PECULIAR TEMPERATURE REGIME IN COLD FROZEN SOILS ALONG THE SOUTHERN BOUNDARY OF THE CRYOLITHOZONE IN THE NORTH-EAST OF EUROPEAN RUSSIA

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The temperature regime was studied in the frozen soils developed along the southern boundary of the cryolithozone in the North-East of European Russia. In the southern tundra the frozen soils with the cold temperature regime are confined to peat and mineral parent materials. The seasonal and long-term temperature dynamics in the seasonally thawed and underlying permafrost-affected layers is shown. The frozen soils are characterized according to temperature indices.

Key words: temperature regime, cold frozen soils, permafrost-affected rocks, seasonally thawed layer.

INTRODUCTION

Special attention was always paid by I.V. Zaboeva to stationary studies of functioning regimes in taiga and tundra soils and the thermic regime in particular. She studied the temperature regime in gley-podzolic soils within the northern taiga zone as well (Zaboeva, 1975). In the tundra zone the temperature regime of virgin tundra soils was studied by A.V. Kononenko (1986); G.G. Mazhitova (2008) has studied in detail the temperature regime in 11 soils developed in diverse landscapes of flat and mountain tundra, being confined to frozen and thawed parent materials. This paper shows the well-expressed differences in winter and annual temperatures in frozen and non-frozen soils as well as the similar summer temperatures in the root layer of these soils. The study of the temperature regime in frozen soils was carried out within the seasonally thawed layer (STL).

The control over the temperature in the main types of frozen soils started in the south-eastern part of Bolshezemelsk tundra in 2007. This monitoring was organized to study the temperature regime within the seasonally thawed layer and in the uppermost permafrost-affected deposits at a depth of 120 cm. It will allow assessing the response of soils with different temperature regime to the dynamics of annual air temperatures and the expected climate changes in case of a greater amount of observations. Due to global climate changing the soils, that have served earlier as a pool for the carbon runoff, can become a source of its storage, thus providing an additional input of carbon-bearing gas to the atmosphere and increasing the climate warming process [2]. The Subarctic of European North-East is one of the regions, most sensitive to climate changes [12, 13]. The great permafrost degradation is observed in the eastern part of Timano-Pecherskiy region [12]. Within the southern tundra and forest tundra are widespread the areas confined to the permafrost-affected deposits, instable to the climate warming. Along the southern boundary of the cryolithozone there are conditions for soils with the severe temperature regime. The so-called cold frozen soils are locally developed on peat and mineral mounds with the shallow snow cover.

The aim of this paper is to characterize the major parameters of the temperature regime in cold frozen soils and permafrost-affected deposits within the tundra zone.

OBJECTS OF RESEARCH AND INVESTIGATION METHODS

The study of the soil temperature regime was carried out in two test areas within the subzone of southern tundra (Bolshaya Rogovaya river basin) and in northern forest tundra (Seida river basin). The region under study is located in the Usa river basin (tributary of Pechora river), within the zone of discontinuous permafrost distribution in the North-East of European Russia [4]. The mean annual temperature is 0…–2°C, a set of surface-gley (frozen and not-frozen), peat-gley and swampy frozen soils is dominant there [6]. According to the data of Vorkuta meteorological station the mean annual air temperature was –5.7°C in the period from 1947 to 2011. The precipitation accounted for 645 mm/year. The data of the hydrological year (October 01– September 30) were used to calculate annual values of the air temperature and precipitation (Table 1).

The objects of research are 4 profiles of cold frozen soils derived from mineral and peat deposits within the southern tundra in the North-East of European Russia (Table 2). According to the classification of temperature regimes [3] these soils are regarded to the frozen type of

Table 1. Climatic parameters (according to data of Vorkuta meteorological station)

Hydrological year (01.10–31.09)	Mean annual air temperature °C	Sum of mean daily air temperatures, °C·days		Annual sum of precipitation mm	Sum of precipitation in June–September, mm	Sum of precipitation in December – February, mm
		> 0°C	>10°C			
2007/2008	–3.6	1126	802	525	195	132
2008/2009	–4.5	1046	701	613	252	124
2009/2010	–7.0	995	602	776	376	129
2010/2011	–4.1	1002	558	668	215	88
Average for 2007–2011	–4.8	1042	666	645	259	118
Average for several years (1947–2011)	–5.7	1015	536	523	225	106
Diapason (1947–2011)	–2.8…–9.9	647–1310	0–1059	294–762	86–393	16–303

temperature regime being characterized by the “continuous” eternal permafrost [6]. The cold frozen soils on mineral deposits are developed predominantly under moss-lichen vegetation. The depth of the seasonally thawed layer is varying from 50 to 120 cm. The frozen soils on peat deposits are widely spread in areas confined to peat mounds where the peat depth is more than 40 cm. The depth of the seasonally thawed layer doesn’t exceed 40–60 cm in peat soils.

The parameters of the temperature regime are given for two mineral (pits 1 and 2) and two peat (pits 3 and 4) frozen soils. Digital loggers at a depth of 0, 20, 50, 100 (120) cm were used to perform measurements 8 times per 24 hours. The logger sensing elements in every soil profile were placed into a hole of 3 cm in diameter at a depth of 100–120 cm. The depth of seasonal thawing was measured by a metal sound at the end of the vegetation period. The thickness of the snow cover was measured in March.

The studies carried out in the period from 2007 to 2011 showed that the sum of negative soil temperatures made up –362…–2508°C (Table 3). The shallow (0–30 cm) snow cover was conducive to severe cooling in soils at a depth of 100–120 cm. The permafrost-affected deposits at a depth 100–120 cm of peat mounds are subjected to cooling to a considerable extent.

Table 2. Characteristics of test areas

No. Soil pit	Coordinate	Landscape	Depth of STL, cm	Average maximal thickness of the snow cover, cm	Profile formula	Soil name (Soil classification in Russia, 2004)	Soil name in this paper
1. Pit U58	Lat. 67°19′ North Long. 62°24′ East	Bolshaya Rogovaya river basin. Mineral mound. Shrubby-moss-lichen vegetation in tundra	100	≤30	T (0–20)–B (20–37)–Bf (37–53)–BC (53–70)–Cg (70–85+)	Peat cryogenic-ferruginous gleyzem on layered heavy loam	Peat cryogenic-ferruginous gleyzem
2. Pit U71	Lat.67°20′ North Long. 62°20′ East	Bolshaya Rogovaya river basin. Flat top of mineral mound. Shrubby-moss-lichen vegetation in tundra	110	≤20	T (0–6)–I (6–12)–II (12–17)–III (17–20)–IV (20–32)–V (32–50)–VI (50–71)–VII (71–80)–VIII (80–89)–IX (90–110)–X (110+)	Layered alluvial soil on schistose loam-sandy lacustrine-alluvial deposits	Layered alluvial soil

No. Soil pit	Coordinate	Landscape	Depth of STL, cm	Average maximal thickness of the snow cover, cm	Profile formula	Soil name (Soil classification in Russia, 2004)	Soil name in this paper
3. Pit S3	Lat.67°03′ North Long.62°56′ East	Seida river basin. Flat top of peat mound (palsa). Shrubby-moss-lichen vegetation in tundra. Exposed peat areas	52	≤10	O (0–7)–TJ (7–40)–T2 (40–52)–T3 (52–100+)	Dry peat soil	Dry peat soil (Seida river basin)
4. Pit U92	Lat.67°19′ North Long.62°23′ East	Bolshaya Rogovaya river basin. Convex top of peat mound. Shrubby-moss-lichen vegetation in tundra	45	≤10	O (0–5)–TJ (5–26)–T2 (26–41)–T3 (41–57)–T4 (57–100+)	Dry peat soil	Dry peat soil (Bolshaya Rogovaya river basin)

Table 3. The sum of negative mean daily temperatures in soils and permafrost-affected deposits, °C · days

Depth, cm	Hydrological year			
	2007–2008	2008–2009	2009–2010	2010–2011
1. Peat cryogenic-ferruginous gleyzem				
0	–1289	–1843	–1720	–1409
20	–943	Not determined	–1405	Not determined
50	–803	–802	–1149	»
100	–647	Not determined	–970	»
2. Layered alluvial soil				
0	–1036	–1324	–1628	–1246
20	–805	–858	–1260	–1030
50	–606	–644	–1049	–847
80	–457	–484	–865	Not determined
120	–362	Non		
3. Dry peat soil (test area in Seida river basin)				
0	–1753	–1974	–2508	–1559
20	–1418	–1684	–2204	–1364
50	–1017	–1273	–1709	–1032
80	–922	–1145	–1599	–981
120	–858	–1068	–1507	–1020
4. Dry peat soil (test area in Bolshaya Rogovaya river basin)				
0	–1304	Не опр.	–2183	–1731
20	–1127	–1411	Not determined	
50	–897	–1081	–1505	–1223
100	–730	Non		–1207

The conditions for the winter frost in soils and underlying deposits are favor for maintaining the eternal permafrost under the recent conditions of the climate changes.

The cold frozen soils are sensitive to changing the air temperature in the winter especially in January or February (Fig.2). The maximal cooling of the permafrost-affected deposits occurs in the period from February to April; the mean monthly temperatures of the permafrost-affected deposits are varying from –4 to –12°C in the most cold month.

The winter factor, i.e. the ratio between the temperature sum <0°C at the soil surface and the air temperatures is highly dependent on the snow cover. The values of winter N-factor reflecting the cold input to soil are varying in the range from 0.44 to 0.76, what is characteristic of the uppermost horizons in frozen soils [11].

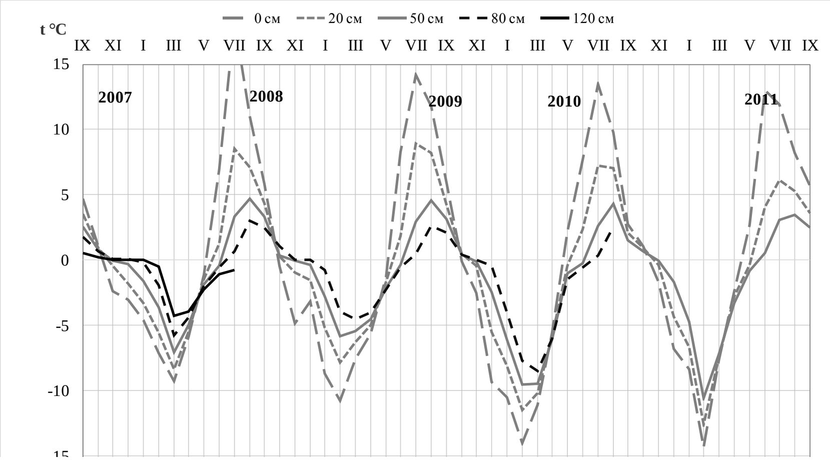

Fig.1. Dynamics of mean monthly temperatures (°C) in the profile of layered alluvial soil.

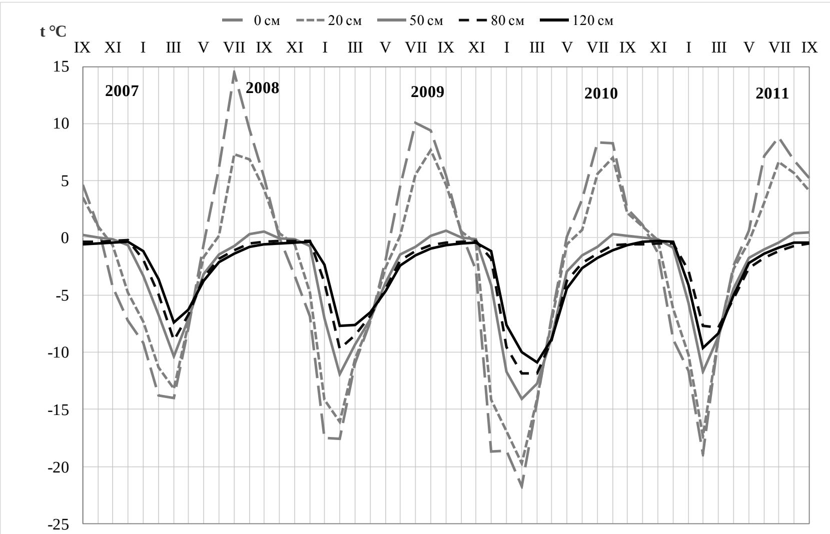

Fig.2 Dynamics of mean monthly temperatures (°C) in the profile of dry peat soil (in the Seida river basin).

Table 4. The sum of positive mean daily temperatures in soils and permafrost-affected deposits, °C ·days

Depth, cm	Sum of mean daily temperatures >0˚C			Sum of mean daily temperatures >10˚C		
	Hydrological years					
	2008–2009	2009–2010	2010–2011	2008–2009	2009–2010	2010–2011
1. Peat cryogenic-ferruginous gleyzem						
0	906	755	970	554	317	388
20	118	175	76	0	0	0
50	85	90	43	0	0	0
100	4	1	3	0	0	0
2. Layered alluvial soil						
0	1272	1138	1312	898	720	814
20	708	594	612	230	108	9
50	325	276	316	0	0	0
80	191	105	Not determined	0	0	0
120	0	0	0	0	0	0
3. Dry peat soil (test area in Seida river basin)						
0	911	719	917	415	211	213
20	568	497	628	49	49	12
50	29	18	29	0	0	0
80	0	0	0	0	0	0
120	0	0	0	0	0	0
4. Dry peat soil (test area in Bolshaya Rogovaya river basin)						
0	Not determined	658	740	90	126	265
20	189	Not determined		0	0	0
50	0	0	0	0	0	0
100	0	0	0	0	0	0

The summer temperature regime in soils. The snow cover is melting on peat and mineral mounds at the end of April–early May. The seasonal thaw of surface horizons starts in the second half of May when the mean daily temperatures become positive. The warmest month is July or August (Fig. 1, 2), the maximal temperatures in lower soil horizons in the seasonally thawed layer are observed in the period from August to October, in permafrost-affected deposits – from September to December. Diapason of the temperature sum >0°C makes up 658–1312°C-days (Table 4).

At a depth of 20 cm the sum of positive temperatures is lower by 1.5–3 times as compared to the soil surface. The maximum sum of positive temperatures at a depth of 20 cm is in layered alluvial and dry peat soils (the area in Seida river basin). In the layered peat soil a shallow peaty (0–6 cm) litter and the light texture are favor for penetrating the positive temperatures downwards the soil profile what is evidenced by the thickness of the seasonally thawed layer (110 cm). The upper horizons of the dry peat soil become heated due to sparse moss-lichen vegetation. The black color of the exposed peat promotes the increased penetration of solar radiation into the soil. In general, in the cold frozen soils the temperatures >10°C penetrate into the depth of 10–15 cm (the root layer). Their deeper penetration is hindered by a thick organogenic horizon and the close boundary of the permafrost.

Annual indices of the soil temperature regime. The total diapason of mean annual temperatures in the seasonally thawed layer is equal to 0.8…–4.8°C at a depth of 0, 20, 50 cm of the studied soils; it is 1.3…–4.4°C in the permafrost-affected deposits (Table 5).

Table 5. Mean annual temperatures in soils and permafrost-affected deposits, °C

Depth, cm	Hydrological years			
	2007–2008	2008–2009	2009–2010	2010–2011
1. Peat cryogenic ferruginous gleyzem				
0	–0.4	–2.8	–2.6	–1.2
20	–2.5	–2.6	–3.7	Not determined
50	–1.7	–2.2	–3.2	
100	–2.2	Non	–2.9	»
2. Layered alluvial soil				
0	0.8	–0.2	–1.7	–0.1
20	–0.4	–0.4	–2.2	–1.3
50	–0.7	–0.9	–2.5	–1.6
80	–0.7	–0.8	–2.3	Not determined
120	–1.3	Not determined		
3. Dry peat soil (within the Seida river basin)				
0	–1.8	–2.9	–4.6	–2.0
20	–2.3	–3.1	–4.4	–2.2
50	–2.7	–3.4	–4.6	–2.8
80	–2.5	–3.1	–4.4	–2.6
120	–2.3	–2.9	–4.1	–2.7
4. Dry peat soil (within the Bolshaya Rogovaya river basin)				
0	–2.5	Not determined	–4.8	Not determined
20	–2.1	–3.8	–4.2	–3.1
50	–2.5	–3.0	–4.1	–3.3
100	–3.0	Non		–3.3

In 4 profiles of the studied soils the mean annual temperature in the seasonally thawed layer was negative being decreased downwards the profile. The negative mean annual temperatures in frozen soils and positive temperatures in non-frozen soils should be considered as the most normal situation [10]. The diapason of seasonal temperature fluctuations is constantly decreasing from the soil surface downwards the profile embracing the uppermost permafrost-affected deposit (Fig.1, 2). Seasonal temperature fluctuations are clearly expressed in frozen horizons at a depth of 50–120 cm what coincides with the formation zone of the transitional layer.

CONCLUSION

Within the zone of discontinuous distribution of the permafrost-affected deposits the frozen soils with lower winter and annual temperatures are developed on peat and mineral mounds under the shallow snow cover. These soils form a group of cold frozen soils with the severe temperature regime. The low mean annual temperatures in the uppermost permafrost-affected deposits serve as evidence of relative stability of the permafrost in soils developed on peat and mineral mounds. The summer temperatures in the upper (0–20 cm) horizons of the studied soils are typical for soils developed under moss-lichen vegetation in tundra; in lower horizons the temperature differentiation is dependent on the depth of permafrost-affected deposits. The positive temperatures in upper horizons of soils on peat mounds are explained by the scanty vegetation cover, in soils on mineral mounds – by the shallow humus horizon and the light soil texture.

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