Research Article

Evgeny Abakumov, Evgeniya Morgun, Alexandr Pechkin, Vyacheslav Polyakov*

Abandoned agricultural soils from the central part of the Yamal region of Russia: morphology, diversity, and chemical properties

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Abstract: The post-anthropogenic and soil cover transformations of former agricultural soils on the abandoned lands in the Russian Arctic territory are poorly investigated due to the active growth of the city complexes and increasing area occupied by agricultural lands. That is lead to an increase in the area of the arable lands surrounding the polar urbanized territories. Today, most of that land allocated for agricultural needs has been abandoned or affected by other types of land use. This study aimed to investigate the abandoned lands surrounding some of the settlements in the central part of the Yamal region. The soil diversity, morphology, and chemical and agrochemical properties were investigated with special reference to the specific transformations that occur to fallow lands under permafrost-affected cryogenic-ecosystem conditions. Analysis of data show that these soils are characterized by features relating to both, previous (and existing), anthropogenic impacts and natural processes such as cryogenic mass transfer. The degradation of the arable humus-enriched horizon was not as pronounced as it has been in more humid boreal environments over recent decades. The organic carbon content in topsoil depends on the land use and varied considerably among the soil types. The former arable topsoil horizon has been stable over time in terms of its morphological features and agrochemical state. Despite the high soil acidity levels, the

nutrient content in the anthropogenically impacted soils was still high, even though being abandoned for 20 years.

Keywords: Soils; Urban environments; Arctic; Nutrients; Permafrost; Podzol

1 Introduction

Research on the dynamics of agriculture land is important for improving the efficiency of agricultural infrastructure management and for achieving food safety and high economic growth. It is also important for identifying a model for transitioning to sustainable development and greening the agricultural sector in Russia. Such analysis has become a priority, both within the regional context and at the level of the country as a whole (Nekrich and Lury 2016; Nikolaeva and Desyatkin 2015). According to the program “Social-economic development of the Arctic zone of the Russian Federation for the period until 2020”, seven development clusters in the Arctic zone are to be organized, with one of the zones located in the Yamal region. One of the main aims of developing Russian economics is connected with studying the natural resources of the Arctic region. The Arctic zone is considered the most urbanized in the Russian Federation, with more than 85% of its population concentrated in cities and urbanized settlements. Nevertheless, support for the local population by agricultural production, especially vegetables, is undeveloped in the region. In Soviet times, numerous programs on the localization and adaptation of vegetable cultivation were elaborated for the Yamal and Yakutsk region. That is why former agricultural lands still exist in the surroundings of some polar cities. These soils can be evaluated in terms of their key properties, which can then be used to frame new programs for Arctic development. Hence, the increasing rates of anthropogenic forces on both natural and urban ecosystems has led to the need to

*Corresponding author: Vyacheslav Polyakov, Department of Applied Ecology, Saint Petersburg State University, Universitetskaya nab., 7-9, Saint Petersburg, 199034, Russia, E-mail: slavon6985@gmail.com

Evgeny Abakumov, Department of Applied Ecology, Saint Petersburg State University, Universitetskaya nab., 7-9, Saint Petersburg, 199034, Russia

Evgeniya Morgun, Alexandr Pechkin, Arctic Research Centre of YANAo, Republic street 20, Salekhard, 629007, Russia

understand the reasons, mechanisms, and consequences of the forcing factors. That is why topics connected with the investigation of urban soils and their dynamics in the changing environment are of such current interest. The anthropogenic alteration of the soil properties of the Russian Arctic are considered to be underestimated, especially with regard to the agricultural impact on their properties. Both anthropogenic forcing and climate change can affect the biogeochemical processes within permafrost-affected landscapes, which are highly sensitive to climate and anthropogenic pressure. The issues of environmental restoration and environmental management have already risen sharply in Yamal, Taz, and the south-eastern Gydan peninsulas (Khitun and Rebristaya 1997; Rebristaya and Khitun 1997). The Yamal region is a key area where the land cover has changed due to intensive resource development and climate change (Forbes, 1999; Dobrinsky 1997; Moskalenko 2005; Walker et al. 2009). Adaptive-landscape agrotechnology should be applied for the local conditions with consideration of the climatic and lithological peculiarities of the remote regions of the Arctic zone (Ivanov and Lazhentsev 2015). The Arctic region has prospects for the development of organic production, and the advantages of northern farming are already in use in the Scandinavian countries and Finland. It has been previously shown that the main risks and threats to agriculture in the Arctic are associated with climatic conditions and the low stability of soils subject to cryoturbation. The peculiarity of agricultural practices in tundra landscapes is that they are usually located in areas with a predominance of sandy textured (Salekhard, Yakutsk) or coarse-grained (Murmansk) source rocks, while the surrounding soils are mainly clay-textured types.

The concept of food provision for the Arctic's regional population should be based on increasing domestic horticultural rates and on the strongly localized production of agricultural goods. The effort should also include the development of facilities for their processing, storage, and realization (Ivanov and Lazhentsev 2015; Dymov and Mikhailov 2017; Archegova and Paniukov 2006). Given these circumstances, the local landscape peculiarities and existing facilities for agricultural development need to be investigated. Although the agricultural soils of permafrost-affected regions, their properties, and agricultural practices have been previously investigated (Hossain et al., 2007; Matsumura, 2014; Michelsen et al., 2014; Stevenson et al., 2014a; Stevenson et al., 2014b), and existing agricultural practices have been discussed (Sjögren and Arntzen 2013; Spiegelhaar and Tsuji 2013), there is little data on the soil diversity in the agricultural landscapes of

Russia (Alekseev and Abakumov 2018; Okoneshnikova et al. 2009).

The area of permafrost distribution on Earth reaches 35 million km², accounting for up to 25% of the world's total land area (Jones et al., 2010). In Russia, the permafrost occupies more than 10.7 million km². More than 60% of the Russian land surface is underlain by continuous and sporadic permafrost (Kotlyakov and Khromova 2002). For climatic reasons, changes in the active layer dynamics (namely, increased thickness) affect the transformation of soil organic matter (Zubrisky et al. 2014; Duarte-Guardia et al. 2019), changing the soil cover spatial pattern (Desyatkin 2011) and soil evolution (Ivanov et al. 2015). One of the most likely and important outcomes of sustained warming in high-latitude ecosystems will be the thawing of permafrost soils and their release of organic carbon into the atmosphere as CO₂ or methane through microbial respiration or by leaching out as dissolved organic carbon (Dutta et al. 2006; Kaverin et al. 2014). Soils affected by permafrost are typical in Canada, Greenland, Scandinavia, Russia, China, and Mongolia. The diversity of permafrost-affected soils is based on the cryopedogenesis process, with the intensity of pedogenesis controlled by the depth of the active layer, the texture and structure of the parent materials and bedrock, and the climatic characteristics of the soil location (Zubrzycki et al. 2014).

Arable lands in Russia as a whole were preserved during this period by plowing up non-fertile lands in the suburbs of the agricultural territories (e.g., in Western Siberia) (Dobrinsky 1997; Moskalenko 2005). Due to the large areas of arable land degradation and the involvement of poor land, the total soil fertility of the arable land declined despite significant government efforts to maintain and increase it (e.g., chalking, gypsum, irrigation, drainage, and mineral and organic fertilizers). In the twentieth century, Russia, after USSR collapsed, managed to maintain high arable land levels in the country because of the relatively satisfactory state of the material and technical base, as well as due to significant direct and indirect production investments from large national economic companies for the development of virgin lands. Thus, under the crisis conditions of more recent decades, the lack of material and technical resources has provoked a decrease in arable land, primarily due to the withdrawal of unproductive soils. At the same time, however, many good-quality lands were also removed from the arable land base, and their ecological potential has remained unclaimed for economic reasons.

Therefore, the aim of this work was to estimate the current state, morphological peculiarities, and properties of former agricultural soils within the city of Salekhard

and its surroundings where the soils are underlain by permafrost. The objectives of the study were as follows:

- distinguish the main morphological and taxonomical features of soil profiles formerly affected by agriculture
- evaluate the main physical, chemical, and agrochemical properties of agricultural soils underlain by permafrost
- describe the morphological peculiarities of the agricultural soils of abandoned former arable lands in the Salekhard region and its surroundings.

2 Materials and methods

This study was conducted in different locations of the city of Salekhard and the surrounding areas (Yamal autonomous region, Russia; Figure 1). Site 1 (Sal1) was located in the experimental field of a former zonal station. Site 2 (Sal2) is attributed to have been a potato cultivation field on the right bank of the Shaitanka river. Site 3 (Sal3) was located in the “Angalsky mys” area near an existing cowshed. Site 4 (Sal4) was at an abandoned site that has not been cultivated for about two years. Site 5 (M1) was located in Muzhi village and consisted of abandoned vegetable gardens near the House of Children’s Creativity. Site 6 (Y1) was located in the Yamgort settlement and comprised abandoned vegetable gardens near an abandoned house, where the soil had not been cultivated for 5 years. Site 7 (H1) was located in the Harsaim settlement on a slope of the river Ob; it is an abandoned garden on the grounds of an abandoned house. Site 8 (H2) was located in the Harsaim settlement and was also an abandoned garden on the grounds of an abandoned house (Table 1).

The climate of Salekhard is characterized by its severity and continentality, with high (70% to 90%) relative humidity throughout the year caused by low air temperatures and its proximity to the cold waters of the Kara Sea. In the southern region, the annual precipitation is about 350–400 mm, with an annual evaporation rate of around 250 mm. Snow cover averages 233 days per year, with winter lasting 7–7.5 months. The average temperature in January is -23°C to -25°C . Spring is usually short (35 days) and cold, with a sharp change in the weather and frequent returns of cold and frost. The vegetation season is only 70 days, and the average temperature of the warmest month is $+5^{\circ}\text{C}$. The average annual temperature is -5.8°C . Autumn is short, with maximal pressure gradient volatility, an abrupt change in temperature, and frequent early

Table 1: Description of the study plots in Salekhard and the surrounding areas

Site	Geographical coordinates	Soil type (WRB / Russian soil classification systems)
Salekhard		
Sal1	66°31′02.3″ N 66°39′22.3″ E	Plaggic Podzol / Al-Fe humic Agrozem
Sal2	66°32′56.8″ N 66°36′43.4″ E	Plaggic Podzol / Al-Fe humic Agrozem
Sal3	66°33′31.9″ N 66°34′07.2″ E	Plaggic Podzol / Al-Fe humic Podzol
Sal4	66°31′41.4″ N 66°38′14.6″ E	Plaggic Podzol / Al-Fe humic Podzol
Muzhi settlement		
M1	65°24′16.1″ N 64°42′20.4″ E	Plaggic Podzol / Al-Fe humic Podzol
Yamgort settlement		
Y1	64°56′31.79″ N E 64°21′39.25″ E	Plaggic Podzol / Al-Fe humic Podzol
Harsaim settlement		
H1	66°36′4.84″ N 67°17′53.60″ E	Plaggic Podzol / Al-Fe humic Podzol
H2	66°36′21.01″ N 67°19′47.17″ E	Plaggic Podzol / Al-Fe humic Podzol

WRB, World Reference Base for Soil Resources; Sal, Salekhard; M, Muzhi; Y, Yamgort; H, Harseim.

frosts. The sites are in a zone of excessive moisture (Shiyatov and Mazepa 1995).

The soil cover of the natural environment surrounding Salekhard is characterized by a predominance of histic gleysols and histic cryosols in the hydromorphic positions of the landscape and podzols in the autonomous positions (Alekseev *et al.* 2017). These soils are characterized by low fertility (low amounts of nitrogen, phosphorus, and potassium). They also have a low cation exchange capacity, base saturation and acidic pH intervals, and highly exchangeable and hydrolytic acidity.

Soil diagnostics were performed using both the Russian soil classification system (RSCs; Shishov *et al.* 2004) and World Reference Base for Soil Resources (FAO 2015). However, the issues of soil profile morphology and classification are discussed under the more detailed scope of the RSCs. The landscape diversity is shown in Figure 2.

Figure 1: Study plots in the Yamal autonomous region (West Russia)

Figure 1: Study plots in the Yamal autonomous region (West Russia)

Russian soil taxonomy divides soils affected by agricultural influence into two orders (both in the trunk of post-lithogenic soils). The first soil order is Agrozems, which unites soils having topsoils consisting of an agro-horizon (humus, grey humus, peaty, or peaty-mineral). In the soil profile, the topsoil should very sharply change

at a natural diagnostic horizon (B) or parent material (C). The authors of this classification system also note that soils from the Agrozems order can develop under any conditions and in any natural zone. The types of agrozems are determined by the features of the agrohorizon and its

Table 2: Morphological characteristics of the soils.

Soil ID	Depth, cm	Description of soil horizons
H1	0-27	Humid, live roots, loose, fine-grained structure, clayey inclusions, 5YR 2,5/1
	27-41	Sandy, live roots, humid, 7,5YR 8/4
	41-42	Sandy, humid, unstructured, 7,5YR 2,5/1
	42-44	Sandy, humid, dark humus spots, humid, 7,5YR 6/6
	44-54	Compacted, with ferrous spots, sandy loam, humid, 7,5YR 5/6
	54-76	Compacted, humid, sandy loam, 7,5YR 6/8
	76-120	Less compacted, humid, sand, 7,5YR 7/6
H2	0-2	Live roots, fine-grained structure, clayey inclusions, 5YR 2,5/1
	2-22	Moderately decomposed organic material, roots, sandy loam, 7,5YR 4/2
	22-30	Stagnic conditions, sandy loam, roots, 7,5YR 5/6
	30-34	Stagnic conditions, sandy loam, water table, roots, 7,5YR 7/6
Sal1	0-4	Live roots, fine-grained structure, 5YR 2,5/1
	7-15	Accumulation of organic matter, roots, 7,5YR 4/2
	32-42	Accumulation of iron, stagnic conditions, 7,5YR 5/6
	65-80	Stagnic conditions, loamy, 7,5YR 7/6
Sal2	0-10	Live roots, fine-grained structure, 5YR 2,5/1
	10-20	Accumulation of organic matter, roots, sandy loam, 7,5YR 4/2
	30-50	Accumulation of iron, stagnic conditions, roots, 7,5YR 5/6
	50-80	Stagnic conditions, loamy, 7,5YR 7/6
Sal3	0-8	Live roots, fine-grained structure, 5YR 2,5/1
	8-11	Accumulation of organic matter, roots, sandy loam, 7,5YR 4/2
	20-25	Slightly decomposed organic material, roots, 7,5YR 5/6
	30-40	Accumulation of iron, stagnic conditions, roots, 7,5YR 5/6
	40-50	Stagnic conditions, loamy, 7,5YR 7/6
Sal4	0-2	Humid, loose, 7,5YR 5/3
	2-12	Humid, loose, moderately decomposed plant residues, 7,5YR 4/2
	12-35	Sand, lumpy, humid, loose, 7,5YR 6/3
	35-40	Compact, humid, unstructured, 7,5YR 3/1
M1	0-1	Dry, rotted remains of vegetation, detritus, 7,5YR 5/3
	1-6	Humid, unstructured, live roots, 7,5YR 5/2
	6-12	Loam, humid, compacted, detritus, 7,5YR 3/2
	12-23	Iron spots, humid, loam, coal inclusions, 7,5YR 6/1
	23-30	Iron spots, prismatic, compacted, loamy, 7,5YR 7/1
	30-70	Humid, loamy, GLEY1 6/5GY
Y1	0-20	Loam, humid, compacted, mixed from different horizons, 7,5YR 5/3
	20-24	Compacted, more humid than the overlying horizon, sandy loam, inclusions of manganese and live roots, coal, 7,5YR 2,5/1
	24-37	Live roots, humid, loam, 7,5YR 5/6
	37-70	Live roots, compacted, structureless, humid, 7,5YR 7/4

*Sal, Salekhard; M, Muzhi; Y, Yamgort; H, Harseim.

Figure 3: Soil diversity in Salekhard and the surrounding area. 1, Sal1; 2, Sal2; 3, Sal3; 4, M1; 5, Y1; 6, H1; 7, H2; 8, Sal4. Sal, Salekhard; M, Muzhi; Y, Yamgort; H, Harsaim

combinations with the underlying natural horizons (Table 2). The soil diversity at the study sites is shown in Figure 3.

2.1 Physico-chemical properties

The carbon, nitrogen, and hydrogen contents were evaluated using a CHN analyzer (Leco CHN-628; Leco Corporation, St. Joseph, MI). The microbiological activity of soils, the basal respiration, using incubation chambers and substrate-induced basal respiration was determined (Assessment methods for soil carbon, 2011).

2.2 Agrochemical properties

Potassium chloride was used for the extraction of ammonium nitrogen following EPA method 350.1 (1993). The mobile phosphorus and potassium contents were deter-

mined by extracting with 0.5 mol/L HCl (Kuo, 1996). Evaluating the main agrochemical characteristics was performed using the standard procedures in GOST 54650-2011 (1985), which is based on extracting mobile phosphorus (P_2O_5) and potassium (K_2O) compounds from the soil with a hydrochloric acid solution and quantitatively determining the phosphorus and potassium content, and in GOST 26489-85 (2011), which first extracts exchangeable ammonium (NH_4^+) from the soil with a potassium chloride solution and then photometrically measures the colored solution.

2.3 Statistical method

For statistical analysis of agrochemical properties in fallow lands in surroundings of Salekhard, PAST (PALEontological STatistics) software was used. Mann-Kendall trend test which is a non-parametric test was used for trend. The procedure followed Gilbert (1987).

3 Results

3.1 Features of soil formation in Salekhard and its surroundings

Soil development in the tundra zone is primarily affected by the processes of cryogenic mass exchange. That is why

only the sand “islands” of coarsely textured parent materials of various origin were used by the earliest colonists who found settlements in northern Russia. In the case of Salekhard and its suburban settlements, Holocene sands with alluvial and aeolian origins were colonized initially, while the surrounding clayey-textured soil regions were where facilities for the growing settlements were located. Arable fields are located on Podzol soils, or in the case of

Table 3: The carbon and nitrogen content of the Salekhard soils. Mean±SD. n=3

Soil ID	Depth (cm)	Basal respiration, mg/g/hour	C (mg·kg ⁻¹)	N (mg·kg ⁻¹)	C/N
H1	0-27	0.08±0.008	19.19±0.95	1.61±0.08	11.91
	27-41	0.07±0.007	14.66±0.73	1.22±0.06	12.01
H2	0-2	0.06±0.006	74.13±3.7	2.83±0.14	26.19
	2-22	0.06±0.006	41.24±2.06	1.67±0.08	24.69
Sal1	0-4	0.06±0.006	6.70±0.33	0.61±0.03	10.98
	7-15	0.005±0.001	8.03±0.4	0.76±0.04	10.57
	32-42	0.005±0.001	0.62±0.03	0.14±0.007	4.43
	65-80	0.002±0.001	0.08±0.004	0.08±0.004	1.00
Sal2	0-10	0.05±0.005	4.49±0.22	0.43±0.02	10.44
	10-20	0.09±0.009	6.34±0.32	0.59±0.03	10.75
	30-50	0.01±0.001	0.24±0.01	0.09±0.004	2.67
	50-80	0.09±0.009	0.12±0.006	0.06±0.003	2.00
Sal3	0-8	0.09±0.009	19.46±0.97	1.94±0.07	10.03
	8-11	0.09±0.009	7.29±0.36	0.51±0.02	14.29
	20-25	0.06±0.006	2.26±0.11	0.27±0.01	8.37
	30-40	0.03±0.003	0.60±0.03	0.13±0.006	4.62
	40-50	0.03±0.003	0.54±0.03	0.15±0.007	3.60
Sal4	0-2	0.02±0.002	2.56±0.13	0.11±0.005	23.27
	2-12	0.03±0.003	3.91±0.19	0.15±0.006	26.06
M1	0-1	0.08±0.008	31.10±1.55	1.15±0.06	27.04
	1-6	0.06±0.006	3.62±0.18	0.18±0.009	20.11
Y1	0-20	0.06±0.006	3.84±0.19	0.17±0.008	22.58
	20-24	0.05±0.005	0.88±0.04	0.06±0.001	1.46

Salekhard, on Entic Podzol types. These soils are located in the quaternary sediments of alluvial origin from Ob Bay. The Podzol type in the region of investigation is not zonal for forest-tundra, but rather from sandy textured parent materials that penetrate a few hundred kilometers north on the Yamal and Gydan peninsulas. These soils were used for localized agriculture and horticulture. As a result of the arable effects, the soil profiles show that a dark-gray or dark-brown arable horizon developed along with an angular soil structure.

3.2 Agrochemical properties of the study soils

The main soil chemical properties determined indicate the soils are characterized by the following features. First, almost all the soil samples were characterized by strongly acidic conditions (pH 3.5–5.9), with the pH values gradually increasing with depth. Prevalent active acidity is typical for soils with the features of the podzolization process. Abandoned agricultural soils also show low pH values because carbonates or lime materials are no longer being applied to improve the soil chemical state. Second, the texture class analysis showed the sand fraction predominated in the soils of all the key plots. The sand content also increased with depth. This could be related to the relative accumulation of fine fractions in the topsoils due to humus accumulation in the soils from past organic fertilizers as well as from weathering of the fine earth in the topsoil horizons. The main chemical characteristics of the Salekhard soils are shown in Table 3.

The carbon content in the soil samples showed relatively high variability (0.08–19.46 mg·kg⁻¹). This was due to the different rates of former anthropogenic fertilization of the soil and the time since the land was last used (practically abandoned territories today). Of note are the extremely low carbon values for the soil from the abandoned potato cultivation field (Sal2). The basal respiration (biological activity) rate data significantly ranged in the topsoil horizons. The highest value was from the area of an existing cowshed (Sal3). This soil had higher rates of biological activity due to the permanent enrichment of the topsoil by waste products from the cows. These results agree with those for the carbon content, which was also highest in this soil. In all cases, the carbon was present in organic forms, as there is an absence of the carbonated form in both the fine earth and coarse fractions.

The mean ammonium nitrogen content as well as that for the elements was low (<20 mg·kg⁻¹) and followed a grade, as previously reported for technogenic/anthropo-

genic landscapes. One reason for this may be connected to vegetation removing nitrogen from the soil.

According to the nutrient dynamics data, the nitrogen availability dynamics were pronounced over time (Figure 4.1). With the exception of ammonium, the mineral N compound forms were represented by nitrates and nitrites. Most of the soil nitrogen, however, was represented by organic compounds.

As an element, phosphorus is much more uniform than nitrogen, although the soil compounds it forms are numerous both in soils in general and in one particular soil (Figure 4.3). Phosphorus enters soil and other biosphere components with plant and animal residues or fertilizers. A significant portion is introduced by soil-forming rock, and some is also introduced with precipitation. The phosphorus in fertilizers is mainly in the form of various calcium phosphates, with superphosphate, double superphosphate, and precipitate widely used in addition to phosphate rock. These phosphorus compounds undergo various transformations in the soil. The mineralization of organic phosphorus compounds, changes in phosphorus compound mobility, phosphorus immobilization, and phosphate fixation are of great importance for soil genesis and fertility. Studies on changes to the phosphate regime in the upper soil layers have shown that an annual application of mineral fertilizers to the soil surface increases the mobile phosphorus content after the first year of use. However, the soil mobility of phosphorus is low, migrating only 1.3–2.5 cm deep in pastures.

Potassium as a nutrient for plants largely depends on the amount of clay particles present and their mineralogical composition (Figure 4.2). The soils in Salekhard and its surroundings are composed of sandy sediments with a low sorption capacity. Based on the exchangeable potassium dynamics in the soils, we can note from studies in the area in the 1960s involving annual soil fertilization that the potassium content was at similar levels as today and was low. Increases in the potassium content at present may be associated with greening of the upper soil layer, since dense root systems contribute to nutrient preservation.

The changes in the pH of the study soils in the past and its decrease now are associated with active leaching processes (Figure 4.4). Changes to pH directly affect the availability of nutrients in soil.

Based on our data, we believe a favorable agrochemical situation exists in Salekhard and its surroundings. With the right reclamation efforts and appropriate mineral and organic fertilizer application rates, such soils can be returned to the agricultural complex and provide significant foodstuffs for the local population.

Figure 4: Dynamics of the agrochemical properties of the soils in Salekhard and surrounding areas. 1, available N; 2, K_2O ; 3, P_2O_5 ; 4, pH value; x axes – fallow soil in surroundings of Salekhard; y-axes – value of agrochemical properties in $mg \cdot kg^{-1} \pm SD$

Table 4: Mann-Kendall trend test for agrochemical properties of study soils

Parametrs	K_2O	P_2O_5	N	pH
S^*	145	102	-87	-66
Z^*	3.599	2.582	2.135	1.617
p (no trend):	0.001	0.001	0.032	0.105
	There is a statistically significant increasing trend	There is a statistically significant increasing trend	There is a statistically significant decreasing trend	There is no statistically significant trend

*S statistic is calculated by summing over all pairs of values; Z statistic which is used to calculate p from the cumulative normal distribution as usual

3.3 Statistical analysis

In results of Mann-Kendall trend (Table 4) test we can see that value of K_2O and P_2O_5 have statistically significant

increasing trend in time from 1962 to 2018. For nitrogen we have statistically significant decreasing trend and for pH is no statistically significant trend.

4 Discussion

The situation in Russia of overgrown abandoned lands and the withdrawal of a huge array of agricultural land from circulation due to economic collapse (1990 to early 2000s) has no analogue in the world. However, even before this, throughout the past century in some regions, agricultural land has been abandoned, mainly in the forest and forest-steppe zones. Thus, huge areas of fallow postagrogenic lands have formed in Russia, where the succession/restoration of natural ecosystems with their vegetation and soil cover have occurred. As a result, significant transformations of the carbon balance, carbon stocks in the soils, and vegetation have occurred over a wide area (Ivanov and Lazhentsev 2015; Kotlyakov and Khromova 2002).

Comparing our data with other sources (Kabata-Pendias and Pendias 1989; Rebristaya and Khitun 1997), we found that nutrient elements (N, P, K) can persistently remain in soil for a long time, and when agricultural activities are resumed, abandoned soils can return to their previous forms. Thus, developing the soils of the agrarian complex in the Yamal region should be successful. In terms of their morphological and chemical properties, they are the most suitable lands for growing agricultural products, as they are classified as having a sandy texture, which prevents the gleying and waterlogging processes that are widespread in the Arctic zone. Unfortunately, the high proportion of bogs and the harsh climatic conditions in the Arctic impede the development of agrarian complexes (Alekseev et al. 2017; Davis 2001; Dobrinsky 1997; Dymov and Mikhailov 2017).

The acidity of soil determines the availability of phosphate compounds to plants. Their solubility and availability to plants decreases both in strongly acidic (<4.5) and in neutral soils ($\text{pH} > 6.5$). However, when the soil is moderately acidified, the solubilities of calcium and magnesium phosphate increase, whereas when the soil is alkalized, their solubilities and availability decrease. In contrast, pH is not a major factor for K_2O , and potassium content remains almost unchanged as pH changes. However, the pH can indirectly affect the potassium content in soil. In Salekhard, the zonal podzolization processes, increased acidity, and the removal of clay and silt particles all affect the soil potassium content. The nitrogen content in soil is directly related to the potassium content. Nitrogenous compounds, which have ionic sizes similar to those of potassium, directly compete with it in soil processes. The interrelation of these cations can be observed both when they are fixed in the soil and when they are mobile (Yaki-

menko 2009; Nikitishen 1984; Mineev 1984; Adhami et al. 2012).

The transformation of nitrogen compounds in soils occurs as a result of a number of processes, among which nitrogen mobilization, ammonification, nitrification, and denitrification are of paramount importance. Organic residues are subject to humification and ammonification. Ionic NH_4 participates in processes of different significances and direction. It is absorbed by plants, involved in humification, partially washed out, or fixed, as well as subject to nitrification. The nitrate ion is partially washed away, actively absorbed by plants, and partially subject to denitrification, thereby closing the nitrogen biogeochemical cycle. In terms of time dynamics, available nitrogen is quickly washed out of soil. Thus, regular nitrogen fertilization is necessary to maintain soil nitrogen levels (Kabata-Pendias and Pendias 1989; Yakimenko 2009).

Our data showed that the soils are characterized by properties caused by both the former anthropogenic impacts (e.g., increased organic matter and fertilizer content in the superficial soil layers and specific structure formation) and by natural processes (e.g., cryogenic mass transfer and podsolization). The organic carbon content in soil depends mainly on the nature of current land use and varied considerably in the study soils. However, there were no intensive organic matter losses within the post-anthropogenic successions, as was previously seen for the more humid and warm regions with a boreal climate (Daugelena and Butkuta 2008).

The introduction of fallow lands into a number of existing ones should be resolved at the political and economic level. It should be part of the overall strategy and strategies of rational use and management of land and soil resources. When developing fallow lands, an important task is the conservation and rational use of that potential of soil fertility (Orlova 2015). At the same time, it requires further study of a number of other methodological issues, such as the timing and technique of soil sampling, rational levels of indicators of soil properties, taking into account the requirements of cultivated crops and types of crop rotation at the regional level in relation to specific soil and climatic conditions. In the boreal zone, active rehabilitation of fallow lands (Bryansk, Omsk regions) is currently underway. The Arctic zone is a more vulnerable natural environment due to the impact of cryogenic processes, therefore, when using these lands, additional problems occur (high water level, cryogenic mass exchange, low microbiological activities, gley processes) that lead to low growth rates of arable land in urban areas of the north of Russia (Alekseev and Abakumov 2018; Desyatkin et al. 2011; Dymov and Mikhailov 2017).

Agriculture always forms the foundation of the economy for any country, and ensuring the food security of their population is an essential part of the economic policy of governments. Given the total area of the abandoned lands in Russia, the ratio of agricultural land areas has decreased. Forests, fallow land, hayfields, and pastures have deteriorated, which has further increased the soil degradation. At the moment, the soils of Salekhard and its surroundings are also under the threat of degradation associated with leaching processes. Thus, these abandoned agricultural lands are an important issue in ensuring the country's food security (Alekseev and Abakumov 2018; Archegova and Paniukov 2006).

5 Conclusions

Based on the analysis of agrochemical properties and features of soil formation in Salekhard city and its surroundings it can be concluded that:

- The predominance of sandy textured parent materials in the surroundings of the urbanized territories in the central Yamal region was the key reason why these locations and substrata were chosen for the organization of agricultural farms and related practices. Due to the prevalence of clayey textured parent material across the main territories of the Yamal region, agricultural practices were based on using the arable lands and are strongly localized on quaternary sands. These “islands” of sandy soils surrounded by extensive clay missives are unique sites for land use and for future agricultural development. However, the taxonomy and morphology of soils affected by agricultural activity is under-investigated, and further discussion about the peculiarities of their classification is still open. The morphological properties of abandoned agricultural soils appear stable over time. This may be because cryoturbation is less pronounced in sandy-textured soils than in the zonal clay-textured soils of the tundra.
- The key nutrient content in the fine earth fraction (i.e., nitrogen and potassium in the soils) can serve not only to assess soil fertility, but also reflects current changes resulting from anthropogenic impacts on the urban ecosystems. Most soil samples showed high nutrient levels. However, in some cases, a relatively high nutrient content was also found in the lower horizons, with a large amount of Al and Fe hydroxides.
- Due to the post-agrogenic transformation of the agropodzols, the upper horizons of the profile are acidified, which has led to increased eluvial removal (leaching) of materials, yet it still shows a clear arable horizon two decades after the last agricultural use of the soil. In the future, the intensity of the eluvial processes will increase, which after 60 years can lead to a complete degradation of the arable horizon. A superimposed type of postagrogenic evolution then begins, with the formation of a complex soil profile that combines the characteristics of the natural original soil, agropodzol, and a secondary podzol, which develops on top of the agropodzol.

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