SOIL SCIENCE ANNUAL
2020, 71(1), 37–46

https://doi.org/10.37501/soilsa/121490

Water holding capacity of Russian Arctic soils (Lena River Delta and Yamal Peninsula)

Vyacheslav Igorevich Polyakov[1,2,3,*], Ivan Ilych Alekseev[1], Ksenia Sergeevna Orlova[1], Evgeny Vasilevich Abakumov[1,*], Jakub Kostecki[4]

[1] Sankt Petersburg State University, Department of Applied Ecology, 16 line 29 Vasilyevskiy Island, 199178, Saint-Petersburg, Russia
[2] FSBI "Arctic and Antarctic Research Institute", Beringa 38, St. Petersburg, 199397 Russia
[3] Department of Soil Science and Agrochemistry, Faculty of Agriculture, Saint-Petersburg State Agrarian University, Petersburg Highway 2, Pushkin, St. Petersburg, 196601, Russia
[4] University of Zielona Góra, Institute of Environmental Engineering, 15 Prof. Z. Szafrana St., 65-516 Zielona Góra, Poland

* V. Polyakov, slavon6985@gmail.com

Received: January 22, 2019
Accepted: December 6, 2019
Associated editor: A. Łachacz

Keywords

Arctic soils
Lena River Delta
Yamal Peninsula
Permafrost
Soil water holding capacity
Flooded area

Abstract

Floodplains are one of the most dynamic and youngest areas of the Earth's Quaternary surface. They are located in transitional conditions (land-ocean) of the permafrost zone of present and of particular interest for ongoing geochemical processes and soil/water balance. The soil thermal and water regimes of polar soils are crucial for the development of vegetation cover as well as production, accumulation and redistribution of organic matter. This work characterizes the hydrological properties of soils formed in Russian Arctic. The data showed differences in water holding capacity between soils formed in conditions of seasonal flooding (soil stratification, redistribution of organic and mineral matter through the soil profile) and those not influenced by flooding in Lena River Delta (gradual decreasing of water holding capacity as a function of depth). Both of the soil profiles from the Yamal Peninsula are characterized by a gradually decreasing water-holding capacity with depth. The hydrological regime characteristics were strongly related to the depth of the active layer. The intensity and rate of the thawing/freezing processes depends on the features of the hydrological regime. In this study, significant differences were noted in the soil characteristics of the two study areas. That is why the profile values of water-holding capacity differed among the study sites. The predicted global climate change and high sensitivity of Arctic ecosystems may lead to significant changes in permafrost-affected landscapes and may alter their water regime in a very prominent way, as permafrost degrades and lateral and vertical water flow in the basins of large arctic rivers changes.

1. Introduction

The floodplains are one of the youngest and the most dynamic landforms on the Earth's surface (Dobrovolsky, 2005). The floodplain soils occur on the most recently formed areas (coastal shallows and overgrown ponds); they are influenced by the soil-forming process and are of variable age (Fedorov, 1993; Dobrovolsky, 2007; Dobrovolsky et al., 2011). Soil formation may be interrupted by several processes, like permafrost-related cryogenic mass exchange and annual flooding (Dobrovolsky, 1994). Peculiar features of the floodplain soils are their initial morphology driven by intensive geomorphic processes. Intensive flooding, delivery of new substrate rather hampered soil forming and cryogenic processes. The biological activity and the dynamics of chemical and biogeochemical processes determine the fertility of floodplain soils (Darmaeva et al., 2009; Dobrovolsky et al., 2011).

Previous studies of the Lena River Delta concentrated on the distribution of trace elements in pristine permafrost-affected soils and identified the main patterns of their distribution (Antcibor et al., 2014) and the effect of frost on soil and carbon stocks (Zubrzycki et al., 2013; Hugelius et al., 2014; Zubrzycki et al., 2014; Gentsch et al., 2015; Rippin and Becker, 2015). These studies were focused on the following: transfer of organic material from the delta to the Laptev Sea, including further remineralization (process of destruction of parent material and deposition of mineral material leading to an increase of fertility) (Dolgopolova, 2011; Winterfeld et al., 2015). Despite the large number of studies on organic carbon and methane fixation and release, there is surprisingly little data on water and soil physical properties and water-holding capacity. The relevance of these soil physical properties is that the soils in the Lena Delta play an important role in landscape drainage and preferential water flow regulation.

Soils formed in the flooding areas have important ecological properties (Witkowska-Walczak et al., 2015). These areas comprise several landforms including floodplain meadows as well as supra-terraced and flat interfluves. Analysis of soil hydrophysical properties can determine the content of water that can infiltrate soil and water retained and adsorbed on the surface of soil units. Data of this kind will be useful for future modeling of the water balance in the region and can help create more robust estimates of available soil moisture within the permafrost zone (Reza et al., 2016). The soil thermal and moisture regimes of polar soils are crucial for the development of vegetation as they play a substantial role in the production and distribution of organic matter.

Therefore, the aim of this study was to characterize the physical properties of the Lena River Delta and coastal areas of the Yamal peninsula soils at two different sites: (1) islands in the Lena River Delta, (Samoylovsky Island and Arga-Belir-Aryta Island) and (2) Subpolar Ural, Yamal Peninsula. Soils were investigated on fully flooded areas as well as at sites that have been already emerged from the influence of flooding.

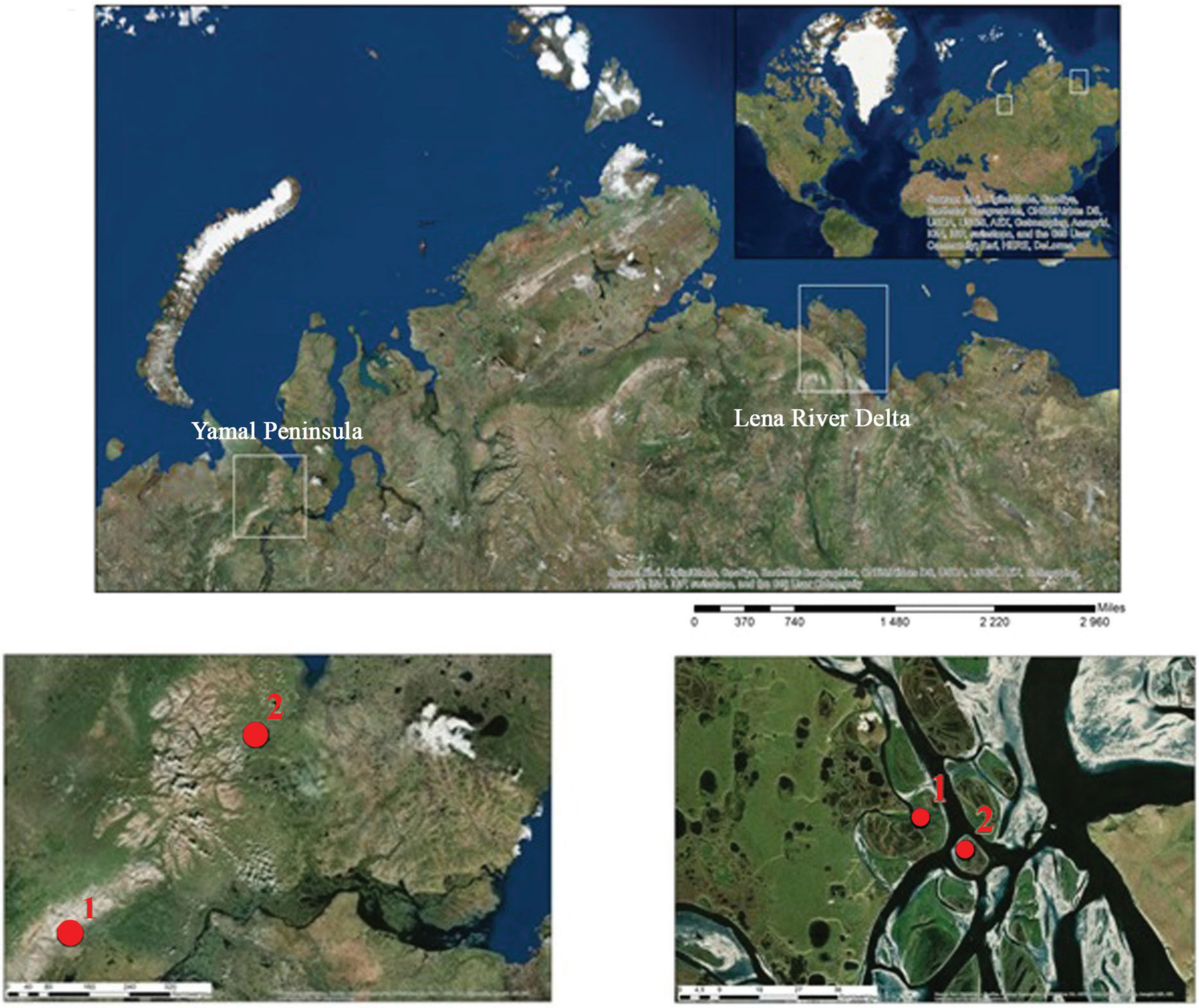
2. Materials and methods

2.1 Study site description

The study sites were located in the Lena River Delta and the Yamal Peninsula (Fig. 1) in the Russian Arctic. The climate parameters are presented in Table 1.

The Lena River Delta is the largest Arctic delta in the world and has an area of about 29630 km². It has a significant impact on the water regime of the Arctic Ocean by virtue of its location and the salty ocean receives a large amount of fresh water from the delta. The Lena River Delta was formed via the coupled action of different river processes: the removal of sediments, erosion, abrasion under the influence of fluctuations in sea level and crustal movements (Galabala, 1987; Bolshiyanov et al., 2013).

Yamal is a peninsula in the north of Western Siberia on the territory of the Yamalo-Nenets Autonomous Okrug of Russia. The peninsula is 700 km long and up to 240 km wide. It is washed by the Kara Sea and the Gulf of Ob river. Altitudes range from



Yamal Peninsula

Lena River Delta

Fig. 1. Location of the study sites. Yamal Peninsula: 1 – Surroundings of Salekhard, 2 – Kerdamon-Shor valley); Lena River Delta: 1 – Arga-Belir-Aryta Island, 2 – Samoylovsky Island. Source: Esri, GeoEye.

1–2 m a.s.l. on the low sides of the seacoast to 85–95 m a.s.l. in the central part of the peninsula (Trofimov et al., 1975; Dobrinsky, 1995; Shiyatov and Mazepa, 1995). The southern part of the peninsula mainly has a parallel-ridge relief, quite rare in the middle and northern latitudes of the Yamal. Excess moisture leads to the formation of numerous lakes and swamps. Description of the study plots are presented in Table 2.

Table 1.
Climate parameters of study areas.

Climate parameters	Lena River Delta	Yamal Peninsula
Mean annual air temperature (°C)	–13.0	–5.8
Mean air temperature (°C)		
of the warmest month (July)	6.5	8.0
of the coldest month (January)	–32	–25
Permafrost table (cm)	79	150
Annual precipitation (mm)	323	380
Relative humidity (%)	75	86
Snow thickness (cm)	23	50
Depth (cm)	Temperature regime of soils (°C)	
0–10	13.0	1.0
10–20	3.0	0.7
20–30	–3.0	0.7
30–40	–7.0	0.6
40–50	n.d.	0.6
50–120	n.d.	–0.2
Water content in field (weight %)		
0–5	10–15	60
5–15	11–19	10
15–25	15–23	28
25–40	n.d.	31
40–55	n.d.	57
55–70	n.d.	120
70–90	n.d.	180
90–110	n.d.	170
110–120	n.d.	200

n.d. – not determined

2.2 Sampling strategy and procedure

The soil samples were collected taking into account the spatial picture of the vegetation cover and the position in the landscape. Samples of soil were selected in various elements of the landforms. Several profiles were made in the areas subject to annual flooding and the places of the already-released conditions.

2.3 Laboratory analyses

Diagnostics of the soils, conducted according WRB has shown that they belong to the following Reference Soil Groups (types): Eutric Fluvisol (Arenic, Ochric), Eutric Fluvisol (Ochric), Turbic Cryosol (Epiloamic, Eutric, Ochric), Haplic Cryosol (Arenic, Fluvic) and Folic Turbic Cryosol (Endoloamic, Eutric, Ochric) (IUSS Working Group WRB, 2015).

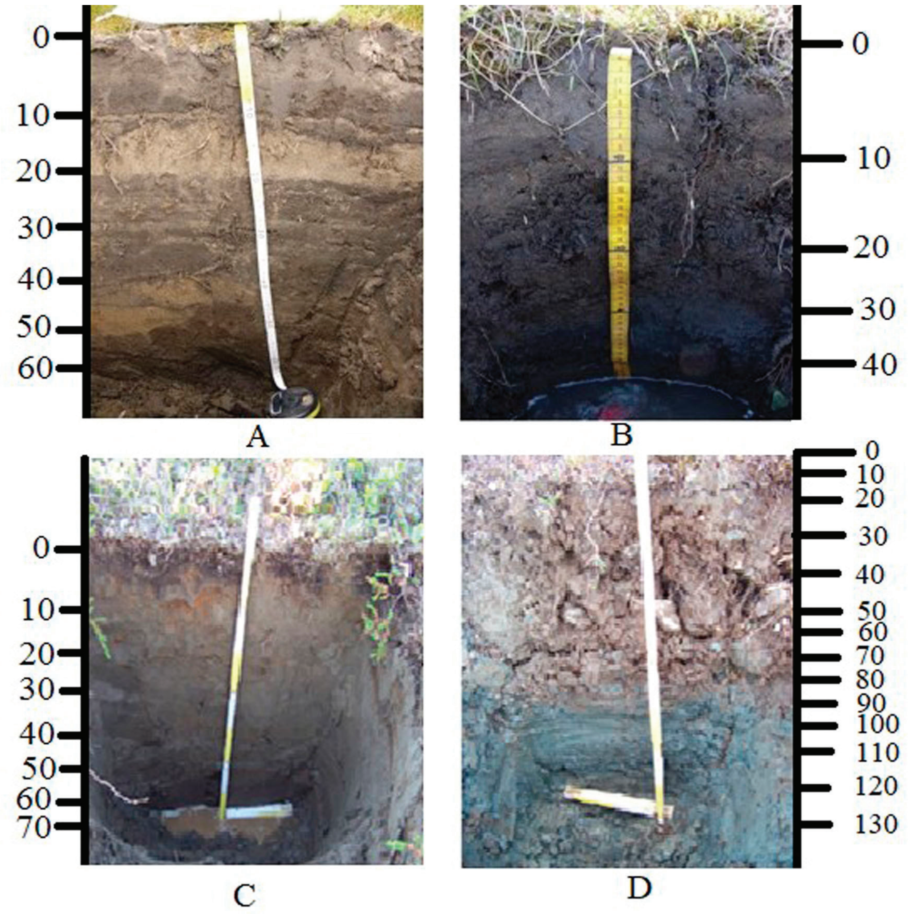
All laboratory analyses were performed with fine earth soil material ($\phi < 2$ mm).

The content of hygroscopic water (HW) was determined as the amount of water contained in the air-dry soil (Rozhkov et al., 2002). Soils were stored for two weeks at room temperature and humidity. To determine the hygroscopic humidity, we weighed the sample before and after drying until constant weight. We used the total water holding capacity (TWC) as creates 98% relative humidity, and air-dry samples were placed in a desiccator for 6 days to dry the samples. The field water capacity (FC) was measured with a cylinder filled with disturbed soil material (Rozhkov et al., 2002). The cylinder was placed in a vacuum dehydrator, and water was added so that it reaches the level of the soil in the cylinder. This is covered with a watch glass and left to stand for one day. During this time, the water fills all the capillary pores in the soil. One day later, the soil material is removed from cylinder, which is then wiped of moisture and weighed. The lowest water capacity (LWC) was determined where the sample is first saturated with water to completely fill all pores. The LWC was the amount of

Table 2.
Description of study plots.

Study plots	Geographical coordinates	Description	Soils
Samoylov Isl.	72°22′39″ N 126°29′15″ E	The islands in the central part of the Lena River Delta. It is located in the first river terrace and is periodically flooded by river waters	Eutric Fluvisol (Arenic, Ochric); Eutric Fluvisol (Ochric)
Arga-Belir-Aryta Isl.	72°23′37″ N 126°24′43″ E	The study plot is situated in western part of Samoylovsky Island. It has a height of 10 meters a.s.l. and is composed of sandy sediments. The island is subjected to flooding processes	Haplic Cryosol (Arenic, Fluvic)
Yamal Peninsula	67°51′26″ N 66°37′05″ E 66°26′28″ N 64°02′50″ E	The Yamal Peninsula has many terraces formed from marine abrasion and accumulation. The terraces has complex structure built of cryogenic-polygonal forms, thermokarst (lakes and depressions), and long-term hydrolacoliths	Turbic Cryosol (Epiloamic, Eutric, Ochric); Folic Turbic Cryosol (Endoloamic, Eutric, Ochric)

Fig. 2. Morphological diversity of soils on Lena River Delta: Samoylov and Arga-Belir-Aryta Islands: A – Eutric Fluvisol (Arenic, Ochric), B – Haplic Cryosol (Arenic, Fluvic); Yamal Peninsula: C – Turbic Cryosol (Epiloamic, Eutric, Ochric), D – Folic Turbic Cryosol (Endoloamic, Eutric, Ochric) (y-axes – depth in centimetres).



water in the soil delayed in a state of equilibrium after maximum hydration followed by removal of water via gravity. All results of water content were presented in % of volume.

The pH was determined in an aqueous extract using a stationary pH meter with soil/water ratio at 1/25. The texture analysis was carried out according to the Kachinsky sedimentation method, which is a Russian analog of analysis by Bowman and Hutka (2002). Carbon content was determined using an elementar analyzer (Euro EA3028-HT Analyser). Statistical analysis of soil properties from both key plots were performed in Statistica 10 software (one-way ANOVA for carbon content, pH, clay content, HW, TWS, FC, LWC).

3. Results and discussion

This work compared the soils from the Lena River Delta and the southern Yamal Peninsula, two regions subjected to permafrost processes. These areas have significant differences in the morphological features of soils. The soils of the Lena River Delta were formed under the influence of alluvial accumulation that result in soil stratification. Soil forming processes are predominantly organic matter accumulation, stagnification (stagnation of water in the soil profile) and cryogenic processes.

3.1 Morphology of soils

The stratification of soil horizons is primarily associated with the flooding of the first terrace of the delta with fresh waters (Fig. 2). In turn, soils of the Yamal Peninsula are developed under the conditions of the zonal type of soil formation.

Soils formed in the Lena River Delta differ greatly from the soils of Yamal region because they form under the conditions of annual periodic flooding. Fluvic materials are deposited in the soils, and reducing conditions with a characteristic color are formed on the border with the permafrost table. With a close occurrence of permafrost in the soil (up to 79 cm), cryogenic processes have a weak pedogenetic alteration, which is due to the active influence of the river and annual flooding. The Cambic horizon is formed in soils under conditions of weak biological activity and transformation of organic material. In the soils of Yamal region, soil formation is associated with the active cryogenic processes resulting in mixed soil material, involutions and organic intrusions, with the observed formation of reducing conditions near the permafrost table. Soil profiles description are presented in Table 3.

Table 3.
Soil profiles description of Lena River Delta and Yamal Peninsula.

Soil horizon*	Depth (cm)	Soil description	Soil color (moist)
Samoylovsky Island, Eutric Fluvisol (Arenic, Ochric)			
O	0–4	partially decomposed litter	10YR 4/3
A	4–14	sandy loam, rooted, well-aerated, fluvic material	7.5YR 7/3
B	14–27	sandy, rooted, fluvic material	7.5YR 6/3
B/C	27–30	sandy, rooted, weak pedogenetic alteration, fluvic material	7.5YR 8/3
C	30–51	sandy, rooted	7.5YR 7/4
O	0–12	partially decomposed litter	10YR 4/3
A	12–29	sandy loam, rooted, well-aerated, fluvic material	7.5YR 8/3
B/C	29–43	stratified sand of different sizes, roots	7.5YR 7/4
Samoylovsky Island, Eutric Fluvisol (Ochric)			
O	0–6	partially decomposed litter	10YR 4/3
A	6–16	sandy, rooted, well-aerated, fluvic material	7.5YR 7/3
B/C	16–30	sandy, rooted, rusty spots, reducing conditions	GLEY 1 6/10GY
Arga-Belir-Aryta Island, Haplic Cryosol (Arenic, Fluvic)			
A	0–12	sandy loam, roots	2.5YR 5/2
B@	12–39	stratified sand of different sizes, roots, reducing conditions, turbic	GLEY 1 6/10GY
Kerdamon-Shor valley, Turbic Cryosol (Epiloamic, Eutric, Ochric)			
O	0–1	partially decomposed litter	10YR 4/3
A	1–11	oxidized, loam, rusty spots around root channels, well-aerated	10YR 4/1
B@1	11–25	loam, rusty spots, cryic	10YR 6/3
B@2	25–35	loam, rusty spots, cryic	10YR 6/2
B@3	45–60	loam, rusty spots, mixed soil material, organic intrusions, cryic	10YR 4/2
B/C	60–70	loam, rusty spots, reducing conditions	GLEY 1 5/10GY
Surroundings of Salekhard, Folic Turbic Cryosol (Endoloamic, Eutric, Ochric)			
O	0–10	partially decomposed litter, folic	10YR 4/3
A	10–21	oxidized, loam, rusty spots around root channels, turbic	10YR 6/3
B@1	53–75	loam, rusty spots, cryic	10YR 6/1
B@2	75–100	loam, rusty spots, cryic	10YR 5/1
B/C	104–125	loam, rusty spots, reducing conditions	GLEY 1 6/5GY

*– according to FAO (2006)

3.2 Permafrost transformation and organic carbon in soils

The main physical and chemical parameters of the soils studied are shown in Table 4. Process of thawing/freezing influenced by following features in the soil cover: polygonal soil, fracturing, humic streaks, cryogenic differentiation of soil particles along the profile, accumulation of water at the contact with permafrost-affected soils and accumulation of chemical elements at the contact with the permafrost-affected soils (Fe_2O_3, Fe^{2+}). There are processes of cryogenic accumulation of iron in the profile. It is associated with the mobilization of active humic acids with aluminum and iron, which are released during the weathering of the primary minerals, after which an accumulative horizon forms on the boundary with permafrost, which includes humus compounds with iron and aluminum. The temperature parameters were recorded during summer seasons of 1998–2011 for the Lena River delta, and for Yamal Peninsula from 2007–2012 (Boike et al., 2013; Kaverin et al., 2016).

Data on the physical and chemical analysis of soils from the Lena River Delta indicate that the soils are acidic (pH 4.5–5.5), slightly acidic (pH 5.5–6.5) or neutral (pH 6.5–7.0). Neutral or slightly acidic values are due to the presence of carbonates. The content of organic carbon is 0.79–2.47%, which indicates that the soils have high biological activity. The activity of the river is associated with the deposition of sand particles. The texture class of investigated soils is loamy sand and silty loam.

The soils from the Kerdamon-Shor valley were strongly acidic (pH 5.1–5.8). Soils from Salekhard were slightly acidic and almost neutral (pH 6.1–6.9). The particle size distribution analysis showed a predominance of silt and clay fraction in both of the studied soils. The lower part of the Folic Turbic Cryosol (Endoloamic, Eutric, Ochric) from the surroundings of Salekhard is characterized by a predominance of sand. The organic carbon content in the soils ranged between 0.10% and 1.1% with an average value 0.80%. Highest values of organic carbon content are not related to topsoil horizons. This confirms the hypothesis on the essential

Table 4.
Selected chemical and physical properties of the studied soils.

Soil horizons*	Depth (cm)	TOC (%)	pH in water	Content of fraction (%)		
				Clay ϕ < 2 µm	Silt ϕ 2–63 µm	Sand ϕ 0.063–2 mm
Samoylovsky Island, Eutric Fluvisol (Arenic, Ochric)						
O	0–4	2.03	5.43	n.d.	n.d.	n.d.
A	4–14	1.98	6.33	6	18	76
B	14–27	1.57	5.98	8	31	61
B/C	27–30	1.01	5.64	4	23	73
C	30–51	0.79	5.83	1	16	83
O	0–12	2.41	5.56	n.d.	n.d.	n.d.
A	12–29	2.34	5.22	0	28	72
B/C	29–43	0.75	5.82	2	18	80
Samoylovsky Island, Eutric Fluvisol (Ochric)						
O	0–6	2.51	5.45	n.d.	n.d.	n.d.
A	6–16	2.47	5.99	7	84	8
B/C	16–30	1.54	5.76	1	11	88
Arga-Belir-Aryta Island, Haplic Cryosol (Arenic, Fluvic)						
A	0–12	2.11	6.71	1	32	67
B@	12–39	1.74	6.51	5	8	88
Kerdamon-Shor valley, Turbic Cryosol (Epiloamic, Eutric, Ochric)						
O	0–1	3.40	5.70	n.d.	n.d.	n.d.
A	1–11	1.10	5.22	42	19	39
B@1	11–25	1.10	5.70	48	22	30
B@2	25–35	0.40	6.46	37	23	40
B@3	45–60	0.30	5.38	54	26	20
B/C	60–70	0.50	5.54	39	36	25
Surroundings of Salekhard, Folic Turbic Cryosol (Endoloamic, Eutric, Ochric)						
O	0–10	2.50	5.47	n.d.	n.d.	n.d.
A	10–21	1.00	6.12	50	30	20
B@1	53–75	0.50	6.48	42	33	25
B@2	75–100	0.80	6.00	23	25	52
B/C	104–125	0.10	6.87	19	22	59

*– according to FAO (2006)

role of cryogenic processes in profile redistribution patterns and heterogeneity of the soil profile (Lupachev and Gubin, 2012).

3.3 Relation between texture and water properties

The results of the soil water content are given in Fig. 3 and 4. Soils from the Lena River Delta have an explicit stratification of the profile. In the profile of Eutric Fluvisol (Arenic, Ochric), we observed an atypical distribution of moisture values, which is due to the fluvial deposition of the material. This distribution of moisture values is typical for flooded areas where fresh soil mass is annually deposited on the soil surface (Li et al., 2014; Polyakov et al., 2018). In the upper organic horizon, the fresh alluvial material is interlayered with the organic material forming stratified soil profiles. In organic horizon the organic carbon content is above 2.5%, with a texture class of silty loam (Preuss et al., 2013).

A decrease in the water content is characteristic of areas no longer affected by seasonal flooding. Textural data point out higher clay content in the upper organic horizons and more organic material that absorbs water more actively than sand particles. Hence, silt accumulation in the upper horizons and active accumulation of organic matter are seen in areas which are not under the influence of annual flooding. According to water-holding capacity data, sands and sandy loams are more aerated than loams and clays, with the space between the particles filled with water. Sands and sandy loam will have a high FC and low LWC. The difference between FC and LWC is 19%. For areas that are no longer affected by the process of flooding, the decrease in the FC

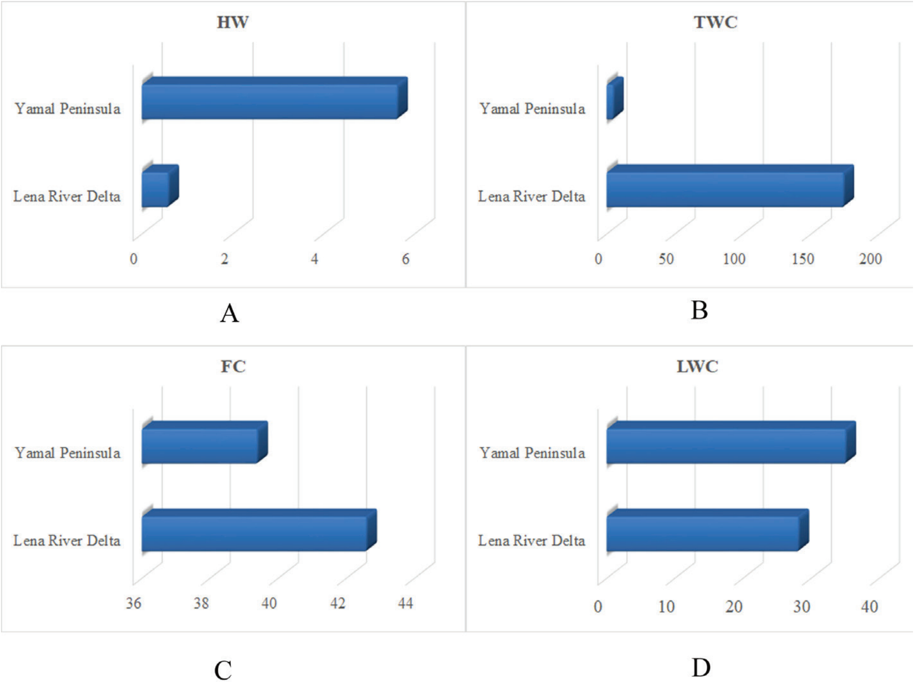


Fig. 3. Basic hydrological characteristics of soil, weight % A – hygroscopic water (HW), B – total water holding capacity (TWC), C – field water capacity (FC), D – lowest water capacity (LWC).

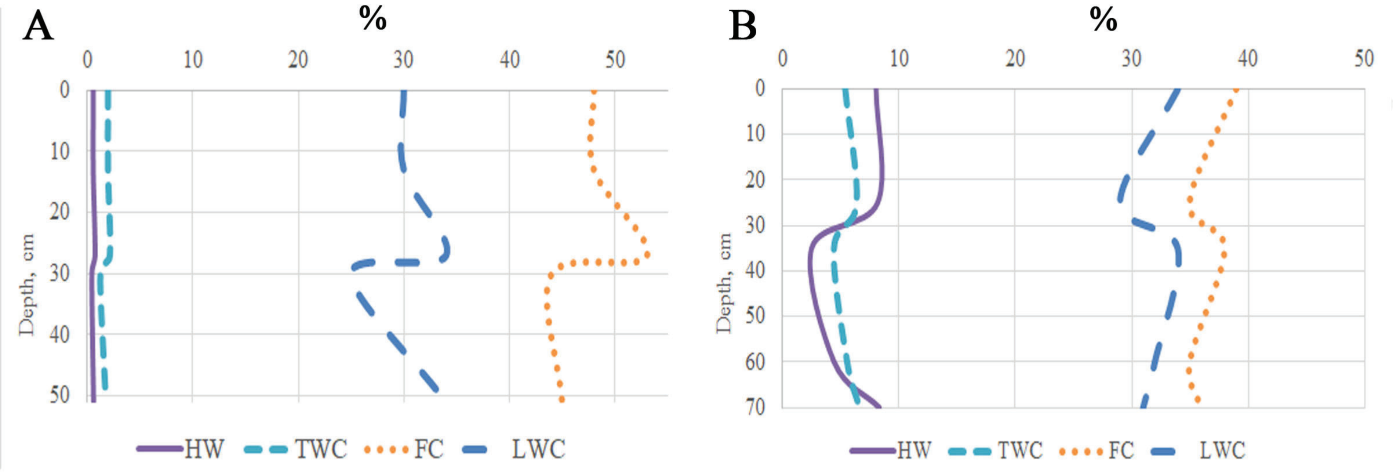


Fig. 4. Distribution of basic hydrological characteristics in soil profiles. A – The Lena River Delta, B – Yamal Peninsula

and LWC in soil profile is also characteristic because the upper horizons contain more organic matter and can hold more water than the organic layers depleted in the topsoil or superficial organic horizons. Here, the LWC is higher in connection with the high content of organic matter.

The LWC is one of the main hydrological parameters of the soil and depends on the texture of the soil. The water-holding capacity decreases with depth. The water-holding capacity of soil depends on its texture and initial moisture. Soils with freezing/thawing phenomena have lower water permeability. This generally determines the vegetation cover in these areas. This has been confirmed in other studies (Luthin and Guymon, 1974; Vlasenko, 2004; Ugarov, 2015).There is no great difference in soils that have passed the regime of seasonal flooding. Soils in drained positions and soils in depressions have practically identical moisture indices. In the soils from drained positions, the HW, TWC, FC, and LWC are higher because of prominent organic horizons with high-water holding capacity are formed here. The underlying horizons are also represented by loamy sand with a low organic carbon content; hence, these are well aerated. In both of the soil profiles from Yamal Peninsula, the values of FC and LWC increase with depth. These are connected with the changes in texture from a predominance of silt and clay fraction in the upper horizons to a sand fraction in the lower horizons. However, the values of these indicators are higher in Turbic Cryosol (Epiloamic, Eutric, Ochric) from Kerdamon-Shor valley due to a higher clay fraction.

The highest water-holding capacity values were from the southern Yamal Peninsula in the middle part of the soil profile. These layers have a predominance of silt and clay with a higher

Table 5.
Statistical analysis of soil properties.

Soil characteristic	Lena River Delta Mean ± SD	Yamal Peninsula Mean ± SD	One-way ANOVA
TOC	1.63 ± 0.62	0.57 ± 0.31	<0.001
pHw	5.98 ± 0.44	5.95 ± 0.53	<0.880
Clay	3.70 ± 2.79	39.6 ± 11.1	<0.001
HW	0.59 ± 0.26	5.63 ± 2.84	<0.001
TWC	1.74 ± 0.69	4.96 ± 2.10	<0.001
FC	42.6 ± 7.68	39.4 ± 5.30	<0.290
LWC	28.2 ± 5.71	35.1 ± 5.13	<0.010

organic matter content. The water holding capacity is increased by the high content of the organic matter in the soils.

The probabilities for one-way ANOVA revealed statistically significant differences for the main chemical and physical soil properties between studied plots (Table 5). The studied plots were united into two groups (Lena River Delta and Yamal Peninsula). The P values for OC, clay content, HW, and TWC were much lower than 0.005. This suggests significant differences between two key plots. There were no significant differences for the rest of soil properties (pH in water, FC, LWC). Soil from the Lena River Delta has the highest standard deviation for field water capacity (7.68%). Soil from southern Yamal Peninsula has highest standard deviation for clay content (11.1%).

Soils with a large content of sand have a water holding capacity that increases due to swelling of the OM. However, heavy soils have soil surface characteristics due to organic matter that appears in the foreground as a strong surface-active substance. Therefore, even relatively small amounts of OM modifying the initial surface of the silty elementary soil particles lead to significant changes in the structural conditional and water holding capacity of mineral horizons (Smagin et al., 2004; Bezkorovaynaya et al., 2005; Machico, 2005). The predicted global warming and possible rapid biodegradation of organic soil material could lead to significant degradation of Arctic soils. The effect of OM on the physical structure of the soil leads to two mechanisms. Firstly, OM is a colloidal and superfine material with has an extremely high water holding capacity; secondly, it acts as a structure-forming agent to promote the adhesion of mineral elementary soil particles to soft aggregates (Gartsman, 2001; Kabala and Zapart, 2012). This also affects the water-holding capacity and physical structure of light soils, especially sandy or sandy loamy soils. The increased content of organic carbon increases the water holding capacity in sandy soils (Rawls et al., 2003; Iwahana et al., 2005; Machico, 2005).

In general, the data show that most water-physical properties of soils depend on the texture and activity of the cryogenic processes. The speed of the water flow has a significant effect on the hydrological regime of soils under the influence of the flooding process. Therefore, faster water flows cause larger particles settle on the flooded areas. This decreases the water-holding capacity of the soil.

4. Conclusions

In this study of water-holding capacity of soils from two Russian Arctic regions, our analysis shows the differences between regions subjected to flooding processes in Lena River Delta and non-flooded area in Yamal Peninsula. The first ones are characterized by fluctuations caused by fluvial deposition of the material while, in contrast, a gradual decreases in the water-holding capacity values with depth was observed in the second region.

The relationship between water-holding capacity and basic soil properties is revealed. Thus, the water-holding capacity is, to a greater extent, related to the texture of the soil and less on the content of organic matter. The average clay content in soils on the Yamal Peninsula is 39% while it is 4% in the Lena River Delta. This results in high values of HW (5.63%), TWC (4.96%), LWC (35.1%) in the Yamal Peninsula. Whereas the FC value, which is related to the amount of water-bearing pores in the soil, is higher in the Lena River Delta.

Acknowledgments

This study was supported by Russian Foundation for basic research, grant 16-34-60010, Russian presidents' grant for Young Doctors of Science № MD-3615.2015.4, the Government of the Yamalo-Nenets Autonomous District and Arctic and Antarctic Research Institute (Saint Petersburg), Grant of Saint-Petersburg State University "Urbanized ecosystems of the Russian Arctic: dynamics, state and sustainable development", and a grant of the Russian Foundation for basic research, grant no. 19-416-890002 "Abandoned soils of agrolandscapes Yamal-Nenets autonomous region: diversity, features, biology and dynamics".

References

Antcibor, I., Eschenbach, A., Zubrzycki, S., Kutzbach, L., Bolshiyanov, D., Pfeiffer E.M., 2014. Trace metal distribution in pristine permafrost-affected soils of the Lena River Delta and its hinterland, northern Siberia, Russia. Biogeosciences 11, 1–15. https://doi.org/10.5194/bg-11-1-2014

Bezkorovaynaya, I.N., Ivanova, G.A., Tarasov, P.A., Bogorodskaya, A.V., 2005. Pyrogenic transformation of soils in pine forests of the middle Taiga of the Krasnoyarsk Region. Siberian Ecological Journal 1, 143–152 (in Russian).

Boike, J. et al., 2013. Baseline characteristics of climate, permafrost and land cover from new permafrost observatory in the Lena River Delta, Siberia (1998–2011). Biogeosciences 10, 2105–2128. https://doi.org/10.5194/bg-10-2105-2013

Bolshiyanov, D.Y., Makarov, A.S., Schneider, V., Shtof, G., 2013. Origin and development of the delta Lena River. St. Petersburg: Arctic and Antarctic Research Institute (in Russian).

Bowman, G.M., Hutka, J., 2002. Particle size analysis. [In:] McKenzie, N., Coughlan, K., Cresswell, H., (Eds), Soil Physical Measurement and Interpretation for Land Evaluation. CSIRO Publishing, Victoria, 224–239.

Darmaeva, N.N., Haidapova, D.D., Badmaev, N.B., Nimaeva, O.D., 2009. Agrochemical and physico-mechanical properties of permafrost soils, determining their potential stability at agricultural use. Agrochemistry 11, 16–21 (in Russian).

Dobrinsky, L.N., 1995. Nature of Yamal. Ekaterinburg: Nauka (in Russian).

Dobrovolsky, G.V., 2005. Soils of the floodplains of the center of the Russian Plain. Moscow: MGU (in Russian).

Dobrovolsky, G.V., Balabko, P.N., Stasyuk, N.V., Bykova, E.P., 2011. Alluvial soils of river floodplains and deltas and their zonal differences. Arid Ecosystems 17(3), 5–13 (in Russian). https://doi.org/10.1134/S207909611103005X

Dobrovolsky, S.G., 2007. The problem of global warming and change in runoff of Russian rivers. Water Resources 34(6), 643–655 (in Russian). https://doi.org/10.1134/S0097807807060012

Dobrovolsky, V.V., 1994. The main features of the geochemistry of the Arctic soil formation. Pochvovedenie 6, 85–93 (in Russian).

Dolgopolova, E.N., Kotlyakov, A.V., 2011. Permafrost in wellheads regions of the Arctic rivers of Russia. Ice and Snow, 1, 81–92 (in Russian).

FAO 2006. Guidelines for Soil Description. 4th edition. FAO, Rome.

Fedorov, K.N., 1993. Genesis, evolution and diagnostic micromorphology of soils Water-accumulative plains of the arid zone. Abstract of the dissertation of PhD. Moscow, MGU (in Russian).

Galabala, R.O., 1987. New data on the structure of the Lena delta. The Quaternary period of Northeast Asia. Magadan: Northeastern Integrated Research Institute of the Far Eastern Branch of the Academy of Sciences of the USSR, 125–171 (in Russian).

Gartsman, B.I., 2001. The phenomenon of flow regulation in the model of the flooding cycle of a small river basin. Geography and Natural Resources, 2, 142–149 (in Russian).

Gentsch, N., Mikutta, R., Alves, R.J.E., Barta, J., Capek, P., 2015. Storage and transformation of organic matter fractions in cryoturbated permafrost soils across the Siberian Arctic. Biogeosciences 14, 4525–4542. https://doi.org/10.5194/bg-12-4525-2015

Hugelius, G., Strauss, J., Zubrzycki, S., Harden, J.W., Schuure, A.G., 2014. Estimated stocks of circumpolar permafrost carbon with quantified uncertainty ranges and identified data gaps. Biogeosciences 23, 6573–6593. https://doi.org/10.5194/bg-11-6573-2014

IUSS Working Group WRB, 2015. World reference base of soil resources. World Soil Resources Report, 106, FAO, Rome.

Iwahana, G., Machimura, T., Kobayashi, Y., Fedorov, A., Konstantinov, P., Fukuda, M., 2005. Influence of forest clear-cutting on the thermal and hydrological regime of the active layer near Yakutsk, eastern Siberia. Journal of Geophysical Research 110, 1–10. https://doi.org/10.1029/2005JG000039

Kabala, C., Zapart, J., 2012. Initial soil development and carbon accumulation on moraines of the rapidly retreating Werenskiold Glacier, SW Spitsbergen, Svalbard archipelago. Geoderma 175, 9–20. https://doi.org/10.1016/j.geoderma.2012.01.025

Kaverin, D.A., Pastukhov, A.V., Lapteva, E.M., Biasi, C., Marushchak, M., Martikainen, P., 2016. Morphology and properties of the soils of permafrost peatlands in the southeast of the Bol'shezemel'skaya Tundra. Eurasian Soil Science 49(5), 498–511. https://doi.org/10.1134/S1064229316050069

Li, X.P., Chang, S.X., Salifu, K.F., 2014. Soil texture and layering effects on water and salt dynamics in the presence of a water table: a review. Environmental Reviews 22, 41–50. https://doi.org/10.1139/er-2013-0035

Lupachev, A.V., Gubin, S.V., 2012. Organogenous derivative accumulative horizons cryosols of the tundra of the North of Yakutia. Eurasian Soil Sciences 1, 45–55. https://doi.org/10.1134/S1064229312010115

Luthin, J.N., Guymon, G.L., 1974. Soil moisture-vegetation-temperature relationships in central Alaska. Journal of Hydrology 23, 233–246. https://doi.org/10.1016/0022-1694(74)90005-5

Machico, A., 2005. Effect of organic carbon on hydrophysical properties of podzolic soil. Vestnik IB 10, 8–11 (in Russian)

Polyakov, V., Orlova, K., Abakumov, E., 2018. Landscape-dynamic aspects of soil formation in the Lena River Delta. Czech Polar Reports 8(2), 260–274. https://doi.org/10.5817/CPR2018-2-22

Preuss, I., Knoblauch, C., Gebert, J., Pfeiffer, E.M., 2013. Improved quantification of microbial CH4 oxidation efficiency in arctic wetland soils using carbon isotope fractionation. Biogeosciences 10, 2539–2552. https://doi.org/10.5194/bg-10-2539-2013

Rawls, W.J., Pachepsky, Y.A., Ritchie, J.C., Sobecki, T.M., Bloodworth H., 2003. Effect of soil organic carbon on soil water retention. Geoderma 16, 61–76. https://doi.org/doi:10.1016/S0016-7061(03)00094-6

Reza, S.K., Nayak, D.C., Chattopadhyay, T., Mukhopadhyay, S., Singh, S.K., Srinivasan, R., 2016. Spatial distribution of soil physical properties of alluvial soils: a geostatistical approach. Archives of Agronomy and Soil Science 62(7), 972–981. https://doi.org/10.1080/03650340.2015.1107678

Rippin, M., Becker, B., 2015. Biological soil crust diversity and variability of the Arctic and Antarctic. European Journal of Phycology 50 (Sup. 1), 172–173. https://doi.org/10.1007/s00300-016-1967-1

Rozhkov, V.A., Bondarev, A.G., Kuznetsova, I.V., Rakhmatulloev, K.R., 2002. Physical and hydrophysical properties of soils. Moscow, MGU (in Russian).

Shiyatov, S.G., Mazepa, V.S., 1995. Climate. [In:] (Dobrynsky, L.N. (Ed.). Nature of Yamal. Ekaterinburg: Nauka, 32–68 (in Russian).

Smagin, A.V., Sadovnikova, T.V., Nazarova, A.B., Kiryushova, A.V., Machico, A.V., Eremina, A.M., 2004. Effect of organic matter on the water-holding capacity of soils. Pochvovedenie 3, 312–321 (in Russian).

Trofimov, V.T., Badu, Y.B., Kudryashov, V.G., Firsov, N.G., 1975. Yamal Peninsula: (Engineering-geological survey). Moscow: MGU (in Russian).

Ugarov, I.S., 2015. The soil hydrological constant of sand, water-permeability of frozen meadow-chernozem soil of the middle currents of rivers Lena and Amga. Successes of Contemporary Natural Sciences 1, 26–28.

Vlasenko, N.G., 2004. Water balance of small Russian catchments in the southern mountainous Taiga Zone: "Mogot" case study. Northern Research Basins Water Balance 290, 65–77.

Winterfeld, M., Laepple, T., Mollenhauer, G., 2015. Characterization of particulate organic matter in the Lena River delta and adjacent nearshore zone, NE Siberia – Part I: Radiocarbon inventories. Biogeosciences 12, 3769–3788. https://doi.org/10.5194/bg-12-3769-2015

Witkowska-Walczak, B., Bartmiński, P., Sławiński, C., 2015. Hydrophysical characteristics of selected soils from arctic and temperate zones. International Agrophysics 29, 525–531. https://doi.org/10.1515/intag-2015-0059

Zubrzycki, S., Kutzbach, L., Grosse, G., Desyatkin, A., Pfeiffer, E.M., 2013. Organic carbon and total nitrogen stocks in soils of the Lena River Delta. Biogeosciences 10, 3507–3524. https://doi.org/10.5194/bg-10-3507-2013

Zubrzycki, S., Kutzbach, L., Pfeiffer, E.M., 2014. Permafrost-affected soils and their carbon pools with a focus on the Russian Arctic. Solid Earth 5, 595–609. https://doi.org/10.5194/se-5-595-2014

Pojemność wodna i właściwości gleb rosyjskiej Arktyki (na przykładzie delty rzeki Leny i Półwyspu Jamalskiego)

Słowa kluczowe

Gleby arktyczne
Delta rzeki Leny
Półwysep Jamalski
Wieloletnia zmarzlina
Pojemność wodna
Tereny zalewowe

Streszczenie

Terasy zalewowe są jednym z najbardziej dynamicznych i najmłodszych obszarów czwartorzędowych strefy arktycznej. Znajdują się w strefach przejściowych (na granicy lądu i oceanu) strefy wiecznej zmarzliny, która jest istotna z puntu widzenia aktualnych procesów geochemicznych (np. wietrzenia) i bilansu wodnego. Stosunki termiczne i wodne gleb polarnych mają kluczowe znaczenie dla rozwoju pokrywy roślinnej, a także akumulacji i redystrybucji materii organicznej. W pracy przedstawiono właściwości hydrologiczne gleb powstających w warunkach przejściowych (granice lądowo-morskie). Badania wykazały różnice w pojemności wodnej między glebami powstałymi w warunkach sezonowego zalewania (wyraźnie przejścia między poziomami, warstwowanie profilu) oraz tymi, które nie podlegają zalewom wodami powodziowymi. Próbki glebowe pobrano w delcie Leny oraz na Półwyspie Jamalskim. Badane gleby cechują się stopniowo zmniejszającą się zdolnością do zatrzymywania wody wraz z głębokością. Stwierdzono, że intensywność i szybkość procesu rozmarzania i zamarzania zależy od charakterystyki reżimu hydrologicznego, który z kolei był silnie związany z głębokością warstwy aktywnej. Różnice między właściwościami analizowanych gleb były istotne. Rozkład pojemności wodnej w profilu różnił się w obrębie punktów badawczych. Globalne zmiany klimatu i duża wrażliwość ekosystemów arktycznych może prowadzić do znaczących zmian na obszarach pokrytych wieczną zmarzliną i mogą w bardzo widoczny sposób zmienić ich reżimy hydrologiczne, prowadząc do degradacji wiecznej zmarzliny i zmianę wertykalnego i horyzontalnego przepływu wody w basenach dużych rzek arktycznych.