability as abiotic factors. According to Mäkilä and Goslar [2008] peat-forming species differ in their capacities for formation and decay of peat.

Statistically significant lower activity of urease was determined in acrotelm and catotelm of *Sphagnum* (1.98 and 2.52 $\mu mol \cdot s^{-1} \cdot kg^{-1}$) than in *Carex* dominated peat soils (2.60 and 2.81 $\mu mol \cdot s^{-1} \cdot kg^{-1}$) in West Siberian peatlands. It suggests lower rate of nitrogen transformation in *Sphagnum* than in *Carex* dominated peat soils (Appendix, table 3). Lower activities of urease in *Sphagnum* than in *Carex* dominated peat soils are in line with the values of bulk density, ammonium, nitrates, and total nitrogen. According to early study of Szajdak et al. [2013] the urease activity was statistically significant higher in Polish fen and raised bog than in above Siberia peatlands. Błońska [2010] found differences of urease activity in the studied peat types which can be associated with statistically significant differentiation in the content of C and N. Differentiation of organic C and total N in the examined soils results from different botanical composition of partly decayed vegetation matter.

We observed statistically significant differences for activity of xanthine oxidase between *Sphagnum* (acrotelm – 5.43 $\mu mol \cdot s^{-1} \cdot kg^{-1}$; catotelm – 4.37 $\mu mol \cdot s^{-1} \cdot kg^{-1}$) and *Carex* dominated peat soils (acrotelm – 2.92 $\mu mol \cdot s^{-1} \cdot kg^{-1}$; catotelm – 2.33 $\mu mol \cdot s^{-1} \cdot kg^{-1}$) in both layers (table 3). Statistically higher activity of xanthine oxidase are in line with higher concentrations of Fe(III) in *Sphagnum* than in *Carex* peat soils and indicate higher oxidizing properties of *Sphagnum* peat soils. Furthermore, Szajdak et al. [2012b] reported higher activity of xanthine oxidase in Polish fen (from 5.44 to 8.16 $\mu mol \cdot s^{-1} \cdot kg^{-1}$) in comparison with West Siberian peatlands as described above. Higher activity of this enzyme in *Sphagnum* than in *Carex* dominated peat soils contribute to the increase degradation of peptides and purine basis which may indicate the dominance of catabolic processes. Peptides, purine basis and aldehydes may be fully degraded and complicated ones are perhaps partially oxidized, thereby generating intermediates. Formed compounds undergo heteropolycondensation giving macromolecules of humic substances. The formation of humino-proteides complexes leads to the inhibition of proteolysis, while humic acids stimulate the deamination of amino acids [Łoginow, 1967].

Our investigations showed that activity of phenol oxidase, peroxidase and nitrate reductase did not differ significantly between *Sphagnum* and *Carex* dominated peat soils in both layers (table 3). The activity of phenol oxidase in *Sphagnum* dominated peat soils at the depth 0-50 cm and 50-100 cm, was 8.62 $\mu mol \cdot s^{-1} \cdot kg^{-1}$ and 8.12 $\mu mol \cdot s^{-1} \cdot kg^{-1}$, respectively (table 3). However, the activity of phenol oxidase in *Carex* dominated peat soils of appropriate layers was 9.40 $\mu mol \cdot s^{-1} \cdot kg^{-1}$ and 8.91 $\mu mol \cdot s^{-1} \cdot kg^{-1}$, respectively. Szajdak et al. [2012a and 2012b] have shown statistically significantly higher activity of phenol oxidase in fen and raised bog in Polish than West Siberian peatlands. In addition, Willams et al. [2000] reported that activity of phenol oxidase in *Sphagnum* and *Carex* peat was strongly dependent on the botanical composition, wetland type, pH than aeration and water level. These authors found positive correlation

between the activity of phenol oxidase and soluble phenolic concentrations in *Carex* wetland. However, Efremova and Ovchinnikova [2008] documented statistically significantly less oxidoreductase activity in zone of 10-30 cm.

The data of peroxidase activities ranged from 1.81 to 1.99 $nmol \cdot s^{-1} \cdot kg^{-1}$ in *Sphagnum* and from 2.24 to 2.56 $nmol \cdot s^{-1} \cdot kg^{-1}$ in *Carex* dominated peat soils (table 3). The results of Szajdak et al. [2012a and 2012b] from Polish fen and raised bogs are in line with that data. Furthermore, Jassey et al. [2012] reported that peroxidase activities from *Sphagnum* mosses were 1000-fold higher irrespective of season and sampling areas. Efremova and Ovchinnikova [2007] observed seasonal average peroxidase activities for the layers in the 0-30 cm soil profile. They postulated that, irrespective of drainage conditions, the highest oxidoreductase activity was measured in the 0-5 cm layer but it significantly decreased with depth due to natural factors like high soil moisture, low temperature, and low microbial activity. However, oxidoreductase activity increased with drainage depth. Sinsabaugh [2010] showed no correlation between peroxidase activity and soil organic matter content. He suggested that high in situ oxidative activities limit soil organic matter accumulation.

Our results showed that the activity of nitrate reductase ranged from 0.02 to 0.03 $nmol \cdot s^{-1} \cdot kg^{-1}$ in both layers of *Sphagnum* and *Carex* dominated peat soils (table 3). However, the activity of nitrate reductase in Polish fen and raised bog were statistically significant higher than in West Siberian peatlands [Szajdak et al., 2012a and 2012b]. In the process of denitrification, dissimilatory nitrate reductase catalyses the first step of denitrification by reducing nitrate to nitrite ions [Singh and Kumar, 2008]. Under natural conditions, nitrification is limited by low pH in *Sphagnum*-mires resulting in low nitrate ions production and low denitrification activity and in pristine *Sphagnum*-mires function as nitrogen sink ecosystems than nitrogen source for the atmosphere [Koops et al., 1996; Francez et al., 2011].

CONCLUSIONS

In the conditions of West Siberia the investigation showed differences in biochemical, chemical and physical parameters between *Sphagnum* and *Carex* dominated peat soils of acrotelm and catotelm.

The studies demonstrated that concentration of total nitrogen is directly proportional to activity of urease, and ammonium ions, bulk density and inversely proportional to C/N, porosity and moisture which indicates lower nitrogen transformation and decrease processes of organic matter decomposition in *Sphagnum* than in *Carex* dominated peat soils.

Statistically significant lower activity of urease was determined in acrotelm and catotelm of *Sphagnum* than in *Carex* dominated peat soils in West Siberian peatlands. It suggests lower rate of nitrogen transformation in *Sphagnum* than in *Carex* dominated peat soils. Decrease activities of urease in *Sphagnum* than in *Carex* dominated peat soils are in line with the values of bulk density, ammonium and total nitrogen.

Under limited oxygen, low pH and phenol oxidase activity slows down degradation of phenolic compounds in peat soils. Phenolic accumulation in soil solution can inhibit urease activity in *Sphagnum* dominated peat soils. This enzyme release ammonium through urea hydrolysis and are essential in the chain of amino compounds. Lower urease activity is related to anabolic processes at the depth of 0-50 and 50-100 cm in *Sphagnum* dominated peat soils.

The increase of xanthine oxidase activity in *Sphagnum* dominated peat soils may be related to rise porosity, concentrations of dissolved organic carbon, and ferric ions. These results indicate that the dominance oxidative properties in *Sphagnum* than in *Carex* dominated peat soils were found to be more effective for the degradation of purine basis and peptides and higher rate anabolic than catabolic processes.

The studies showed that organic matter from *Sphagnum* dominated peat soils has undergone the most significant biochemical and chemical transformation (oxidation hydrolysis and polymerization) with the accumulation of resistant compounds compared to the organic matter from *Carex* dominated peat soils.

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ФИЗИЧЕСКИЕ, ХИМИЧЕСКИЕ И БИОХИМИЧЕСКИЕ СВОЙСТВА СФАГНОВЫХ И ОСОКОВЫХ ТОРФОВ ЗАПАДНОЙ СИБИРИ

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Было проведено сравнительное исследование физических, химических и биохимических свойств акротелма (торфогенный горизонт) и катотелма (горизонт накопления торфа) участков с доминированием сфагновых и осоковых торфов в Западной Сибири. Концентрация общего азота прямо пропорциональна содержанию нитрат-ионов и ионов аммония, активности уреазы, объемной плотности, и обратно пропорционально отношению C/N, пористости и влажности в обоих рассматриваемых типах почв. Полученные результаты указывают на низкий уровень азотной трансформации и замедление процессов разложения органического вещества в сфагновых и осоковых типах почв. Исследование показало, что сфагновые торфа претерпевают значительные химические и биохимические трансформации (окисление, гидролиз, полимеризация) с аккумуляцией наиболее устойчивых соединений по сравнению с органическим веществом осоковых торфов.

Ключевые слова: сфагновые и осоковые торфяные почвы, ферментативная активность, физические, химические и биохимические свойства.

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APPENDIX

Table 1. Location, botanical composition of vegetation cover, type of peat and decomposition degree of *Sphagnum* and *Carex* dominated peat soils

Place of sampling	GPS Localisation	Botanical composition of vegetation cover of investigated places	Depth cm	Type of peat based on macrofossil analysis	Degree of decomposition (von Post)
		***Sphagnum* dominated peat soils**			
KM2	N 60° 89' 50.5" E 68° 69' 20.9"	*Sphagnum angustifolium, S. fuscum, S. magellanicum, Ledum palustre, Rubus chamaemorus, Chamaedaphne calyculata, Betula nana, Pinus sylvestris, Pinus sibirica.*	0-50	*Sphagnum*	H1
			50-100	*Sphagnum*	H2
KM3	N 60° 53' 43.88" E 68° 40' 46.84"	*Sphagnum fuscum, Ledum palustre, Chamaedaphne calyculata, Cladonia* sp., *Rubus chamaemorus, Pinus sylvestris, Betula nana.*	0-50	*Sphagnum*	H1
			50-100	*Sphagnum*	H2
KM4	N 60° 53' 44.22" E 68° 40' 12.47"	*Sphagnum fuscum, Ledum palustre, Chamaedaphne calyculata, Rubus chamaemorus, Oxycoccus palustris, Pinus sylvestris.*	0-50	*Sphagnum*	H1
			50-100	*Sphagnum*	H1
KM10	N 60° 53' 29.12" E 68° 41' 33.50"	*Sphagnum capillifolium, S. angustifolium, S. fuscum, Ledum palustre, Chamaedaphne calyculata, Oxycoccus microcarpus, Vaccinium uliginosum, Vaccinium vitis-idaea, Rubus chamaemorus, Pinus sylvestris, Pinus sibirica, Betula nana.*	0-50	*Sphagnum*	H1
			50-100	*Sphagnum*	H2
KM17	N 60° 52' 33.1" E 68° 36' 55.3"	*Sphagnum magellanicum, S. angustifolium, Chamaedaphne calyculata, Oxycoccus palustris, Andromeda polifolia, Eriophorum vaginatum, Betula pendula.*	0-50	*Sphagnum*	H1
KM18	N 60° 53' 43.5" E 68° 38' 20.4"	*Sphagnum papillosum, Carex limosa, Rhynchospora alba, Drosera anglica, Scheuchzeria palustre, Menyanthes trifoliata, Oxycoccus microcarpus, Eriophorum russeolum, Andromeda polifolia.*	0-50	*Sphagnum*	H1
			50-100	*Sphagnum*	H1
		***Carex* dominated peat soils**			
KM1	N 60° 53' 41.6" E 68° 41' 51.9"	*Sphagnum fuscum, S. capillifolium, S. magellanicum, S. angustifolium, Ledum palustre, Rubus chamaemorus, Carex globularis, Chamaedaphne calyculata, Vacinium vitis-idaea, Oxycoccus microcarpus, Vaccinium myrtillus, Pleurozium schreberi, Polytrichum strictum, Dicranum polysetum, Aulacomnium palustre, Pinus sylvestris, P. sibirica.*	0-50	sedge woody	H2
			50-100	woody-cotton grass	H3/H4
KM15	N 60° 53' 55.2" E 68° 44' 59.9"	*Carex juncea, Comarum palustre, Phalaris arundinacea, Lactuca sibirica, Calamagrostis stricta* (*C. neglecta*), *C. phragmitoides, Lythrum salicaria, Lysimachia thyrsiflora, L. vulgaris, Rumex aquatilis, Galium ruprechtii, Lathyrus palustris, Anemone dichotoma, Betula pubescens, Salix pentandra, Salix cinerea.*	0-50	sedge woody	H5
			50-100	sedge woody	H6
KM16	N 60° 52' 35.9" E 68° 36' 46.7"	*Carex rostrata, C. lasiocarpa, C. limosa, S. riparium, Menyanthes trifoliate, Lysimachia thyrsiflora, Eriophorum vaginatum, Betula pendula, B. pubescens.*	0-50	sedge-*Sphagnum*,	H2
			50-100	herbaceous (*Equisetum*)	H2
KM17	N 60° 52' 33.1" E 68° 36' 55.3"	*Sphagnum magellanicum, S. angustifolium, Chamaedaphne calyculata, Oxycoccus palustris, Andromeda polifolia, Eriophorum vaginatum, Betula pendula.*	50-100	sedge-*Scheuchzeria*	H1

KM1, KM2, KM3, KM4, KM10, KM15, KM16, KM18, KM17 – Mukhrino Field Station

Table 2. Mean contents and ranges (italics) of chemical compounds, physical parameters, enzyme activities in *Sphagnum* and *Carex* dominated peat soils in 0-50 cm and 50-100 cm layers

Parameters	*Sphagnum* dominated peat soils		*Carex* dominated peat soils	
	0-50 cm	**50-100 cm**	**0-50 cm**	**50-100 cm**
pH in 1N KCl	2.40-3.28	2.41-2.77	3.72-4.43	3.75-4.33
pH in H_2O	3.14-3.71	3.30-4.02	4.21-5.32	4.15-4.86
Moisture %	93.09±0.56 *91.38-94.96*	88.13±3.92 *75.02-94.62*	86.20±3.85 *80.82-90.32*	81.92±1.90 *76.67-92.21*
Bulk density kg·m^{-3}	98.17±1.00 *95.01-101.12*	105.80±3.02 *97.00-112.05*	157.67±15.98 *115.05-178.15*	114.00±4.35 *103.00-141.00*
Porosity %	93.00±0.50 *92.70-93.42*	92.57±0.16 *91.55-93.41*	88.88±3.19 *91.10-92.90*	91.90±0.15 *91.24-93.10*
TOC g·kg^{-1}	413.68±8.45 *407.70-437.70*	437.54±9.00 *421.40-451.00*	416.93±16.65 *353.40-461.10*	447.45±13.73 *378.20-449.40*
DOC g·kg^{-1}	15.33±1.33 *12.30-18.09*	14.67±1.58 *10.73-17.94*	14.64±3.74 *10.51-21.75*	10.12±2.61 *7.25-14.90*
N_{total} g·kg^{-1}	12.10±0.82 *6.05-22.74*	11.16±1.88 *6.72-16.80*	13.66±0.50 *8.96-17.02*	16.13±2.53 *11.65-20.38*
N-NH_4^+ mg·kg^{-1}	25.30±1.27 *22.80-30.30*	18.64±2.47 *13.02-25.99*	37.86±5.40 *8.37-68.70*	28.94±7.00 *9.00-37.78*
N-NO_3^- mg·kg^{-1}	26.53±3.87 *20.30-42.63*	15.96±1.18 *13.02-18.41*	32.14±4.96 *11.16-54.24*	22.78±7.12 *9.05-33.40*
C/N	34.19±1.05 *18.46-62.34*	39.20±3.56 *26.29-62.71*	30.52±2.10 *20.76-47.58*	27.74±4.26 *22.22-42.87*
Fe(II) mg·kg^{-1}	35.72±5.09 *16.92-49.63*	37.82±8.88 *23.27-63.17*	34.68±7.83 *15.16-54.48*	38.92±7.74 *17.48-57.53*
Fe(III) mg·kg^{-1}	30.54±3.58 *17.21-40.49*	37.98±7.50 *22.40-57.70*	33.05±9.61 *14.24-50.48*	26.18±3.50 *15.18-40.49*
Fe_{total} mg·kg^{-1}	66.26±8.51 *34.13-90.12*	75.81±16.32 *45.67-120.87*	67.73±15.24 *29.40-104.96*	65.10±12.96 *32.66-80.12*

TOC – total organic carbon; DOC – dissolved organic carbon; N_{total} – total nitrogen; UA – urease activity; $\overline{X} \pm \Delta X$ – confidence interval of average at confidence level α=0.05 for n-1 degree of freedom

Table 3. Mean and ranges (italic) of enzyme activities in *Sphagnum* and *Carex* dominated peat soils in 0-50 cm and 50-100 cm layers

Parameters	***Sphagnum* dominated peat soils**		***Carex* dominated peat soils**	
	0-50 cm	**50-100 cm**	**0-50 cm**	**50-100 cm**
UA μmol·s^{-1}·kg^{-1}	1.98±0.30 *1.40-2.33*	2.52±0.15 *1.53-3.33*	2.60±0.15 *1.60-3.20*	2.81±0.08 *2.01-4.06*
XOA μmol·s^{-1}·kg^{-1}	5.43±0.42 *4.49-7.08*	4.37±1.43 *1.30-8.78*	2.92±0.66 *1.83-3.69*	2.33±0.15 *1.32-4.55*
POA μmol·s^{-1}·kg^{-1}	8.62±0.98 *5.66-13.73*	8.12±0.73 *4.39-10.72*	9.40±0.83 *4.66-12.68*	8.91±0.88 *3.25-12.66*
PA nmol·s^{-1}·kg^{-1}	1.99±0.73 *0.79-4.94*	1.81±0.58 *0.56-3.06*	2.56±0.58 *0.87-4.10*	2.24±0.63 *1.01-4.30*
NRA nmol·s^{-1}·kg^{-1}	0.03±0.01 *0.01-0.07*	0.02±0.01 *0.01-0.05*	0.03±0.01 *0.02-0.05*	0.02±0.01 *0.01-0.03*

UA – urease activity; XOA – xanthine oxidase activity; POA – phenol oxidase activity; PA – peroxidase activity; NRA – nitrate reductase activity;

$\overline{X} \pm \Delta X$ – confidence interval of average at confidence level α=0.05 for n-1 degree of freedom