Change of the chemical composition of potato plants when applying organic fertilizers under the conditions of the Chuvash Republic

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Abstract. The experiments were carried out with the use of urban wastewater sludge from the city of Novocheboksarsk (Russia), crushed horns and hooves of cattle (horn-hoofed sawdust), semi-rotted cattle manure and wood ash on typical gray forest heavy loamy soil. By using sewage sludge as fertilizer for potatoes, the yield of tubers increased by almost 50%. However, the quality of potatoes in the first year of setting the experiment (2017) with the use of sewage sludge deteriorated: the ratio of K2O/CaO in tubers decreased more than twice, the starch content decreased, and the amount of nitrates increased. The reason for the deterioration in the quality of tubers is the violation of the ratio of chemical elements (Ca, Mg and K) in the wastewater sludge, which led to the immobilization of potassium in the soil by microorganisms. The main indicators of the fertility of a typical gray forest soil at the end of the experiment improved significantly - the content of organic matter, mobile phosphorus and exchangeable potassium increased significantly. The possibility of one-time use of sewage sludge in increasing the fertility of depleted and degraded soils with the simultaneous use of potash mineral fertilizers to optimize the balance of potato nutrients in the soil is allowed.

1. Introduction

As a result of the annual removal of plant nutrients by crops, a negative balance of humus and nutrients has developed in the soils of the republic, and soil fertility is degrading. The use of mineral fertilizers compensates for the decrease in soil fertility and contributes to an increase in crop yields, but the quality of crop production often deteriorates, the microbiological activity of the soil is suppressed, and the arable layer loses agronomically valuable water-resistant aggregates [1-3]. It is no accident that the organic farming movement has emerged in many countries of the world. Some farms of Chuvash Republic (LLC "Atalanu" of the Kanashsky region, the Eco-settlement "Yasna" of the Cheboksary region, etc.) have switched to organic farming. Farms, when switching to organic farming, as fertilizer for potatoes, mainly use semi-rotted cattle manure, which is applied, as a rule, in the fall for the main tillage. In recent years, the possibilities of using semi-rotted manure as fertilizer have decreased due to a sharp decline in the number of cattle in the republic. Therefore, it is relevant to search for alternative organic fertilizers, for example, urban wastewater sludge (UWS), the remains of the meat-processing industry (crushed horns and hooves - HFS), and mineral fertilizers - wood ash [4-6].

The attention of farmers and scientists in Russia and around the world is increasingly paid to the study of urban wastewater sludge with the aim of using them as organic fertilizers for agricultural
crops. In the Chuvash Republic, experiments using the UWS of the city of Novocheboksarsk have already been carried out earlier from 2001 to 2014 under various crops. In general, they revealed a positive effect of a one-time UWS application on the agrochemical, biological and physical properties of soils, yield and quality of crop production. However, the physiological symptoms of changes in the shape and color of the leaf surface of cultivated plants, caused by a change in the mobility of chemical elements in the soil, have not been studied well enough. Thus, even with a small dose of UWS (15 t/ha), potato leaves acquired a bronze tint and wrinkling, and at a dose of 30 t/ha, additional marginal burns of brown leaves appeared [7].

If the negative impact on the quality of potato tubers of excessive amounts of mineral fertilizers has been well studied, the study of the effect of alternative organic fertilizers is unclear, since it depends on additional factors - agrochemical properties of the soil and climatic features of the growing season. Meanwhile, the chemical composition of tubers is the most important indicator of the quality of tubers, which makes it possible to assess their taste and the safety of potatoes in winter. In organic farming, knowledge of the properties and effects of alternative organic fertilizers on potatoes allows you to optimize the chemical composition and quality of tubers by choosing the type of fertilizer or mixing them before application [8]. In this regard, research is relevant.

The purpose of the research is to reveal the effect of optimal doses of alternative organic fertilizers (UWS, manure, RLS) and ash of woody plants on the growth and development of potato plants, the yield and quality of tubers, and the agrochemical properties of typical gray forest soil. To achieve the goal in field experiments in 2017, we used doses of fertilizers that showed the maximum yield in previous experiments on various agricultural crops and showed the most characteristic signs of physiological changes (UWS - 60 t/ha, Manure - 60 t/ha, HFS - 5 t/ha, Ash - 2 t/ha) [2-4].

2. Materials and methods

The soil of the experimental site is typically gray forest, heavy loamy on loess-like loam. The predecessor is natural meadow vegetation on a 16-year old fallow. The thickness of the arable layer is 20 cm, the subsurface horizon A2B - 18 cm. The content of organic matter in the arable layer of the soil of the experimental plot varies from 3.35 to 3.37%, mobile phosphorus according to Kirsanov - 134-141 mg/kg, exchangeable potassium - 140 -145 mg/kg, pH of exchange acidity - 5.48-5.50 (weakly acidic). The amount of exchangeable bases varies from 14.2 to 15.3 mg-e/100 g of soil; hydrolytic acidity - from 1.80 to 1.95 mg-e/100 g. Vegetation periods 2017 - 2019 characterized by relatively warm summers and sufficient precipitation. In the experiments, we used scales, weighing containers, tape measure, shovel, walk-behind tractor.

Field experiments were carried out according to the following scheme: 1). Control; 2). UWS – 6 kg/m² (60 t/ha); 3). Manure - 6 kg/m² (60 t/ha); 3). HFS - 0.5 kg/m² (5 t/ha); 2) Ash - 0.2 kg/m² (based on 2 t/ha). The plots had an area of 4 m² in 5 replicates (plot size –2.0 m x 2.0 m). The location of the plots is systematic. The options were located every 1 m. The procedure for setting up the experiment is as follows: the soil was loosened to a depth of 20 cm, then the experimental plot was divided into variants (2 m x 10 m), which were divided into plots using pegs and twine.

Organic fertilizers were weighed in a container, transferred to the plots and manually spread evenly over the surface with shovels. Then each section separately was again processed with a walk-behind tractor until uniform mixing.

The used potato variety is Luck (2 reproductions). Non-germinated tubers were planted with shovels into holes to a depth of 6 cm with a distance between tubers in a row of 33-34 cm, and in row spacings - 70 cm. A total of 45,000 potato seed tubers were planted per 1 ha. In 2018 and 2019 on the same experimental plots, after mechanical tillage, potato tubers were also planted.

The biological (cellulose-decomposing) activity of the soil was determined by the intensity of the decomposition of linen applications. For this, linen cloth 10 x 30 cm in size, previously weighed and sewn onto a polyethylene film, was buried vertically immediately after planting in a row of potatoes, three pieces per plot. During the harvesting of potatoes, the applications were taken out, cleaned and weighed on an analytical electronic scale "Scout Pro SPS202F".
The biological activity of the soil was defined as the weight loss of the application, calculated as a percentage.

The content of mobile plant nutrients in the soil was determined according to the Kirsanov method in a soil extract with 0.2 N hydrochloric acid in the ratio: 1 part of soil to 5 parts of acid solution (GOST R 54650-2011) using an atomic absorption spectrophotometer "AA - 6300" and colorimeter photoelectric concentration "KFK-2".

Organic matter was studied by Tyurin's method - the oxidation of soil organic matter with a solution of potassium dichromate in sulfuric acid. A finely crushed soil sample of 200-300 mg is placed in a 100 ml flask and 10 ml of chromium mixture is poured, then the contents of the flask are gently mixed and boiled for 5 minutes then the contents of the flask are titrated with 0.1 N Mohr's salt in the presence of 0.2% phenylanthranilic acid solution until the color changes and converted to humus (GOST 26213091).

The exchangeable acidity of the soil was determined using a 1 N solution of potassium chloride at a ratio of 2.5 parts of solution to 1 part of soil (GOST 26483-85) using a laboratory ionometer "I-160 MI". The content of nitrates in tubers was investigated ionometrically, while 50 ml of a 1% solution of potassium alum were added to a 10 g sample of finely ground tubers; then the resulting suspension was stirred for 5 minutes and examined on a laboratory ionometer "I-160 MI" with a nitrate ion-selective electrode (GOST 29270-95).

The redox potential of soils was studied using a portable field device "I-102" with a platinum electrode.

The chemical composition of tubers was determined by burning dried and shredded potatoes in a muffle furnace at a temperature of 700 °C, followed by weighing the ash, dissolving it in 20% hydrochloric acid and then analyzing the solution on an AA-6300 atomic absorption spectrophotometer and UV 1800 spectrophotometer. Mathematical processing of the analysis results was carried out in the Excel program.

3. Research results
The UWS used in the experiments, according to the data of chemical analyzes, has a moisture content of 45%, the content of organic matter - 37% (in dry matter), nitrogen - 1.75% (in dry matter), phosphorus oxide (P₂O₅) - 2.75%, calcium oxide - 7.5%, magnesium oxide - 2%, and potassium oxide - 0.05%. The content of heavy metals in UWS is within the maximum permissible concentration in accordance with GOST R 17.4.3.07-2001.

Semi-rotted cattle manure stored in an open area for 2 years has an organic matter content of 31%, nitrogen - 0.53%, phosphorus oxide - 1.55%, calcium oxide - 2.2%, magnesium oxide - 0.6%, and potassium oxide - 0.37%. The content of plant nutrients in manure, especially nitrogen and potassium, is below average.

HFS is a well-free-flowing substance of brownish-brown color, consisting of particles up to 10 mm in size, having a flat shape, matte sheen and consisting of casein protein; it contains 12 to 17% nitrogen and traces of phosphorus and potassium. The advantage of HFS as a fertilizer is manifested in the gradual decomposition in the soil, which makes it a constant and stable source of nitrogen during the growing season of plants.

Wood ash, formed by burning mainly birch wood, contains potassium oxide - 9.5%, calcium oxide - 36.4% and phosphorus oxide - 3.9%.

Potato seedlings in all variants of the experiment appeared almost simultaneously. In the early stages of development, the options for experience differed little.

Potato leaves had a slightly better appearance (combination of dark green color of leaves and their size) in the variant with the use of HFS. With the further development of potato plants, in the budding phase, in the variant with the use of UWS, a bronze tint already familiar to us from previous experiments and a weak marginal burn of the leaves appeared on the leaves, indicating potassium starvation (figures 1-3).
Figure 1. On July 15, there were signs of potassium starvation of potatoes in the variant with the use of UWS 60 t/ha (right), the control variant was on the left.

Figure 2. On August 20 - potato leaves in the version with the use of UWS in a dose of 60 t/ha.

Figure 3. On August 20 - potato leaves variant with the use of UWS 60 t/ha, treated July 15 with a 0.2% solution of potassium sulfate.

Root and foliar feeding of potatoes, carried out on July 15 with a 0.2% potassium sulfate solution, stopped the process of leaf dying. By August 15, leaves treated with potassium sulfate solution looked better than untreated leaves (figures 2, 3). The studies carried out visually record the potassium starvation of potato plants in the variant with UWS. Potassium starvation is clearly manifested in the flowering phase of plants and is confirmed by chemical analysis of the crop.

The cause of potassium starvation is, firstly, the low content of potassium in the UWS, and the high content of calcium, magnesium, and easily degradable organic matter. Soil microorganisms feeding on organic matter of UWS, poor in potassium, immobilize the available potassium of the soil. In addition, calcium and magnesium are antagonists of potassium and prevent it from entering the plant.

Observation of the growth and development of potatoes in the experiments was carried out periodically throughout the growing season. The results of weighing the mass of tops and tubers of plants are shown in table 1.

Table 1. The mass of tops and tubers of potato plants in 2017 by dates.

| Options | July 15 | July 30 | August 15 |
|---------|---------|---------|-----------|
|         | The mass of tops, g/bush | The mass of tubers, g/bush | The mass of tops, g/bush | The mass of tubers, g/bush | The mass of tops, g/bush | The mass of tubers, g/bush |
| The control | 226 | 45 | 232 | 135 | 253 | 366 |
| UWS | 402 | 76 | 425 | 280 | 412 | 620 |
| Manure | 394 | 63 | 416 | 295 | 420 | 601 |
| HFS | 370 | 54 | 375 | 305 | 355 | 510 |
| Ash | 265 | 62 | 270 | 196 | 305 | 395 |

During the period of potato budding, potato plants had the best appearance in variants with the introduction of HFS and Dung into the soil. In these variants, the potato bushes were well leafy, the leaves were formed large, dark green. The leaves of potato plants in the variant with ash were small in size, had a pale green color due to a lack of nitrogen. It should be noted that weak visual signs of potassium starvation were observed on potato leaves and in the variant with manure. The reason for
this is long-term storage of manure in an open area, during which potassium could be washed out of it by precipitation.

The data of table 1 show that in variants 2, 3 and 4, the mass of the tops is much ahead of the mass of potato tubers, however, as early as July 30, the mass of tubers was comparable to the mass of the tops, and on August 15, the mass of tubers was higher than the mass of the tops.

This pattern is clearly reflected in figure 4.

![Figure 4](image)

Figure 4. The ratio of the mass of tops and tubers of potatoes from July 15 to August 15, 2017
a) The mass of tops and tubers on July 15, g/bush; b) The mass of tops and tubers on July 30, g/bush; c) The mass of tops and tubers on August 15, g/bush.

The maximum yield of potato tubers was in the variant with the use of HFS - 20.5 t/ha. It turns out to be significantly lower in variants with the use of manure and USW. The use of ash insignificantly increased the yield of potatoes (table 2).

Table 2. Yield and chemical composition of young potato tubers on August 15, 2017.

| Options | Productivity, t/ha | Starch in the natural substance of tubers, % | Nitrates, mg/kg | CaO | K₂O | P₂O₅ | K₂O/ CaO ratio |
|---------|--------------------|---------------------------------------------|-----------------|------|------|-------|----------------|
| The control | 12.2               | 12.7                                        | 37              | 0.171 | 1.715 | 0.171 | 10.03 |
| UWS     | 18.6               | 11.3                                        | 98              | 0.258 | 1.263 | 0.223 | 4.90  |
| Manure  | 19.0               | 12.2                                        | 60              | 0.245 | 1.387 | 0.196 | 5.66  |
| HFS     | 20.5               | 11.5                                        | 53              | 0.212 | 1.398 | 0.121 | 6.59  |
| Ash     | 13.0               | 11.6                                        | 30              | 0.182 | 1.499 | 0.188 | 8.24  |
| SSD₀₅   | 1.2                | 0.4                                         | 8               | 0.056 | 0.11  | 0.043 | 0.59  |

The data show that the application of fertilizers slightly reduced the starch content in potato tubers (table 2). The ratio of potassium to calcium in potato tubers turned out to be minimal in the variant with the use of UWS, which confirms the assumption of potassium starvation of plants during the
growing season. At the same time, in the variant with the use of UWS, an increased content of phosphorus and nitrates in potato tubers is recorded, which indicates a disturbed balance of incoming nutrients during the period of growth and development of potatoes. Violation of the balance of nitrogen, potassium and calcium in potato tubers impairs its marketability [9, 10]. So, potatoes grown using UWS quickly darkened in air after cleaning. When peeled potatoes were quickly immersed in water, dark spots were not observed, however, after boiling the tubers and cooling them in air, they appeared. The deterioration in the quality of tubers affects both the shelf life in the winter and the susceptibility to diseases during storage. Peeled potatoes grown using semi-rotted manure, HFS and ash also darkened in the air, but much less intensely.

However, knowledge of the chemical composition of organic fertilizers used in the experiment makes it possible to supplement them with the necessary elements - potassium - and to balance the balance of nutrients. With a harvest, potatoes take out potassium from the soil more than other elements, and are referred to as "potassium philes" in terms of their consumption. Therefore, immediately after spreading organic fertilizers over the field, it is necessary to additionally apply the calculated amount of potassium sulfate and then mix with the topsoil.

Soil samples for agrochemical analysis and linen to determine the biological activity were taken during the harvesting of potatoes at the end of August. The research results are shown in table 3.

Table 3. Agrochemical indicators and biological activity of soils.

| Options | Soil moisture, % | Redox potential mV | pH exchange | Humus, % | Mobile P2O5, mg/kg | Exchange K2O, mg/kg | Biological activity, % |
|---------|-----------------|--------------------|-------------|----------|-------------------|----------------------|-----------------------|
| The control | 15.4 | 392 | 5.45 | 3.34 | 135 | 140 | 39.8 |
| UWS | 16.9 | 338 | 6.14 | 3.58 | 168 | 156 | 58.4 |
| Manure | 16.2 | 359 | 5.83 | 3.45 | 154 | 175 | 49.1 |
| HFS | 15.7 | 361 | 5.40 | 3.35 | 142 | 138 | 53.0 |
| Ash | 16.1 | 395 | 6.27 | 3.38 | 157 | 195 | 41.9 |
| SSD05 | 1.2 | 10 | 0.10 | 0.04 | 11 | 15 | 6.2 |

The values of the redox potential are especially strongly reduced in the variant with the use of UWS, which correlates with the biological activity of the soil. A decrease in the redox potential leads to an increase in the mobility of heavy metals in the soil. This is especially true for the variant with the introduction of UWS into the soil, since they have a relatively high content of heavy metals.

The organic matter of UWS contributes to an increase in the biological activity of the soil, and when exposed to soil microorganisms and microfauna, it undergoes transformation processes (destruction, humification and mineralization), during which heavy metals are released, and under conditions of a low redox potential can increase their mobility and concentration in soil solution.

The study of the after-effect of UWS on potatoes in 2018 showed that the visual signs of potassium starvation in the variant with the introduction of UWS into the soil were weak, in the form of slight bronzing of the leaves, which did not significantly affect the quality of tubers. The potassium oxide to calcium oxide ratio in tubers varied slightly, from 6.7 to 7.4. In 2019, the signs of potassium starvation were even weaker, and the yield of potato tubers was 18% higher than in the control variant. Apparently, most of the organic matter of the fertilizer UWS was mineralized in the first year of application.
The aftereffect of HFS appeared only in 2 years of research. In the third year of the study (2019), the potatoes in the variant with the use of HFS differed slightly from the control variant both in the state of the tops and leaves during growth, and in the yield of potato tubers. On the contrary, in the variants with the use of UWS, Manure and Ash, the aftereffect was clearly noticeable, and was clearly traced both in the physiological state of tops and leaves of potato plants, increased productivity, and agrochemical parameters of the soil. HFS consists mainly of keratin, which is completely decomposed in the soil in two years; however, in the first two years it showed very high efficiency as a fertilizer for potatoes.

4. Conclusion
Scientific studies carried out in 2017-2019 showed that the introduction of urban wastewater sludge in the city of Novocheboksarsk as a fertilizer at a dose of 60 t/ha increases the yield of potatoes, however, in the first year of use, it worsens its quality. The reason for this is a decrease in the supply of potassium to the plant against the background of a good supply of nitrogen and phosphorus. However, the use of UWS as an organic fertilizer contributes to an increase in the biological activity of the soil and the content of mobile elements of plant nutrition. Fertility indices of typical gray forest soil at the end of the experiment increased significantly - the content of organic matter, mobile phosphorus and exchangeable potassium increased, the pH of exchangeable acidity reached optimal values. Despite a number of positive aspects in the use of UWS, they are not recommended for use in organic farming due to pronounced disadvantages - an imbalance in the ratio of biophilic chemical elements. However, UWS can be used as a fertilizer for agricultural crops and to increase the fertility of degraded soils of the Chuvash Republic, using them both in pure form and together with a calculated dose of potassium sulfate. The most effective organic fertilizers from the point of view of quality turned out to be semi rotten manure, HFS and ash of woody plants. Their application will allow farms to specialize in growing environmentally friendly products without the threat of depletion and soil degradation.

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