Potassium regime in postagrogenic soils that came out of cultivation at different time periods and are currently at different vegetation cover succession stages

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Abstract. We present the results of a study of the potassium regime of postagrogenic soils at different stages of vegetation recovery carried out in the Leningrad region, Russia. The objects of the study were sites with meadow-shrub vegetation and young deciduous stands with regeneration of pine and spruce on postagrogenic soils formed on two-member sediments. For agrochemical analysis, soil samples were taken from an arable (0-20 cm) and underlying (20-40 cm) horizons. The content of available forms of mobile potassium correlated more closely with the soil pH at the beginning of the growing season than at the end of it. With a decrease in elevation, both the content of mobile forms of potassium and soil acidity increased, which was associated both with the migration of potassium forms along the soil profile and with the granulometric composition of soils. Potassium in the sandy loam horizon of the soil was the most mobile, in contrast to that in the light loamy former arable horizon. With age, under vegetation developing on postagrogenic soils on two-member sediments, an accumulation of both water-soluble and mobile forms of potassium in the former arable horizon can be observed, which indicates restoration of soil fertility.

1. Introduction

For plants, soil is a source of nutrients, and the main property of soil – fertility – is formed under the influence of certain plants. Therefore, the parameters of soil fertility, which is formed under the influence of vegetation, including certain plants, are informative indicators of the relationship between soil and vegetation cover [1-8].

Recent studies demonstrated that an increase in the soil nutrient content in the course of succession gives advantages to plant species capable of active growth and producing rapidly decaying litter [6, 8, 9-12]. Numerous observations of the influence of plants, soil animals and microorganisms on the substrate allow us to conclude that these organisms affect soil fertility and moisture in such a way that over time the substrate becomes more suitable for their growth and development.

Woody and herbaceous vegetation play different roles in soil formation. This is due to the depth of penetration into the soil layer and the distribution of root systems, as well as to differences in the size and nature of plant residues, and their mineral composition. The totality of the processes of absorption
of chemical elements from the soil by plants, the synthesis and decomposition of organic matter, and the return of chemical elements to the soil is called the biological cycle of substances in the “plant-soil” system [1, 3, 4]. The amount of potassium involved by herbaceous vegetation in the biological cycle is the largest compared with other elements. At the same time, potassium is the third, after calcium and nitrogen, chemical element most consumed by woody plants. On soils insufficiently supplied with physiologically available potassium compounds, the development of the grass cover can significantly affect the availability of potassium to tree species [5, 7, 12].

The gross content of potassium in soils is about 2% (K2O). Soil potassium is subdivided into non-exchangeable, exchangeable (1-2% of the total) and water-soluble; the latter two forms are available to plants. When plants use exchangeable potassium, an insignificant part of non-exchangeable potassium is able to pass into an exchangeable form under the influence of root exudates. Potassium is mostly found in sand and dust fractions of feldspars, microcline, orthoclase, and micas (biotite, muscovite). The best source of nutrition for plants is soluble potassium salts (0.5-2% of the gross soil reserves) [6, 7, 11]. The transformations of potassium forms in the soil are oppositely directed processes. On the one hand, potassium aluminosilicates inaccessible to plants, as well as non-exchangeable and organic ones, gradually pass into a water-soluble and exchangeable state. So, with the weathering of minerals in soddy-podzolic soils, 15-30 kg per ha of available potassium compounds are formed annually [6, 10]. With the consumption of mobile forms of potassium, its reserves in the soil can be replenished due to exchangeable forms, and with a decrease in the latter, due to non-exchangeable, fixed forms of potassium. Alternating soil drying and moistening, as well as the activity of plant root systems and microorganisms, contribute to the transition of potassium into accessible forms.

With long-term agricultural use of soils, a parallel decrease in the content of all forms of soil potassium, primarily the most mobile ones, occurs [10]. In addition to the mineralogical and granulometric composition, soil absorption capacity for potassium is significantly influenced by its moisture content, humus content, pH, and biological activity [6, 10]. The main source of potassium for plants is metabolized potassium. It is this form that characterizes the fertility of soil in relation to potassium. The patterns of distribution of soils with different potassium content are not yet clear enough. Apparently, the local lithological features of parent rocks play an important role here. Differences in the mechanical composition of postagrogenic soils are also of some importance. Therefore, it is important to know the degree of changes in the potassium regime in connection with the different successional status of postagrogenic lands.

2. Methods and Materials
The objects of the study were elevated agricultural lands that came out of cultivation at different periods of time. They were located on the Oredezhsky plateau in the Gatchinsky district of the Leningrad region, Russia. The aim of the study was to determine the potassium regime of sod-podzolic soils of sandy loamy or loamy granulometric composition, underlain by red-colored moraine boulder loams. These soils occupy about 40% of agricultural and forest lands in the study area [11].

Soil samples were taken at permanent locations along the slope of the study area in the first ten days of May and in the second ten days of September during four growing seasons. Soil samples were taken from the former arable horizon (0-20 cm) and underlying horizon (20-40). The analyzes of soil samples were carried out according to generally accepted methods [13, 14]. The mobile forms of potassium were determined by the method of A G Kirsanov with an ionometric probe. Soil pHKCl was measured by the potentiometric method.

When conducting studies of the potassium regime in postagrogenic lands, the following works were performed:

- the characteristics of water-soluble and exchangeable forms of potassium in the soil complex under phytocenes of different age were determined;
- an assessment of the potassium content in soils under natural with various species composition, and on postagrogenic lands was carried out.

The available scientific information and recommendations on these subjects are currently limited.
The research results were processed by statistical methods using variance, correlation and rank analyses [15, 16].

3. Results and Discussion

On the elevated site with sandy loam and loamy soils on moraine boulder loam haymaking stopped 15 years ago, and the site is currently at the meadow-shrub recovery stage. The highest content of mobile potassium was observed in the upper horizon (0-20 cm) of the soil profile (Figure 1). This is likely due to the nature of postagrogenic vegetation. Specifically, potassium is supplied with litter of herbaceous vegetation, birch undergrowth and willow shrubs. Over a four-year observation period, exchangeable K$_2$O in the upper soil horizon of the former arable land stabilized at the level of 6.69 mg per 100 g, and in the underlying soil horizon (20-40 cm), at the level of 3.34 mg per 100 g.

To study the regime of mobile and water-soluble forms of potassium at the beginning of the growing season (in May) and at the end of it (September), soil samples were taken from the soil horizons. The obtained results showed that the quantitative indicators of the most accessible water-soluble forms of potassium were related to the actual acidity of the soil during the growing season (figure 1).

![Figure 1](image_url)

**Figure 1.** Changes in the content of water-soluble potassium in the former arable ((a), 0-20 cm) and underlying ((b), 20-40 cm) horizons the postagrogenic soil during the growing season.

In spring, the correlation was positive and characterized by a reliable correlation coefficients of 0.45-0.55 for both soil horizons. However, at the end of the growing season, the relationship between these agrochemical parameters was weak and virtually untraceable, which is probably due to a decrease in water-soluble forms of potassium assimilated by vegetation.

When considering the quantitative indicators of available forms of mobile potassium during the growing season, one can observe their closer dependence on the level of actual soil acidity at the beginning of the growing season, which contributes 75% to the sum of all factors in the former arable horizon (0-20 cm), and 95%, in the underlying horizon (20-40). However, at the end of the growing season, the contribution in the former arable horizon is already lower and amounts to only 68% of the sum of all factors. For the underlying horizon, this relationship has the opposite direction and makes only 15% of all factors (figure 2).
Figure 2. Changes in the amount of mobile potassium in the former arable ((a), 0-20 cm) and underlying ((b), 20-40 cm) horizons of the postagrogenic soil during the growing season.

Considering the influence of terrain on the migration of mobile forms of potassium during the growing season, depending on the change in the reaction of the soil solution, it can be noted that with a decrease in elevation, both the content of mobile forms of potassium and the level of actual soil acidity increase (figure 3).

Figure 3. Changes in the content of mobile potassium in the former arable (0-20 cm) and underlying horizons (20-40 cm) along the slope with the postagrogenic soil during the growing season. Marked ‘1’ – the upper part of the slope; ‘2’ – the middle part of the slope; ‘3’ – the bottom of the slope.

This is due to both the migration of potassium forms along the soil profile and the granulometric composition of the soil. In the upper part of the site, the soil profile is of a transitional type, from sandy loam to loam with boulders and stony cartilages on the underlying loamy moraine. Down the hill, the grain size increases, and in the middle part of the slope, light loam is already present. At the bottom of the hill, loam with a larger amount of physical clay than in the soil higher up the slope can be observed.

The second site was a 25-year-old former arable land with sandy-loamy, two-member soils underlain by red-colored loamy moraine on Devonian sandstones. The site was at the stage of a young deciduous stand with regeneration of pine and spruce in areas affected by periodic spring fires. Deciduous species were represented by tree-like and shrub-like willows, and aspen and birch trees. The stand had high crown density. At this site, soil samples were taken along a 400 m long line. An
agrochemical analysis of the former arable horizon (0-20 cm) and the underlying horizon (20-40 cm) of the soil was carried out to assess the quantitative content of various forms of potassium. The results obtained show a close nonlinear relationship between the amount of water-soluble forms of potassium in the former arable horizon and the actual soil acidity ($\text{pH}_{\text{KCl}}$) (figure 4).

The correlation coefficient with the $\text{pH}_{\text{KCl}}$ index was 0.77 for the water-soluble form of potassium. For the exchangeable form of potassium, the correlation coefficient was 0.65. For mobile forms of potassium in general, this indicator was 0.66. In general, a tendency can be observed for a decrease in water-soluble and exchangeable forms of potassium with an increase in $\text{pH}_{\text{KCl}}$, that is, a decrease in the reaction of the soil environment, which is probably associated with the establishment of an equilibrium state. This is due to the lower strength of the bonds of potassium with the soil absorbing complex of soddy-podzolic soils, which, in the case of a leaching water regime and an acidic reaction of the medium, leads to exchange substitutions of absorbed potassium and its displacement into the soil solution.

In the underlying sandy loam horizon we observed lower quantities of potassium fractions than in the former arable horizon (figure 5).
The relationship with the actual soil acidity of water-soluble forms of potassium in this soil horizon was not observed, which indicates the equilibrium of these forms in this horizon. In the underlying horizon, the same tendency was observed as in the former arable soil horizon, that is a decrease in water-soluble and exchangeable forms of potassium with an increase in pH$_{KCl}$. When exchangeable forms of potassium and its mobile forms in general were considered, there was a significant correlation (R = 0.55–0.56) with the pH$_{KCl}$ indicators. Soil horizons with different granulometric composition differed substantially in the desorption capacity of exchangeable potassium. The most mobile was the potassium of the sandy loam soil horizon, in contrast to the light loamy former arable horizon.

The Spearman's rank correlation analysis of the dependence of the mobile forms of potassium in the soil horizons showed that the strongest relationship between the forms of potassium and the pH$_{KCl}$ level existed in the former arable horizon. However, a closer relationship was recorded with the water-soluble form of potassium, which was associated with its greater mobility in the soil horizons (table 1).

Table 1. Dependence of water-soluble and exchangeable forms of potassium on pH$_{KCl}$ in postagrogenic soil horizons.

| Soil horizon | Forms of mobile potassium | N   | R Spearman | t (N-2) | p    |
|--------------|---------------------------|-----|------------|---------|------|
| 0-20         | Mobile                    | 19  | -0.44      | -2.01   | 0.06 |
| 0-20         | Water-soluble             | 19  | -0.72      | -4.30   | 0.00 |
| 0-40         | Mobile                    | 19  | -0.37      | -1.63   | 0.12 |
| 0-40         | Water-soluble             | 19  | -0.53      | -2.58   | 0.02 |

The properties of a postagrogenic soil change with the development of natural vegetation. As a result of the studies, it was revealed that on sod-podzolic sandy-loamy soils, depending on the stage of vegetation cover regeneration, there was a gradual accumulation of mobile forms of potassium.

4. Conclusion

The study of the potassium regime of the soil complex at different stages of woody vegetation regeneration on postagrogenic lands showed that the presence of mobile forms of K$_2$O in soddy-podzolic soils was mainly determined by the granulometric composition and increase in weight. Along the slope, a decrease in elevation was associated with an increase in both the content of mobile forms of potassium and the actual soil acidity level.

With age, under vegetation developing on postagrogenic soils on two-member sediments, an accumulation of both water-soluble and mobile forms of potassium in the former arable horizon can be observed, which indicates restoration of soil fertility.

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