Ecological Assessment of the Cucumber Plants Reaction to the Use of Production Waste and Natural Minerals in the Composition of Nutrient Soils

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Abstract. The article discusses one of the waste management areas – the use of fertilizer properties of chemical compounds that make up various types of production waste. The salt aluminum slag of the Mtsensk metallurgical plant AOOT Non-ferrous Metals and Alloys was chosen as the object of pollution. The presented studies indicate that the presence of macro- and microelements in the composition of slag fertilizers significantly increases the value of these fertilizers and partially solves the problem of complex application of the necessary elements into the soil [10]. The effectiveness was evaluated of the fertilizing properties of the salt screenings of aluminum slag, vermicompost and zeolites when using them as a part of nutrient soils for growing cucumber [8]. An increase in the toxic load for the analyzed period was established [7]. Also, all the studied forms and types of fertilizer nutritional compounds have a physiological effect, increase the growth and development of cucumber plants, product quality, and contribute to plant resistance to adverse environmental conditions and to the production of environmentally friendly products [13]. The effectiveness has been proved of the method of using plant cell juice electrical conductivity to assess the physiological state at different growth phases as a reaction to the fertilizer levels of production waste and natural minerals [9].

1. Introduction

Production waste and the chemical elements contained in it have a significant impact on the ecological state of biogeoecosenses, causing irreversible changes and soil degradation [10]. All this determines the relevance of developing techniques and technologies for the disposal of emerging production waste. One of the directions of waste disposal is the use of fertilizer properties of chemical compounds that make up various types of production waste [4]. Studies show that the presence of macro- and micronutrients in the composition of slag fertilizers significantly increases the value of these fertilizers and partially solves the problem of application of the necessary macro- and microelements into the soil.
[6]. At the same time, trace elements in metallurgical slags mostly are in compounds assimilated by plants, which further increases their value [7].

In this regard, it is relevant to study the fertilizing properties of aluminum salt slag screenings, natural zeolites and vermicompost [1], the conditions for their environmentally friendly use in nutrient soils and the reaction of cucumber plants.

**Research objective** is to establish the environmental effectiveness of the fertilizing properties of salt screenings of aluminum slag, natural zeolites and vermicompost for use as part of nutrient soils for growing cucumber plants.

2. Research tasks
- to establish the effect of production wastes and natural minerals on the composition and mobility of heavy metals in nutrient soils for growing vegetable crops;
- to determine the effect of the fertilizing properties of slag screenings, natural zeolites, vermicompost and the conditions of their use on the electrical conductivity of cucumber plant cell juice [8];
- to study the effect of the fertilizer forms on the concentration and composition of water extracts from soil and the number of protozoa;
- to determine the effect of the studied fertilizer forms based on production waste on the quality of cucumber fruits.

3. Characteristics of research objects

Screenings of aluminum salt slag from the Mtsensk Metallurgical Plant AOOT Non-Ferrous Metals and Alloys are characterized by the following physical and chemical properties: aggregative state is bulk material, fractions of 3 mm, color – light gray, odor – specific, pH value of aqueous extract is pH8, the main phases are potassium chloride (KC1), sodium chloride (NaCl), aluminum oxide (Al2O3), silicon oxide (SiO2).

The chemical composition of salt waste slag, %: Al2O3 – 50.02; Cu – 0.54; Si – 3.22; Mg – 1.64; Mn – 0.21; Ti – 0.03; Sb – 0.03; Co – n/a; As – 0.0002; Ca – 0.2; Zn – 0.49; Fe – 0.69; Ni – 0.08; Pb – 0.08; Sn – 0.018; Na – 2.39; K – 7.37; Cl – 8.6; SO4 – 0.28; Fe3+ – 1.0; LOI – 23,1028.

Screenings of aluminum salt slag belong to the IV class of low-hazard substances according to GOST 12.1.007–76 “Harmful substances in industry. Classification and general requirements”.

In the experiments, a fine slag fraction of less than 0.5 mm was studied.

Zeolites are represented by zeolite-containing bergmeal of the Khotynets field with the following indicators: pH – 8.3, CaO – 8.17%, MgO – 2.20%, K2O – 1.82%, Cu – 2.37x10-3%, Zn – 7.4x10-3%, Mn – 46x10-3%, Co – 0.12x10-3%, Mo – 0.72x10-3%. The crystalline structure of the zeolite contains: clinoptilolite – 35%, cristobalite – 27%, montmorillonite – 5%, ghist – 8%, calcite – 3%, the cation exchange capacity reaches 600 mEq/100 g.

Vermicompost: Corg. – 8.8%; N – 6.37%; P2O5 – 2.2%; K2O – 7.03 mg/100 g; the amount of absorbed hexone bases is 43.25 mEq/100 g; pH – 7.24; humus – 14.0%; Pb – 3.7 mg/kg; Cu19.2 mg/kg; Cd – 0.12 mg/kg; Ni – 15.0 mg/kg; Co – 2.2 mg/kg; Zn – 75.5 mg/kg.

Sodium humate: Biologically mobile substances were obtained by extraction of humic substances from vermicompost with an alkaline extract of 0.1 n NaOH; in a ratio of 1:5 by weight, followed by precipitation of 1 n H2SO4. Water-soluble organic matter was recovered from vermicompost in an aqueous extract.

The soil is dark gray forest, medium loamy, a humus horizon (the content of physical clay is 40-42%; humus – 5.4-5.5%; pHsalt – 5.2-5.5, pHwater – 5.8-6.0; the amount of absorbed hexone bases is 35 mEq/100g; P2O5 – 12.5-15.0 mg/100g, K2O – 12.0-12.6 mg/100g).

Cucumber (Cucumis sativus L.) is an annual plant [8]. It is demanding on heat. Its seeds begin to germinate at a temperature of 12–13 °C. Optimum plant growth occurs at a temperature of 24 ± 4 °C. At a temperature of 6–8 °C, growth and vital activity are suspended, and with a further decrease, plant death occurs. The root system consists of the main root going to a depth of 1 m and numerous lateral
ones located in the upper arable layer to a depth of 20–25 cm. The surface location of the root system and the rapid growth of the leaf surface determine the increased requirements for soil and air humidity. The optimum soil humidity is 75–85% and air humidity is 85–95%.

Seeds were sown directly in 1 liter polymer pots filled with a nutrient mixture. The studied components of the nutrient mixtures in the experiments were taken in a mass ratio. To obtain even sprouts and leveled seedlings, the cups with sown seeds were covered with a plastic film, so that, until the seedlings appeared, maintain the set temperature (27 °C). The mass of the substrate in the pot was 300 g, humidity was 70–75% of the dry weight. In the initial period, seedlings were watered every other day, and then 1-2 times a day, depending on the temperature and humidity of the substrate [5]. To assess the quality of seedlings, biometric observations and measurements were performed. In the experiments there was made a study of the water-physical properties, indicators of agrochemical properties and the content of heavy metals. The experiment was carried 4 times.

4. Results and discussion

The content of the element’s mobile form in the soil cannot be considered a reliable criterion of its availability to plants, since one or another element may not enter the plants for many reasons, including when the ratio of elements is unfavorable, the plants are inhibited by toxicants, the bond of ions with solid state is very strong and the rate of their exit from the solid phase into the solution is slow.

With existing methods for determining the mobile forms of nutrients in soils, the content of an element in a certain extract is estimated, but the study is not made of bond strength of elements with the solid phase of the soil, and the rate of their transition from solid phase to solution [3]. Moreover, the concentration of the element in the extract is not evidence of an estimate of ions number in a given bond strength in the soil solid phase, and the degree to which plants are supplied with these ions.

In this regard, there is a need to find new ways to assess the needs of plants for nutrients and the rapid regulation of the nutritional regime, the use of new methods for assessing the availability of nutrients in soil.

So, the established changes in the characteristics of electromagnetic radiation with passive and mobile location of the underlying terrain are the estimates of plants state. (Vinogradov B.V., 1982; Kanevskiy V.A. et al., 1985; Nielson T.A. et al., Tucker C.J., 1979; 1980; 1986).

The properties of electromagnetic radiation reflected from a phytocenosis are determined by five factors: the optical properties of leaves and other parts of plants; architectonics of vegetation; reflectivity ability of the soil; the nature of the lighting; parameters of measuring equipment; atmospheric transmission parameters during observations. Each of these factors affects one or another characteristic of the reflected flow, while knowledge of the reflection characteristics of leaves and soil is the basis for remote optical research and its interpretation. However, the disadvantage of such changes is the incomplete fixation of the whole complex of influencing factors, which limits their practical use.

Measuring the electromagnetic characteristics of plants and individual leaves in the ranges of the electromagnetic spectrum is very informative.

Heavy metals (HM) play an important role in metabolic processes, but in high concentrations they cause soil contamination and harmful effects on the ecosystem [12]. The toxic load for the analyzed period increased [7]. The toxic effect of HM can be direct and indirect. In the first case, reactions involving the enzyme are blocked, which leads to a decrease or termination of its catalytic effect. Indirect effect is manifested in the transmission of nutrients into an inaccessible state and the creation of a “foodless” environment. The danger caused by HM is compounded by their weak removal from the soil.

Heavy metals undergo chemical transformations in the soil, during which their toxicity varies over a very wide range. The most dangerous are mobile forms of HM, the most accessible for living organisms. Activity essentially depends on soil and environmental factors [13], the main among which are the content of organic matter, soil acidity, redox conditions, soil density, etc.
It is important to know how many heavy metals and other ballast elements entering the plant are acceptable for use without pathological consequences. Possible negative manifestations from the use of fertilizers can be avoided only with the obligatory observance of scientifically based regional fertilizer systems and technologies for their application with the obligatory regulation of the cycle and balance of not only biophilic elements, but also ballast substances. Fertilizers themselves, when used correctly, become a powerful factor in the development of wildlife.

The data obtained convincingly show that the addition of zeolite and slag to the soil increases the gross content of lead, cadmium, copper, zinc, chromium, cobalt and manganese. So, the gross lead content increased by 2.42 times, cadmium – by 2.1 times, copper and zinc – by 1.39 and 1.59 times respectively (Table 1).

### Table 1. Effect of slags, zeolite and vermicompost on the gross content of heavy metals in nutrient soils (mg/kg).

| Experiment Options          | Pb  | Cd  | Cu  | Zn  | Ni  | Cr  | Co  | Mn  |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Control (Soil)              | 6.14| 0.55| 48  | 37  | 21  | 9.0 | 6.98| 256 |
| Soil + zeolite + slag (1:1:1) | 14.88| 1.15| 67  | 59  | 7.0 | 27.0| 7.25| 267 |
| Zeolite + slag + vermicompost (1:1:1) | 71.38| 4.68| 379 | 758.5 | 152.5| 66.5| 6.53| 223 |
| Slag + sodium humate (20 ml) | 82.45| 3.97| 190 | 150 | 65.2| 43.1| 4.23| 280 |
| APC                         | 130 | 2   | 132 | 220 | 80 | 90 | 24 | 1500 |

The coefficient of total accumulation relative to the gross content of heavy metals in the control was 5.89 units, which indicates slight soil pollution.

The number of mobile forms of the studied heavy metals varies both in the soil itself and when zeolite and slag are added to it (Table 2).

### Table 2. Effect of slag, zeolites and vermicompost on mobile forms of heavy metals in nutrient soils (mg/kg).

| Experiment Options          | Pb  | Cd  | Cu  | Zn  | Ni  | Cr  | Co  | Mn  |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| 1. Control (Soil)           | 0.84| 0.20| 5.74| 2.38| 2.62| 0.15| –   | 30  |
|                            | 13.68*| 36.36| 11.95| 6.43| 12.61| 1.66| –   | 11.71|
| 2. Soil + zeolite + slag (1:1:1) | 2.25| 0.32| 8.76| 7.93| 0.71| 0.36| –   | 25.0|
|                            | 15.12| 27.82| 13.07| 13.44| 10.14| 1.33| –   | 9.36|
| 3. Zeolite + slag + vermicompost (1:1:1) | 9.73| 0.53| 141.0| 69.98| 12.74| 0.98| –   | 59.0|
|                            | 13.63| 11.32| 37.2| 9.22| 8.35| 1.47| –   | 26.45|
| 4. Slag + sodium humate (20 ml) | 4.75| 0.41| 11.82| 41.93| 3.78| 0.67| –   | 45.72|
|                            | (5.76) | (10.33) | (6.22) | (27.95) | (0.06) | (1.03) | –   | (16.33) |
| APC                         | 6   | 0   | 3   | 23  | 4   | 6   | –   | 140 |

* denominator – percentage of gross content

As can be seen from the data in Table 2, the number of mobile forms of heavy metals is 1.7–36.4% of the total content, while the mobility of cadmium is 36.4% of its total content, the amount of mobile lead is 13.7%, nickel – 12.6%, copper – 11.95% of the gross amount of these metals. The addition of
zeolite and slag to the dark gray forest soil has a significant effect on reducing the mobility of heavy metals [11]. So, the content of mobile forms of lead is 15.1% of its total amount, the amount of mobile cadmium is reduced and is 27.8%, which is 8.6% lower than the value in the control variant. The mobility of manganese and nickel decreases, but the mobility of copper, zinc, and lead slightly increases in comparison with the control variant.

The number of mobile forms of heavy metals in this type of nutrient soil is sharply reduced in comparison with their gross content (Table 1). So the amount of mobile copper is 37.2%, manganese – 26.45%, lead – 8.35% of their total content. However, the number of mobile forms of lead, copper, zinc, nickel exceeds the maximum permissible concentrations by 1.62, 47.0, 3.04, 3.18 times, the coefficient of total accumulation relative to the APC was 52.07 units.

It should be noted that the increase in both gross and mobile forms of heavy metals when using the fertilizing properties of zeolite, slag and vermicompost occurs mainly due to biophilic trace elements [2].

Studies have shown that zeolites, slags and vermicomposts in the composition of nutrient soils contribute to an increase in the gross content of heavy metals, but at the same time they affect their mobility due to the phenomena of sorption, adhesion, and organic and mineral complexation, which reduces their entry into plants and makes it possible to use them in various types of geochemical barriers to protect the environment from pollution by toxicants [9].

**Table 3.** The effect of various types of nutrient substrates on the electrical conductivity of the cell juice of a cucumber plant (% of dry matter).

| Experiment Options | Time, days | Current frequency, Hz | Ratio 4/3 |
|--------------------|------------|-----------------------|-----------|
|                    |            | 1-8                   | 64        |           |
| 1. Control (Soil)  | 2          | 3                     | 4         | 5         |
|                    | 1-3        | 17.9±1.3              | 67.8±0.2  | 3.8       |
|                    | 7-30       | 28.6±2.7              | 71.0±1.0  | 2.5       |
| 2. Zeolite + slag + vermicompost (1:1:1) | 7-30 | 28.3±1.6 | 71.0±1.0 | 2.7 |
| 3. Soil + vermicompost (1:1) | 7-30 | 24.1±2.2 | 73.5±4.5 | 3.0 |
| 4. Slag + sodium humate (20 ml) | 7-30 | 21.9±1.7 | 69.7±2.3 | 3.2 |

In our studies, an attempt was made to determine the electrical conductivity of the leaves of cucumber plants on nutrient soils with different content of elements and the level of soil and plant pollution. The obtained data on the influence of the studied factors on the electrical conductivity of cucumber cell juice presented in Table 3 showed that the most informative were the ratios of electrical conductivities at 64 and 1-8 Hz. The value of electrical conductivity increased with the age of plants and decreased with increasing level of pollution of nutrient soils. At the same time, the ratio of electrical conductivities at frequencies of 64–8 Hz decreased with age in control, and increased with the introduction of fertilizer forms, which was evidence of rejuvenation and stimulation of plant growth, and, as a result, an increase in the yield of cucumber.

Cucumber by its biological characteristics accumulate little nitrate. Nitrates mainly accumulate in those organs of plants along which nutrients (roots, stems, petioles, and veins) move. In the generative organs, nitrates accumulate much less, therefore leaves and root crops are richer in nitrates than fruits.

Among the organs of cucumber, as shown by studies, stems are in the first place in the accumulation of nitrates, since they are rich in vascular conduction tissue and store soluble nitrogen compounds. The least amount of nitrate is observed in the roots. In our experiment, an increased concentration of NO\textsubscript{3}– is observed in the fruits of cucumber. A high concentration of nitrates in the reproductive organs of cucumber can be caused by the predominance of nitrogen over other elements in the soil.
Table 4. The effect of various types of nutrient substrates on the nitrate content in the organs of a cucumber plant (% of dry matter).

| Experiment Options                  | Stems | Leaves | Roots | Fruits | Productivity, g/vessel |
|------------------------------------|-------|--------|-------|--------|------------------------|
| 1. Control (Soil)                  | 0.27  | 0.71   | 0.09  | 0.44   | 263                    |
| 2. Zeolite + slag + vermicompost (1:1:1) | 6.87  | 2.48   | 0.85  | 1.06   | 470                    |
| 3. Soil + vermicompost (1:1)       | 11.10 | 4.65   | 1.40  | 1.60   | 323                    |
| 4. Slag + sodium humate (20 ml)    | 3.42  | 2.39   | 0.35  | 0.65   | 145                    |

Nitrates are characterized by high mobility. In humid climates and plentiful watering, they can be washed out of the root layer of the soil. In an arid climate, nitrates with an upward flow of water [14] move to the surface of the soil and go beyond the distribution of the mass of active roots [9]. Due to the increased use of nitrogen fertilizers, an excessive accumulation of nitrates in vegetables is possible. A way to solve the problem of eliminating the excessive accumulation of nitrate is the combined use of zeolite with slag and vermicompost.

The effect was studied of zeolite, slag waste, vermicompost on the composition of water extracts from nutrient soils used in the cultivation of cucumber seedlings.

Studies have shown that zeolites, slags and vermicomposts in the composition of nutrient soils contribute to an increase in the gross content of heavy metals, but at the same time they affect their mobility due to the phenomena of sorption, adhesion, and organic and mineral complexation, which reduces their entry into plants and makes them possible use in various types of geochemical barriers to protect the environment from toxicants pollution.

Analysis of aqueous extracts from the tested nutrient soils showed that the use of the sorption properties of zeolite helps to reduce the concentration of anions and increase the alkalinity of the medium (table 5).

Table 5. Effect of slag, zeolites, vermicompost and Na humate on the composition of aqueous extracts from nutrient soils.

| Experiment Options                  | pH     | NH\textsubscript{4}\textsuperscript{+} | NO\textsubscript{2} | NO\textsubscript{3}\textsuperscript{−} | PO\textsubscript{4}\textsuperscript{3−} | Microscopy 1:10, cells/cm\textsuperscript{3} | Daphnia viability of 10 replicates |
|------------------------------------|--------|-------------------------------|----------------|----------------|----------------|--------------------------------|---------------------------------|
| Control (dark gray forest, A\textsubscript{1}) | 7.10   | 0.720                         | 0.559          | 0.805          | 0.736          | 40×10\textsuperscript{6}          | 24 hours 8+                       |
| Soil + zeolite (2:1)               | 7.15   | 0.428                         | 0.0083         | 0.345          | 0.231          | 102.5×10\textsuperscript{6}       | 24 hours 1+                      |
| Soil vermicompost                  | 7.80   | 3.634                         | 9.165          | 1.955          | 11.579         | 270×10\textsuperscript{6}         | 24 hours 6-                       |
| Zeolite + slag + vermicompost (1:1:1) | 7.9    | 3.374                         | 0.01           | 7.59           | 6.484          | 55×10\textsuperscript{6}         | 48 hours 10-                      |
| Slag + sodium humate (20 ml)       | 7.8    | 0.493                         | 0.0096         | 3.45           | 0.139          | 120×10\textsuperscript{6}        | 48 hours 10-                      |

- + - live daphnia;
- - daphnia died
As can be seen from table 5, aqueous extracts from nutrient soils had a neutral and slightly alkaline environment (pH 7.10–7.9). The composition of the ions of an aqueous solution indicates the presence of various forms of nitrogen: ammonium, nitrate, and nitrite. It should be noted that in the variant where vermicompost was used, the concentration of ammonium increased – 3.63–3.37, nitrite – 9.2 mg and phosphate ions – 11.6 mg/dm³.

In the variant with the combination of zeolite, slag and vermicompost, the amount of nitrates significantly increases – 7.6 mg/dm³ and phosphate ions – 6.5 mg/dm³.

Of interest are data on the microscopy of water extracts. The use of zeolite, slag, vermicompost as part of nutrient soils contributes to an increase in the number of unicellular microorganisms in 1 cm³ from 40×10⁶ cells in the control variant to 102.5×10⁶ cells when zeolite is added to the soil (2:1) and to 270×10⁶ cells when combination of soil with vermicompost (1:1). The combination of zeolite with slag and vermicompost causes an increase in the number of unicellular microorganisms to 55×10⁶ cells in 1 cm³.

Since microorganisms are highly sensitive to environmental pollution, an increase in their numbers indicates the ecological well-being of nutrient soils.

This position is confirmed by the viability indicators of daphnia used to determine the degree of soil toxicity.

The largest number of viable daphnia is established in the soil with the addition of vermicompost. Adding zeolite to soils reduced the number of viable Daphnia. A daphnia viability bioassay showed that the addition of zeolite and vermicompost reduces the viability of daphnia after 48 hours. Within 24 hours, in almost all cases, the viability of Daphnia was established, which indicates the low toxicity of the studied soils (table 6).

| Experiment Options                               | Cu (mg/kg) | Zn (mg/kg) | Pb (mg/kg) | Cd (mg/kg) | As (mg/kg) | Hg (mg/kg) |
|--------------------------------------------------|------------|------------|------------|------------|------------|------------|
| 1. Control (Soil)                                | 0.074      | 0.600      | 0.015      | 0.004      | 0.02       | 0.0015     |
| 2. Zeolite + slag + vermicompost (1:1:1)         | 0.183      | 0.433      | 0.012      | 0.004      | 0.02       | 0.0015     |
| 3. Soil + vermicompost (1:1)                     | 0.074      | 0.300      | 0.012      | 0.004      | 0.02       | 0.0015     |
| 4. Slag + sodium humate (20 ml)                   | 0.110      | 0.467      | 0.012      | 0.004      | 0.02       | 0.0015     |

As can be seen from the data in table 6, the amount of heavy metals does not exceed the maximum permissible concentrations in the fruits for any of the metals being determined, both in the control version and when using slags in the soil composition.

Knowledge of the patterns of HM distribution in the organs and tissues of plants makes it possible to elucidate the mechanisms of their redistribution and accumulation in the process of plant growth and development, develop methods for evaluating the yield, and competently certify products.

5. Conclusion

Our studies have shown that all the studied forms and types of fertilizer nutritional compounds have a physiological effect, increase the growth and development of cucumber plants, product quality, and contribute to plant resistance to adverse environmental influences and the production of environmentally friendly products.

The effectiveness has been proved of using the method of electrical conductivity of plant cell juice to assess their physiological state at different phases of plant growth and development as a response to the fertilizer levels of production waste and natural minerals.
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