THE INTENSITY OF THE HEAVY METALS BY TOPINAMBUR IN THE CONDITIONS OF THE OIL-POLLUTED AREAS

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ABSTRACT

This study was aimed to investigate the ability of Jerusalem artichokes (*Helianthus tuberous* L.) to absorb heavy metals in an oil-contaminated ecosystem. The research was carried out in a territory of the oil and gas pipeline at the village of Bytkiv of Nadvirna district. Jerusalem artichokes were used for this study and planted on an area of 25 m^2. The area of the experimental field in the village of Maidan of Tysmenytsia district (control option № 1). A total of eight treatments of the experiment with different rates of sewage sludge. It is established that the concentration of heavy metals in oil-contaminated soil and Jerusalem artichoke plants increases with increasing the amount of fertilizers in the soil. The maximum content of metals in the tested soils, green mass and Jerusalem artichoke roots was observed mainly in the variant of sewage sludge application at the rate of 40 t/ha and fertilizer $N_{10}P_{14}K_{58}$.The green mass and roots of Jerusalem artichoke exhibited the highest content of heavy metals absorption the transition coefficients of metals in the system "roots - green mass" increase in the following : Pb → Co → Ni → Cd. The coefficients of biological absorption of metals by Jerusalem artichoke increase in a number of elements: Co → Ni → Ld → Ca. Where as The coefficients of biological accumulation of heavy metals with Jerusalem artichoke increase in a number of elements following series : L → Co → Ni → Ca. It is recommended to use Jerusalem artichoke as a phytoremediator of man-made areas.

Keywords: Jerusalem artichoke, oil-contaminated territory, accumulative capacity, energy n.

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كثافة المعادن الثقيلة بواسطة توبينامبور في ظروف المناطق الملوثة بالنفط

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المستخلص

هدفت هذه الدراسة إلى معرفة قدرة خرشوف القدس (Helianthus tuberous L.) على امتصاص المعادن الثقيلة في النظام البيئي الملوث بالزيت. تم إجراء البحث في منطقة خط أنابيب النفط والغاز في قرية بايتكيف التابعة لنادفيرنا. تم استخدام خرشوف القدس لهذه الدراسة وزُرعت على مساحة 25 م 2. مساحة الحقل التجريبي بقرية ميدان التابعة لناحية تيسمينيتسيا (خيار التحكم № 1). ما مجموعه ثمانية معالجات للتجربة بمعدلات مختلفة من حمأة الصرف الصحي. ثبت أن تركيز المعادن الثقيلة في التربة الملوثة بالزيت ونباتات الخرشوف بالقدس يزداد مع زيادة كمية الأسمدة في التربة. لوحظ الحد الأقصى من محتوى المعادن في التربة المختبرة والكتلة الخضراء وجذور الخرشوف القدس بشكل رئيسي في متغير تطبيق حمأة الصرف الصحي بمعدل 40 طن / هكتار والسماد N10P14K58. أظهرت الكتلة الخضراء وجذور خرشوف القدس أعلى محتوى لامتصاص المعادن الثقيلة ، تزداد معاملات الانتقال للمعادن في نظام "الجذور – الكتلة الخضراء" في العناصر التالية: Pb → Co → Ni → Cd. تزداد معاملات الامتصاص البيولوجي للمعادن بواسطة خرشوف القدس في عدد من العناصر: Co → Ni → Ld → Ca. حيث تزداد معاملات التراكم البيولوجي للمعادن الثقيلة مع خرشوف القدس في عدد من العناصر التالية على التوالي: L → Co → Ni → Ca.يوصى باستخدام خرشوف القدس كوسيط نباتي للمناطق التي من صنع الإنسان.

الكلمات المفتاحية: الخرشوف القدس ، المنطقة الملوثة بالنفط ، القدرة التراكمية ، الطاقة.

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INTRODUCTION

Oil pollution is one of the global environmental problems to today, and the restoration of oil-contaminated ecosystems is a priority practical task for scientists. Phytorecultivation is an integral part of a set of measures used to improve the quality of man-made environment due to oil production and refining (1, 8, 9, 14, 18, 23). In this regard, promising phytoremediators are energy plants, among which the prominent place belongs to Jerusalem artichoke, which has the ability to absorb petroleum products, counteract soil erosion and enrich low-yielding degraded soils. Among a wide range of pollutants, petroleum contains heavy metals that have a mutagenic, carcinogenic effect on living systems and lead to premature death of organisms (2, 3, 4, 6, 7, 13). Therefore, the problem of detecting the accumulation of heavy metals by fast-growing energy plants-hyperaccumulators is relevant. Jerusalem artichoke, or pear, belonging to the Aster family and native to North America, is used as a fodder, technical, pharmaceutical and food plant (15, 20, 24, 32). Due to the large leaf surface that accumulates solar energy in the process of photosynthesis, is one of the record holders in the harvest. Jerusalem artichoke is used for the production of bioethanol and biogas, the energy value of this energy plant is 25.38 t ha of dry matter or 475.2 GJ/ha (16, 31). The use of organic and mineral fertilizers increases the yield of plant biomass by 2-3 times. Jerusalem artichoke is characterized by a powerful phytomeliorative ability, withstands soil salinity, short-term droughts frost-resistant, resistant to pests (17, 21, 26). According to the literature (5, 10, 19, 30). Jerusalem artichoke belongs to the plants-accumulators of heavy metals, among which the most intensively absorbs manganese, zinc, cadmium, nickel, slightly less absorbs chromium, copper and lead. Jerusalem artichoke plantation with an area of 1 ha absorbs twice as much carbon dioxide and produces 1.5 times more oxygen than a forest of the same area. Jerusalem artichoke has the ability to quickly adapt to changing environmental conditions due to its inherent polymorphism (25, 33). Waterlogging of the soil leads to a decrease in the growth processes of Jerusalem artichoke and increase its pathogenic damage (11, 12). Jerusalem artichokes produce the best harvest with a rainfall of 500 mm per year (21, 28). Under optimal growth conditions, the dry matter production of the plant varies from 20 to 30 tons per hectare. Comfortable conditions for the growth of energy plants are drained, fertile and moist soils with an acidity of 4.4 to 8.6 , (22, 27). The above unique characteristics of Jerusalem artichoke led to its choice as the object of our research in the oil-contaminated area. The purpose of this study is to investigate the metal-accumulating ability of Jerusalem artichoke in the conditions of oil-polluted ecosystem under the condition of sediment and mineral fertilizers introduction into the soil and to find out phytorecultivation prospects of Jerusalem artichoke in oil-contaminated territories.

MATERIALS AND METHODS

This research was carried out on the territory of the oil and gas pipeline in the village of Bytkiv of Nadvirna district. Jerusalem artichoke variety was planted on an area of 25 m^2 according to the planting scheme 0.45 X 0.70 m. The area of the experimental field in the village of Maidan of Tysmenytsia district (control option № 1). During the cultivation of Jerusalem artichokes fertilizers were applied at the following sequence:

option №2 - $N_{60}P_{60}K_{60}$; -treatment

option №3 - $N_{90}P_{90}K_{90}$; -treatment

option №4 - SS 20 t/ha + $N_{50}P_{52}K_{74}$;; -treatment

option №5 - SS 30 t/ha + $N_{30}P_{33}K_{66}$; -treatment

option №6 - SS 40 t/ha + $N_{10}P_{14}K_{58}$;- -treatment

option №7 - compost (SS+ straw 3: 1) 20 t/ha + $N_{50}P_{16}K_{67}$; -treatment

option №8 - compost (SS + straw 3: 1) 30 t/ha + $N_{30}K_{55}$. : -treatment

The content of gross and mobile forms of heavy metals in oil-contaminated soil for growing Jerusalem artichokes, as well as the content of heavy metals in Jerusalem artichoke tubers and green mass of the plant were studied according to proven methods (1, 2). The coefficient of biological absorption was determined by the ratio of the content of the chemical element in the plant ash to its gross content in the soil (1). The index of intra-tissue contamination of plants was determined by the ratio of the content of the element in the vegetative part of the plant to the content of the element in the vegetative part of the control plants (1, 2). Coefficients of concentration of heavy metals were determined by the ratio of the content of the element in the soil to its content in the soil of the background area (control option) (1, 2). The coefficients of mobility of elements were determined by the ratio of the content of the movable form of the element to its gross form in the soil (1, 2). The coefficients of transition of heavy metals from the roots to the aboveground part of the plant were calculated by the ratio of the content of the element in the aboveground part of the plant to its content in the roots. (1, 2). The coefficients of translocation of heavy metals from the soil to the aboveground and root part of the plant were determined by the ratio of the concentration of metal in the plant part to the concentration of mobile metal in the soil (1, 2).

RESULTS AND DISCUSSION

The maximum concentrations of tightly bound forms of lead, cadmium, nickel, cobalt and mobile forms of the studied elements were obtained in the soil for growing Jerusalem artichoke after the introduction of sewage sludge at the rate of 40 t/ha and $N_{10}P_{14}K_{58}$ (Fig. 1-2).

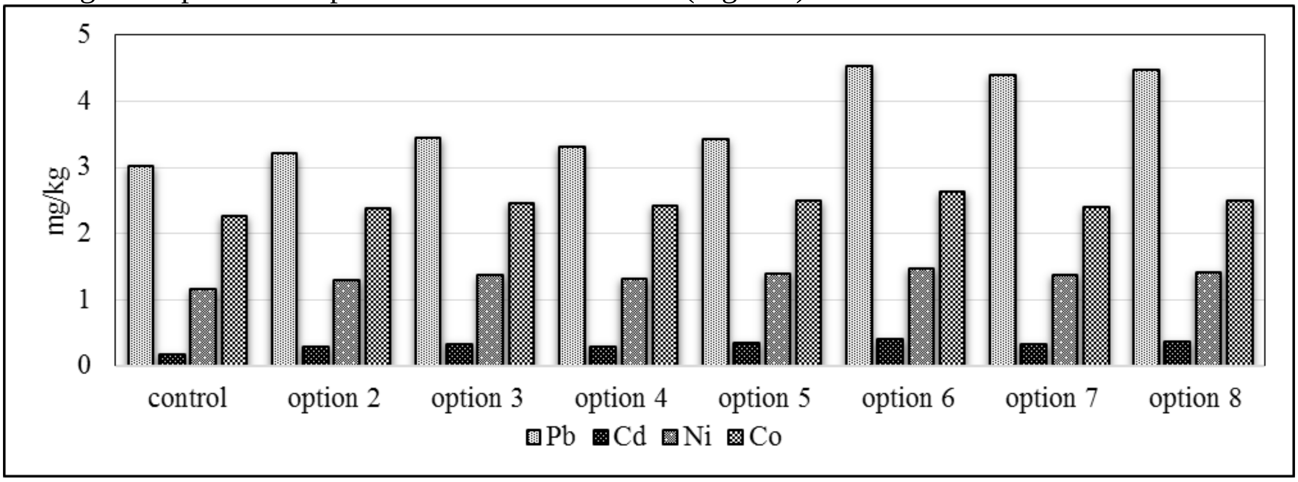

Figure 1. The content of mobile forms of heavy metals in oil-contaminated soil for growing Jerusalem artichokes

The highest content of mobile forms of lead was observed in the soil with the application of SS 40 t/ha and $N_{10}P_{14}K_{58}$ (option 6) and compost at the rate of 30 t/ha and $N_{30}P_{33}K_{66}$ (option 8) is 4.54 and 4.47 mg/kg, respectively. The cadmium content varies according to the fertilizer application rates was reached a maximum in option 6 and is 0.4 mg/kg, which is 0.1 mg/kg more than the option where the lowest rate of SS was applied. The nickel content varies in the range of 1.29-1.48 mg/kg of soil, which is 0.13 - 0.32 mg/kg of soil exceeds the control. The highest content of Nickel in the soil with the introduction of fresh SS at the rate of 40 t/ha and $N_{10}P_{14}K_{58}$ and is 1.48 mg/kg of soil. Content of c obalt in the soil varied according to the study variant, it was mostly contained in variant 6 - 2.63 mg/kg of soil, and the least in variants where compost based on SS + straw was applied in the ratio 3: 1 at the rate of 20 t/ha and $N_{50}P_{16}K_{67}$ is 2.4 mg/kg of soil, which is 0.23 mg/kg of soil less than option 6 and 0.13 mg/kg more than the control. The content of gross forms of the studied elements was differed slightly, the content of lead ranged from 12.4 mg/kg in the control and 13.9 mg/kg in option 8 (compost (SS + straw in a ratio of 3: 1) 30 t/ha + $N_{30}K_{55}$), which is 1.5 mg/kg more than the control. Content of gross forms of cadmium for the application of SS at a rate of 20-40 t/ha is 0.65 - 0.82 mg/kg, which is 0.04 - 21 mg/kg of soil exceeds the control. Content of gross forms of nickel varies between 25.3 mg/kg in the control and 26.41 mg/kg of soil in option 6. The content of gross forms of cobalt with the introduction of SS at a rate of 20 - 40 t/ha is 20.33 - 20.53 mg/kg of soil, which is 0.32 - 0.52 mg/kg of soil more than the control. However, the gross forms of cobalt were concentrated in options 7 and 8 and reached from 21.31 - 21.45 mg/kg of soil, respectively (Fig. 2). The content of gross forms of the studied elements was differed slightly, the content of lead ranged from 12.4 mg/kg in the control and 13.9 mg/kg in option 8 (compost (SS + straw in a ratio of 3: 1) 30 t/ha + $N_{30}K_{55}$), which is 1.5 mg/kg more than the control. The content of gross forms of cadmium for the application of SS at a rate of 20-40 t/ha is 0.65 - 0.82 mg/kg, which is 0.04 - 21 mg/kg of soil exceeds the control. The content of gross forms of nickel ranged between 25.3 mg/kg in the control and 26.41 mg/kg of soil in option 6. The content of gross forms of cobalt with the introduction of SS at a rate of 20 - 40 t/ha was 20.33 - 20.53 mg/kg of soil, which is 0.32 - 0.52 mg/kg of soil more than the control. However, the gross forms of cobalt where, concentrated in options 7 and 8 and are 21.31 - 21.45 mg/kg of soil, respectively (Fig. 2). In the second version of the experiment, the lowest content of gross and mobile forms of heavy metals was established.

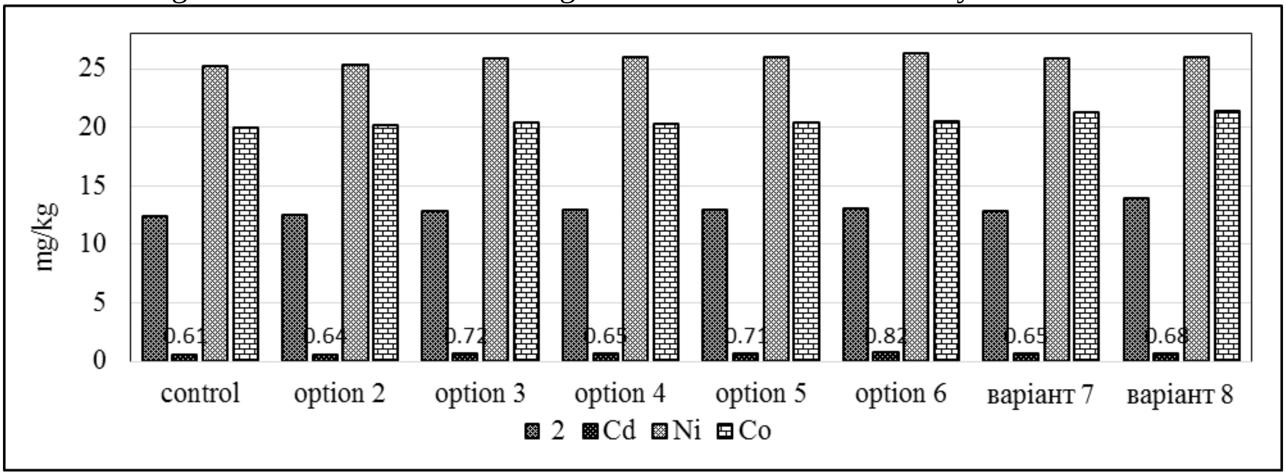

Figure 2. The content of gross forms of heavy metals in oil-contaminated soil for growing Jerusalem artichokes

There was no excess of the maximum concentration limit in soils in all variants of the experiment. The content of mobile forms of heavy metals in soils for growing erusalem artichokes was increased in the following order , Cadmium → Nickel → Cobalt → Lead. The content of gross forms of heavy metals in soils for growing Jerusalem artichokes increases in a number: Cadmium → Lead → Cobalt → Nickel. The concentration coefficient of heavy metals was determined, which reflects the change in the content of the element in the test soil relative to the content of metals in the background soil. The coefficients of concentration of mobile forms of heavy metals in oil-contaminated soil for growing Jerusalem artichoke after the application of fertilizers based on sewage sludge and compost based on them, were increased in the following order: Cobalt → Nickel → Lead → Cadmium. The coefficients of concentration of gross forms of heavy metals in oil-contaminated soil for growing Jerusalem artichoke after the introduction of organic fertilizer based on sewage sludge were increased in the following order: Nickel → Cobalt → Lead → Cadmium (Table 1).

Table 1. Coefficients of concentration of heavy metals in oil-contaminated soil for growing Jerusalem artichokes

№ options	Pb	Cd	Ni	Co	Pb	Cd	Ni	Co
	movable forms				gross forms			
$N_{60}P_{60}K_{60}$	1,06	1,71	1,11	1,05	1,02	1,05	1,00	1,01
$N_{90}P_{90}K_{90}$	1,14	2,00	1,18	1,09	1,04	1,18	1,02	1,02
SS – 20 t/ha + N_{50} $P_{52}K_{74}$	1,10	1,76	1,14	1,07	1,04	1,07	1,03	1,01
SS -30 t/ha + $N_{30}P_{33}K_{66}$	1,14	2,06	1,21	1,10	1,05	1,16	1,03	1,02
SS – 40 t/ha + N_{10} $P_{14}K_{58}$	1,50	2,35	1,28	1,16	1,05	1,34	1,04	1,03
Compost (SS + straw (3:1)) – 20 t/ha + $N_{50}P_{16}K_{67}$	1,46	1,94	1,19	1,06	1,04	1,07	1,02	1,06
Compost (SS + straw (3:1)) – 30 t/ha + $N_{30}K_{55}$	1,48	2,18	1,22	1,11	1,12	1,11	1,03	1,07

In order to find out the possibility of converting heavy metals from gross form into movable forms available to plants, was determined the mobility coefficient according to our research for growing Jerusalem artichokes was determined. The mobility of metals wasincreased in the following sequence: Nickel (0.05) → Cobalt (0.10) → Lead (0.29) → Cadmium (0.47). The total rate of transition of heavy metals from gross to mobile form during the cultivation of Jerusalem artichoke is 1.27. The highest content of heavy metals in the green mass of Jerusalem artichoke was recorded during the cultivation of Jerusalem artichoke after the introduction of sewage sludge at the rate of 40 t/ha and $N_{10}P_{14}K_{58}$ (option 6) (Fig. 3).

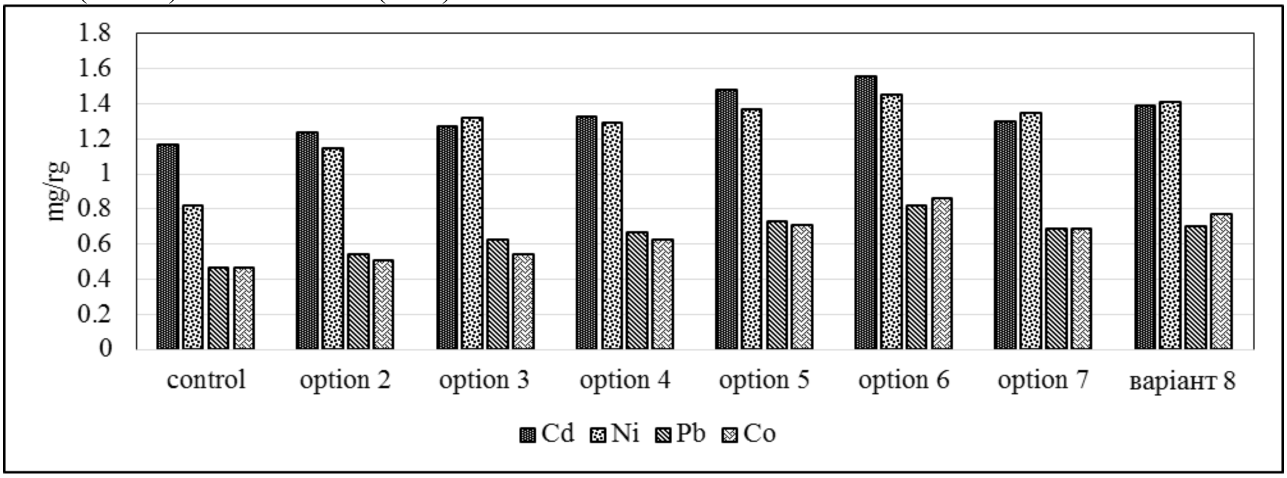

Figure 3. Gross content of heavy metals in the green mass of Jerusalem artichoke for the application of fertilizers based on sewage sludge

According to the obtained data, the minimum content of heavy metals was obtained in the green mass of Jerusalem artichoke with the introduction of $N_{60}P_{60}K_{60}$. The exception is cadmium, the minimum pollution index of which green mass of Jerusalem artichoke is set in the version for the introduction of $N_{90}P_{90}K_{90}$. Green mass of Jerusalem artichoke has the ability to accumulate heavy metals in the following ascending order: Lead → Nickel → Cadmium → Cobalt. Indices of intra-tissue contamination with heavy metals of green mass of Jerusalem artichoke for the application of fertilizers based on sewage sludge increase in a number: Cadmium → Cobalt → Lead → Nickel (Table 2).

Table 2. Indices of intra-tissue contamination with heavy metals of green mass of Jerusalem artichoke after fertilizer application to the soil

№ options	Cd	Ni	Pb	Co	Cd	Ni	Pb	Co
	Green mass of Jerusalem artichoke				Jerusalem artichoke tubers			
1	1,13	1,40	1,15	1,09	1,08	1,21	1,23	1,16
2	1,09	1,61	1,34	1,15	1,10	1,45	1,88	1,22
3	1,14	1,57	1,43	1,34	1,16	1,38	1,71	1,49
4	1,26	1,67	1,55	1,51	1,28	1,47	1,90	1,65
5	1,33	1,77	1,74	1,83	1,34	1,59	2,06	1,92
6	1,11	1,65	1,47	1,47	1,15	1,42	1,81	1,53
7	1,19	1,72	1,49	1,64	1,20	1,51	1,63	1,67

Indices of intra-tissue contamination with heavy metals of Jerusalem artichoke tubers with the application of fertilizer based on sewage sludge was increased the following order : Cadmium → Nickel → Cobalt → Lead (Table 2). The lowest indices are set for all metals in the variant for application of mineral fertilizers $N_{60}P_{60}K_{60}$ (option 2), the highest - for application of sewage sludge in the soil at the rate of 40 t/ha and $N_{10}P_{14}K_{58}$ (option 6). Jerusalem artichoke showed heavy metals absorption by the root system in the following ascending order: Cobalt → Lead → Nickel → Cadmium (Fig. 4). The relationship between the cadmium content in the green mass from the metal content in Jerusalem artichoke tubers and in the studied soil with the rate of fertilizer application, ie the more test metal is in the green mass, respectively, it is contained in the aboveground mass and the studied soil (Fig. 4).

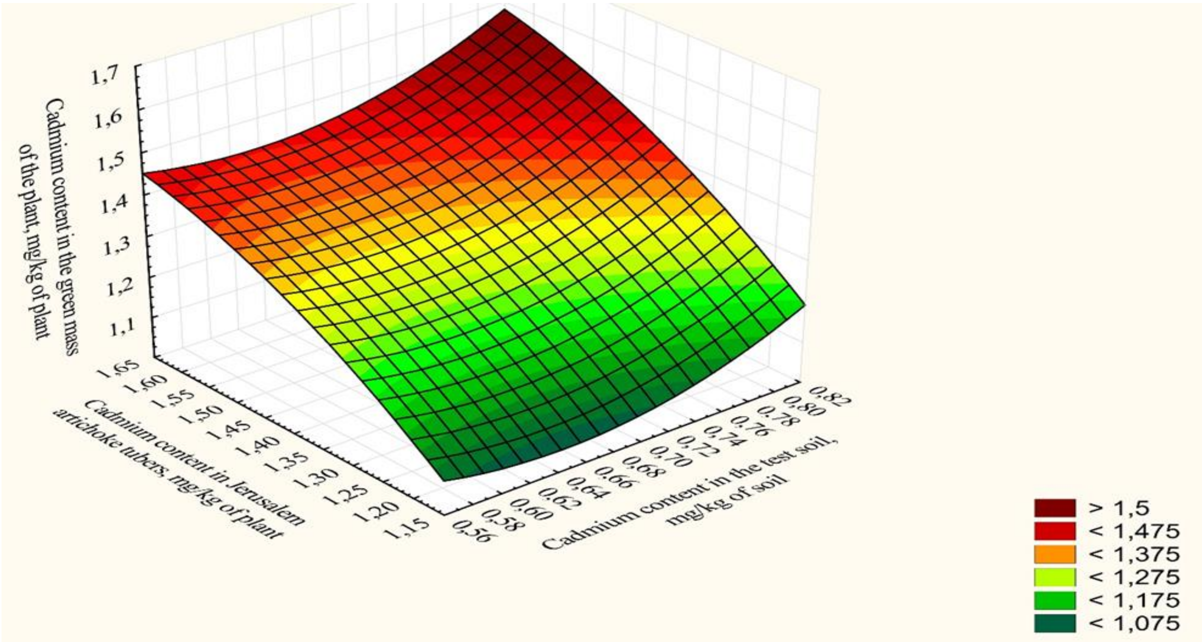

Figure 4. Dependence of Cadmium content in green mass on metal content in Jerusalem artichoke tubers and in the studied soil

With the introduction of sewage sludge at a the rate of 20 - 40 t/ha (options 4 - 6) the cadmium content in the green mass reached 1.33 - 1.56 mg/kg, the cadmium content in Jerusalem artichoke tubers was 1.39 - 1.61 mg/kg, and in the soil - 0.65 - 0.82 mg/kg. With the application of composts at the rate of 20 - 30 t / ha (options 7 - 8) the cadmium content in the green mass reached 1.3 - 1.4 mg/kg, the cadmium content in Jerusalem artichoke tubers was 1.38 - 1.44 mg/kg, and in the soil - 0.69 - 0.68 mg/kg.

$$c = 0.1679 + 4.4392x - 1.5192y - 8.3726x^2 + 5.3098xy - 0.4562y^2$$

where c is the Cadmium content in the green mass, mg/kg

x - Cadmium content in the studied soil, mg/kg

y - Cadmium content in Jerusalem artichoke tubers, mg/kg

The multiple coefficient of determination (R^2 = 0.72) indicates a close correlation between these indicators

The relationship between the Nickel content in the green mass the metal content in Jerusalem artichoke tubers and in the studied soil was noted (Fig. 4).

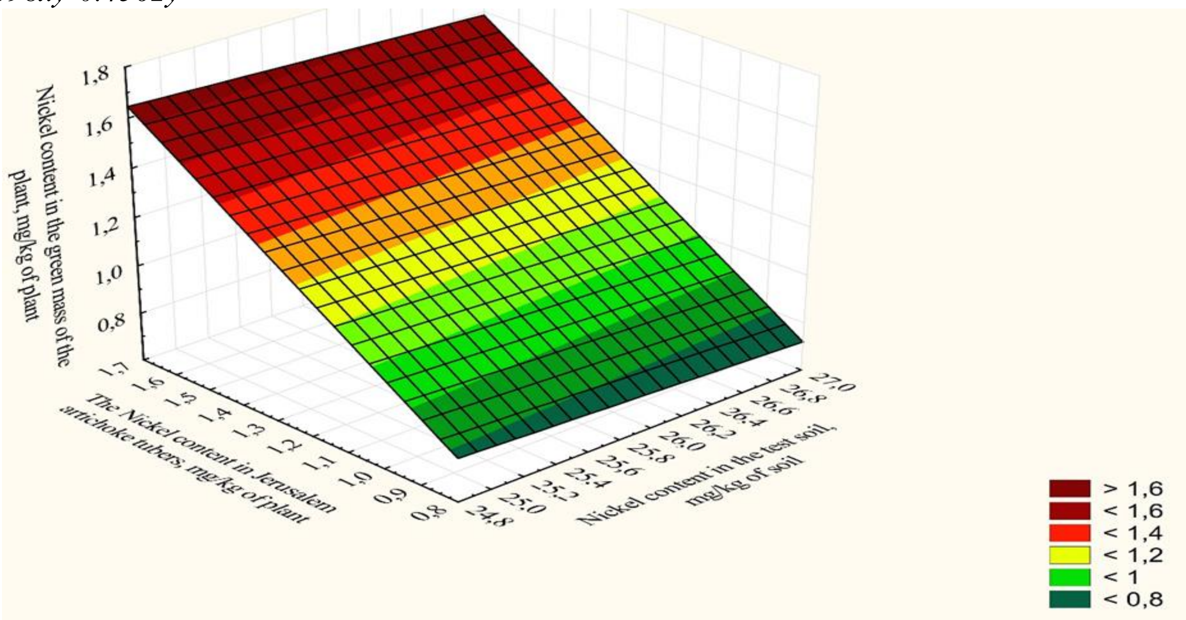

Fig. 5. Dependence of Nickel content in green mass on metal content in Jerusalem artichoke tubers and in the studied soil

With the introduction of sewage sludge at the rate of 20 - 40 t/ha (options 4 - 6), the nickel content in the green mass reached 1.29 - 1.45 mg/kg of plants, the cadmium content in Jerusalem artichoke tubers, respectively, was fanged from 1.37 - 1, 57 mg/kg of plant, and in the soil - 26.0 - 26.4 mg/kg of soil. With the application of compost at the rate of 20 - 30 t/ha (options 7 - 8), the nickel content in the green mass reached 1.35 - 1.4 mg/kg of plant, the nickel content in Jerusalem artichoke tubers was 1.4 - 1.5 mg/kg of plant, and in the soil –25.9– 26.1 mg/kg of soil

c = 0.6807 - 0.0271x + 0.9622y

where *c* is the Nickel content in the green mass, mg/kg of plant

x - Nickel content in the studied soil, mg/kg of soil

y - Nickel content in Jerusalem artichoke tubers, mg / kg of plant

The multiple coefficient of determination (R^2 = 0.78) indicates a close correlation between these indicators

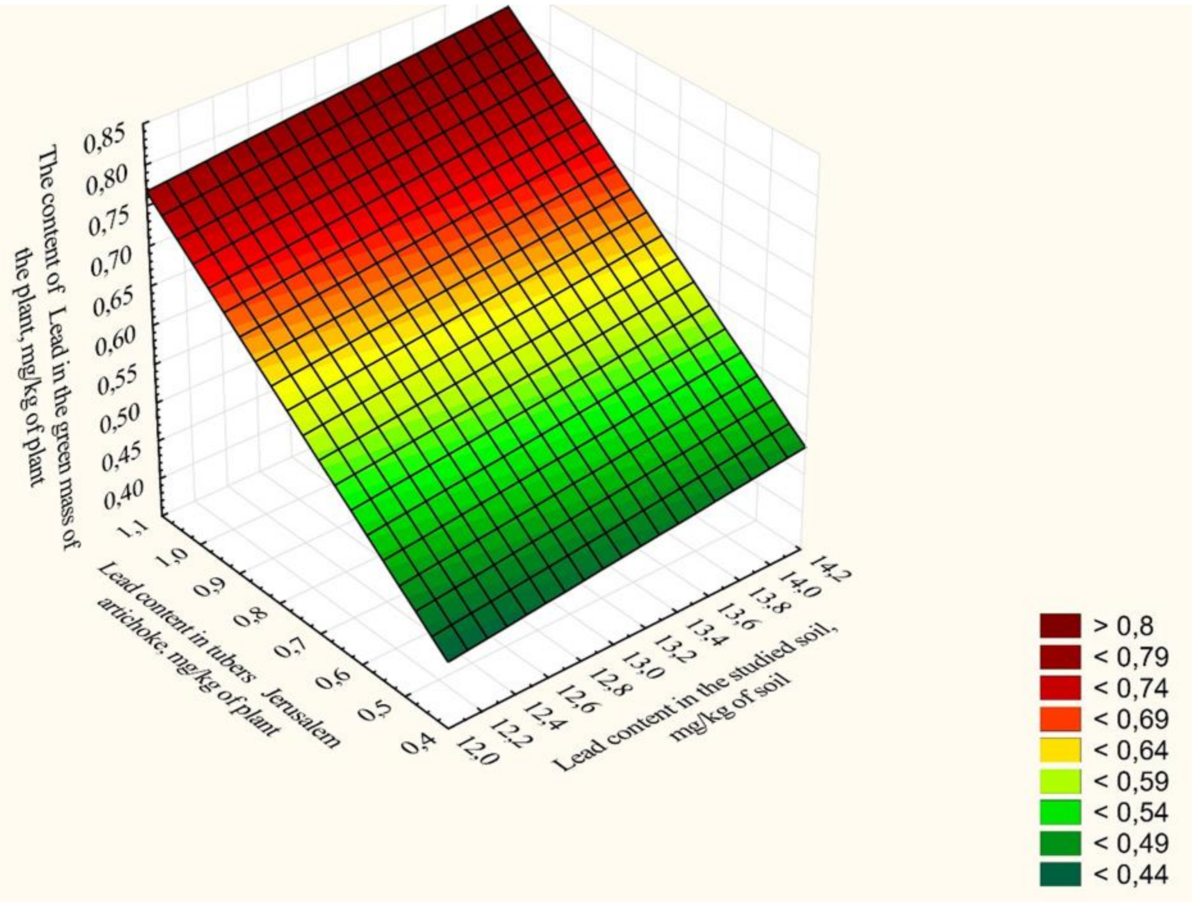

Fig. 6. Dependence of Lead content in green mass on metal content in Jerusalem artichoke tubers and in the studied soil

With the introduction of sewage sludge at a rate of 20 - 40 t/ha (options 4 - 6) the content of lead in the green mass reached 0.7 - 0.8 mg/kg of plant, the content of Lead in Jerusalem artichoke tubers, respectively, was 0.8 - 0,9 mg/kg of plant, and in the soil - 12.9 - 13.1 mg/kg of soil. With the application of composts at the rate of 20 - 30 t/ha (options 7 - 8) the content of lead in the green mass reached 0.69 - 0.71 mg/kg, the content of Lead in Jerusalem artichoke tubers was recorded 0.9 - 0.8 mg/kg of plant, and in the soil was12.9 - 13.9 mg/kg of soil.

c = -0.02332 + 0.0224x + 0.4741y

where *c* is the content of Lead in the green mass, mg/kg of plant

x - Lead content in the studied soil, mg/kg of soil

y - content of Lead in Jerusalem artichoke tubers, mg/kg of plant

The multiple coefficient of determination (R^2 = 0.75) indicates a close correlation between these indicators

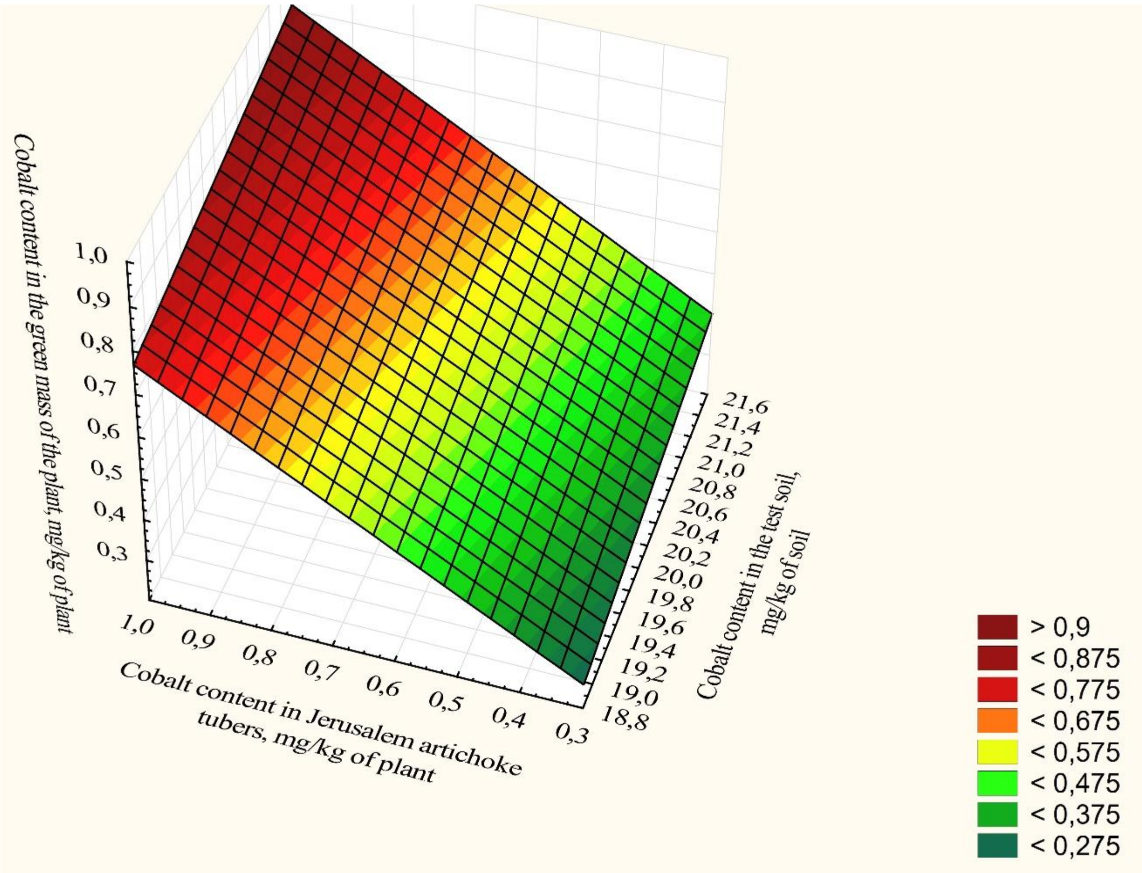

Fig. 7. Dependence of Cobalt content in green mass on metal content in Jerusalem artichoke tubers and in the studied soil

With the introduction of sewage sludge at the rate of 20 - 40 t/ha (options 4 - 6) the Cobalt content in the green mass reached 0.63 - 0.86 mg/kg, the Cobalt content in Jerusalem artichoke tubers was reached 0.7 - 0.9 mg/kg, and in the soil - 20.3 - 20.5 mg/kg. With the application of composts at the rate of 20 - 30 t/ha (options 7 - 8), the Cobalt content in the green mass was reached 0.7 - 0.8 mg/kg, the Cobalt content in Jerusalem artichoke tubers was recorded 0.7 - 0.8 mg/kg, and in the soil - 21.3 - 21.5 mg / kg

$$c = -12.6478 + 1.2553x - 0.9477y - 0.0312x^2 + 0.107xy - 0.3747y^2$$

where c is the Cobalt content in the green mass, mg/kg

x - Cobalt content in the studied soil, mg/kg

y - Cobalt content in Jerusalem artichoke tubers, mg/kg

The multiple coefficient of determination ($R^2 = 0.78$) indicates a close correlation between these indicators

The degree of accumulation of mobile forms of HM in the soil is one of the factors that determines the toxicity of these elements to plants. The heavy metal translocation coefficient is one of the most important parameters that used to predict the content of heavy metals in agricultural plants. Jerusalem artichoke is characterized by an increase in the transition coefficients of heavy metals in the system "root-green mass" in the series: Pb → Co → Ni → Cd

The highest translocation coefficient of cadmium in the system "soil - aboveground phytomass" of Jerusalem artichoke was recorded in the control version of the experiment, Lead - after composting at the rate of 30 t/ha and fertilizer $N_{30}P_{33}K_{66}$, Cobalt - for application of $N_{90}P_{90}K_{90}$ fertilizer to the soil (Table 4).

Table 4. Heavy metal translocation coefficients for Jerusalem artichoke cultivation

№	Pb	Cd	Ni	Co	Pb	Cd	Ni	Co
	in the system "soil - aboveground phytomass"				in the system "soil - root system (tubers)"			
1	0,16	6,88	0,71	0,21	0,16	7,06	0,85	0,22
2	0,17	4,28	0,89	0,21	0,18	4,45	0,93	0,24
3	0,18	3,74	0,96	0,22	0,26	3,88	1,05	0,24
4	0,20	4,43	0,98	0,26	0,25	4,63	1,04	0,30
5	0,21	4,23	0,98	0,28	0,27	4,40	1,04	0,32
6	0,18	3,90	0,98	0,33	0,22	4,03	1,06	0,36
7	0,16	3,94	0,98	0,29	0,20	4,18	1,02	0,31
8	0,16	3,76	0,99	0,31	0,17	3,89	1,05	0,33

The maximum coefficients of cobalt transition in the system "soil - root system" of Jerusalem artichoke was recorded for the introduction of sewage sludge at the rate of 40 t/ha and $N_{10}P_{14}K_{58}$, Lead - for the introduction of sewage sludge at the rate of 30 t/ha and fertilizer $N_{30}P_{33}K_{66}$, - in the control version of the experiment (Table 4). The maximum coefficients of biological absorption of Nickel, Lead and Cobalt by Jerusalem artichoke was observed for growing Jerusalem artichoke on the studied soil with the introduction of sewage sludge at the rate of 40 t/ha and $N_{10}P_{14}K_{58}$, Cadmium - for the introduction of SS at the rate of 20 t/ha and $N_{50}P_{52}K_{74}$.

Table 5. Coefficients of biological absorption of heavy metals by Jerusalem artichoke after repeated application of fertilizers to the soil

№ options	Cd	Ni	Pb	Co
Without fertilizers – control	129,67	2,75	3,35	1,62
$N_{60}P_{60}K_{60}$	125,47	2,79	3,40	1,67
$N_{90}P_{90}K_{90}$	113,47	2,76	3,39	1,67
SS – 20 t/ha + $N_{50}P_{52}K_{74}$	148,31	3,26	3,43	1,93
SS -30 t/ha + $N_{30}P_{33}K_{66}$	139,58	3,34	3,66	2,13
SS – 40 t/ha + $N_{10}P_{14}K_{58}$	124,02	3,40	3,77	2,20
Compost (SS + straw (3:1)) – 20 t/ha + $N_{50}P_{16}K_{67}$	147,38	3,23	3,40	1,82
Compost (SS + straw (3:1)) – 30 t/ha + $N_{30}K_{55}$	144,85	3,32	3,33	2,00

The minimum values of biological absorption coefficients of cadmium Jerusalem artichoke were set during tillage with $N_{90}P_{90}K_{90}$ fertilizer, Cobalt - in the control version, Lead - for compost introduced into the soil at the rate of 30 t/ha and $N_{30}K_{55}$ fertilizer. The coefficients of biological absorption of metals by Jerusalem artichoke increase in a number of elements: Cobalt → Nickel → Lead → Cadmium. The coefficients of biological accumulation of lead and cobalt are maximum for the cultivation of Jerusalem artichoke after the introduction of SS at the rate of 30 t/ha and $N_{30}P_{33}K_{66}$ (Fig. 8).

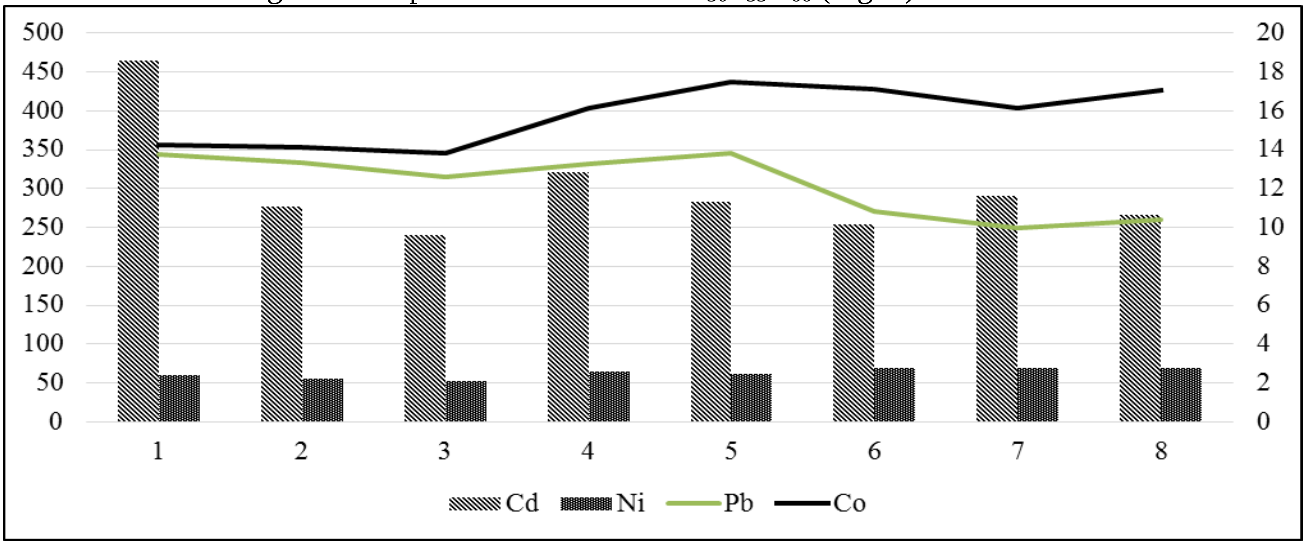

Fig. 8. Coefficients of biological accumulation of heavy metals by Jerusalem artichoke after application of fertilizers in the soil

The lowest coefficients of biological accumulation of Cadmium, Nickel and Cobalt were determined for the cultivation of Jerusalem artichoke in the variant whereas mineral fertilizers $N_{90}P_{90}K_{90}$ were applied, of lead - for compost application at the rate of 20 t/ha and $N_{50}P_{16}K_{67}$. The coefficients of biological accumulation of heavy metals with Jerusalem artichoke increase in a number of elements: lead → cobalt → nickel → cadmium. The concentration of heavy metals in oil-contaminated soil and Jerusalem artichoke plants were increased with increasing amount of fertilizers in the soil. The maximum content of metals in the experimental soils, green mass and Jerusalem artichoke roots was observed mainly in the variant of sewage sludge application at the rate of 40 t/ha and fertilizer $N_{10}P_{14}K_{58}$. The highest concentration of gross and mobile forms of Iron was observed in soils, the lowest concentration is Cadmium. Minimal exceedances of background concentrations were recorded for gross forms of Nickel, mobile forms of Cobalt. The green mass and roots of Jerusalem artichoke absorb the largest amounts of heavy metals, and the transition coefficients of metals in the system "roots - green mass" increase in the series: Pb → Co → Ni → Cd. The coefficients of biological absorption of metals by Jerusalem artichoke were increased in the number of elements: Cobalt → Nickel → Lead → Cadmium. The coefficients of biological accumulation of heavy metals with Jerusalem artichoke increase in a number of elements: Lead → Cobalt → Nickel → Cadmium. The elements of intensive absorption by an energy plant include lead and cobalt, and the elements of very intensive absorption include cadmium, zinc and nickel. Due to the strong absorption capacity of heavy metals by Jerusalem artichoke, it is advisable to use the energy plant as a phytoremediator of oil-contaminated and other man-made transformed ecosystems.

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