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Permafrost-affected former agricultural soils of the Salekhard city (Central part of Yamal region)

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Abstract

Soil cover transformation in Russian Arctic is considered as underinvestigated. In 1920s it was started systematical studying and exploitation of natural resources of Far North of Russia. Due to development of industry and growth in area population necessity in agricultural products was growing intensively and arable soils became typical component of the soil cover in polar cities surroundings. Nowadays, however, almost all the former cultivation fields are abandoned or in poor use. Abandoned agricultural soil in sub urban territories of the Salekhard city were studied with aim to evaluate alteration of soil morphology and chemistry under agricultural impact and clarify the specificity of this process in case of permafrost-affected soils. The predominance of sandy textured parent materials within Salekhard city area was one of the main reason of favorable agricultural using of land in the north of Western Siberia in previous years. Data obtained revealed that studied soils are characterized by properties caused both by former (or existing) anthropogenic influence and natural processes (*e.g.* cryogenic mass transfer). Soil organic carbon content depends mainly on the character of current land use and varies significantly in studied soils. Most of the soil samples showed the highest levels of soil nutrients in the topsoil. Former arable horizon is stable in time in terms of morphological features and agrochemical state. In spite of high level of soil acidity, content of nutrients in antropogenically affected topsoils is still high after 20 years of abandoned state of soils. This indicates that agrosoils with relatively high fertility of arable topsoils could exist during long time in case of sandy-textured parent materials.

Key words: urban environments, Arctic, nutrients, permafrost

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Introduction

According to the program "Social-economic development of the Arctic zone of Russian Federation for the period until 2020" it would be organized seven clusters of development of the Arctic zone, one of the zone is located within the area of Yamal region. One of the main aims of development of Russian economics is connected with studying natural resources of the Arctic region. Arctic zone is considered as most urbanized in Russian Federation, more than 85% of Arctic zone population is concentrated in cities and urbanized settlements. Nevertheless, support of local population by agricultural production, namely by vegetable is not developed in Arctic zone. In Soviet times numerous programs on localization and adaptation of vegetable cultivation were elaborated for Yamal and Yakutsk region. That is why there are still former agricultural lands exist in surroundings of some polar cities and these soil can be evaluated in terms of their key properties, which can be used in frames of new programs of Arctic development. Hence, increasing rates of anthropogenic forcing on both natural and urban ecosystems lead to necessity of knowing reasons, mechanisms and consequences of forcing factors. That is why the topics connected with investigation of urban soils and their dynamics in changing environment seem to be of current interest. Soils of the Russian Arctic are considered as underestimated in terms of anthropogenic alteration of the properties, especially in context of agricultural impact on their properties.

Both anthropogenic forcing and climate change may affect biogeochemical processes within the permafrost-affected landscapes which are highly sensitive climate and anthropogenic forcing. The issue of environmental restoration and environmental management has been already very sharply risen in Yamal, Taz and southeast Gydan peninsulas (Khitun et Rebristaya 1997, Rebristaya et Khitun 1997). Yamal region is a key area of land-cover change due to intensive resource development, active geomorphic change, climate change and growth of local reindeer herds (Forbes 1999, Dobrinsky 1997, Moskalenko 2005, Walker et al. 2009).

In general, direct human impacts on ecosystems of the Arctic can be even more important than climatic change in the next few decades (Chapin et al. 1997, Callaghan et al. 1998). Soil cover of Arctic region is characterized as highly influenced by permafrost. Processes of cryogenic mass transfer and supra-permafrost accumulation of matter reflect in specific profile distribution of soil characteristics (*e.g.* chemical pollutants) (Vodyanitsky 2009). The main geochemical feature of industrial, transport and municipal influence on urban environment is formation of technogenic geochemical anomalies within various components of urban landscape (Kabata-Pendias et Pendias 1989). Also urban areas can be considered as areas with increased risk in context of trace elements and will continue to be so for a long time, according to predictions (Linde 2015).

Urban ecosystems are characterized by disjunctive character of soil cover. In this regard, the questions of identification of separate soil bodies within the urban ecosystems, their spatial limitation and vertical stratification with the aim of adequate ecological assessment are sharply risen. Within the urban areas soils are highly transformed or absent at all. Often soil-like bodies without having any analogues in natural environments are developed (Dymov et al. 2013).

Systematical studying and exploitation of natural resources of Far North of Russia has began in 1920s. Due to development of industry and growth in area population necessity in fresh meat and dairy products, potato and vegetables has risen sharply. For this area transportation of these types of products from southern parts of Soviet

Union was complicated due to long travel distances. That is why for the settlements of Russian Far North (*e.g.* Salekhard) the aim of creation of domestic vegetable-fodder base has risen.

Nowadays, modernization of agriculture sector of Russian Far North became more and more required, especially in terms of localization of agriculture with aim to decrease dependence of remote regions of Russia on the agricultural oligopolies. Adaptive-landscape agrotechnologies should applied for local conditions with taking into account climatic and lithological peculiarities of remote regions of the Arctic zone (Ivanov et Lazhentsev 2015). Arctic region has perspectives in development of organic production. Advantages of northern agriculture are already used in Scandinavian countries and Finland. It has been shown earlier that the main risks and threats of agriculture in the Arctic are connected with climatic conditions and low stability of soil cover in conditions of cryotubations. The peculiarity of the agricultural practice in tundra landscapes is that these landscapes usually situated on the areas with dominance of sandy textured (Salekhard, Yakutsk) or coarse gravel (Murmansk) parent materials, while surrounding soils presented mainly by clayely textured types. Normally, cleyely textured soils of tundra with pronounced features of solifluction and cryoturbation are less favorable for arable agriculture than sandy textured ones.

The conception of food provision of Arctic region population should be based on increasing rates of domestic, horticulture and strongly localized production of agricultural goods, development of facilities for their processing, storage and realization (Ivanov et Lazhentsev 2015). In this context, local landscape peculiarities and exiting facilities for development of agriculture should investigated.

Systematical investigations and explorations of natural sources of energy in the area of Yamal peninsula started in 1920s. In regard of developing industry and population the issue of higher consumption of meat, milk products and vegetables has been sharply risen. For this region the transportation of these perishable products from the southern regions of country was complicated due to big distance from them. That is why the idea of development of domestic fodder base for the settlements of Yamal region has been revealed.

Agricultural soils of permafrost-affected regions, their properties and agricultural practices have been investigated previously (Hossain et al. 2007, Matsumura 2014, Michelsen et al. 2014, Stevenson et al. 2014a, Stevenson et al. 2014b). It has been also discussed existing agricultural practices (Sjögren et Arntzen 2013, Spiegelaar et Tsuji 2013). Only few data are known about soil diversity in agricultural landscapes of Russia.

Nitrogen, phosphorus and potassium are traditionally in the list of the main plant supply elements from the soils. Their contents in soil horizons determine not only soil fertility, but also the rates of stability and self-restoration of ecosystems (Nikitina 2015). Content of these elements as well as content of such technogenic pollutants as heavy metals and pesticides serve as a good indicator for estimation of the level of anthropogenic influence on urban ecosystems (Bullock et Gregory 1991).

The aim of this work is to estimate the current state, morphological pecularities and properties of former agricultural soils within Salekhard city in conditions of underlain by permafrost. The objectives of our study are:

- to describe morphological peculiarities of agricultural soils of abandoned former arable lands in surrounding of Salekhard city,
- to evaluate the main physical and chemical properties of agricultural soils underlained by permafrost;
- to distinguish the main morphological and taxonomical features of soil profiles formerly affected by agriculture.

Material and Methods

This study was conducted in different locations of the Salekhard city (Yamal autonoumous region, Russia) (Table 1, Fig. 1). Site-1 (Sal1) is located on the experiment field of former zonal station. Site-2 (Sal2) is attributed to the field for potato cultivation (the right bank of Shaitanka river). Site-3 (Sal3) is located in the area of “Angalsky mys” in the area of existing cowshed.

The climate of Salekhard is characterized by severity and continentality. Relative humidity is high (70-90%) throughout the year. It is caused by low air temperatures and proximity to the cold waters of the Kara Sea. Annual precipitation is about 350 – 400 mm in the southern part. The annual evaporation rate is about 250 mm (Shiyatov et Mazepa 1995). The number of days with snow cover is 233 per year. Winter lasts 7 – 7.5 months, the average temperature of January is -23 – -25°C. Spring is usually short (35 days) and cold, with a sharp change in weather, with frequent returns of cold and frost. The vegetation season is 70 days. Average temperature of the warmest month is + 5°C. The average annual temperature is -5.8°C. Autumn is short, with a maximal volatility of the pressure gradient, an abrupt change in temperature and frequent early frosts. The site is in a zone of excessive moisture (Shiyatov et Mazepa 1995).

Fig. 1. Location of Salekhard on the map of Yamal region and sample sites. 1 – Sal1; 2 – Sal2; 3 – Sal3.

The soil cover of natural environments in surroundings of Salekhard is characterized by predominance of Histic Gleysols and Aquiturbic Cryosols in hydromorphic positions of the landscape and Podzols in autonomous positions (Alekseev et al. 2017 . These soils are characterized by low fertility level (low amount of nitrogen, phosphorus and potassium). They have low cation exchange capacity, base saturation and acid intervals of pH, high exchangeable and hydrolytic acidity.

Site	Geographical coordinates	Functional zone	Soil type (WRB/Russian soil classification system)
Salekhard			
Sal1	N 66° 31' 02.3"; E 66° 39' 22.3"	Recreational functional zone	Spodic Anthrosol/ Al-Fe humic Agrozem
Sal2	N 66° 32' 56.8"; E 66° 36' 43.4"	Recreational functional zone	Spodic Anthrosol/ Al-Fe humic Agrozem
Sal3	N 66° 33' 31.9"; E 66° 34' 07.2"	Recreational functional zone	Spodic Anthrosol/ Al-Fe humic Podzol

Table 1. The principle data on key plots of investigation.

Soil diagnostics has been performed both by Russian soil classification system (Shishov et al. 2004) and WRB ([4] - FAO 2014). However, issues of soil profile morphology and classification have been discussed more detailed in scope of Russian soil classification system (RSCs).

Objects of investigation are presented in Fig. 2. These are agricultural soils from 3 key plots in recreational functional zone of Salekhard.

Russian soil classification system divides soils affected by agricultural influence into 2 orders (both are reffered to the trunk of Postlithogenic soils). The first order is agrozems. It unites soils with topsoil consists with agrohorizon (humus agrohorizon, grey humus agrohorizon, peaty agrohorizon or peaty-mineral agrohorizon). In the soil profile such a topsoil should be changed by the natural diagnostic horizon (B) or parent material (C) very sharply. The authors of classification system also notice that soils from mentioned above order can be developed in any conditions and any natural zone. The types of agrozems are determined by features of agrohorizon and its combination with underlain natural horizons.

The second order is Agroabrazems. Soils from this order are deprived with the topsoils and in some cases diagnostic (B) horizons of natural soil due to erosion, deflacion, mechanical cutting *etc*. The specific feature of agroabrazems is presence of specific agroabraded horizon formed due to transformation of diagnostic (B) horizon or parent material (C). The types of agroabrazems are determined by features of horizons underlain the arable horizons. In studied soil profiles we have not found any feature of agroabrazems and agroabraded horizon.

Is should be noticed that the character of parent material described in studied soil profiles and prevailed within the Salekhard city area (sandy material) was one of the main reason of favorable agricultural using of land in the north of Western Siberia.

At the same time, in WRB system it is determined only one Reference Soil Group reffered to the soil affected by agricultural activities – Anthrosols. This Reference Soil Group is characterized by the soils which have been formed or heavily modified by long-term human activity (addition of organic materials or household wastes, irrigation or cultivation *etc*.). Anthrosols often can occur in association with a variety of Reference Soil Groups. It should be noticed that these linkages have been mainly studied for non-permafrost landscapes. So, for the zones with predominance of wetland soils such as Fluvisols, Gleysols, Histosols and Podzols and presence of agricultural activity it is usually observed Terric Anthrosols.

Fig. 2. Studied soil profiles. Sal1- Sandy Agrozem with overcompaction properties underlained by permafrost (Spodic Anthrosol); Sal2- Sandy Agrozem underlained by permafrost (Spodic Anthrosol); Sal3- Sandy Podzol underlained by permafrost (Spodic Anthrosol).

The evaluation of carbon, nitrogen, hydrogen contents has been done using CHN analyzer Leco CHN-628. For the extraction of ammonium nitrogen it has been used KCl ([1] - EPA method 350.1., 1993). Mobile phosphorus and potassium content was determined using their extraction by 0.5 mol/L HCl (Kuo 1996). The evaluation of the main agrochemical characteristics has been performed by the standard procedures named in GOST 54650-2011 [2] (for evaluation of mobile phosphorus and potassium contents) and GOST 26489-85 [3] (for evaluation of exchangeable ammonium content).

To perform vertical electrical resistivity sounding it is commonly used Schlumberger geometry. The Schlumberger array consists of four collinear electrodes. The inner two electrodes (MN) are the potential electrodes whereas the outer two (AB) electrodes are current electrodes. The potential electrodes are installed at the center of the electrode array with a small separation. The current electrodes are increased to a greater separation during the survey while the potential electrodes remain in the same position until the observed voltage becomes too small to measure (Keller 1966, Sharma 1997). The advantages of this method are that small amount of electrodes need to be moved in order to perform each sounding and the cable length for the potential electrodes is shorter. In comparison with Wenner array, Schlumberger soundings generally have better resolution, greater probing depth, and less time-consuming field deployment.

Permafrost significantly complicates profile distribution of electrical resistivity values, because unfrozen soil characterizes by Ra values about 10-799 Ohm m and frozen layers characterizes by Ra values of thousands Ohm m.

Results and Discussion

Soil development in tundra zone is essentially effected by the processes of cryogenic mass exchange. That is why only the “islands” sands of coarse textured parent materials of various origin were used for foundation of setllements by the earlies colonists in Russian north. In case of the Salekhard city and suburban settlements sands of Holocene alluvial and Aeolian origin were colonized initially, after what surroundings, represented by clayely textured soil were used for location of facilities of growing settlements. Arable fields are located on soils of Podzol or Entic Podzol types in case of Salekhard city. These soil are located on the quarternal sediments of alluvial origin of Ob bay. Soil of Podzol type are not zonal for forest-tundra in the region of investigation, but in case of sandy textured parent materials they penetrate even few hundred kilometers northen, on Yamal and Gydan peninsulas. These soil were used for localized agriculture and horticulture. As result of arable effect soil profiles demonstrate developen arable horizon with dark-gray or dark-brown structure and developen crum and angular soil structure.

Data on the main soil chemical determined for fine earth (Table 2) indicates that soils are characterized by following features. Soils were characterized principally by strongly acidic conditions (pH 4.1 – 4.9) in almost all the soil samples, pH values are gradually increasing to the depth. Prevalence of active acidity is considered as typical for soil with features of podzolisation. There were now any application of carbonates or lime materials for improvement of soil chemical state, that is why abandoned agricultural soils demonstrate low pH values. Particle size distribution analysis showed predominance of sand fraction in soils of all the key plots (Table 2).

Soil ID	Depth, cm	pH_{H20}	pH_{KCl}	Exchangeable acidity, cmol(+) kg^{-1}	Hydrolytic acidity, cmol(+) kg^{-1}	Basal respiration, gCO2/100g day	Particle size distribution, %		
							Clay	Silt	Sand
Sal1	0-4	4.33	3.58	0.90	2.70	120.92	-	-	-
	7-15	4.50	3.07	2.40	2.40	11.00	25	25	50
	32-42	4.03	3.08	2.80	3.00	10.23	17	32	51
	65-80	6.55	3.43	0.35	0.6	5.13	12	20	68
Sal2	0-10	4.88	3.37	1.70	2.00	41.18	-	-	-
	10-20	4.81	3.49	0.95	2.20	234.76	28	20	52
	30-50	4.21	3.37	1.25	1.25	201.11	23	25	52
	50-80	4.36	3.58	0.10	0.90	190.66	8	19	73
Sal3	0-8	4.95	3.78	0.01	0.03	1084.76	-	-	-
	8-11	4.57	2.72	3.40	5.50	567.87	15	25	60
	20-25	4.77	3.21	3.60	3.60	124.46	14	25	61
	30-40	4.12	3.10	2.40	5.00	49.50	7	20	73
	40-50	4.32	3.10	2.80	2.80	71.50	10	20	70

Table 2. The main soil characteristics of studied soils.

However, the content of sand was increasing to the depth as well. This could be related with relative accumulation of fine fractions in topsoils due to humus accumulation and amendment of soils by organic fertilizers in the past time. The data on the main agrochemical characteristics of studied soils are represented in Table 2.

The carbon content in studied soil samples showed relatively high variability (values ranged between 0.08 and 19.46 mg kg^{-1}). It is connected with different rates of former anthropogenic fertilization of studied soils and time past from the last year of land use (now it is practically abandoned territories). Herewith, it should be noticed very low values of carbon for the soil studied on the abandoned field for potato cultivation. Data on basal respiration rates revealed that its values are significantly ranged in topsoil horizons. The highest value is characterized for Spodic Anthrosol from the area of existing cowshed (Sal3) and connected with higher rates of biological activity due to permanent enrichment of topsoil by waste products of cows. It coincides with the data on carbon which is the highest in this soil as well. In all cases carbon presented by organic forms because of absence of the carbonated in both fine earth and coarse fraction.

The mean level of ammonium nitrogen these elements content is low (< 20 mg kg^{-1}) according to gradation reported for technogeneous-anthropogenic landscapes (Glebova et al. 2000). One of the reasons for that could be connected with removing of nitrogen from the soils by vegetation, since in case of urban landscape chemical elements recovery is not taking place due to elimination of litter.

Soil ID	Depth, cm	C, mg kg^{-1}	N, mg kg^{-1}	C/N	Available P, mg kg^{-1}	Available K, mg kg^{-1}	Ammonium N, mg kg^{-1}
Sal1	0-4	6.70	0.61	10.98	783.00	406.00	33.73
	7-15	8.03	0.76	10.57	749.00	63.00	27.50
	32-42	0.62	0.14	4.43	20.00	55.00	4.77
	65-80	0.08	0.08	n.d.	55.00	20.00	1.51
Sal2	0-10	4.49	0.43	10.44	401.00	84.00	12.85
	10-20	6.34	0.59	10.75	416.00	51.00	10.27
	30-50	0.24	0.09	n.d.	86.00	34.00	2.75
	50-80	0.12	0.06	n.d.	70.00	22.00	2.58
Sal3	0-8	19.46	1.94	10.03	739.00	995.00	57.69
	8-11	7.29	0.51	14.29	150.00	269.00	56.46
	20-25	2.26	0.27	8.37	17.00	0.00	11.90
	30-40	0.60	0.13	4.62	23.00	128.00	3.87
	40-50	0.54	0.15	3.60	39.00	95.00	2.24

Table 3. The main agrochemical characteristics of studied soils.

The content of available potassium for the most of soil samples should be stated is (for the most of soil samples. Topsoil horizons from Sal1 and Sal3 key plot have very high levels of mobile potassium content >300 mg kg^{-1}). In case of Sal1 it is connected with the character of previous using of the soil for cultivation of potato and amendment of fertilizers. For Sal3 key plot it seems to be connected more with existing of urban garbage layer near to the key plot and less probably with water supply from Shaitanka river.

It has been found very high levels of available phosphorus content for all the topsoil horizons (>500 mg kg^{-1}). However, for the lowest horizons it has been found low levels of this element content (<200 mg kg^{-1}). So, agrochemical state of the topsoil is stable even after 20 years staying in abandoned state.

It has been previously found that in urban landscapes accumulation of phosphorus and potassium and increasing of their content are observed in the end of vegetation period (Nikitina 2015). Possible technogenic accumulation of the nutrients in urban agricultural soil could be considered as a reason of stable agrochemical state of soil investigated.

Relative accumulation of mobile K in Sal3 one of the lower horizons could be explained by its adsorption on amorphic aluminium and ferrum hydroxides (which are accumulating in Al-Fe humic soil horizons, where sand fraction is predominant).

The active layer depths have been distinguished using vertical electrical resistivity sounding (Fig. 3). Studied soil profiles are characterized by relatively common distribution of electrical resistivity (Ra) values.

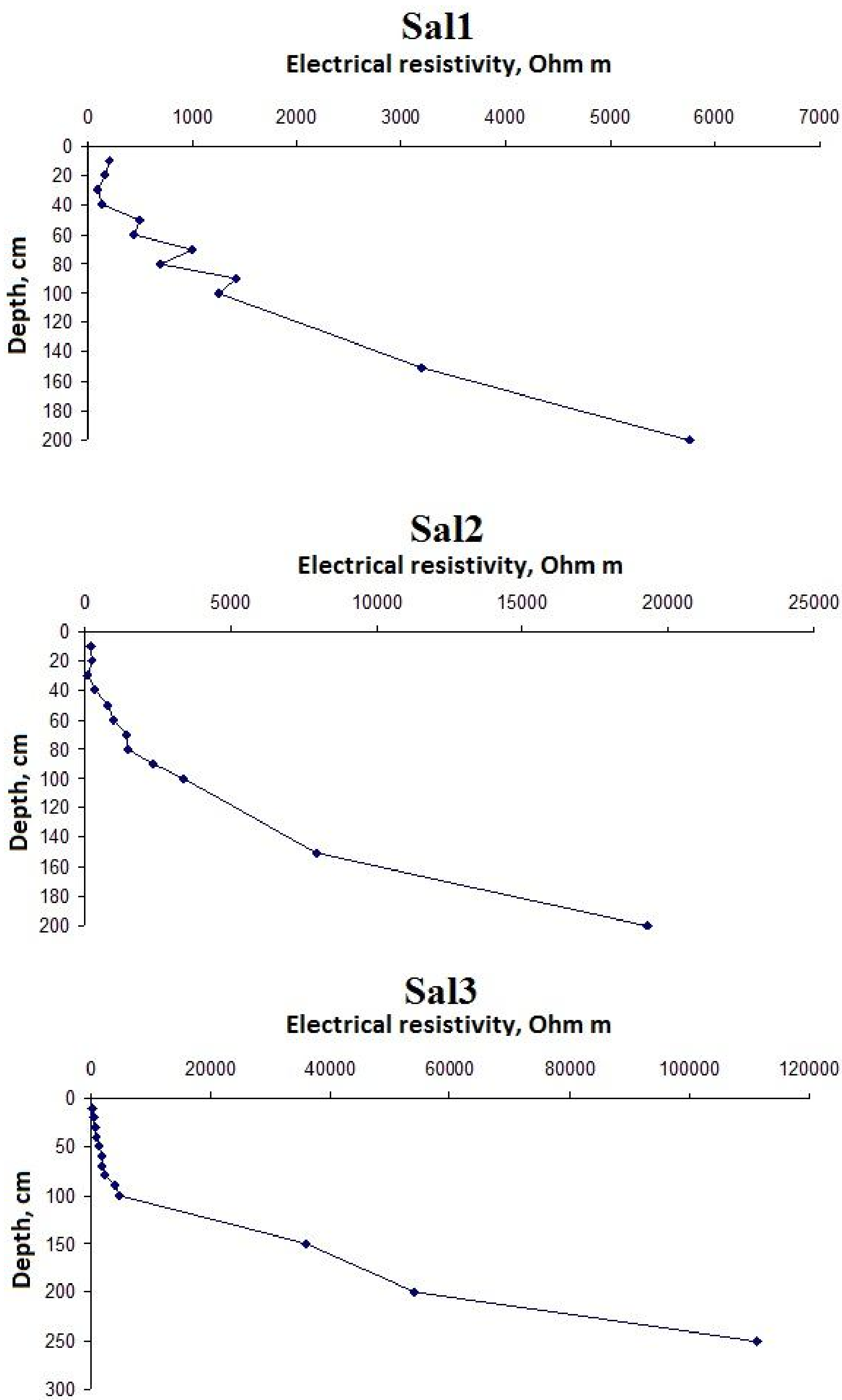

Fig. 3. Profile distribution of electrical resistivity values in studied soil profiles.

Vertical profile of electrical resistivity value in urban soils is more complicated and has a number of fluctuations due to higher rates of ground mixing, mechanical pressure and high amount of artefacts. The main trend of their change within the soil profiles is connected with gradual increasing of Ra values with the depth, which is caused by lower temperatures lower amount of gravitational water and higher amount of sand fraction in lower parts. The trend observed coincides with one theoretically described earlier (Pozdnyakov et al. 2006). The active layer depth was identified as equal to 60-95 cm in soils investigated. Higher values of active layer depths and higher rates of permafrost thawing compared to natural site soil profile at this site are caused by predominance of sand fraction (Table 1).

Data obtained coincide also with soil profile morphology data on active layer – permafrost border depth. The main trend of increasing Ra values within the permafrost strata observed in both soil profiles can be explained by morphology of permafrost. To the depth it is usually becoming more homogenous, number/size of cracks are reduced. This explains lower amount of water, iron oxides, dissolved organic matter accumulated in lower parts of permafrost layer compared to the gleyic-permafrost geochemical border (Abakumov et Parnikoza 2015). Thus, results obtained revealed the principal possibility of long-term existence of agricultural soils in forest tundra zone of Western Siberia in case of presence of parent materials with predominance of sandy fractions, which overlap frozen loams.

Conclusions

The predominance of sandy textured parent materials within Salekhard city area was one of the main reason of favorable agricultural using of land in the north of Western Siberia in previous years. Moreover, it should be noticed that clayey parent material is predominant within the Yamal region. Hence, these “islands” of sandy soils are unique objects for land use. At the same time, taxonomy and morphology of soils affected by agricultural activities should be stated unclear and discussion is opened. Morphological properties of abandoned agricultural soil are stable in time. This could be related with fact that cryoturbations are less pronounced in sandy textured soil than in zonal clayely textured soils of tundra.

Data obtained revealed that studied soils are characterized by properties caused both by former (or existing) anthropogenic influence and natural processes (*e.g.* cryogenic mass transfer). Soil organic carbon content depends mainly on the character of current land use and varies significantly in studied soils.

The content of such soil nutritents as nitrogen and potassium in soils could serve not only for estimation of soil fertility, but also reflects current changes in urban ecosystems caused by anthropogenic influence. Most of the soil samples showed the highest levels of soil nutrients in the topsoil. However, in some cases relatively high contents have been found also in lower horizons with high amount of Al and Fe hydroxides.

Studied soil profiles revealed significant differences in profile distribution of electrical resistivity values and active layer depths. Predominance of sand fraction determines higher rates of thawing process compared to the natural sites where sand fraction content is lower. These differences caused by predominant texture class of the soil should be used for geoengineering purposes, while the data on active layer depths in permafrost-affected landscapes and its dynamics should be significantly broadened. Cryopedogenesis leads to cryogenic mass transfer, homogenization of soil mass and to complication of profile distribution of electrical resistivity values, but these processes are overlapped by anthropogenically caused extra-mixing of soil mass leading to appearance of more fluctuations in profile distribution of electrical resistivity values.

Despite of the fact of current abandonment of former agricultural soils of Yamal region, they save high fertility levels. The data reported in this work could be used for the assessment of anthropogenic influence on urban ecosystems and should be used for the further ecological monitoring on key plots.

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