Effect of mineral and organic fertilizers on potassium leaching in sandy loam soils

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Abstract. In a model experiment, a study was carried out on potassium leaching from the soil. Soil samples were taken from a protective strip of long-term experiment (established in 1981). Various fertilizers and their mixtures were introduced. The effect of organic matter on the capacity formation of the cationic soil exchange was considered. Significant differences were noted in the potassium migration during various fertilizers application. A significant role is played by liming of acidic soils. Potassium ions displace calcium ions more easily than aluminum. Therefore, when liming, leaching of potassium may be reduced. With the introduction of peat and peat-based fertilizers, the cation exchange capacity of the soil increased significantly. The leaching of potassium did not increase. Introduction of cattle manure without heat treatment significantly increased the migration of potassium in the soil and its leaching to the lower lying horizons. In general, the migration and leaching of substances in arable soil rely upon a number of factors and their combinations: natural and climatic factors, physical and chemical properties of the soil, the intensity of agricultural use of arable land, the type and composition of fertilizers, and the mineralogical composition of the soil. When growing plants on calcareous, fertilized with potash fertilizers soils, the loss of potassium does not exceed its leaching from non-fertilized soils.

1. Introduction

The role of potassium and minerals including K for the soil complex is enormous. Of the many nutrients for plant species, soil potassium and minerals including K are important. In his experiments, J. R. Glauker (17th century) received the greatest increase in plant growth from the addition of nitrate (KNO₃) to the soil, and potassium was found to be useful for plant growth. Since the works of von Liebig published in 1840, the importance of K for plant growth has been confirmed [1, 2].

The total K content in soils ranges from 3,000 to 100,000 kg ha⁻¹ in the upper 0.2 m soil profile. Of this total content, 98 % of potassium is bound in mineral form, and only 2 % is in soil solution and metabolic phases [3].

Plants need in potassium is second only to the need for nitrogen. An increase in nitrogen in the soil can be achieved by including legumes into organic crop rotations, while potassium needs to be introduced into the fields. A lack of potassium in legumes can reduce nitrogen accumulation. Due to the low cation exchange capacity on coarse-grained sandy soils, there is a potentially high risk of...
losses in potassium leaching, which, according to various estimates, ranges from 20-50 kg ha\(^{-1}\) per year [4].

Potassium, along with nitrogen and phosphorus, is an important macronutrient for plants and plays an important role in the development of plants. This element has a wide range of functions in plant nutrition, through the cell membranes it provides gradients of electric potential, maintaining turgor and activating enzymes. Potassium is necessary for plants for photosynthesis, protein synthesis and regulation of stomata and is the main cation in maintaining anion-cation balances [1]. Methods of cultivation, types of crops, type of soil-hydrological and climatic conditions affect the provision of potassium to plants. Compared to nitrogen, in many developing countries, the use of potash fertilizers was ignored, which led to the constant deficiency of the soil this element [5, 6].

Rate and timing of fertilizer and organic fertilizers are often based on the optimum nitrogen, not potassium requirements of plants. This often leads to potassium deficiency or excess depending on the size of the harvest and crop rotation. In the agricultural crop rotations with a predominance of perennial herbs, including many organic farming systems, the potassium was an important element, especially in areas dominated by sod-podzolic or peaty soils. One needs to consider managing potassium regime in relation to the long-term sustainability of soil as resource, and the production of crops of high yield and quality. Some regions, where clay-rich soils dominate, have the potential to provide a sufficient amount of K, while other areas with poor sandy or peaty soils have a very low potential for weathering and, thus, will require the introduction of potassium [7].

In Lithuania, the study on the comparison of several systems of crop rotations to reduce leaching losses of potassium from soils was performed [8].

In several studies it was noted that the total losses in a clay soil were more than twice the losses in sandy soil (13 and 6 kg ha\(^{-1}\), respectively) due to the development of preferential flow in clay soil [9].

A serious problem in areas of intensive agricultural production is the use of nitrogen with consequent large nitrogen losses and environmental pollution. A serious problem in areas of intensive agricultural production is the use of nitrogen with its subsequent large losses and pollution. Nitrogen-potassium interaction is currently of interest in many studies, however, focuses on plant nutrition with potassium at different doses of nitrogen. Fixation and release of potassium from the soil, as well as absorption, transport, and reuse in crops, are affected by the form and rate and time of nitrogen use. High-yielding crops can be obtained in optimal nutrient ratios N: K. High rates of N and K application do not necessarily lead to increasing in increments of productivity and can even reduce the yield. A better understanding of the mechanism of nitrogen - potassium interaction may be a useful guide to better management of nutrients in agricultural practices to achieve high yields with high efficiency of nutrient use [10]. Years of experience in agriculture shows that it is impossible to achieve high yields in sod-podzolic soils of light granulometric composition without regular use of mineral fertilizers, including potash, [11,12,13]. However, this significantly increases the migration of bases in soil. Leaching of potassium in arable soils of light granulometric composition can reach 20 kg ha\(^{-1}\) according to our linematics studies [14,15]. On acidic soils in the conditions of washing water regime it is very important to preserve the bases in the soil. Liming of acidic soils plays a special role in potassium migration. In nature, everything is interconnected, so leaching is the result of the interaction of a number of factors. We have tried to simulate the impact on the soil of various fertilizers and their combinations in the laboratory, taking into account the average annual rainfall for the research region.

2. Methods & objects

The object of study is acid sod-podzolic sandy soil. Agrochemical research of soils was carried out according to standard procedures [16, 17, 18]. The soil was taken from the protective strip of a long field experiment. The experiment examines the effect of seven doses of lime at four levels of application of mineral fertilizers. The model experiment was carried out in lysimetric columns. The scheme of the experiment included the use of fertilizers on a limed and non-limed background [19, 20]. We tested the effect of mineral and organic fertilizers. The experiment was carried out without plants. The soil was washed with distilled water. Five washings have been done. In total, the average
annual rainfall for the conditions of the Leningrad region was passed through the soil. Potassium in the lavage was determined by flame photometric method [21]; organic matter by phenylantranilic acid titration after wet combustion in a mixture of sulfuric acid ($\text{H}_2\text{SO}_4$) and potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) according to the method of Tyurin. The cation exchange capacity was determined by the Bobko-Askinazi-Aleshin in the modification of the TSINAO. The soil was saturated with a buffer solution of barium chloride ($\text{BaCl}_2$), washed with sulfuric acid ($\text{H}_2\text{SO}_4$) and titrated with sodium hydroxide ($\text{NaOH}$).

3. Results & Discussion

Migration and leaching of substances in arable soils depend on a number of factors: climatic, physico-chemical properties of soil, intensity of agricultural use of arable land, the mineralogical composition of the soil. One of the most important properties of soil is the cation exchange capacity. It is also the result of the interaction of a number of factors. An important role in shaping the capacity of cationic exchange plays the contents in soil organic matter.

Table 1 shows a rather strong dependence of capacity of cation exchange from the organic matter in the soil when applying various fertilizers and their combinations. Rank analysis and Spearman correlation coefficient at the 95% significance level was used to determine the relationships. The results showed a wide range of fluctuations in the potassium concentration in the wash water.

Table 1. The value of the capacity of cation exchange (ECO) of the soil at different content of organic matter

| Options            | Organic matter content, % ($X$) | ECO, mg-eq. per 100 g of soil ($Y$) |
|--------------------|---------------------------------|-------------------------------------|
| Control            | 2.46                            | 4.88                                |
| NPK                | 2.19                            | 12.59                               |
| Lime               | 1.92                            | 15.23                               |
| Peat               | 5.17                            | 19.65                               |
| Manure             | 2.86                            | 15.93                               |
| NPK + lime         | 2.23                            | 18.38                               |
| NPK + peat         | 5.23                            | 18.98                               |
| NPK + peat + lime  | 4.99                            | 22.10                               |
| NPK + manure       | 2.28                            | 16.59                               |
| NPK + manure + lime| 2.76                            | 18.40                               |
| The accuracy of the experiment | 6.8 % | 1.23% |
| NSR05              | 0.65                            | 0.62                                |
| Correlation coefficient (Rs) | 0.745             |                                      |

There were no clear relationships between the doses of lime and mineral fertilizers with the concentration of potassium in the washing waters. The effect of liming on potassium leaching was twofold: in some cases, it did not have a significant impact on potassium migration, in others it reduced leaching. This may be due to the following reasons:

1. liming leads to the replacement of exchange aluminium in the soil absorbing complex with calcium. Potassium in dilute solution displaces calcium from the exchange complex of the soil absorption easier than exchange aluminium. This keeps the potassium from leaching out.
2. liming increases the cation exchange absorption capacity and helps to keep potassium in the exchange form from leaching. Previous lysimetric experiments have shown that an increase in the dose of potash fertilizers by 10 kg per 1 ha leads on average to an increase in potassium leaching on light soils by 0.52 kg ha per year. The use of peat did not increase the leaching of potassium in comparison with mineral fertilizers. When introducing cattle manure (KRS) without heat treatment, potassium leaching increased.
It is important what the value of the absorption capacity is related to. In figure 2 it is possible to allocate two zones: The 1st, upper zone, is associated with the presence of organic components of manure in the soil. The lower zone characterizes the leaching of potassium when applied to the soil minerals and peat. The introduction of manure stimulates increasing migration of bases, including potassium. This is due, in our opinion, to the presence of organic substances in the dissolved form and the alkaline reaction of the medium due to the content of ammonia salts and ammonium hydroxide in the manure.

The results of the study of the migration dynamics of substances in the soil showed that when cattle manure is applied to the produced, fertilized soil with mineral fertilizers, the migration ability of the bases, including potassium, increases approximately twice as much as the option of applying mineral fertilizers and lime with peat (Figure 3). The cation exchange capacity of the soil and the organic matter content were higher on the options of peat use than on the options of manure introduction.
4. Conclusion
When characterizing the potassium regime of sod-podzolic soils, it is necessary to take into account the granulometric and mineralogical composition of soils, the level of liming and the availability of soil with potassium, as well as the composition of cations in the soil. An increase or decrease in fixation or migration of potassium in the soil is not a general pattern, but depends on a combination of many factors. The leaching of potassium largely depends on the granulometric composition of the soil, the composition of the cations of the soil absorbing complex, and the presence of mobile forms of organic substances. The introduction of potassium-containing fertilizers increases the migratory capacity of potassium. When growing plants on calcareous, fertilized with potash fertilizers soils, the loss of potassium does not exceed its leaching from non-fertilized soils.

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