Anthropogenic changes in podzolic soils of different biogeocenoses

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Abstract. The features of the formation of the arable layer at the initial stages of agricultural development of podzolic soils are considered. On the example of sites of different ages, it is shown that the specificity of this phenomenon is determined by the stress state of the soil at this stage of development. This is manifested in the features of the morphological organization of the upper soil layer and changes in agrochemical indicators – the content of humus, nutrients phosphorus and potassium, and the value of acidity. In the process of cultivation, these parameters are improved in comparison with the soils of the forest biogeocenosis. But even ten years in specific production conditions is not enough to create a full-fledged arable horizon. It is shown that the soils of a fallow garden plot in the post-agrogenic period successfully resist the influence of zonal factors of soil formation and maintain agrochemical indicators of cultivation at a high level. To implement the tasks of soil cultivation, the introduction of a sufficient amount of organo-mineral fertilizers, soil liming, and the introduction of grass-field crop rotation and optimization of processing techniques are of priority. If necessary, drainage reclamation should be carried out.

1. Introduction
One of the most powerful anthropogenic interventions in the development of the soil component of various biogeocenoses is human agricultural activity. The most significant changes in the upper treated layer, compared to the initial state, occur at the initial stages of development of podzolic soils. First of all, this concerns the morphological structure of the upper soil layer [1], when the natural sequence of soil horizons is replaced by the emerging arable layer. At the same time, there are concomitant changes in most agrophysical [1] and agrochemical [2] indicators of soils. The different quality of the material composing the treated layer leads to an increase in its morphological heterogeneity at this stage and, as a result, to an increase in the variability of the soil properties of the emerging agroecosystem [3]. In the future, the stress load on the soil component is replaced by a gradual transformation of the material of the arable horizon in the process of systematic cultivation of soils. At the same time, it should be remembered that the ongoing processes of transformation of soil material are characterized by different directions and are accompanied by differentiation of soil material even during the same growing season [4]. It is known that when crop rotation is observed and the necessary amount of organic and mineral fertilizers is applied, the cultivation of podzolic soils proceeds relatively quickly. Within the first five years, agrochemical properties can reach a relatively stable equilibrium state [5]. On the other hand, in the post-agrogenic period, arable podzolic soils begin to experience an increasing impact of zonal factors of soil formation and go through certain stages of degradation [6]. Such transformations are especially
noticeable during the withdrawal of soils from agricultural use [7] and during the passage of fallow lands through the stage of forest renewal [8]. The observed phenomena in various biogeocenoses are the reason for maintaining the heterogeneity of podzolic soils, which, along with other reasons, leads to variegation in agrocenoses and a decrease in crop yields [9]. Therefore, it is important to know the features and speed of formation of a full-fledged arable horizon in order to successfully predict the level and quality of future crops in newly developed territories. Moreover, it is known that the unfavorable properties of acidic podzolic soils (weakened microbiological activity, low nutrient content, a large number of harmful compounds, such as mobile aluminum) lead to disruption of normal life processes in plants [10]. The purpose of this study is to assess the specifics of the initial stage of cultivation of podzolic soils and determine the necessary measures for its implementation on the example of sites of different ages.

2. Methods
The research was carried out on medium-loamy podzolic soils of the Arkhangelsk region (Primorsky district, village of Lyavlja), developed on cover loams. The objects of study were close to the village Lyavlja located on the banks of the river Lyavlja – right tributary of the Northern Dvina. This is about 50 km south to the city of Arkhangelsk (figure 1). The soils of emerging agrocenoses with different terms (2, 4, 6 and 10 years) of agricultural development were studied as direct objects. Organic and mineral fertilizers, lime (from 7 to 15 t/ha) were applied to the fields of the cultivated areas after deforestation and partial planning of territories. Plowing and sowing of perennial grasses were carried out. Additionally, fallow soils (age 15 years) of the garden plot were examined as a variant of well-cultivated podzolic soils.

![Figure 1. Location of research objects.](image)

Relatively undisturbed soils of the neighboring forest biogeocenosis served as a control. The studied virgin soils were formed under canopy of a spruce forest with poor herbaceous vegetation, characterized by a classical profile structure for such soil formation conditions. A noticeable thin layer of litter formed the surface layer, consisting mainly of the remains of semi-decomposed woody, herbaceous and moss vegetation. Under the litter (horizon O) was the humus horizon A and the transition horizon AE, which combined formed about 10 cm of humus thickness. Below a powerful eluvial podzolic horizon was deposited to a depth of 20–25 cm on average. The transition from the eluvial strata to the illuvial horizon Bt was characterized by the presence of a transition horizon EB with a thickness of about 15–20 cm. Below, up to a depth of 55–60 cm, there was an illuvial horizon Bt.

In samples taken from different depths (0–10 and 10–20 cm), which corresponded to the depth of tillage, several agrochemical indicators were determined using the methods below [11].
The carbon content was determined by the Tyurin method in the Nikitin modification. The method is based on the oxidation of organic matter in a specially prepared extract from soil sample using the potassium bichromate (K$_2$Cr$_2$O$_7$)/sulfuric acid solution and incubation in a drying oven at a temperature of 150 °C for 20 minutes. The spectrophotometric study determines the optical density of the final solution at a wavelength of 590 nm. Potassium bichromate (K$_2$Cr$_2$O$_7$)/sulfuric acid solution was used as blank. The carbon content of samples was determined according to the calibration curve.

The content of mobile forms of phosphorus (P$_2$O$_5$) and potassium (K$_2$O) was determined by the Kirsanov method. The method is based on extraction of mobile compounds of phosphorus and potassium from soil using extracting solution of hydrochloric acid with molar concentration 0.2 mol/dm$^3$. The quantitative determination of mobile compounds of phosphorus in the extracts was performed using photometer and mobile forms of potassium using flame photometer.

The pH$_{HCl}$ value (hereinafter referred to as pH) was determined by the potentiometric method in a salt soil suspension using a glass measuring electrode and a silver-chloride reference electrode.

The sample size for each of the surveyed objects is 12. The obtained data were processed by methods of mathematical statistics [12] – arithmetic mean values of values and standard deviations were calculated. The significance of differences was evaluated for the average using the student's test, and for standard deviations – the Fisher test. Plots of different ages cultivation length, including fallow soils, were compared with the virgin version.

It should be added that for soils of forest biogeocenosis, the designated sampling depth of 0–10 cm corresponds to the combined thickness of humus (A) and transition (AE) genetic horizons. The depth of 10–20 cm corresponds to the eluvial thickness represented by the podzolic horizon (E). The degree of cultivation of podzolic soils in relation to the studied indicators was determined in accordance with the classification division of soils into developed (low cultivated), cultivated (medium cultivated) and cultural (highly cultivated) soils [13].

3. Results and discussion

Comparative morphological analysis of the soils in reclaimed areas after deforestation with the control and long-arable land showed that the topsoil is mainly formed on the material from different morphons of the podzolic horizon of virgin soil [14]. In our case, these morphological elements differ in color (from whitish and light fawn tones to brownish) and the number of Fe-Mn particles (ortsteins) with a diameter of 3–4 mm. The structure is finely lumpy-powdery with signs of horizontal divisibility. According to the granulometric composition it can be classified as a light powdery loam. In the emerging arable horizon in the first years of development, the presence of material of the illuvial thickness was noted, in some cases visible on the soil surface. The material of horizon Bt and the transition horizon EB involved in the formation of arable horizon is thick and sometimes represented by the whole blocks. This fact can be probably related to the consequences of deforestation and possible flaws in the subsequent planning of the territory. The material of the horizon itself was characterized by a non-uniform color-spots, and the entire zones of brown color were distinguished on a light fawn background. The structure was small, nutty-lumpy, with signs of horizontal divisibility on the split surface. According to the granulometric composition – medium loamy soil. The Fe-Mn ortsteins, well separated small manganese ortstein with ferruginization on the perimeter were presented as concretions. The section shows manganese primers and silica powder. The material of the horizon Bt which could be also found in the processed thickness was characterized by a more uniformed brown color, the structure was prismatic. Prisms tended to break up into thin-pore soil aggregates of different sizes. Clay cutana were present along the faces of the structural separations, and when larger blocks were broken into smaller ones the clay cutana was overlaid with dusty material in the upper part. The considerable accumulation of silty material was present in the large cracks. According to the granulometric composition – medium loamy soil. Manganese primers were visible on the cuts.

The presence of heterogeneous and low-yielding material in the arable layer significantly reduced the rate of soil cultivation in some of its locations. The thickness of the humus layer in the fields involved into crop rotation 2 and 4 years ago was 7–10 cm average, in some places it reached 15 cm, and in some
places was practically absent. On 6 and 10-year-old plots, the thickness of the humus layer varied from few to 30 cm, which was associated with extremely uneven application of peat compost and agrotechnical flaws in soil treatment. The organic matter of the soil was weakly connected to its mineral part, had signs of detachment, which in turn indicated on weak humification of the compost. Inclusions of organic remains of semi-decomposed wood, grassy, moss and other forest vegetation were also characteristic to this layer on all the surveyed developed areas. There were also areas composed of a looser organo-mineral substrate. Usually this is the smell of sod or stubble left after harvesting perennial grasses and cereal plants. Despite the close to neutral pH reaction (pH reaches 6.5 in some places) and the development of a large grass biomass, almost all the "humus" reserves of these soils were determined by the applied organic fertilizers.

Nevertheless, a comparative analysis of the behavior and changes in agrochemical indicators of podzolic soils in the surveyed areas showed that over time there was quite obvious improvement of land involved in agricultural turnover (table 1). In the very first years, compared to the virgin version, there was a statistically significant increase in the organic carbon content for both depths – from 1.14 and 0.86% (2–4 years) to 1.61 and 1.22% (6–10 years), respectively. At the same time, the carbon values remained highest in the fallow area – 3.50 (0–10 cm) and 2.90% (10–20 cm). It is also noteworthy that the values of standard deviations in this case indicate a higher and statistically significant variability of the property in comparison with virgin land for a few to 30 cm, which was associated with extremely uneven application of peat compost and the development of a large grass biomass, almost all the "humus" reserves of these soils were determined by the applied organic fertilizers.

Table 1. Agrochemical parameters of podzolic soil under different-age arable land and forest.

| Agrochemical parameters | 2–4 years | 6–10 years | 15 years | Forest |
|-------------------------|-----------|------------|----------|--------|
| X | S | t | F | X | S | t | F | X | S |
| depth 0–10 cm |
| C, % | 1.14 | 0.33 | + | + | 1.61 | 0.29 | + | - | 3.50 | 0.20 | + | - | 0.84 | 0.17 |
| pH | 4.70 | 0.52 | + | - | 5.05 | 0.49 | + | - | 6.45 | 0.24 | + | + | 4.06 | 0.31 |
| P₂O₅, mg/kg | 165 | 29.5 | + | + | 232 | 23.1 | + | + | 300 | 20.8 | + | + | 63 | 7.94 |
| K₂O, mg/kg | 100 | 24.8 | - | - | 92 | 24.4 | - | - | 150 | 11.9 | + | - | 84 | 13.7 |
| depth 10–20 cm |
| C, % | 0.86 | 0.32 | + | + | 1.22 | 0.23 | + | + | 2.90 | 0.18 | + | + | 0.28 | 0.06 |
| pH | 4.65 | 0.52 | + | + | 4.80 | 0.69 | + | + | 5.30 | 0.23 | + | - | 4.15 | 0.16 |
| P₂O₅, mg/kg | 125 | 24.0 | + | + | 164 | 18.9 | + | + | 250 | 18.7 | + | + | 75 | 8.25 |
| K₂O, mg/kg | 113 | 25.5 | + | + | 103 | 26.7 | + | + | 170 | 11.9 | + | - | 68 | 12.1 |

*a* – arithmetic mean.

*b* – standard deviation.

*c* – student’s test.

*d* – Fisher’s test.

*e* "+" – significance of differences with the significance level a = 0.05.

The received data of soil acidity in the studied areas indicate an unambiguous decrease compared to the control. These changes are statistically significant and, of course, are the result of liming of the soils in the developed territories. For the age of 6–10 years, in contrast to 2–4 years, there is also some differentiation of the property within the studied depths. Most likely, this is due to a decrease in the prolonged effect of lime after its introduction in significant quantities (up to 15 t/ha) at the initial stage of development. An indirect confirmation of this is approximately the same level of variation of the property for both depths, with the statistical significance of differences from virgin land only for a depth of 10–20 cm. In general, the pH values for both depths continue to shift towards a neutral environment
and in the age category of 6–10 years are equal to 5.05 and 4.80, respectively. In accordance with the classification for this parameter, the soils of the first and second age groups belong to developed (low cultivated) and cultivated (medium cultivated) soils, respectively. It is important to note that liming not only eliminates excess acidity, which is harmful to the normal development of plants and beneficial microflora, but also improves the physical properties of the soil, increases the efficiency of fertilizers. All this affects the yield of agricultural crops.

The obtained data for the content of the mobile forms of phosphorus showed the stable tendency of growth for both depths in comparison with the original virgin soil (63 and 75 mg/kg). Thanks to the use of mineral fertilizers and peat compost, in the first years the phosphorus content increased by more than 2.5 times for the depth of 0–10 cm (165 mg/kg) and more than 1.5 times for the depth of 10–20 cm (125 mg/kg). These changes are statistically significant. This fact is significantly important for podzolic soils that are poor in available forms of phosphorus. Undoubtedly, the positive role in this process is played by the shift in the pH reaction towards a neutral one, which helps to release sparingly soluble phosphorus compounds. At the same time, property variability in agroecosystem conditions is significantly higher compared to the control. Most likely, this is due to uneven application of fertilizers and shortcomings in agricultural work. At the same time, it should be noted that there is a general tendency to decrease the variation of property values over time, which may be due to the processes of homogenization of the soil mass of the treated layer. According to this indicator, the surveyed soils belong to the group of cultivated soils.

The behavior of mobile forms of potassium is not so clear compared to phosphorus. First, for a depth of 0–10 cm, there is no statistical significance of differences in the potassium content compared to the control. Moreover, over time, even some decline here is detected as well as in depth of 10–20 cm. Secondly, for the first depth, there are no significant differences in the variability. This may be due to the higher potassium mobility and migration capacity against the background of its biogenic accumulation compared, for example, with phosphorus. The behavior of the potassium content at a depth of 10–20 cm preserves the marked trends for the top depth. The difference is that these changes acquire statistical significance for both the values of the mean and the values of standard deviations. This circumstance is caused, on the one hand, by an increase in the potassium content in the lower part of the arable layer compared to the upper one, and, on the other hand, by a decrease in the potassium content in the virgin version at this depth. This increase due to maxima in the content also leads to an increase in property variability at a given depth. Both age groups of soils by the degree of cultivation belong to the developed soils in this parameter.

A fundamentally different picture is observed when analyzing the available data for the soil of a highly cultivated fallow area. Foremost it should be noted that all the studied agrochemical parameters of this object for both depths differ statistically significantly from the soils of the forest biogeocenosis. The carbon content also significantly exceeds the values of this indicator for the soils of developed territories at both depths (3.5 and 2.9%, respectively). Despite the considerable time that has passed since the removal of anthropogenic load, it remains high and corresponds to the cultural level of development in accordance with the classification of soils used by the degree of cultivation. There is also a fairly high provision of soil in the garden plot with nutrients. The phosphorus content is 300 and 250 mg/kg, and the potassium content is 150 and 170 mg/kg, respectively, for each of the surveyed depths, which is significantly higher compared to the developing territories. Moreover, for mobile forms of phosphorus it corresponds to the cultural level of development. According to the content of mobile forms of potassium these soils fall into a lower category of cultivated soils. Very comfortable environmental conditions for crops (pH is 6.45 and 5.30 for each depth, respectively) they also distinguish the soils of a fallow area in comparison not only with the virgin version, but also with the territories recently involved in agricultural use. As for the variability of the studied indicators, we can say that in almost all cases it is higher compared to the virgin version, and in some cases, it is statistically significant. At the same time, the values of standard deviations in comparison with the developing areas are lower in all cases. This is probably due to the lower natural variability of the parameters under consideration. Therefore, even a long post-agrogenic time period is not enough to reduce the variation
in properties inherited from the period of active agricultural use of the garden plot. These results are in good agreement with the morphological appearance of the arable horizon (Ap) of the soils under consideration. Its thickness is not less than 25 cm, reaching 30 cm in some locations. The color of the material is dark gray, relatively uniform. The structure is lumpy and well defined. Lumps break down into smaller structural units in the form of grains. Its thickness in all locations is not less than 20 cm, the color is dark gray, uniform. The structure is lumpy and well defined. Lumps break down into smaller structural units in the form of grains. Thus, the old-arable soil of the fallow area is characterized by a well-defined morphologically arable horizon and high values of agrochemical indicators even 15 years after the termination of processing. This circumstance may indicate that soils that have reached a high degree of cultivation are able to withstand post-agrogenic transformation in the direction of zonal type of soil formation for a long time.

4. Conclusion
This study shows that in the first years of agricultural development of territories after deforestation, the upper part of the profile of the studied podzolic soils undergoes the most significant changes. Their morphological structure is also influenced by planning work, which, unfortunately, is not always performed efficiently. The composition of the soil material from which the arable layer is formed is heterogeneous and is mostly represented by morphons of the podzolic horizon. The presence of material from the underlying illuvial horizons is often noted, which is largely due to the technical feature of work when reducing the forest and subsequent surface planning. The heterogeneous mineral mixture is supplemented with organic matter inclusions. On one hand, it is an organic material that is inherited from the forest stage of soil formation – semi-decomposed wood, forest floor, remnants of grassy and moss vegetation. On the other hand, these are organic fertilizers applied to the soil in the form of peat compost. A gradual homogenization of the soil mass due to the continuous processing of the soil under the current crop rotation was observed. Morphological features of the materials involved in the processed layer included various genetic horizons transform and become less noticeable. Over time, they disappear altogether, which was well illustrated by a fallow area. However, this time period is not enough for the formation of a relatively full-fledged arable horizon in the conditions of developing agroecosystems.

The studied agrochemical parameters indicate significant changes in the treated soils in comparison with each other and the soils of the forest biogeocenosis. Foremost, this is due to the ongoing measures for the cultivation of the studied podzolic soils – the introduction of organic and mineral fertilizers, liming, the use of perennial grasses in crop rotation, and drainage works. There is a noticeable increase in the content of organic carbon, mobile forms of phosphorus and potassium, and a shift in the reaction of the medium towards a neutral one. These changes are typical for all age categories of the studied objects and in most cases are statistically significant. At the same time, the results of agrochemical analyses show that the improvement of individual indicators is completely insufficient to form a full-fledged arable horizon. To successfully solve the problems of cultivating podzolic soils at the initial stage of their development, an integrated approach is necessary, aimed at creating a sustainable agroecosystem. In addition to the measures already listed, more attention should be paid to the culture of performing agricultural work and optimizing individual soil treatment techniques. This applies to plowing, cultivation and harrowing of the soil in the system of tillage within the framework of the current crop rotation.

At the same time, in each individual case, it is necessary to use an individual approach in accordance with the characteristics of the soil cover, water-air and heat regimes, the composition and properties of the soils of the original forest biogeocenoses. The ability to maintain the achieved level of fertility even in the Northern conditions of the country demonstrates the state of fallow land that was not cultivated for 15 years after it was withdrawn from agricultural use. Taking into account that podzolic soils are widely distributed, have long been used in agriculture and need to be cultivated more than others, the provided data can serve as a guide when performing corresponding work.
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