SECTION 3. GENERAL AGRICULTURE

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3.1 Influence of sediment of wastewater on the change of agro-ecological indicators of a sod-pedosal soil under energy willow

The introduction of sewage sludge (SS) as fertilizer for agricultural crops is becoming widespread in the world, which is due to objective circumstances related to the growth of municipal waste and the limitation of valuable suburban areas for long-term storage of this waste. In view of its chemical composition, SS is now considered as a potential rich source of a range of plant nutrients and soil organic matter, and is promising for use as a ground cover phytoremediation agent. [195]. Numerous scientific sources contain information on the high efficiency of the use of PES for food and industrial crops [140, 147, 158].

However, many researchers [137, 151-154] are concerned about the potential impact on food crop productivity and product quality safety, as well as changes in the agroecological state of the soil environment. In our opinion, a compromise option for the relatively safe use of SS as a fertilizer is to apply it under perennial energy crops to obtain biomass [136,143, 165-168].

The use of SS during the cultivation of energy crops is a compromise strategy for reducing municipal waste and increasing the yield of biomass as a source of renewable energy.

One of the most promising energy crops is energy willow (Salix spp.). Due to its high energy and growth rate and adaptability to cultivation on marginal land, which is important because this crop does not compete with food crops for cultivation area.

Studies have shown that the use of SS at rates of 40 – 80 t/ha per growing cycle for energy willow contributes to an increase in the biomass yield by 34-42- %, leading to an improvement in plant biometric indicators, in particular stem diameter and leaf area [158-160].

Overall, the use of SS in energy willow production showed promising results in terms of biomass yield and nutrient supply. However, more research is needed to fully understand the potential risks associated with the use of SS, especially with regard to the accumulation of heavy metals in soil and changes in its agroecological status.

The purpose of our research was to determine the degree of influence of the reuse of sewage sludge and composts based on it on the change of agro-ecological indicators introduced under energy willow.

It is known that a promising way of using SS as a fertilizer is its composting, in particular with cereal straw and tree sawdust [183]. During SS composting, degradation of high-molecular compounds into precursors occurs, then polymerization into humus-like compounds, which play a significant role in humus formation of the soil cover and its phytoremediation, as they can enhance plant growth, contribute to the improvement of water-physical properties of the soil, enrich with nutrients and suppress diseases [197]. Before starting the field experiment, three types of compost were also produced:

1. Compost (SS + sawdust (3:1));
2. Compost (SS + straw (3:1));
3. Compost (SS + straw (3:1) + cement dust 10%).

The main agrochemical indicators were determined in each of the options of manufactured composts.

Field studies to determine the agrochemical efficiency of sewage sludge for growing energy willow on the sod-podzolic soils of Precarpathia were carried out according to the following scheme:

1. Control – without fertilizers; 2. Mineral fertilizers - $N_{100}P_{100}K_{100}$; 3. SS – 40 t/ha; 4. SS – 60 t/ha; 5. SS – 80 t/ha; 6. Compost (SS + sawdust (3:1)) – 60 t/ha; 7. Compost (SS + straw (3:1)) – 20 t/ha; 8. Compost (SS + straw (3:1)) – 40 t/ha; 9. Compost (SS + straw (3:1)) – 60 t/ha; 10. Compost (SS + straw (3:1) + cement dust 10%) – 40 t/ha. Planting scheme of energy willow – 0.33 x 0.70 m. Plot width 4.0 m; length – 7 m; area – 28 m^2. Repetition - three times, placement of plots - systematic.

After the establishment of plantations in our research, the four-year-old willow was cut in autumn so that 8-10 cm of the trunk remained above the soil surface. The following year, after cutting the vegetative mass in early spring, immediately after the cessation of persistent frosts until the germination of the willow cuttings, the soil was loosened between the rows with an improved milling cultivator, and sewage sludge and composts based on sewage sludge and sawdust of coniferous trees, straw of grain crops were re-applied according to the specified scheme of the experiment [157]. Appropriate work was carried out in the first year to ensure the vitality of the plants. In the first year after felling, 5 – 8 branches with a length of about 3 – 4 m sprout from one trunk. The length of the branches depends on the water regime and the level of mineral nutrition. After the end of the fourth year of vegetation, the willow was cut by hand and samples were taken for quantitative analyzes [Lopushniak 2020].Soil samples were taken at a depth of 0 – 20 cm, and green mass (leaves and shoots) and the root system were taken in the summer period, which in the experiment was from June to August. Average values of indicators were determined in the obtained results.

Sampling for agrochemical analyzes was carried out in accordance with DSTU 4287. Determination of the humus content in the soil was carried out according to the Tyurin method according to DSTU 4289; labile forms - after each crop rotation rotation according to DSTU 4732. The fractional group composition of humus was determined by the method of Ponomaryova - Plotnikova according to MVV 31-497058-008. The selection of soil samples for physical and chemical analyzes was carried out in accordance with DSTU ISO 11464. the determination of trace elements and heavy metals was carried out according to the methods of DSTU 4770.1 – DSTU 4770.9. Analysis of plants was carried out according to standard methods: Cu –27995; Zn – 27996; Fe –27998; Mn –27997; Mg –30502; Ca –26570; N –13496; P –26657; K - by the flame-photometric method. Heavy metals and trace elements in the plant were determined by the atomic absorption method. To assess the contamination of energy willow by the content of heavy metals, generally accepted MPCs for plants were used [160]. The biological activity of the soil was determined by the method of appliqués made of linen fabric, which was laid in the 0-40 cm layer of the soil, the essence of which is to quantify the intensity of decomposition of the fiber laid for a certain period of exposure in the soil. Fertilizers were applied before plowing in early spring with a disc harrow. Fertilizer doses were calculated based on the dry organic matter content of fertilizers.

In the process of searching for sensitive test objects for assessing the level of soil toxicity in different versions of the experiment, we germinated the seeds of three different types of plants, namely common flax (*Linum ustatissimum L.*), annual sunflower (*Helianthus annuus L.)*, watercress (*Lepidium saivum L.*).

For the study, testing of soil samples in thermostat conditions was chosen t = (+ 25) °C. 1 g of crushed soil was placed in Petri dishes on filter paper and 5–7 ml of settled boiled tap water was poured. Then 5 seeds of the test culture were laid out. Petri dishes were placed in a thermostat. After 96 hours, the length of the root and stem systems was measured. The phytotoxic effect was determined as a percentage of plant weight, length of root or stem system, number of damaged plants or number of seedlings. Based on the amount of plant mass formed, the phytotoxic effect (PE) was calculated according to the formula:

$$PE = \frac{M_0 - M_x}{M_0} \cdot 100$$

where M_0 is the mass or growth indicators of plants in a Petri dish with control soil;

M_x is the mass or growth rate in a Petri dish with the soil under study.

Processing and generalization of the research results was carried out using the methods of mathematical statistics with the help of the STATISTICA 6.0 and EXEL programs. Systematic application of SS as fertilizer over a long period can increase the content of heavy metals in the soil to a critical level, which can negatively affect plants. The accumulation of heavy metals in plant products also depends on the ability of plants to transform metal forms into a physiologically inactive state [159].

Entering the soil, compounds of heavy metals are transformed and distributed between the phases of the soil due to various physical and chemical processes [159, 178]. Most of the heavy metals have an important biogenic value, and at a low level of their content, a deficiency of elements may occur. Indicators of the mobility of elements are often used to normalize pollution in soil and plants, since an adequate assessment is the condition of plants due to the gross amount of heavy metals absorbed only at high concentrations.

The content of heavy metals in the soil due to the introduction of SS. According to researchers, high soil bioproductivity depends on the content and composition of organic matter and the availability of trace elements for plants. Their lack or excess contributes to the reduction of the harvest and deterioration of its quality.

SS contains a significant amount of trace elements, as well as heavy metals. A certain part of heavy metals can be assimilated by the root systems of cultivated plants. Therefore, there is a danger of heavy metal contamination of agricultural products with the introduction of SS, which is significantly reduced when used for crops that are used for energy purposes.

Among the tasks of the research was to determine the danger of contamination of the soil and plant material of energy willow with heavy metals due to the introduction of SS and composts based on it. The results of the research indicate a significant impact of SS application on the content of mobile compounds of heavy metals in the sod-podzolic soil of Precarpathia, particularly zinc (Fig. 1).

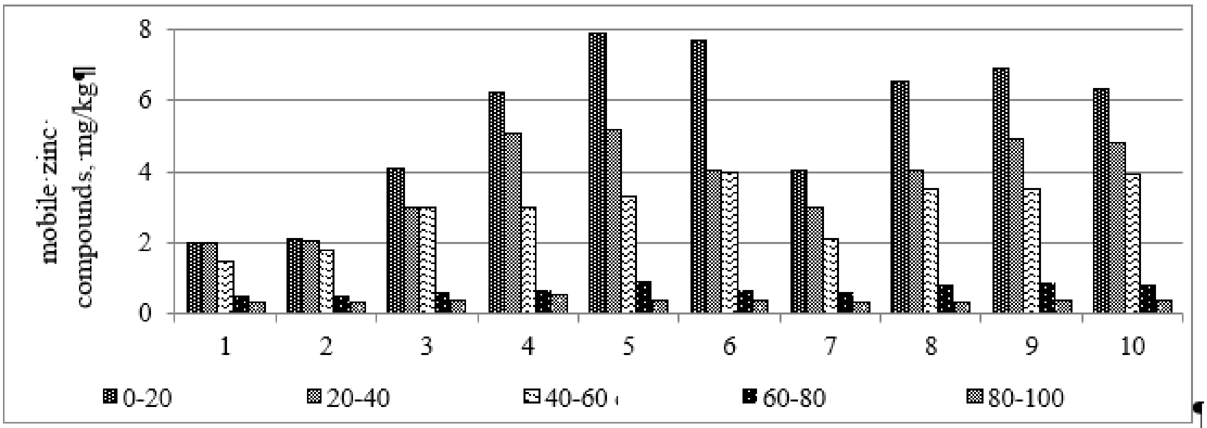

Fig. 1. The content of mobile zinc compounds in the sod-podzolic soil of Precarpathia under the influence of repeated application of sewage sludge, average for 2016-2021:

There is practically no data on the influence of trace elements on the productivity of willow energy in the scientific literature. However, it is known that the lack and excess of trace elements significantly affect the photosynthesis of green plants, the deficiency of Mg, S, Ca, Fe, Mp, Cu, B, Zn, Mo negatively affects the intensity of photosynthesis [142, 141]. Zinc, as a trace element involved in many biochemical processes, is found in the soil in small amounts.

In our research, the content of mobile zinc compounds in the arable (0-20 cm) layer was 2.0 mg/kg of soil in the control without fertilizers. Application of mineral fertilizers increased its content by 0.24 mg/kg of soil compared to the control without fertilizers. The highest index of the content of mobile zinc compounds was observed for the application of SS at a dose of 80 t/ha and compost based on it + sawdust (3:1) at a dose of 60 t/ha, which was 7.9 and 7.8 mg/kg of soil, respectively.

The model of the dependence of the index of the content of mobile zinc compounds in the upper layer (0 – 20 cm) of sod-podzolic soil on the introduction of SS under the energy willow can be described by the following linear regression equation:

$$y = 0{,}4712x + 2{,}8033$$

where *y* is the content of mobile zinc compounds, mg/kg of soil;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination (R^2 = 0.43) indicates a moderate relationship between the content of mobile zinc compounds and the doses of SS application.

In a layer of 20 – 40 cm of soil, the content of mobile zinc compounds in the control without fertilizers was equal to 2 mg/kg of soil, with the application of mineral fertilizers it increased by 0.4 mg/kg compared to the control without fertilizers. The equation for the regression of the content of mobile zinc compounds due to the introduction of SS in this layer took the following form:

$$y = 0{,}2605x + 2{,}3953,$$

where *y* is the content of mobile zinc compounds, mg/kg of soil;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination was (R^2 = 0.41).

In the layer (40 – 60 cm), the zinc content in the control without fertilizers was 1.5 mg/kg of soil. With the introduction of fresh SS, its content increased by 1.0 – 2.4

mg/kg of soil compared to the control without fertilizers, the zinc content of composts based on SS was 3.0 – 4.9 mg/kg of soil.

The model of the dependence of the content of mobile zinc compounds on the introduction of SS can be described by the following linear regression equation:

$$y = 0{,}2034x + 1{,}8673$$

where *y* is the content of mobile zinc compounds, mg/kg;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination was ($R^2 = 0.50$).

The dependence of the content of zinc in the soil on the added SS at a depth of 60 – 80 cm can be described by the following regression equation:

$$y = 0{,}0281x + 0{,}5873,$$

where *y* is the content of mobile zinc compounds, mg/kg of soil;

x – dose of SS application under energy willow, t/ha.

The multiple coefficient of determination was ($R^2 = 0.49$), and at a depth of 80-100 cm of the soil - ($R^2 = 0.47$), which indicates a moderate relationship between the dose of SS application and the content of mobile forms of zinc along the entire turf- of podzolic soil to a depth of 1 m. At a depth of 80 – 100 cm, the zinc content was the same according to the test options and amounted to 0.4 mg/kg. It should be noted that the content of zinc in the options where composts based on SS were applied is lower than in the options where fresh SS was applied.

Lead belongs to toxic pollutants and especially dangerous heavy metals. Among all heavy metals, it is the least labile, and its content in soils is relatively low and varies depending on the type of soil.

In our studies, the content of lead at a depth of 0 – 20 cm ranged from 1.18 to 1.90 mg/kg of soil (Fig. 2).

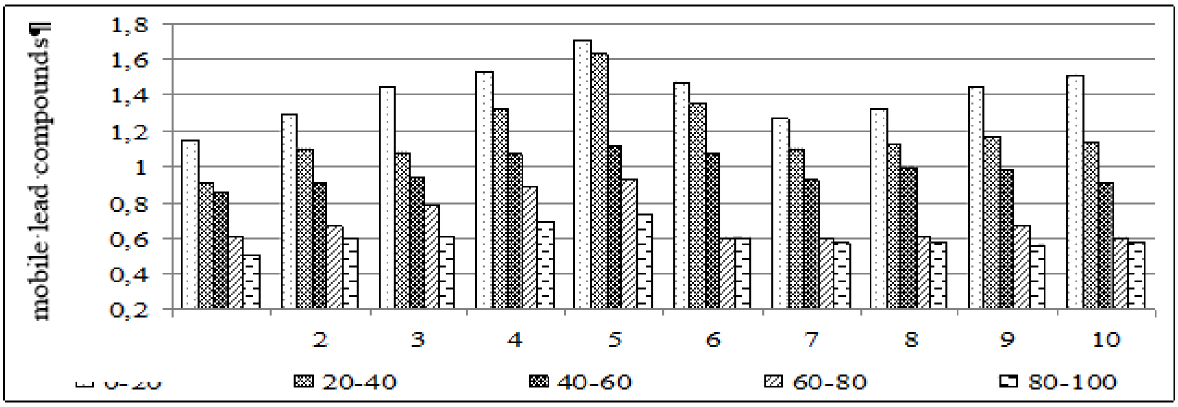

Fig. 2 The content of mobile lead compounds in sod-podzolic soil under the influence of repeated application of sewage sludge, average for 2016-2021:

Indicators of the content of mobile forms of lead depended on the doses and forms of applied fertilizers. The application of mineral fertilizers contributed to an increase in the content of mobile lead compounds by 0.7 mg/kg of soil. We observed a clear line of growth of the index of lead content in sod-podzolic soil during the application of SS. In particular, with an increase in the doses of SS application from 40 to 80 t/ha, the content of this element increased to 1.7 mg/kg of soil in the arable (0-20 cm) layer. The effect of increased doses of lead in the soil is neutralized by adding copper to the soil. The researchers studied the process of lead accumulation in the soil. Lead enters the soil from the atmosphere most often in the form of oxides, where it gradually dissolves, turning into hydroxides, carbonates, or the form of cations.

With the introduction of composts based on SS, the indicator of lead content increased compared to the control and decreased compared to the options where fresh SS was applied. Comparing the option where compost was applied based on SS and straw (3:1) at the rate of 40 t/ha, and the option with the same dose of compost only with the addition of 10% cement dust, the lead content in the soil was 1.3 mg/kg of soil, which is 0.1 more compared to the application of SS compost + straw (3 : 1) – 40 t/ha. Therefore, mobile lead compounds were concentrated in the upper (0-20 cm) layer of sod-podzolic soil.

Copper is one of the least mobile elements in soil. The degree of mobility of this element depends on the acidity of the soil and the conditions of the soil environment [169]. In soils, copper is contained in the form of salts and complex organometallic compounds. Copper in soils can be in a water-soluble form, exchangeable and absorbed by colloids. This element has a positive effect on drought resistance and frost resistance of plants. It affects the assimilation and translocation of a number of other trace elements in plants.

Our research established the dependence of the copper content in the soil on the application of SS and composts based on it (Fig. 3).

The content of mobile copper compounds in the arable (0 – 20 cm) soil layer in the control without fertilizers was 5.8 mg/kg of soil. With the introduction of mineral fertilizers, this indicator increased by 3.2 compared to the control without fertilizers and was 9 mg/kg of soil. Under the influence of the application of fresh SS, the content of mobile copper compounds gradually increased with increasing doses of SS application, in particular, in the version where it was applied at a dose of 80 t/ha, the content of mobile copper compounds was 9.9 mg/kg of soil, which is 4.1 mg /kg of soil is greater than the control without fertilizers.

In the control variant in the arable (0-20 cm) soil layer, the content of mobile copper compounds was 6.1 mg/kg of soil, and in the variants where fertilizers were applied, it ranged from 8.0 to 11.4 mg/kg of soil.

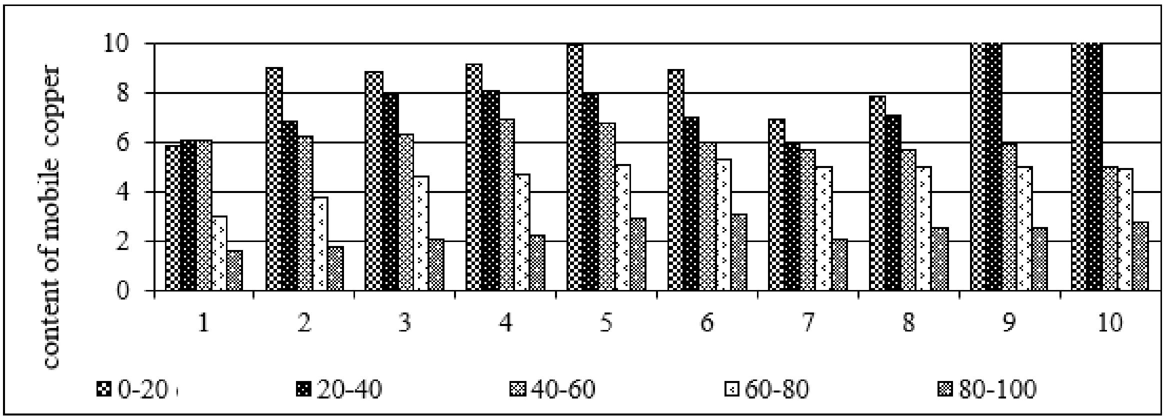

Fig. 3 Dynamics of the content of mobile copper compounds in sod-podzolic soil depending on the re-introduction of sewage sludge, average for 2016-2021:

Dynamic changes in the content of mobile copper compounds in the soil under the influence of fertilizers can be described by the following regression equation:

$$y = 0,3211x + 7,122$$

where y is the content of mobile copper compounds, mg/kg of soil;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination was (R^2 = 0.31), which indicates a weak relationship between the doses of SS application and the increase in the content of mobile copper compounds.

The content of mobile copper compounds in the subsoil layer can be described by the following regression equation:

$$y=0,4523x+5,5713$$

where y is the content of mobile copper compounds, mg/kg of soil;

x – dose of re-introduction of sewage sludge under energy willow, t/ha.

The multiple coefficient of determination compared to the similar indicator in the 0-20 cm layer grew and was (R^2 = 0.43), which indicates a moderate relationship between applied fertilizers and the content of mobile copper compounds. The content of mobile copper compounds in the 40-60 cm layer ranged from 6.1 to 6.9 mg/kg of soil.

The dependence of the content of mobile compounds of copper on the application of fertilizers, namely SS, can be described by the following regression equation:

$$y= –01171x + 6,704$$

where y is the content of mobile copper compounds, mg/kg of soil;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination was (R^2 = 0.42), which also indicates a moderate relationship at a depth of 20 – 40 cm.

As the depth increased, the dependence of the content of mobile copper compounds on the dose of applied SS increased. Thus, at a depth of 60 – 80 cm, the regression equation took on the following form:

$$y = 0,1725x + 3,694$$

where y is the content of mobile copper compounds, mg/kg of soil;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination was (R^2 = 0.55), which indicates a significant relationship between the introduced SS and the increase in the content of mobile copper compounds.

Dependence of the content of mobile copper compounds on applied fertilizers at depth 80 – 100 cm can be described by the following regression equation:

$$y = 0{,}1089x + 1{,}762$$

where y is the content of mobile copper compounds, mg/kg;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination was (R^2 = 0.47), which indicates a moderate relationship between applied fertilizers and an increase in the content of mobile copper compounds.

A low content of cobalt in the soil causes chlorosis, necrosis and even drying of leaves, and its excess can harm the consumption and assimilation of other trace elements. Cobalt is contained in the soil less than other trace elements. The amount of cobalt largely depends on soil-forming and biological processes, the presence of iron and manganese in these soils [171].

As a result of research, the relationship between applied fertilizers and the content of mobile cobalt compounds was revealed. The content of mobile cobalt compounds increased in all layers of the sod-podzolic soil with the introduction of SS (Fig. 4).

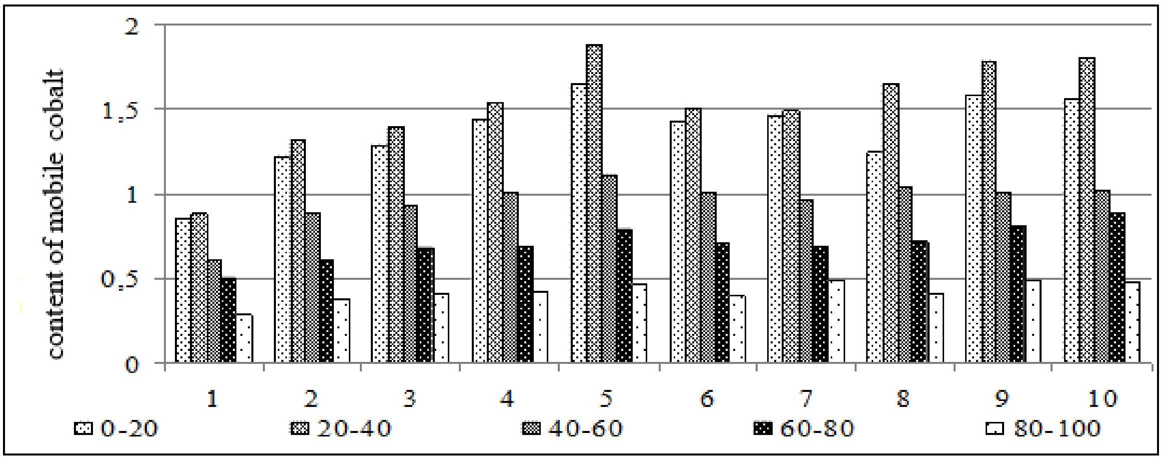

Fig. 4. Dynamics of the content of mobile cobalt compounds in sod-podzolic soil depending on the re-introduction of sewage sludge, average for 2016-2021:

An increase in the rate of introduction of SS provided an increase in the content of mobile cobalt. The regression model of the content of mobile forms of cobalt under the influence of the application of various fertilizers under the energy willow in the arable (0 – 20 cm) layer can be described by the following regression equation:

$$y = 0{,}0524x + 1{,}0867,$$

where y is the content of mobile forms of cobalt, mg/kg of soil;

x – the dose of repeated application of SS, t/ha.

The multiple coefficient of determination ($R^2 = 0.45$) indicates a moderate relationship between increasing SS doses and the content of mobile forms of cobalt in the soil.

A similar trend remained in the 20 – 40 cm layer, but the absolute indicators of the content of mobile forms of cobalt were somewhat higher. The dependence of the content of mobile forms of cobalt on the use of fertilizers for energy willow can be described by the following regression equation:

$$y = 0{,}0748x + 1{,}1153$$

where y is the content of mobile forms of cobalt, mg/kg;

x – dose of re-introduction of sewage sludge under energy willow, t/ha.

The multiple coefficient of determination ($R^2 = 0.61$) indicates a stronger relationship between the introduction of sewage sludge and the content of mobile forms of cobalt in the soil compared to the upper (0 – 20 cm) layer.

In the 40-60 cm layer, a trend similar to the upper layer was preserved. The ratio between the mobile forms of cobalt decreased according to individual options according to the doses of SS application, and the multiple regression equation took the following form:

$$y = 0{,}0293x + 0{,}798$$

where y is the content of mobile forms of cobalt, mg/kg of soil;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination was $R^2 = 0.42$.

In the 60 – 80 cm layer, the dependence of the amount of mobile forms of cobalt on the introduction of SS can be described by the following linear regression equation:

$$y = 0{,}0299x + 0{,}5453$$

where y is the content of mobile forms of cobalt, mg/kg;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination (R^2 = 0.76) indicates a significant relationship between increasing SS doses and the content of mobile forms of cobalt compounds in the soil.

In the 80-100 cm layer, the dependence of the content of mobile forms of cobalt on the introduction of SScan be described by the following regression equation:

$$y = 0{,}0159x + 0{,}335$$

where y is the content of mobile forms of cobalt, mg/kg;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination was R^2 = 0.62.

The analysis of the indicators of the multiple coefficient of determination of the content of mobile cobalt compounds in the soil depending on the introduction of SS by soil layers indicates an increase in dependence with depth, which may indicate a certain migration of this element along the soil profile.

The cobalt content in the upper layer (0-20 cm) in the control was 0.85 mg/kg of soil. With the introduction of fresh SS, the content of mobile cobalt compounds increased to 1.29-1.65 mg/kg, which is 0.44-0.80 mg/kg of soil more than the control without fertilizers. With the introduction of composts based on SS, the content of mobile cobalt compounds decreased compared to the options where fresh SS was applied and amounted to 1.43 - 1.59 mg/kg of soil.

The content of mobile forms of cobalt decreased down the profile and at a depth of 80-100 cm was 0.3 mg/kg of soil in the control without fertilizers. When applying fresh SS, the content of mobile cobalt was 0.41-0.46 mg/kg of soil, composts based on SS - 0.40-0.49 mg/kg of soil.

The level of nickel concentration in the soil depends on soil-forming processes and man-made pollution. The highest nickel content is noted in clayey and loamy soils and soils rich in organic substances. The nickel content in soils is 0.004%, in natural surface waters - 0.00000034%.

M.M. Miroshnychenko points out the danger of nickel migration through the soil profile into the lower layers.

Our research established that the content of mobile forms of nickel depends on the use of SS, composts based on it, and mineral fertilizers. As the SS dose decreased, the content of mobile forms of nickel decreased (Fig. 5).

The content of mobile forms of nickel in the control without fertilizers was 0.95 mg/kg in the upper (0-20 cm) soil layer. With the introduction of mineral fertilizers, the content of this element increased by 0.14 mg/kg of soil compared to the control without fertilizers.

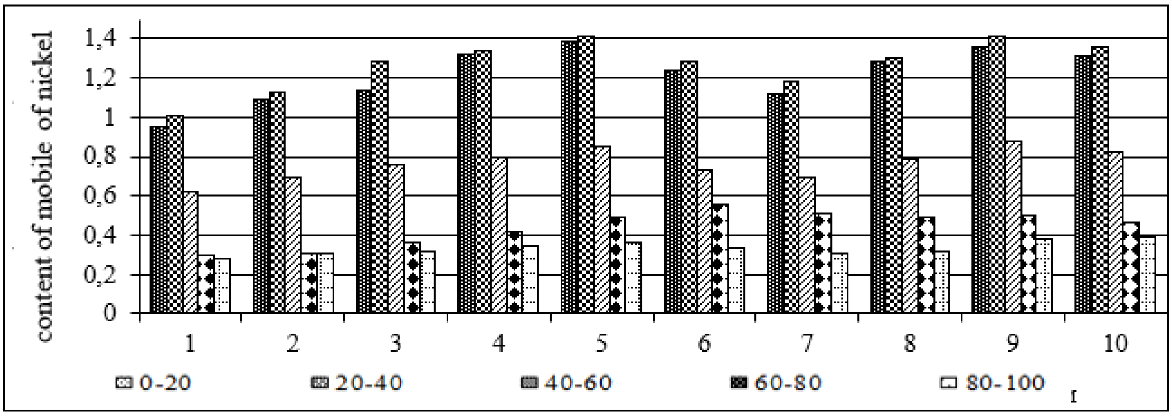

Fig. 5 Dynamics of the content of mobile forms of nickel in the soil along the 0-100 cm profile, average for 2016-2021:

With the introduction of fresh SS the content of mobile forms of nickel was 1.14 - 1.39 mg/kg of soil. In particular, when applying composts based on SS + straw (3:1) at a dose of 40 t/ha, the content of mobile forms of nickel was 1.28 mg/kg of soil.

The content of this element in the subsoil (20 – 40 cm) layer of the soil increased and amounted to 1.01 mg/kg of soil in the control variant.

With the introduction of mineral fertilizers, the nickel content increased by 0.12 mg/kg, compared to the control without fertilizers. When SS was applied, the content of mobile forms of nickel was 1.28 mg/kg - 1.41 mg/kg of soil, that is, it increased by 0.27 - 0.40 mg/kg, depending on the dose of SS application.

With depth, the nickel content gradually decreased and at a depth of 80 - 100 cm was at the level of 0.28 mg/kg of soil in the control without fertilizers and increased to 0.31 - 0.36 mg/kg of soil in the variants with application of SS. When applying composts based on SS + straw (3:1) + cement dust 10% at a rate of 40 t/ha, the nickel content was 0.39 mg/kg of soil.

The dynamics of the content of mobile forms of nickel in the 0-20 cm layer under the influence of the introduction of SS under the energy willow can be described by the following linear regression equation: $y = 0,0308x + 1,0507$

where y is the content of mobile nickel compounds, mg/kg of soil;

x – the dose of re-application of SS under energy willow, t/ha.

The closeness of the relationship between applied fertilizers and the content of mobile nickel compounds in the soil can be estimated as moderate, since the value of the multiple coefficient of determination (R^2) was at the level of 0.44, which in the deeper layers of the soil remained at the level of values of 0.41 - 0.43 .

The obtained results of the nickel content in the soil testify to the process of accumulation of this element in the upper layers of the soil.

N. A. Makarenko and other researchers claim that cadmium harms the development and growth of green plants. Cadmium is a rare element, but its soil contamination is one of the most dangerous environmental phenomena. Cadmium enters the atmosphere through the burning or processing of plastic products. The average content of cadmium in the soil ranges from 0.2 to 4.0 mg/kg of soil. Cadmium in the soil is mainly in ion-exchangeable forms. Hrebelna N.V. [192] claims that most of the cadmium is fixed in the arable (0-20 cm) layer, and the rest is redistributed along the profile depending on the content of organic substances. Other researchers confirm that organic compounds have the ability to fix cadmium in the soil. With a low content of humus, the migration of cadmium along the profile occurs more intensively.

In our studies, the content of cadmium in the soil profile varied depending on the doses of SS application (Fig. 6).

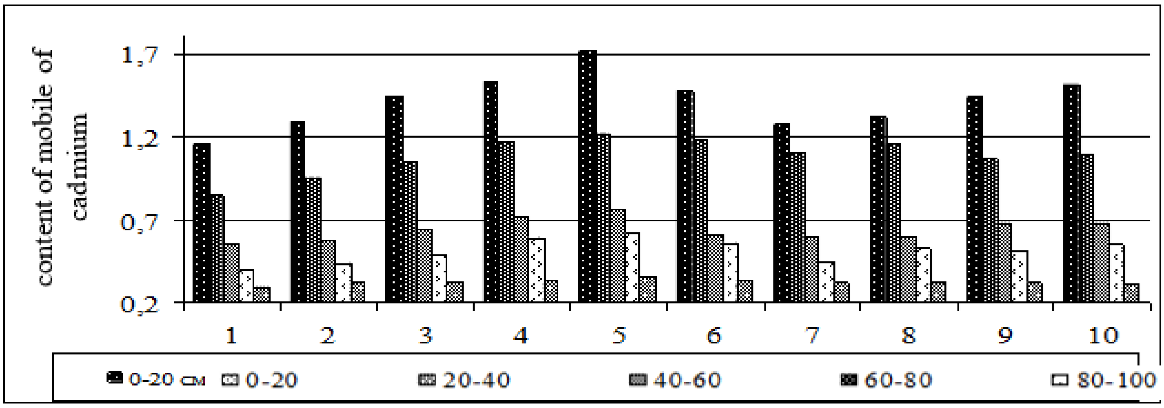

Fig. 6 Dynamics of the content of mobile forms of cadmium in sod-podzolic soil under the influence of repeated application of sewage sludge, average for 2016-2021.

The indicator of cadmium content in the upper (0-20 cm) layer in the control version was 1.15 mg/kg of soil. With the introduction of SS at the rate of 40-80 t/ha, the content of this element increased from 1.30 to 1.71 mg/kg of soil, respectively.

In the soil layer of 20-40 cm, the cadmium content was determined to be the highest after applying 80 t/ha of sewage sludge and amounted to 1.22 mg/kg of soil, which was 0.37 mg/kg of soil higher than the control without fertilizers. The 60-80 cm soil layer contained the least amount of cadmium in the control variant. With the application of fertilizers, the content of this pollutant varied between 0.58 and 0.76 mg/kg of soil. At a depth of 80-100 cm, the cadmium content was within 0.30-0.36 mg/kg of soil. Iron in the soil is mainly in the form of oxides and hydroxides. Iron, together with manganese, as well as oxygen and hydrogen, forms a redox regime in soils [189]. In our research, a certain dependence of the content of mobile iron compounds on the introduced SS and composts based on it was recorded (Fig. 7).

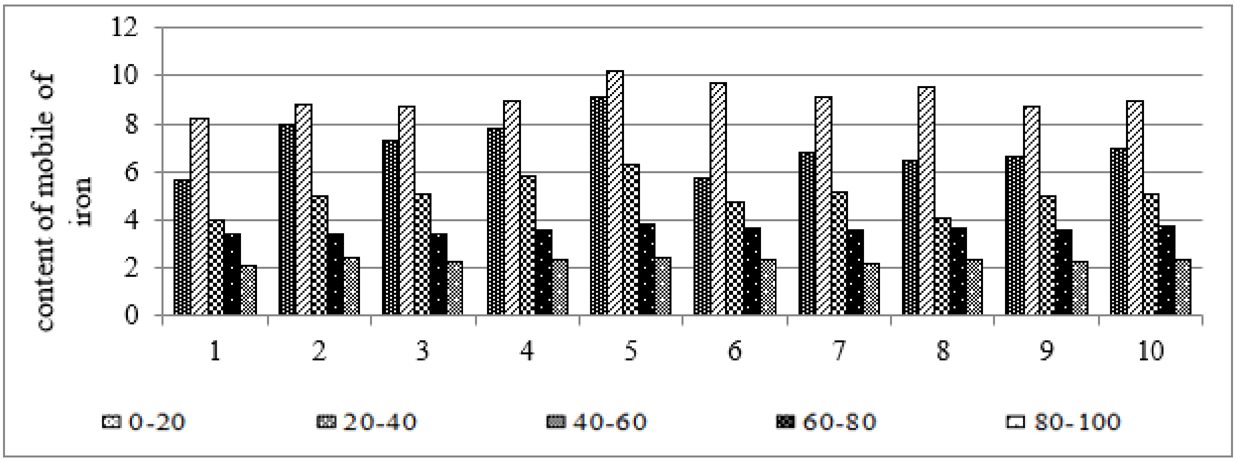

Fig. 7 Dynamics of the content of mobile iron compounds in sod-podzolic soil under the influence of repeated application of sewage sludge, average for 2016-2021.

The introduction of mineral fertilizers provided a slight increase in the content of mobile forms of iron, and the use of sewage sludge contributed to a certain decrease of mobile forms of iron to 5.43 mg/kg. The increase in the content of mobile iron compounds, especially in the upper layers of the soil, was facilitated by the application of SS. The use of SS-based composts significantly reduced the content of mobile iron compounds in the soil.

The regression model of the content of mobile forms of iron under the influence of different fertilization systems in the arable (0-20 cm) layer can be described by the following equation:

$$y = 0.3561x + 9.1673$$

where y is the content of mobile forms of iron, mg/kg of soil;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination ($R^2 = 0.43$) indicates a moderate relationship between the increase in the dose of SS application and the content of mobile forms of iron in the soil. A similar trend remained in the 20-40 cm layer, but the absolute indicators of the content of mobile forms were somewhat lower. The dependence of the content of mobile forms of iron on the application of fertilizer systems can be described by the following regression equation:

$$y = 0.3169x + 10.828$$

where y is the content of mobile forms of iron, mg/kg of soil;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination (R^2 = 0.42) also indicates a moderate relationship between the introduction of SS and the content of mobile forms of iron in the soil.

In the 40-60 cm layer, a trend similar to that observed in the upper layers was preserved. The ratio between the mobile forms of iron decreased according to individual options depending on the doses of SS application, and the regression equation took the following form:

$$y = 0{,}2392x + 6{,}8493$$

where y is the content of mobile forms of iron, mg/kg of soil;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination was R^2 = 0.43.

In the 60-80 cm layer, the regression equation took the following form:

$$y = 0.0685x + 3.164$$

where y is the content of mobile forms of iron, mg/kg of soil;

x – the dose of re-application of SS under energy willow, t/ha.

The multiple coefficient of determination (R^2 = 0.36) indicates a weak relationship between the reduction of SS doses and the content of mobile forms of iron in the soil.

In the 80-100 cm layer, the dependence can be described by the following regression equation:

$$y = 0.0351x + 2.572$$

where y is the content of mobile forms of iron, mg/kg of soil;

x – the dose of re-application of SS under energy willow, t/ha.The multiple coefficient of determination was R^2 = 0.36.

The results of the analyzes show that the content of mobile iron compounds under the conditions of the experiment was higher with the application of fresh SS and with the mineral fertilizer system compared to the control without fertilizers. In our opinion, this is due to an increase in general acidity in the arable (0-20 cm) and sub-arable (20-40 cm) layers of the sod-podzolic soil. Comparing the indicators of the content of mobile forms of iron in the meter layer, it should be noted that mobile compounds are mainly concentrated in the underground (20-40 cm) layer. The iron content in the control without fertilizers at a depth of 0-20 cm was 5.66 mg/kg. With the introduction of mineral fertilizers, the content of mobile iron compounds increased to 7.98 mg/kg of soil. With the introduction of fresh SS, the iron content increased, in particular, at a dose of 80 t/ha, it was 9.08 mg/kg of soil, which is 3.42 mg/kg of soil higher compared to the control without fertilizers. At a depth of 20-40 cm, the content of this element was 8.23 mg/kg of soil in the control without fertilizers.With the introduction of SS, the index of mobile forms of iron was 8.71–10.23 mg/kg of soil. The content of mobile forms of iron increased by 0.49 - 1.30 mg/kg of soil when composts based on SS were applied compared to the control.

An increased content of iron in the soil was observed after applying compost based on SS and straw (3:1) - 60 t/ha, which was 9.68 mg/kg of soil at a depth of 20-40 cm. The content of mobile forms of iron gradually decreases along the soil profile and at a depth of 80 - 100 cm it was 2.13 - 2.44 mg/kg of soil, which is 0.06 - 0.32 mg/kg of soil more compared to the control without fertilizers.

Therefore, it can be stated that the mobile forms of iron are concentrated in the subsoil (20-40 cm) layer of the soil, and their content increases with increasing doses of SS application. Soil is a specific component of the biosphere, as it not only geochemically accumulates pollution components, but is a natural buffer that controls the transfer of chemical elements and compounds into the atmosphere, hydrosphere, and living matter. A variety of soil types, plant species, and growing conditions affect the state of lead, cadmium, and other pollutants in ecosystem components. Soil resistance to lead and cadmium contamination is determined by the critical levels of these metals, at which toxic effects are detected in plants and in the environment as a whole, and is closely related to the cation exchange capacity. Application of SS and composts based on them under energy willow in sod-podzolic soil affected the total content of heavy metals and the share of their mobile forms (Table 1).

Table 1. The content of heavy metals in the soil after re-introduction of sewage sludge, average for 2016-2021.

option	Tightly bound form				A moving form				Share of movable form from gross form, %			
	мг/кг грунту											
	Pb	Cd	Ni	Co	Pb	Cd	Ni	Co	Pb	Cd	Ni	Co
	11,93	0,52	16,51	11,41	1,15	0,09	1,05	1,05	9,6	17,3	6,4	9,2
	12,78	0,78	17,11	11,72	1,29	0,10	1,20	1,22	10,1	12,8	7,0	10,4
	13,51	0,71	18,16	11,69	1,44	0,13	1,27	1,29	10,7	18,3	7,0	11,0
	14,62	0,74	19,12	13,41	1,53	0,14	1,36	1,54	10,5	18,9	7,1	11,5
	16,10	0, 91	20,51	13,59	1,75	0,18	1,45	1,65	10,8	19,7	7,2	12,1
	13,68	0,73	19,10	13,11	1,47	0,14	1,30	1,53	10,7	19,1	6,8	11,7
	12,85	0,65	18,11	12,38	1,27	0,12	1,22	1,17	9,9	18,5	6,7	9,5
	13,49	0,69	18,49	13,10	1,32	0,12	1,12	1,25	9,7	17,3	6,1	9,5
	14,61	0,77	19,47	13,53	1,40	0,13	1,16	1,30	9,6	16,8	6,0	9,5
	15,71	0,89	20,10	13,69	1,51	0,15	1,21	1,31	9,6	16,8	6,0	9,5
IP$_{0,5}$	1,34	0,26	1,50	1,41	1,12	0,01	0,11	0,15				
normal	30,0	3,0	85,0	50,0	6,0	0,7	4,0	5,0				

The content of tightly bound forms of such metals as lead, cadmium, nickel and cobalt did not exceed permissible norms in the soil. When SS was applied at a dose of 80 t/ha, the content of metals was the highest compared to the control without fertilizers, in particular, the content of lead was 16.10 mg/kg of soil, cadmium – 1.01 mg/kg of soil, nickel and cobalt were at the level of 20, respectively. 51 and 13.59 mg/kg of soil.

The indicator of the content of mobile forms of cadmium did not exceed the maximum permissible concentration of this element in the soil. Indicators of the content of mobile forms of cobalt, nickel and cadmium increased in the arable (0 – 20 cm) and decreased in the sub-arable (20 – 40 cm) soil layer, compared to the control without fertilizers.

The indicator of the content of mobile forms of nickel reflected some accumulation of this element at a depth of 20 – 40 cm in sod-podzolic soil. With the introduction of SS, the content of mobile forms of cobalt increases by 0.24 – 0.60 mg/kg of soil, nickel by 0.19 – 0.34 mg/kg of soil, cadmium by 0.29 – 0.56 mg/kg of soil, lead at 0.24 – 0.51 mg/kg of soil.It should be noted that for heavy metals, which are introduced into the soil together with SS, there are often additional conditions for changes in mobility. Accumulation of mobile forms of heavy metals occurs in soil with a low content of organic matter. At the same time, their transition into a sedentary form occurs all the more intensively due to the increase in humic acids in the composition of humus.

We determined the proportion of mobile forms of heavy metals from the firmly bound form and established its dependence on the doses of sewage sludge and composts introduced into the soil. For cobalt, this dependence can be presented in the form of a graph (Fig. 8 and Fig. 9). The dependence of the content of the share of mobile forms of cobalt on the doses of sewage sludge application can be described by the following linear regression equation:

$$y = 0.92x + 8.65$$

where y is the share of mobile forms of cobalt in sod-podzolic soil under the influence of applying fresh SS, %; x – dose of fresh sewage sludge application, t/ha. The high correlation between the introduction of fresh SS and the content of the share of mobile forms of cobalt in the sod-podzolic soil is confirmed by the value of the multiple coefficient of determination (R^2 = 0.90).

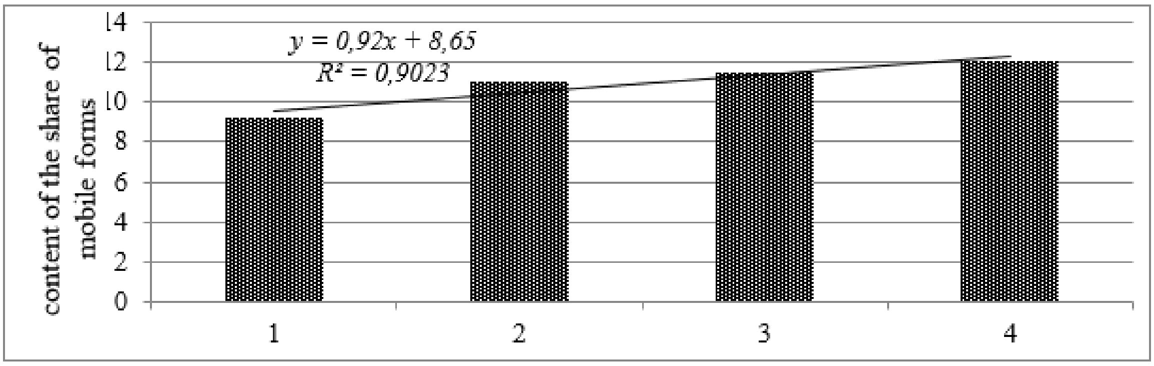

Fig. 8 Dependence of the content of the share of mobile forms of cobalt on the dose of re-introduction of sewage sludge in the sod-podzolic soil of Precarpathia:

1. Control – without fertilizers; 2. SS - 40t/ha; 3. SS - 60t/ha; 4. SS - 80 t/ha.

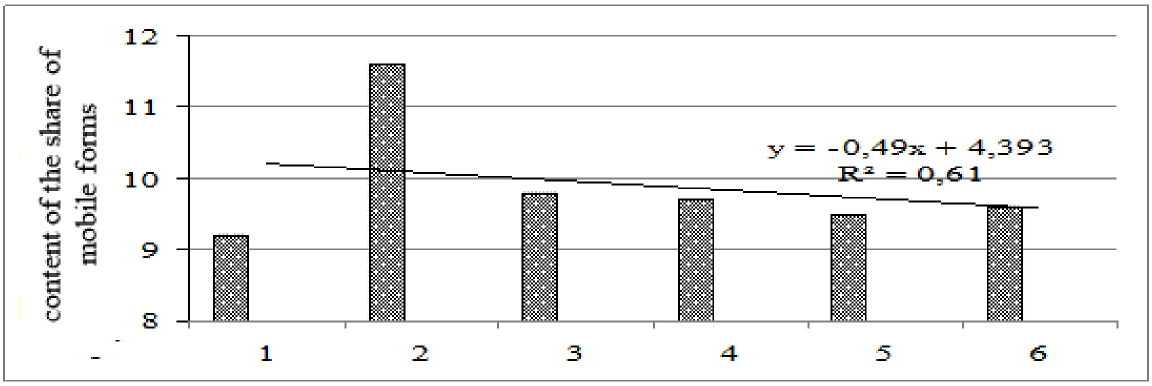

Fig. 9 Dependence of the content of the share of mobile forms of cobalt on the dose of repeated application of composts based on sewage sludge in the sod-podzolic soil of Precarpathia:

1. Control – without fertilizers; 2. Compost (SS + sawdust (3:1)) – 60 t/ha; 3. Compost (SS + straw (3:1)) – 20 t/ha; 4. Compost (SS + straw (3:1)) – 40 t/ha; 5. Compost (SS + straw (3:1)) – 60t/ha; 6. Compost (SS + straw (3:1) + cement dust 10%) – 40 t/ha.

The dependence of the content of the share of mobile forms of cobalt on the dose of composting based on sewage sludge can be described by the following linear regression equation:

$$y = -0.49x + 4.393$$

where y is the share of mobile forms of cobalt in sod-podzolic soil under the influence of applying fresh SS, %; x – the dose of repeated application of composts based on SS, t/ha. Determining the share of mobile forms of nickel in the soil depending on the dose of sewage sludge and compost application, a high dependence was established (Fig. 10 and Fig. 11). The dependence of the content of the share of mobile forms of nickel on the dose of sewage sludge application can be described by the following linear regression equation:

$$y = 0.25x + 6.3$$

where y is the share of mobile forms of nickel in sod-podzolic soil under the influence of applying fresh SS, %; x – application dose of SS, t/ha. Multiple coefficient of determination ($R^2 = 0.80$).

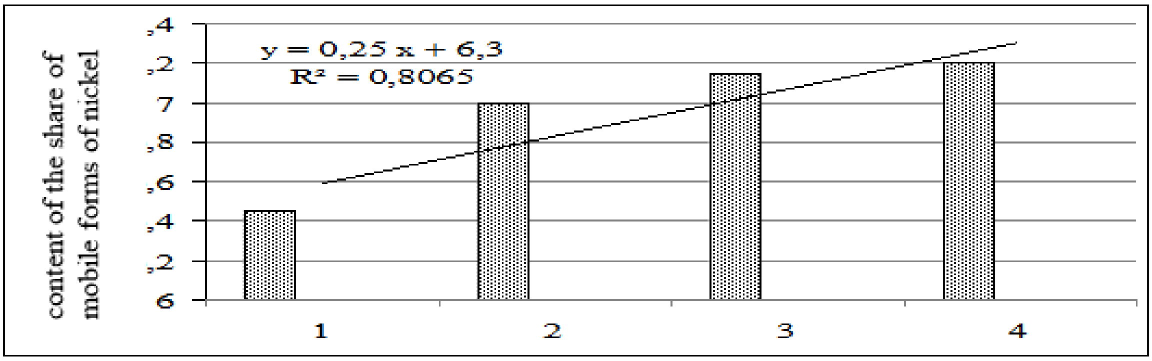

Fig. 10 Dependence of the content of the share of mobile forms of nickel on the dose of re-introduction of sewage sludge in the sod-podzolic soil of Precarpathia:

1. Control – without fertilizers; 2. SS - 40t/ha; 3. SS - 60t/ha; 4. SS - 80 t/ha.

The dependence of the content of the share of mobile forms of nickel on the dose of composting based on sewage sludge can be described by the following linear regression equation:

$$y = 0.23x + 7.24$$

where *y* is the share of mobile forms of nickel in sod-podzolic soil under the influence of applying fresh SS, %; *x* – the dose of repeated application of composts based on SS, t/ha. The multiple coefficient of determination $R^2 = 0.84$ shows a high degree of connection.

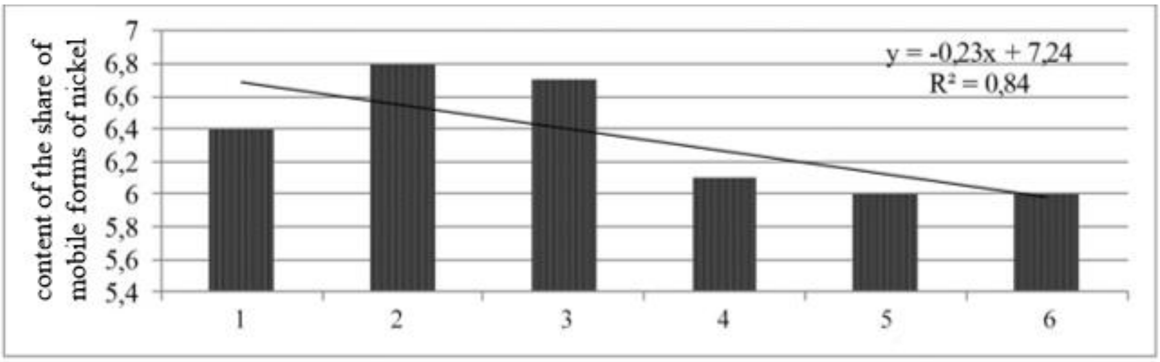

Fig. 11 Dependence of the content of the share of mobile forms of nickel on the dose of repeated application of composts based on sewage sludge in the sod-podzolic soil of Precarpathia:

1. Control – without fertilizers; 2. Compost (SS + sawdust (3:1)) – 60 t/ha; 3. Compost (SS + straw (3:1)) – 20 t/ha; 4. Compost (SS + straw (3:1)) – 40 t/ha; 5. Compost (SS + straw (3:1)) – 60t/ha; 6. Compost (SS + straw (3:1) + cement dust 10%) – 40 t/ha.

In our research, the share of mobile forms of cadmium in the soil depends on the dose of fresh SS and composts (Fig. 12 and Fig. 13). The dependence of the content of the share of mobile forms of cadmium on the rate of introduction of sewage sludge can be described by the following linear regression equation:

$$y = 0{,}78x + 16{,}6$$

where y is the share of mobile forms of cadmium in sod-podzolic soil under the influence of applying fresh SS, %; x – the dose of repeated application of SS, t/ha. The high closeness of the relationship between the application of fresh SS and the share of mobile forms of cadmium in the sod-podzolic soil is confirmed by the high value of the multiple coefficient of determination (R^2 = 0.99).

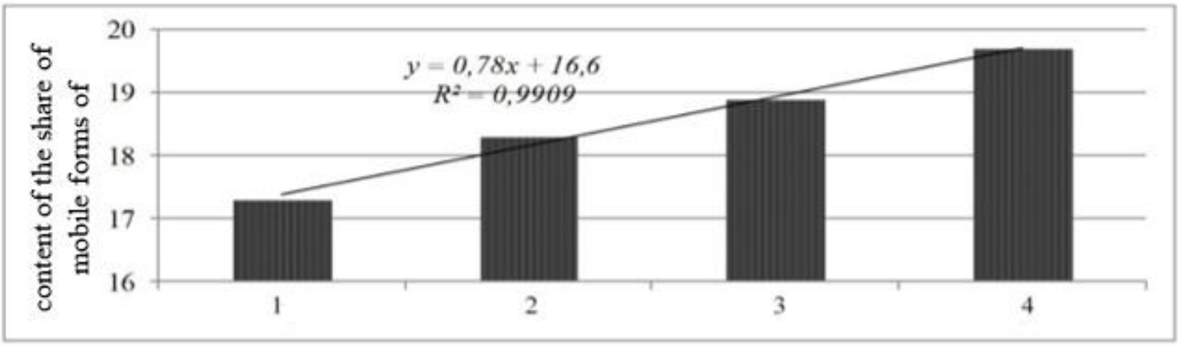

Fig. 12 Dependence of the content of the share of mobile forms of cadmium on the dose of repeated application of sewage sludge in the sod-podzolic soil of Precarpathia:

1. Control – without fertilizers; 2. SS - 40t/ha; 3. SS - 60t/ha; 4. SS - 80 t/ha.

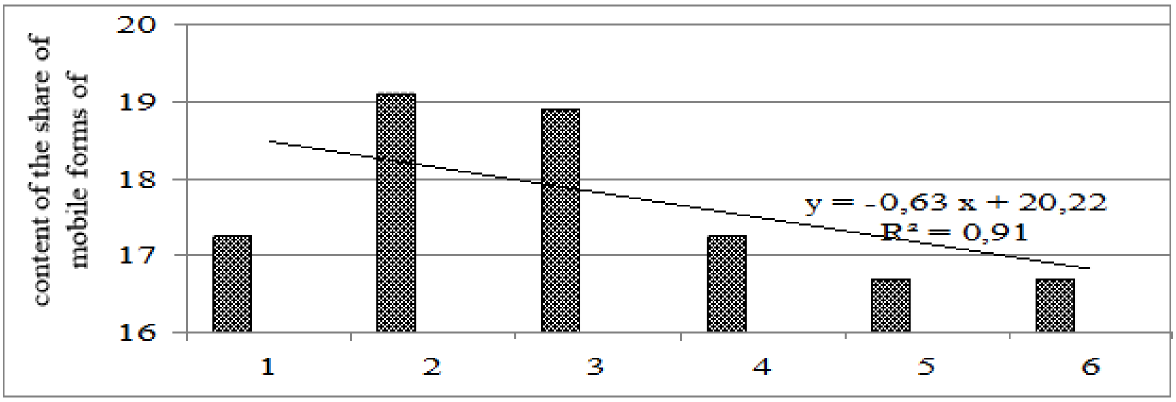

Fig. 13 Dependence of the content of the share of mobile forms of cadmium on the dose of repeated application of composts based on sewage sludge in the sod-podzolic soil of Precarpathia:

1. Control – without fertilizers; 2. Compost (SS + sawdust (3:1)) – 60 t/ha; 3. Compost (SS + straw (3:1)) – 20 t/ha; 4. Compost (SS + straw (3:1)) – 40 t/ha; 5. Compost (SS + straw (3:1)) – 60 t/ha; 6. Compost (SS + straw (3:1) + cement dust 10%) – 40 t/ha.

The dependence of the content of the share of mobile forms of cadmium on the dose of application of composts based on sewage sludge can be described by a linear regression equation, which has the following form:

$$y = – 0638x + 20,22$$

The multiple coefficient of determination R^2 = 0.91 shows a high degree of connection. The share of mobile forms of lead due to the application of SS in the sod-podzolic soil of Precarpathia is closely related, like other metals, to the content of humic acids in humus (Fig. 14 and Fig. 15). The dependence of the share of mobile forms of lead on the dose of sewage sludge application can be described by the following linear regression equation:

$$y = 0,34x + 9,55$$

where *y* is the content of the share of mobile from gross forms of lead in sod-podzolic soil under the influence of applying fresh SS, %; *x* – the dose of repeated application of SS, t/ha. A significant correlation between the introduction of fresh SS and the share of mobile forms of lead in turf-podzolic soil is confirmed by the value of the multiple coefficient of determination (R^2 = 0.64).

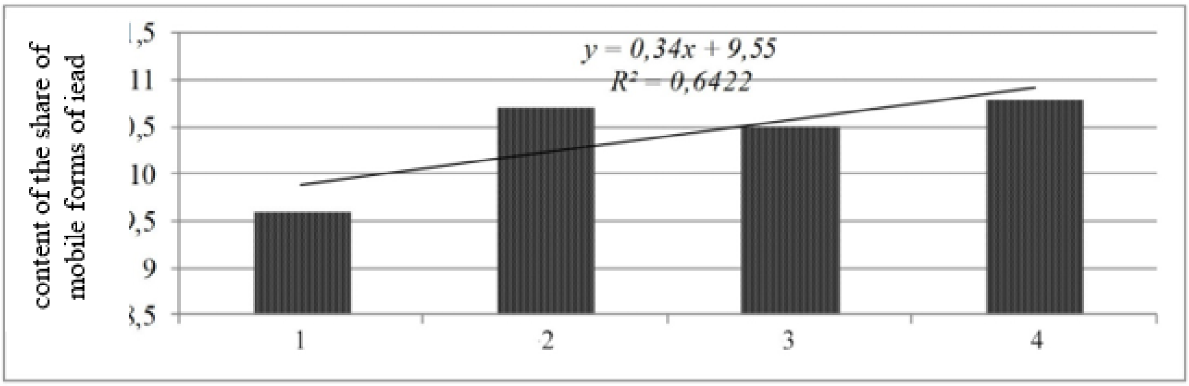

Fig. 14 Dependence of the share of mobile forms of lead on the dose of re-introduction of sewage sludge in the sod-podzolic soil of Precarpathia:

1. Control – without fertilizers; 2. SS - 40 t/ha; 3. SS - 60t/ha; 4. SS - 80 t/ha.

The dependence of the content of the share of mobile forms of lead on the dose of composting based on sewage sludge can be described by the following linear regression equation:

$$y = -0{,}25x + 10{,}9$$

where y is the content of the share of mobile from gross forms of lead in sod-podzolic soil under the influence of applying fresh SS, %; x – doses of compost application based on SS, t/ha. The significant relationship is confirmed by the value of the multiple coefficient of determination ($R^2 = 0.73$).

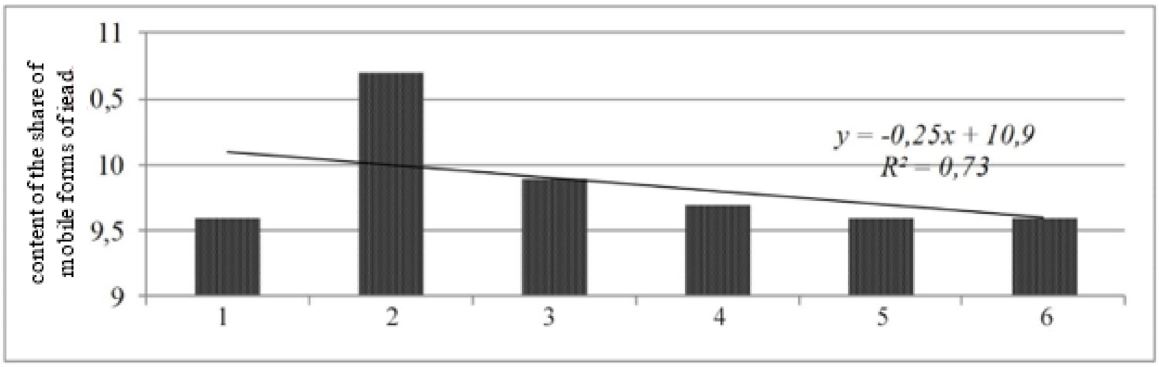

Fig. 15 Dependence of the content of the share of mobile forms of lead on the dose of compost application based on sewage sludge in the sod-podzolic soil of Precarpathia:

1. Control – without fertilizers; 2. Compost (SS + sawdust (3:1)) – 60 t/ha; 3. Compost (SS + straw (3:1)) – 20 t/ha; 4. Compost (SS + straw (3:1)) – 40 t/ha; 5. Compost (SS + straw (3:1)) – 60t/ha; 6. Compost (SS + straw (3:1) + cement dust 10%) – 40 t/ha.

The use of composts based on sewage sludge contributes to the reduction of absolute indicators of mobile forms of heavy metals, compared to options where fresh sewage sludge was introduced and their share compared to the content of gross forms, which indicates a reduction in environmental risks due to its introduction in the form of composts.

A comparative analysis of the content of mobile forms of heavy metals in the soil after applying sewage sludge compost with straw at a dose of 60 t/ha indicates lower absolute indicators and their share by 1.1% in terms of lead content, 2.2% in cadmium and cobalt and by 0.8% in terms of nickel content compared to similar indicators for the application of compost with sawdust.

Biological activity and phytotoxicity of the soil due to the introduction of sewage sludge

An important indicator of the agroecological state of the soil is not only the content of heavy metals in it, but also its biological activity and level of toxicity.

Restoration and increase of soil fertility, improvement of root nutrition of plants is the basis of obtaining high and sustainable harvests and is related to the regulation of the activity of useful soil microflora [184]. An important indicator of soil biological activity is the intensity of decomposition of organic compounds [195, 196]. Assessment of biological activity can be given by the intensity of decomposition of strips of linen fabric in the soil (application method), which gives good comparative results for the assessment of the intensity of mineralization by different applied means of soil use techniques [184].

Determining the biological activity of the soil according to the degree of decomposition of linen fabric showed an increase in microbiological activity during the application of fertilizers, however, the intensity of decomposition varied significantly according to the variants of the experiment (Table 2).

Our research showed that the intensity of decomposition of linen fabric varied both according to the experimental options and the depth of the soil. On average, over 4 years of research, in all variants of the experiment, without exception, the highest biological activity was observed in the soil layer 0 – 20 cm. When applying composts based on SS and straw (3: 1) in a dose of 20 – 60 t/ha in the first month in arable land in the soil layer, from 30.0 to 37.9% of the linen was decomposed, and in two months - more from 44.9 to 52.7%. The difference with the control in the arable (0 – 20 cm) layer reached an average of 9.8 – 12.5%.

When SS was applied at a dose of 80 t/ha, tissue decomposition compared to the control increased by 11.8% in the first month. In July, the level of decomposition was 45.4% in the arable and 39.3% in the subsoil layers of the soil.

Table 2

Dynamics of soil biological activity under the influence of repeated application of sewage sludge (linen decomposition), average for 2016-2021, %

Option	Soil layer, see	June	July	August
1. Without fertilizers	0-20	26,6	39,7	59,9
	20-40	20,4	30,2	51,6
2. $N_{100}P_{100}K_{100}$	0-20	22,1	37,1	56,7
	20-40	17,0	28,7	50,9
3. SS 40 t/ha	0-20	31,8	36,3	60,3
	20-40	20,9	33,1	53,2
4. SS 60 t/ha	0-20	36,1	42,4	69,4
	20-40	20,5	42,6	58,7
5. SS 80 t/ha	0-20	38,4	45,4	70,8
	20-40	21,7	39,3	51,5
6. Compost (SS + sawdust (3:1)) – 60 t/ha	0-20	35,1	46,5	64,3
	20-40	21,9	41,2	54,8
7 Compost (SS+ straw (3:1)) – 20 t/ha	0-20	30,0	44,9	63,6
	20-40	20,9	40,8	56,1
8. Compost (SS + straw (3:1)) – 40 t/ha	0-20	34,4	49,3	67,1
	20-40	21,6	43,5	59,4
9. Compost (SS + straw (3:1)) – 60 t/ha	0-20	37,9	52,7	71,1
	20-40	22,4	49,1	63,2
10. Compost (SS + straw (3:1) + cement dust 10%) – 40 t/ha	0-20	37,1	50,6	69,3
	20-40	22,1	44,7	60,1
LSD_{05}	0-20	1,0	3,4	1,8
	20-40	0,2	4,4	3,1

In three months, the decomposition of the fabric was the greatest when applying SS at a dose of 80 t/ha and was 70.8% in the 0 – 20 cm layer. When applying SS compost + straw at a dose of 60 t/ha, the degree of decomposition of linen fabric was 71.1% in the upper layer, which is 11.2% more compared to the control without fertilizers.

The intensity of fabric decomposition depended on weather conditions. In dry years, tissue decomposition slowed down somewhat (for example, in 2011), and in conditions of sufficient moisture, mineralization processes occurred more intensively. Increasing the doses of organic fertilizers ensured an increase in the intensity of tissue decomposition already at the early stages of vegetation. The organic system was somewhat inferior to the system where composts based on SS and straw were applied.

Thus, on the basis of the analysis of the data of studies of the biological activity of the soil by the intensity of decomposition of linen fabric, it can be concluded that the introduction of all types of fertilizers activated, to one degree or another, the vital activity of the soil microflora. The greatest positive impact on the biological activity of the soil was achieved by the application of composts based on SS, and the greatest biological activity was noted in the 0 – 20 cm soil layer. The application of mineral fertilizers did not significantly affect this indicator.

Table 3. Sensitivity of common flax (*Linum usitatissimum L.*) to repeated application of sewage sludge in sod-podzolic soil

Option	Root length		Shoot height	
	min-max, cm	Variation coefficient, %	min-max, cm	Variation coefficient, %
1. Without fertilizers - control	2,40-2,55	3,90	1,97-2,15	2,70
2. $N_{100}P_{100}K_{100}$	2,34-2,39	3,41	1,84-1,97	2,31
3. SS 40 t/ha	2,28-2,49	3,03	1,69-1,89	2,11
4. SS 60 t/ha	2,25-2,39	2,86	1,69-1,81	1,69
5. SS 80 t/ha	2,18-2,35	2,81	1,65-1,77	1,65
6. Compost (SS + sawdust (3:1)) – 60 t/ha	2,37-2,48	3,00	1,72-1,98	1,69
7 Compost (SS+ straw (3:1)) – 20 t/ha	2,40-2,51	3,10	1,79-1,99	1,80
8. Compost (SS + straw (3:1)) – 40 t/ha	2,39-2,46	3,21	1,80-1,90	1,73
9. Compost (SS + straw (3:1)) – 60 t/ha	2,36-2,47	2,89	1,75-1,84	1,70
10. Compost (SS + straw (3:1) + cement dust 10%) – 40 t/ha	237-2,43	2,94	1,81-1,94	1,80

Plants are the primary links of trophic chains, play an important role in absorbing various pollutants and are constantly affected by them due to their fixation on the substrate. That is why plants are considered the most convenient objects for soil biomonitoring [196]. Soil toxicity was determined by the method of Grodzinsky [195]. Common flax (*Linum usitatissimum L.*), annual sunflower (*Helianthus annuus L.)* and watercress (*Lepidium sativum L.*) were used as test crops. On the basis of the conducted studies, the ambiguity of various types of plants on the test - reaction was revealed (Table 3, Table 4).

A high sensitivity to the effect of SS as a soil pollutant was established: the root length and shoot height of common flax was 2.18-2.35 cm and 1.65-1.77 cm, respectively. The coefficient of variation of morphological indicators was about 2.81% for root length and 1.65% for shoot height.

Table 4

Levels of toxicity of sod-podzolic soil with repeated application of sewage sludge, %

Option	Phytotoxic effect for:			Level of toxicity
	ordinary flax	annual sunflower	watercress	
1. Without fertilizers - control	19	18	20	weak
2. $N_{100}P_{100}K_{100}$	26	24	29	average
3. SS 40 t/ha	41	40	41	above average
4. SS 60 t/ha	42	41	42	above average
5. SS 80 t/ha	44	41	43	above average
6. Compost (SS + sawdust (3:1)) – 60 t/ha	39	38	38	average
7 Compost (SS+ straw (3:1)) – 20 t/ha	34	34	34	average
8. Compost (SS + straw (3:1)) – 40 t/ha	36	36	36	average
9. Compost (SS + straw (3:1)) – 60 t/ha	38	39	36	average
10. Compost (SS + straw (3:1) + cement dust 10%) – 40 t/ha	37	38	39	average
LSD_{05}	1,6	1,2	1,7	

The length of the root and the height of the shoot of the annual sunflower were 3.12 - 3.17 cm and 1.45 - 1.57 cm, respectively. The coefficient of variation of morphological indicators for sunflower was about 7.7% for root length and 2.1% for shoot height (Table 6.4).

The control variant for annual sunflower and watercress had the following results: root length 3.90–4.41 cm and 2.93 – 3.06 cm, respectively, shoot height 1.59–1.70 cm and 1.01–1 ,12 cm respectively.

The coefficient of variation of morphological indicators of annual sunflower and watercress was about 8.86 and 2.31% for root length and 2.31 and 2.51% for shoot height. The conducted soil analysis shows that the levels of inhibition of the growth processes of phytoindicators in the test options for the application of composts (options 6 - 10), although they range from 34 to 39% for common flax, annual sunflower and watercress, they determine the toxicity of the samples soil at the "average" level. In soil samples, with the introduction of SS at a dose of 40 – 80 t/ha, the toxicity of the soil was noted within the limits of the "above average" level.

SS and composts based on it significantly influenced the content of heavy metals and the agroecological condition of sod-podzolic soil. Under their influence, the following patterns appear:

– the content of mobile forms of heavy metals in the soil increases with the introduction of sewage sludge compared to the control without fertilizers. In particular, mobile forms of cobalt - by 0.24 – 0.60, nickel - by 0.19 – 0.34, cadmium - by 0.29 – 0.56, lead - by 0.24 – 0.51 mg/kg soil The highest doses of sewage sludge application do not lead to the accumulation of gross and mobile forms of heavy metals in the soil in volumes exceeding the maximum permissible reaction, but provide the highest share of mobile forms of heavy metals from their gross content, namely for lead – 10.8, cadmium - 19 .7, nickel – 7.2 and cobalt – 12.1%;

- the use of composts based on sewage sludge contributed to a decrease in the absolute indicators of mobile forms of heavy metals, compared to the introduction of fresh sewage sludge and their share compared to the content of gross forms, which indicates a decrease in environmental threats due to its introduction in the form of composts;

- application of fertilizers activates the biological activity of sod-podzolic soil. The greatest positive effect on the biological activity of the soil (71% decomposition of linen fabric in three months of growing season) was provided by the application of composts based on sewage sludge and straw at a dose of 60 t/ha, and the highest degree of decomposition of linen fabric was noted in the upper (0 – 20 cm) layer soil

Application of mineral fertilizers does not significantly affect the indicator of biological activity of sod-podzolic soil;

- the intensity of suppression of growth processes of phytoindicators for common flax, annual sunflower and watercress determine the toxicity of the soil at the "average" level for the introduction of composts made on the basis of sewage sludge. With the introduction of sewage sludge at a dose of 40 – 80 t/ha, the toxicity of sod-podzolic soil is "above average" and ranges within 40% of the phytotoxic effect.