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SOME CHARACTERISTICS OF FOREST-TUNDRA (WEST SIBERIA) SOIL GROUPS DISTINGUISHED ON THE BASIS OF THERMAL PROPERTIES

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Abstract: This paper contains the results of the forest-tundra soils studying. The key sites were situated on the permafrost territory, which is under scrutiny in connection with the global climate changes. The soil position in landscape, parent rock texture, vegetation conditions and thickness of organic horizons were taken into account. On the base of seasonal thawing or active layer depth measurements and soil temperature vertical gradients calculating, four main soil groups which are different in their thermal properties were identified. The physical-chemistry properties are rather close in various soil types. Similarities in the profile distribution of humus fractions are also revealed in the soil humus formed under different conditions. Despite of estimated relatively low level of carbon stocks in forest-tundra soils, half of them exist in mobile humus forms, which are less stable. Data on the soil thermal regime types and stocks of different humus forms in soils of various conditions are useful for long-term forecasting of soil status.

Keywords: thermal properties, permafrost, humus compound, carbon stock, soils, West Siberian plain, forest-tundra

1. Introduction

A possible increase in the depth of soil seasonally melting layer in the permafrost zone is of particular concern. Because of close connections between freeze-thaw dynamics and nearly all aspects of tundra ecosystems, including carbon uptake and decomposition (Zhuang, McGuire et al. 2003; Epstein, Raynolds et al. 2012), this phenomenon could increase the additional emission of greenhouse gases into the atmosphere. According to the principle of positive feedback it can lead to uncontrolled changes in climatic conditions. In this case the system of permafrost soil humic substances can leave a quasi-equilibrium state and the least stable part of it (primarily mobile humic substances) may be subjected to additional mineralization that will increase soil CO_2 emissions. The information about soil thermal properties and stocks of carbon in various humus forms in soils of different forming conditions is required for long-term forecasting of soil behavior.

Recently, the interest to the thermal properties of permafrost soils studying grows (Hopmans, Zimunek, Bristow 2002; Archegova 2007; Mazhitova 2008; Karelin, Zamolodchikov 2008, etc.). The soil formation in tundra conditions is characterized by following features (Vasilievskaya et al. 1986):
– a small rate of destruction and changes of soil-forming rocks;
– the relative slowness of the soil formation product removal from soil thickness;
– weak profile differentiation of the silt and mineral components distribution along with metamorphism of the mineral just in the place of existence;
– the presence of a constant or periodic gleying in all genetic horizons of soil profile;
– the relative slowness of the decomposition processes and synthesis of organic substances;
– synthesis acidic organic matter with high mobility in the humification processes;
– a great influence of cryogenic processes on the morphology and chemical properties of soils.

Specificity of soils near the Ural Mountains consists mainly in rather loamy parent rocks. This causes more close to the surface occurrence of permafrost layer, as a consequence, lesser territory drainage and its water logging (Firsova, Dedkov 1983).

Despite of soil process similarities, several soil types are spread in the forest-tundra zone. Soil position in the landscape, soil texture or vegetation community lead to the forming of various soil types. One of our aims was to investigate thermal properties of different forming condition forest-tundra soils.

Under stable conditions, the system of soil humic substances is in a state of equilibrium, meaning the dynamic balance between the newly formed and mineralized fragments of macromolecules. In this case, the proportion of CO_2 emissions due to humus mineralization is estimated at 1.1–4.2% of the total emission (Orlov, Biryukova 1998). However, even during seasonal thawing of permafrost, soils destruction of cryogenic units entails a sharp increase in the mobility of organic matter in their profiles (Dergacheva 1984). The possible changes in thermal conditions of soils in the permafrost zone can influence on the humus substance system. For this reason soil humus characteristics and connected with them physical-chemistry ones were obtained for the other purpose of calculating carbon stocks in various humus forms in these soils.

2. Study area

The objects of the research were the vegetation and soils of western edge of the West Siberian plain on the left bank of the Ob river in Labytnangi area (Yamalo-Nenets Autonomous District). According to climatic division location of key sites related to the Atlantic-Arctic moderately cold humid area (National… 2008). The average temperature of the territory is –7.1°C, the sum of the temperatures more than 10° – equal to 800°C, the annual precipitation – near 400 mm. Studied area belongs to the forest-tundra zone. The country is flat, soils are formed on layered sediments of Quaternary period and have different texture.

Key sites of 1 km^2 were selected to cover three main types of vegetation: tundra, peatbog and forest as well as different parent rock texture: sand (sandy loam) and clay (loam). Height above sea level in all key areas varies slightly (from 90 to 110 m). Within each key site the experimental squares of 100 m^2 were selected. The sites are situated on a line oriented from the North-West to South-East.

3. Materials and methods

The main soil types were defined and morphologically described. Temperature and moisture sensors were installed in each type of soil profile at different depths. Measurements were done at the whole period of field research works. Automatic sensors, produced by Decagon Devices, were installed in one wall of the vertical soil section at the depths 2–10–20–50–100 cm, when it was possible, or only till the permafrost table. After that the soil pit was filled by soil horizons in the same order position of genetic horizons. The vegetation was also restored at its place. Permafrost thawing depth was measured at chosen sites (more than 700 numbers) with the probe length 2.0 m on the experimental squares of 100 m^2 with a step of one meter.

In order to obtain some soil characteristics the soil sampling was done every 5–10 cm in border of visible horizons in each soil type, and special samples were taken for obtaining bulk density, which is necessary for calculating humus stocks. Determination of particle size distribution was carried out by laser diffraction. The magnetic susceptibility (MC) was determined, using Kappabridg KLY-2. The pH of water and salt extraction were measured potentiometrically at Anion 4100. Hydrolytic acidity was estimated in 1.0 n CH_3COONa extract by titration with 0.1 n NaOH, exchangeable cations – in 0.1 n HCl extract by titration with 0,1 n NaOH.

Total carbon was determined by combustion in the chromic mixture (0.4 n $K_2Cr_2O_7$ in dilute 1:1 H2SO4), followed by titration with 0.2 n $(NH_4)_2SO_4{\cdot}FeSO_4{\cdot}6H_2O$. Group and fractional composition of humus – by the method of Ponomariova and Plotnikova (1975).

4. Results

Despite the relatively small area of the investigated sites – 1 km², soil cover pattern varies as the result of complex systems of soil-forming factors: relief and the complex structure of the vegetation; differences in hydrological conditions, as well as the presence of cryogenic and erosion processes. It is therefore reasonable to describe soil combinations or complexes. Such combinations can be contrasted and low-contrasted, with clear or mild genetic connection (Dedkov 1995). The names of the soil types in this paper are given in accordance with the base work, carried on for this territory by V. Dedkov (1995), and classified by World Reference Base (WRB 2006).

In automorphic conditions on sandy soil-forming rocks, which are characterized by large drainage and good thermal conductivity, illuvial-humus-iron soil, representing by podzols (Albic Podzols) and cryogenic-gley podburs (Entic Podzols) are formed. Woodland soils on the sands on the crossed elements of mesorelief, allowing groundwater discharge, are very similar to the zonal podzols of middle and northern taiga, according to their morphological characteristics. Permafrost table lays at relatively large depth in these conditions.

The section 4.1.1 was laid in the larch-birch shrub-lichen-green forest woodland, under which cryogenic deep gley Al-Fe-humus podzol (Albic Podzol) was formed (Fig. 1, № 1). The description of the soil profile is given below.

O1 – 0–2 cm – living lichens, which are inseparable from rough humic horizon.

O2 – 2–3 cm – rough humic, semi-decomposed litter.

A – 3–5 cm – gray, lamellate sandy loam with inclusions of small and large, sometimes decayed roots, wavy border, clear color transition to the next horizon.

E – 5–13 cm – light gray, layered sandy loam, inclusions of individual small and large roots, single Fe-Mn formations diameter of less than 1 mm, the wavy border, clear color and density transition.

Bhs1 –13–29 cm – reddish-brown, more dense than the previous horizon, contains inclusions of the different size roots, stones smaller than 2 cm in diameter and Fe-Mn neoplasms; structureless silt loam, wavy border, clear color transition.

Bhs2 – 29–47 cm – reddish-brown gravel, with inclusions of single roots and gruss of a layered sandy loam, smooth border, clear color transition.

BC – 47–69 cm – gravel, with stones diameter up to 2 cm inclusions, stratified sandy loam, smooth border, clear color and density transition.

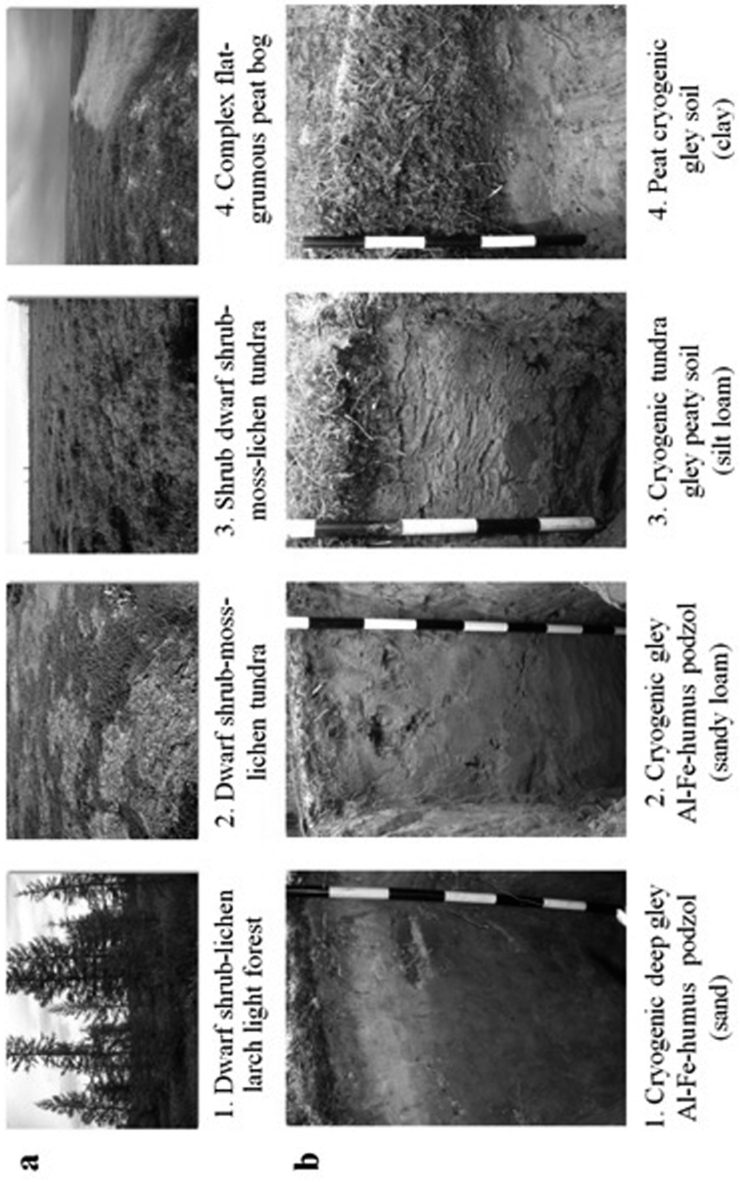

Fig. 1. The forest-tundra plant communities (a) and related soils (b)

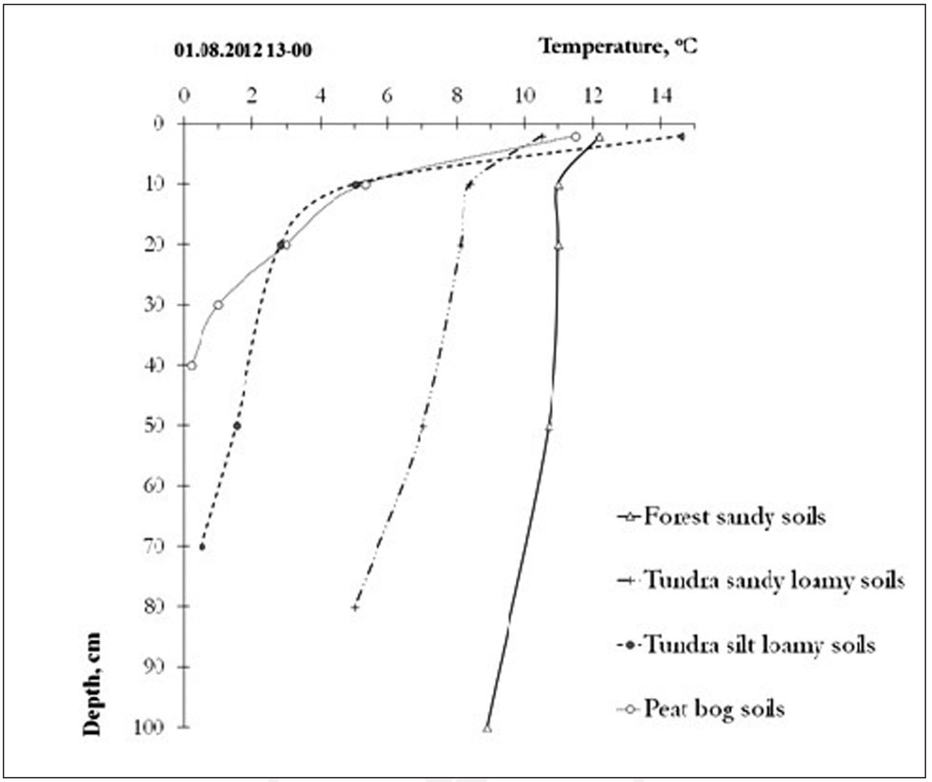

Fig.2. The temperature profile of different soil groups on the key sites at 1 pm 01.08.2012

C – 69–119 cm – beige-gray, with stones diameter up to 2 cm inclusions, which constitute 20% of the area, sandy loam. The depth of the layer of permafrost is more than 3 m.

In automorphic conditions, but more flat elements of the relief under the tundra vegetation, the eluvial-illuvial processes also dominated. But, despite the sandy compound of parent rocks, peat formation develops here to a greater extent because of poor drainage. The main are cryogenic deep gley Al-Fe-humus podzols (Spodic Cryosols), podburs (Spodic Cryosols), combined with the tundra cryogenic gley peat soils (Turbic Cryosols Reductaquic or Histic Turbic Cryosols). In connection with well-developed peat horizons and due to the low drainage of the territory the average depth of permafrost table for these types of soils is close to 100 cm.

At higher elements of the microrelief in the conditions of better drainage small areas spotty tundra on sandy-loam and sandy soil-forming rocks are formed under predominantly lichen vegetation (Fig. 1, № 2). About 80% of such plot surface is occupied by Al-Fe-humus podzols (Albic Podzols Gelic) interspersed with podburs (Entic Podzols Gelic), the remaining 20% is Turbic Cryosols.

On slightly sloping watersheds, composed by loam and clays, small drainage of territory and its strong water logging is observed. In such circumstances, complexes of zonal tundra cryogenic gley peaty soils (Turbic Cryosols Reductaquic or Histic Turbic Cryosols Reductaquic) with peatbog cryogenic gley soils (Cryic Histosols) are spread. The thermal conductivity of these soils is significantly lower than in previous cases, drainage is difficult; permafrost table is founded on the average depth of 60 to 75 cm.

The section 3.1.2 was made on the knob in that type of tundra (Fig 1, № 3) and has the following morphological structure:

H1 – 0–5 cm – light-brown poorly decomposed residues of green moss and sphagnum.

H2 – 5–8 cm – brown, composed of moss, shrub twigs and well decomposed peat.

HA – 8–12 cm – light gray well decomposed organic matter, loam, wavy border.

Bg – 12–14 cm – light brown, with blue-gray and reddish-brown spots, with rare inclusions of fine roots, silt loam. Horizon is thixotropic.

Br – 14–28 cm – blue-gray, uniformly colored, with a few buffy spots, with root inclusions, loam, wavy border, clear color transition.

BCg – 28–50 cm – blue-brown with buffy spots wet loam. Permafrost lays at 70 cm.

The section opened cryogenically tundra gley peaty soil (Histic Turbic Cryosol Reductaquic).

The section 5.1.1 was made in complex oligotrophic bog. On flat and negative forms of relief in the areas of supreme and complex bog peaty cryogenic gley soils (Histic Cryosol) distributed (Fig 1, № 4). Peat thickness can vary in broad range till 250 cm (Dedkov 1995). The description of this soil type is given below.

H1 – 0–14 cm – yellow-brown undecomposed sphagnum moss.

H2 – 14–34 cm – layered, well-decomposed remains of sphagnum, indistinguishable to the species.

BCrf – 34–42 cm – blue-gray structure less clay.

Permafrost table is on the depth of 40 cm.

To identify the differences in the temperature of the soil profile and the depth of active layer (AL), four major factors were taken into account: the soil position in mesorelief, soil texture, vegetation condition and thickness of organic horizons. All soils function in one climatic area. Soil profile variation of the temperature was studied in all of these soil groups (Fig. 2).

For comparative heat conductivity of different soil groups, soil temperature vertical gradients were calculated for temperature changes every 10 cm of the depth – average for profile as a whole or separately for different soil layers. Table 1 contains data

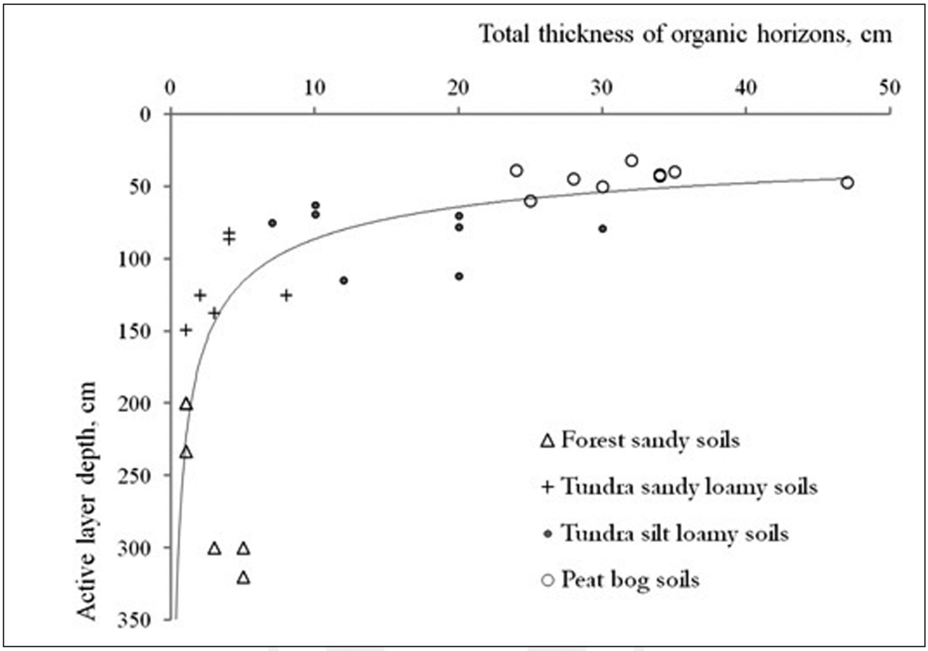

Fig. 3. The depth of active layer and the total thickness of soil organic horizons

on the depth of seasonal thawing, and the calculated temperature vertical gradients in the soils (both characteristics are calculated based on the evidences of temperature sensors at 1 pm on the 1st of August 2012 year, the depth of AL was measured in the same period).

Thus, the average temperature vertical gradients in the different groups of Yamal forest-tundra soils can vary by order of magnitude, which leads to differences in warming of these soils and, as a consequence, in the depth of seasonal thawing. The upper 10 cm of organic peat horizons have the best insulating ability: the temperature gradient to our data is 9.69–15.00°C/10 cm in August, which is consistent with the data of other authors (Mandarov, Skriabin 1979). Figure 2 shows the relationship of the active layer depth and the organogenic horizon thickness of different texture soils, forming under various vegetation communities.

On the base of the active layer thickness and soil temperature vertical gradients the following main soil groups, which are different in their thermal properties were identified.

1. Forest sandy loam and sand soils. Forest litter and turf horizon are well distinguishable in such soils. The thickness of podzolic (Albic) horizon is rather high.

Table 1. Seasonal thawing thickness and temperature vertical gradients in the soils

Soil, parent rock texture	Plant community	Number of measurements	Temperature vertical gradient, °C/10 cm	Thickness of AL, см
Cryogenic deep gley Al-Fe-humus podzol (Albic Podzol) sand	Dwarf shrub-lichen-moss larch-birch forest	121	0.29	> 300.0
Cryogenic deep gley Al-Fe-humus podzol (Albic Podzol Gelic) sandy loam	Dwarf shrub-moss-lichen tundra	121	0.71	140.5 ± 10.7
Cryogenic tundra gley peaty soil (Turbic Cryosol Reductaquic or Histic Turbic Cryosol Reductaquic) silt loam	Ledum-dwarf birch-shrub--grass-lichen and moss	100	1.57	61.1 ± 7.2
Peat cryogenic gley soil (Histic Cryosols) clay	Complex bog	86	2.61	42.6 ± 7.9

Illuvial ferrous horizon (Bhs) is saturated by iron $Fe3^{+}$ and has a bright color. Continuous gley layer is absent. Active layer depth is more than 2–3 m.

2. Tundra sandy loam soils. They are wet, thixotropic characteristics appear from the depth of 10–20 cm, cryoturbic processes are present. Turf horizon is practically absent. Podzol (Albic) horizon has low thickness (or sometimes is absent in Entic Podzols). Gley illuvial-ferric horizon is not well distinguishable and lies close to surface. Thixotropic gley horizon is distinctively marked and is situated on the low depth. As a consequence permafrost table is relatively deep to the surface (from 1 to 1.5 m).
3. Tundra loam soils. These soils are wet, have a thick lay of peat, are thixotropic and gley just under the peat layer. Humic horizon is practically absent, Fe3+ can be found as a brown-orange border under the peat horizon and as spots in gley horizon. Thickness of active layer is very rare more than 1m.
4. Oligotrophic bog soils. They can be found usually on supreme and complex sloppy bogs and have the most thick organic horizon – mainly peaty, sphagnum at the upper layers. Permafrost table usually is just under peat layer at the depth of 35–45 cm.

Humus compound and connected with it physical-chemistry characteristics were also obtained for soils of one key site (table 2). The studying soils are formed under different plant communities (larch, lichen and moss) and have various soil textures. The depth of permafrost table ranges in two times, for this reason the thickness of soil profiles also varies. The soils belong to different soil types with specific

Table 2. Some forest-tundra soils characteristics

Characteristics	Soils		
	Cryogenic gley Al-Fe-humus podzol (Albic Gleyic Podzol) Section 3.3.1	Cryogenic gley Al-Fe-humus podzol (Albic Gleyic Podzol Gelic) Section 3.4.1	Cryogenically tundra gley peaty soil (Turbic Cryosol Reductaquic) Section 3.1.3
Plant community	Dwarf shrub-lichen larch light forest	Shrub-grass-moss-lichen	Ledum-dwarf-birch-shrub--grass-lichen and moss
Soil texture	Sand	Sandy-loam	Silt loam
The depth of permafrost, cm	233	149	97
Soil horizons	O-E-Bhs-Bg-BCg	O-E-Bhs-Br	H1-H2-Bg-Br-BCg

horizons. Podzols are formed under forest (Section 3.3.1) and lichen plant communities (Section 3.4.1), Cryosol – under moss one (Section 3.1.3).

All forest-tundra soils have the acid reaction (pH_{KCl} is less than 4.4), pH decreases in the lower soil horizons (Fig. 4).

The volumes of hydrolytic acid (Fig. 4) reached 13–25 mmol/kg of the soil in the organic horizons, but in mineral horizons it lowers till average 1 mmol/kg of the soil. The content of exchangeable cations is not high (less than 24 mmol/kg of the soil), especially in podzols. The mineral horizons are saturated by exchangeable cations just greater, then the organic ones. It can be connected with the parent rock peculiarities, saturating by Ca and Mg and it correlates with pH values increasing in the soil depth.

The distribution character of organic carbon in the studied soils (Fig. 4) is regressive-accumulative (Rozanov 2004). The maximum content (9–30%) was found in the surface horizons, the minimum – on the lower part of the soil profile, where it amounts to 0.05–0.20% According to the meanings of specific magnetic susceptibility, the soils under tundra communities (Sections 3.4.1 and 3.1.3) are formed on the parent rocks with rather close magnetic properties. The soil under larch community has the larger values of magnetic susceptibility.

Carbon stocks in the upper 20 cm of studying soils vary in more than 4 times under different vegetation communities (Fig. 5), accounting for 950–4400 tones per km^2. It corresponds to the very low level (Orlov 1990). Maximum values occur in Cryosol, minimum – in Podzols.

The humus content of the studying soils is rather similar and shown (Fig. 6) on the example of tundra Podzol.

Fulvic acids (FA) are the dominate group of humic substances, sometimes their content is near 60%. The amount of humic acids (HA) low its volumes with the

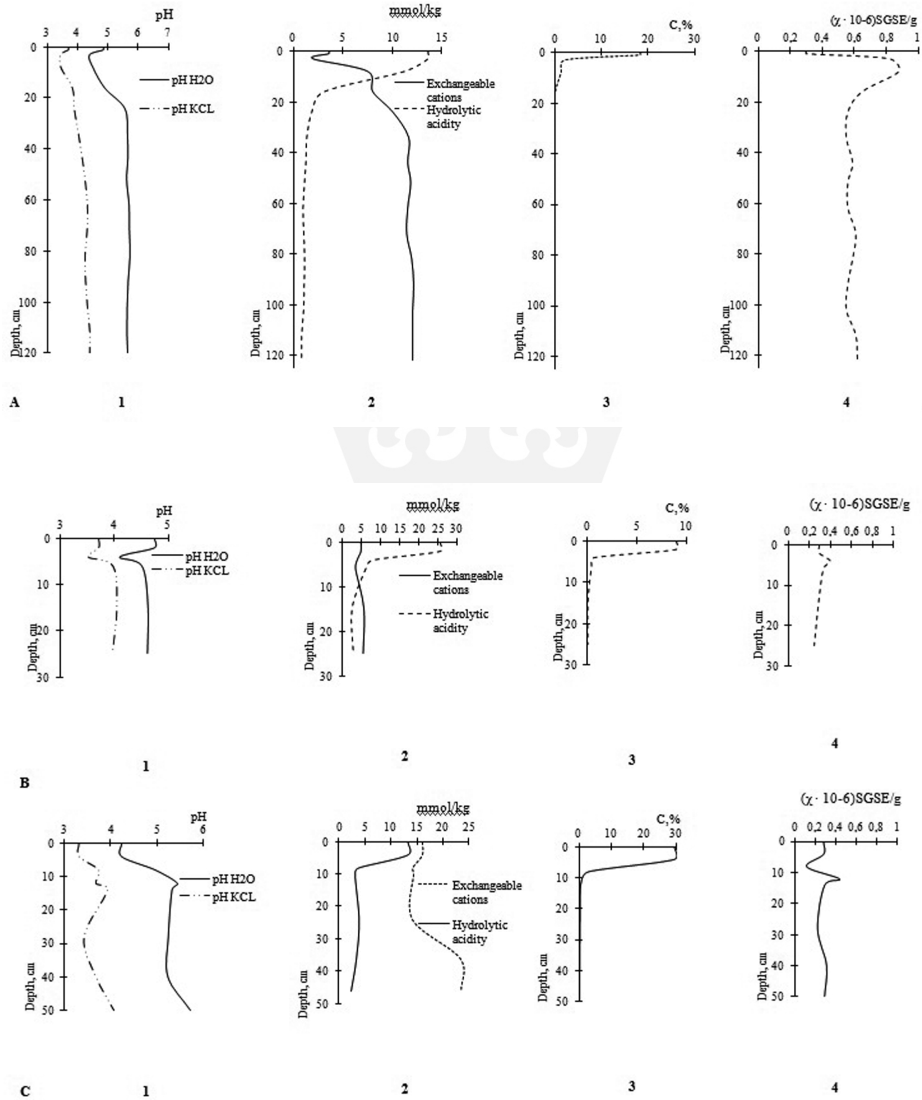

Fig. 4. Some physical-chemistry characteristics of soils

Explanations: A – forest Podzol, B – tundra Podzol, C – Cryosol

1 – pH of water and salt extract; 2 – the hydrolytic acidity volumes and exchangeable cation content; 3 – total organic carbon content; 4 – magnetic susceptibility

depth. This is reflected in the ratio CHA/CFA, which is less then 0.5, except the organic horizon. Mobile brown humic acid fraction (HA1) prevails over the other fractions, varying from 41% to 65% to total HA content. The content of these free and bound with sesquioxides humic acids has the highest volumes in the upper part of the soil. Connected with clay particles humic acid fraction (HA3) has the average content 37% to the HA sum. Black humic acid fraction (HA2), associated with calcium is present in the least amount. Connected with humic acids (FA1) and the aggressive (FA1a) fulvic acid fraction prevail among the fulvic acids.

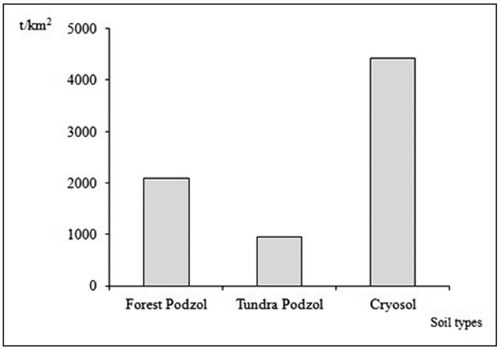

Fig. 5. Carbon stocks in the upper 20 cm of different soil types

Thus, mobile fractions of humus acids (brown humic acids and related with them fulvic acids) are dominated in the composition of humus, a significant share is also on the aggressive fraction of fulvic acids, their amount in humus composition

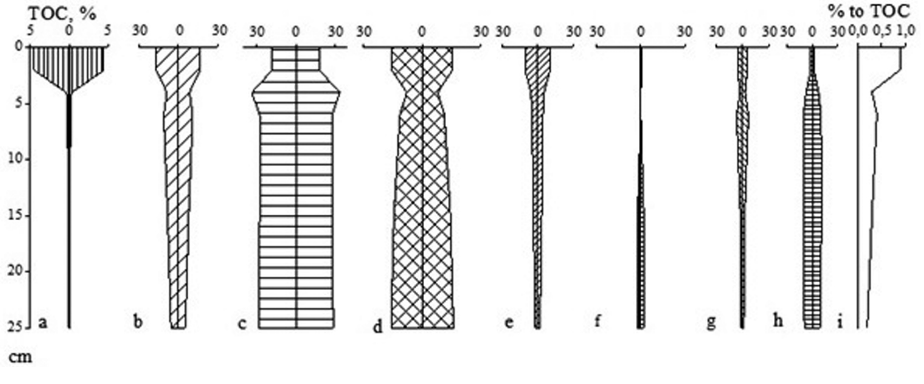

Fig. 6. Humus profile of tundra Podzol (section 3.4.1)

Explanations: a – total organic carbon (TOC), % to the soil; % to TOC: b – the humic acid (HA) sum, c – the fulvic acid (FA) sum, d – non-hydrolysable humus forms, e – HA fraction 1, f – HA fraction 2, g – HA fraction 3, h – FA fraction 1a, i – $C_{HA:CFA.}$

is near 50%. Therefore, half of the carbon stock in the forest-tundra soils is in rather mobile humus substances.

5. Conclusions

Temperature vertical gradients were calculated and depth of AL, varying on the order of magnitude, was measured in forest-tundra watershed soils. The soils under investigation have rather different thermal properties, influencing on the permafrost state. Thermal properties are dependent to a certain degree on the soil position in the relief, parent rock texture and the type of vegetation and the total thickness of soil organic horizons. Four main soil groups based on thermal properties were estimated. As for the physical-chemistry properties, they are rather close in various soil types. Similarities in the profile distribution of free and bound with mobile sesquioxides humic acid fraction and aggressive fulvic acid fraction were also revealed in the soil humus formed under different plant communities. Estimated carbon stocks of forest--tundra soils are rather low, but near 50% of them are included in the least stable mobile fractions of humus. It can cause the rapid increasing of soil CO2 emissions in the case of global climate warming.

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