Ecological and Economic Reasoning for Growing Vegetable Crops

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Abstract: The problem of growing ecologically safe vegetable crops with minimal economic costs in modern conditions of agricultural production is extremely urgent. At the same time, it is very important to study the features of heavy metals migration in the soil-plant system under the influence of fertilizers, as well as to justify the economic feasibility of their application. The article analyzes the aspects of translocation of heavy metals to vegetable produce under the effect of organic fermented fertilizer (made based on of chicken manure and peat), as well as a complex microbiological preparation.

It was found that the use of organic fermented fertilizer and microbiological preparation under different fertilization systems decreased the intake of toxic metals – cadmium and plumbum – to carrots and cabbage heads, and increased the content of trace metals – zinc and copper. Separate application of 11 t/ha FF, integrated application of 5.5 t/ha with the Azoter formulation, as well as tillage with the formulation on the background of N30 provided a decrease of the plumbum intake rate in carrot root crops compared to the control by 34; 42 and 26%, cadmium – by 7; 14 and 28%, and increase the intensity of copper translocation in to roots, respectively, by 9; 5 and 6%, zinc – by 2; 3 and 1%. The intensity of plumbum intake in cabbage heads with the introduction of 10 t/ha FF separately, 5 t/ha in combination with a microbiological preparation and after application of the preparation on the background of N25 decreased by 20, 36 and 24% respectively, cadmium – by 17; 17 and 34%, and the conversion factor of copper in the product increased by 26; 10 and 7%, zinc – by 6; 2 and 1%. The economic expediency of using fertilizers for growing vegetable crops is also studied.

Keywords: Heavy metals, soil, carrots, white cabbage, organic fermented fertilizer, microbiological preparation, profitability, economic efficiency, net profit.

1. INTRODUCTION

Today, in conditions of excessive anthropogenic pressure on the environment, including soil resources, solving the problem of providing the population with good-quality safe food is extremely important. It is known that the quality of food, the degree of its harmfulness and hazard impacts not only the health of the population but also the gene pool of the state, the level of development of science and industry (Koshkalda et al., 2018; Chorna, 2016).

Product quality, its ecological purity and safety for the environment are the main factors of competitiveness of modern agricultural production. In addition, products, especially vegetables, grown on environmentally friendly technologies have improved taste and high nutritional value (Koltunov, 2007; Koshkalda et al., 2022).

During the cultivation of environmentally friendly products, controlling heavy metals content is especially acute. If the hygienic limits of man-caused pressure are exceeded, heavy metals (including microelements) can accumulate in components of agrolandscapes in significant quantities, causing deterioration of agronomic and ecotoxicological properties of soils (Buslaieva et al., 2011; Buzina & Khainus, 2019; Opara et al., 2019).

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Heavy metals such as mercury, plumbum, and cadmium are hazardous for plants and human health, even at low concentrations. Scientists have established that the main negative effect of heavy metals is manifested in their entry into the human body through food chains, denaturation of metabolically important proteins, conversion of phosphorus into the form of sparingly soluble phosphates, as well as competition in absorption with the necessary elements of mineral nutrition (Muhammad et al., 2021; Shefali, Sudhanshu & Rajender, 2020). Excessive intake of cadmium and plumbum in the human body plumbums to anemia, liver damage, renal dysfunction. They have mutagenic, teratogenic and embryotoxic effects (Koval, 2021).

In turn, the use of fertilizers affects the processes of entry, accumulation and transformation of heavy metals into products. On the one hand, fertilizers contain heavy metals that can potentially contaminate the soil, plants and groundwater, on the other – fertilizers, changing the agrochemical properties of the soil, can affect the mobility of heavy metals and their entry into plants. The contamination probability of plant products with heavy metals is primarily determined by the direction of transformation of chemical element compounds entering the soil, and as a consequence, by changing the degree of their availability to the root system. The availability of heavy metals for plants depends mainly on the content of organic matter in the soil and the reaction of the soil solution: the higher is the humus content, the lower is the mobility of heavy metals and the higher is the acidity, the greater is their availability to plants (Binggan et al., 2020). Thus, for the cultivation of crops in order to control the content of heavy metals in the resulting products, it is crucial to study the peculiarities of their migration in the soil-plant system under the influence of fertilizers.

The use of economically profitable technologies is extremely important when growing environmentally safe vegetable products (Popov et al., 2019). Therefore, our research also provides for determining the economic efficiency of using organic fermented fertilizer and microbiological preparation for growing table carrots and white cabbage.

2. METHODOLOGY

Our research was aimed at studying the peculiarities of the migration of heavy metals in the soil-plant system under the effect of environmentally friendly fertilizers, namely fermented organic fertilizer and a complex microbiological preparation.

Organic fermented fertilizer (FF) is made by the method of controlled aerobic fermentation of chicken manure and peat with subsequent granulation (manufacturer LLC "Starland", Ukraine). Agrochemical characteristics of fertilizer (dry matter) are as follows: pH – 7.2 units, humidity – 50.0 %, organic matter content – 60.0 %, nitrogen – 1.82 %, phosphorus – 1.70%, potassium – 1.10 %, calcium (CaO) – 1.90%, copper – 8.00 mg/kg, zinc – 22.5 mg/kg, plumbum – 12.8 mg/kg, cadmium – 0.25 mg/kg.

The investigated microbiological preparation Azoter (LLC "Azoter Ukraine"), made on the basis of bacteria *Azotobacter Croococcum* ($1{,}54*10^{10}$ CFU in cm^3), *Azospirillium Braziliense* ($2{,}08*10^{9}$ CFU in cm^3), *Bacillus Megatherium* ($1{,}58*10^{8}$ CFU in cm^3), as well as its composition includes heteroauxins, gibberellins, B-vitamins. It was used by pre-sowing tillage followed by wrapping, with a rate of 10 l/ha. To activate the activity of microorganisms and maintain plant growth in the initial periods of development, together with the formulation were introduced "starting" doses of nitrogen – N_{25} and N_{30} depending on the culture of cultivation.

The research scheme ensures the comparison of two fertilization systems: one with the application of environmentally friendly fertilizers and another with mineral-based fertilizers.

The study of the effect of organic fermented fertilizer and microbiological preparation on the peculiarities of heavy metal migration in the soil-plant system for growing white cabbage on dark gray podzolic light loam soil was carried out according to the scheme: 1. Without fertilizers (control); 2. $N_{90}P_{60}K_{90}$; 3. Cattle manure – 16.5 t/ha; 4. FF – 5 t/ha; 5. FF – 5 t/ha + Azoter; 6. FF – 5 t/ha + Azoter + N_{25}; 7. FF – 10 t/ha; 8. Azoter + N_{25}.

The study of the effect of organic fermented fertilizer and microbiological preparation on the peculiarities of heavy metal migration in the soil-plant system for growing table carrots on sod-slightly podzolic sandy soil was carried out according to the scheme: 1. Without fertilizers (control); 2. $N_{100}P_{60}K_{120}$; 3. Muck – 18 t/ha; 4. FF – 5.5 t/ha; 5. FF – 5.5 t/ha + Azoter; 6. FF – 5.5 t/ha + Azoter + N_{30}; 7. FF – 11 t/ha; 8. Azoter + $N_{30.}$

To achieve this goal, field research, laboratory determinations and statistical processing of the results were performed. Field research was conducted in the conditions of Western Polissya of Ukraine.

Soil sampling was carried out according to DSTU (State Standards of Ukraine) 4287:2004. The content of cadmium mobile compounds in the soil was determined according to DSTU 4770.3:2007; the content of mobile plumbum compounds – according to DSTU 4770.9:2007; content of mobile copper compounds – according to DSTU 4770.6:2007; the content of mobile zinc compounds – according to DSTU 4770.2:2007. The content of heavy metals in crop products was determined by the atomic absorption method.

Mathematical processing of research result (SSD – smallest significant difference) was carried out by the method of analysis of variance, using computer programs MS Excel and Alfa.

To establish the peculiarities of heavy metals entry in vegetable products, the content of mobile compounds in soils and total content in produce was determined, and the transition coefficient (Tc – the ratio of plant content to the content of mobile compounds in soil) was calculated.

The calculation of the economic efficiency of the use of organic fermented fertilizer and microbiological preparation was carried out according to such indicators as the increase in net income and the level of fertilizers use profitability (Roik et al., 2013). The increase in net income was defined as the difference between the value of the increase in yield and the additional costs associated with fertilizer. Additional costs include the cost of fertilizers, costs related to their

Table 1. The Effect of FF and Microbiological Preparation on the Content of Mobile Compounds of Heavy Metals in SOD-Podzolic soil (Soil Layer 0–20 cm).

Variant	Content, mg/kg			
	Pb	Cd	Cu	Zn
Without fertilizers (control)	0.29	0.08	0.09	0.78
$N_{100}P_{60}K_{120}$	0.42	0.10	0.10	1.09
Muck– 18 t/ha	0.32	0.06	0.13	1.27
FF – 5.5 t/ha	0.35	0.07	0.10	0.97
FF – 5.5 t/ha + Azoter	0,33	0.06	0.10	1.00
FF – 5.5 t/ha + Azoter + N_{30}	0.36	0.07	0.11	1.05
FF – 11 t/ha	0.31	0.06	0.12	1.20
Azoter + N_{30}	0.30	0.07	0.09	0.83
SSD_{05}	0.02	0.01	0.01	0.08
MCL (Fatieiev & Samokhvalova, 2012)	6.0	0.7	3.0	23.0

transportation, mixing, application, as well as transportation and harvesting of additional crops. The level of profitability of fertilizer use (in percent) characterizes the relationship between the obtained effect (increase in net income) and the number of additional costs.

3. RESULTS AND DISCUSSION

According to the results of the research, it was found that the application of different types of fertilizers affected the content of mobile compounds of heavy metals in the studied soils in various ways. In particular, the maximum accumulation of plumbum in the arable layer of sod-slightly podzolic sandy soil was observed at the application of mineral fertilizers: its content was 0.42 mg/kg against 0.29 mg/kg in the control (Tabl. 1). This is apparently due to the high metal content of mineral fertilizers, in particular phosphorus fertilizers (the plumbum content in simple superphosphate is 42.5 mg/kg (Kulidzhanov et al., 2022)).With regard to cadmium, a similar trend was observed with the application of mineral fertilizers: the content of the element increased by 0.02 mg/kg with respect to the option without fertilizers. In addition to the intake of metals with mineral fertilizers, this pattern of heavy metals content growth may be due to their impact on the reaction of the soil environment as well. Our previous studies found that the rate of soil pH_{KCl} in the mineral fertilizer system decreased compared to the control by 0.1 units (Abramovych & Povkh, 2014; Povkh, 2014).

With application of environmentally friendly fertilizers a significantly lower content of plumbum in the soil was observed compared to the option of applying mineral fertilizers. For the application of 11 t/ha FF the content of plumbum in the soil was 0.31 mg/kg, for the integrated application of 5.5 t/ha FF and the Azoter formulation – 0.33 mg/kg, for a separate application of microbiological preparation – 0.30 mg/kg. With regard to cadmium, the introduction of FF and microbiological preparation (both individually and in combination) showed a decrease in its content in the soil compared to the control by 0.01–0.02 mg/kg.

As for the metals-trace elements copper and zinc, with the effect of application of organic fermented fertilizer and microbiological preparation, an increase in their content in sod-slightly podzolic soil was observed. In the conditions of Western Polissya, the soils of which are characterized by low content of these microelements, while the elements themselves are vital for the growth and development of plants, including vegetables, the increase in the content of zinc and copper in the soil resulting from fertilizers is a positive phenomenon.

With the introduction of 11 t/ha FF copper content in sod-slightly podzolic soil compared to the control increased by 0.03 mg/kg, with the use of 5.5 t/ha FF in combination with the Azoter formulation – by 0.01–0.02 mg/g (see Table **1**). Regarding the treatment of the soil with a microbiological preparation against the background of N_{30}, the indicator of the copper content in the soil relative to the fertilizers-free variant remained unchanged and amounted to 0.09 mg/kg.

The content of zinc in the sod-slightly podzolic soil under the action of integrated application of 5.5 t/ha FF and the formulation increased by 0.22 mg/kg, after additional application of N_{30} – by 0.27 mg/kg. With the application of 11 t/ha FF, the content of the element in the soil was 1.20 mg/kg, which is 0.48 mg/kg higher than the control. After application of the Azoter formulation on the background of N_{30}, the content of zinc in the soil did not significantly exceed that of the option without fertilizers.

According to the results of determination of the content of heavy metals in the products, it was found that the use of FF and the Azoter formulation provided a decrease in the concentration of toxic metals (Pb, Cd) in the carrot root crops relative to control without fertilizers (Table **2**). After application of 11 t/ha FF, the content of Pb in the roots decreased by 0.05 mg/kg, Cd – by 0.007 mg/kg. According to the complex application of 5.5 t/ha FF and the Azoter formulation, the content of plumbum was 0.14 mg/kg, cadmium – 0.015 mg/kg, after additional application of nitrogen fertilizers – 0.19 and 0.018 mg/kg, respectively, for

Table 2. The Content of Heavy Metals in the Roots of Carrots Under Different Fertilizer Systems.

Variant	Pb	Cd	Cu	Zn
Without fertilizers (control)	0.20	0.023	0.18	1.04
$N_{100}P_{60}K_{120}$	0.33	0.034	0.28	1.70
Muck-18 t/ha	0.14	0.016	0.29	1.76
FF – 5.5 t/ha	0.15	0.015	0.22	1.38
FF – 5.5 t/ha + Azoter	0.14	0.015	0.21	1.37
FF – 5.5 t/ha + Azoter + N_{30}	0.19	0.018	0.25	1.45
FF – 11 t/ha	0.15	0.016	0.26	1.62
Azoter + N_{30}	0.16	0.015	0.19	1.12
SSD_{05}	0.01	0.01	0.01	0.07
MCL (Voitovych, 2013)	0.50	0.03	5.0	10.0

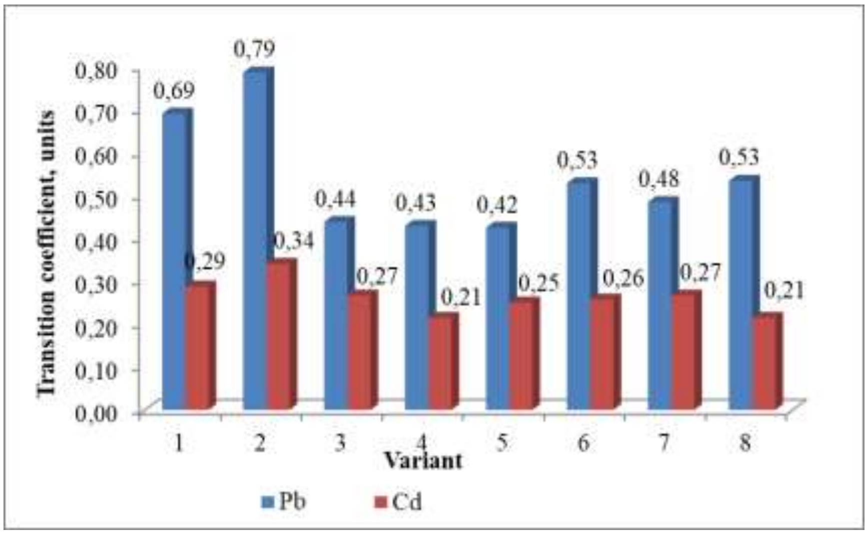

Fig. (1). The intensity of toxic metals transition to the roots of carrots under the influence of fertilizers.
1. Without fertilizers (control); 2. $N_{100}P_{60}K_{120}$; 3. Muck – 18 t/ha; 4. FF – 5.5 t/ha; 5. FF – 5.5 t/ha + Azoter; 6. FF – 5.5 t/ha + Azoter + N_{30}; 7. FF – 11 t/ha; 8. Azoter + N_{30}.

tillage microbiological preparation on the background of N_{30} – 0.16 and 0.015 mg/kg, against 0.20 and 0.023 mg/kg on the control without fertilizers.

Based on the calculation of the element transition coefficient, it was found that the lowest intensity of plumbum transition to the root crops of table carrot was provided by the integrated application of 5.5 t/ha FF and Azoter: the value of Kp was 0.42 units, which is 0.27 lower than the option without application fertilizers (Fig. **1**). The application of 11 t/ha FF and the use of the formulation on the background of N_{30} also reduced the intensity of translocation of plumbum to products: Kp values were 0.48 and 0.53 units, respectively, compared to 0.69 units in the control without fertilizers.

Regarding Cd, the lowest value of the transition coefficient is 0.21 units, against 0.29 units in the control without fertilizers, recorded for tillage with Azoter on the background of N_{30} (see Fig. **1**). With the application of 11 t/ha FF separately and in combination with 5.5 t/ha with a microbiological preparation, the Cd transition coefficient decreased compared to the variant without fertilizers by 0.02, respectively; 0.03 and 0.04 units.

It should be noted that the highest intensity of the transition of cadmium and plumbum to the root crops of table carrot is characteristic of the mineral fertilizer system (Tc of Pb was 0.79 units, Cd – 0.34 units).

The content of metal-trace elements (copper and zinc) in the carrot root crops due to the effect of the application of organic fermented fertilizer and microbiological preparation increased (see Table **2**). Copper and zinc play an important role in the functioning of the human body, and therefore the production of vegetable products with a high content of trace elements, but within the Maximum Contaminant Level (MPL), is an important criterion for the effectiveness of the fertilization system.

The copper content in carrot root crops with the introduction of 11 t/ha FF increased relative to the control by 0.08 mg/kg. With the complex application of 5.5 t/ha FF and microbiological preparation, the copper content was 0.21

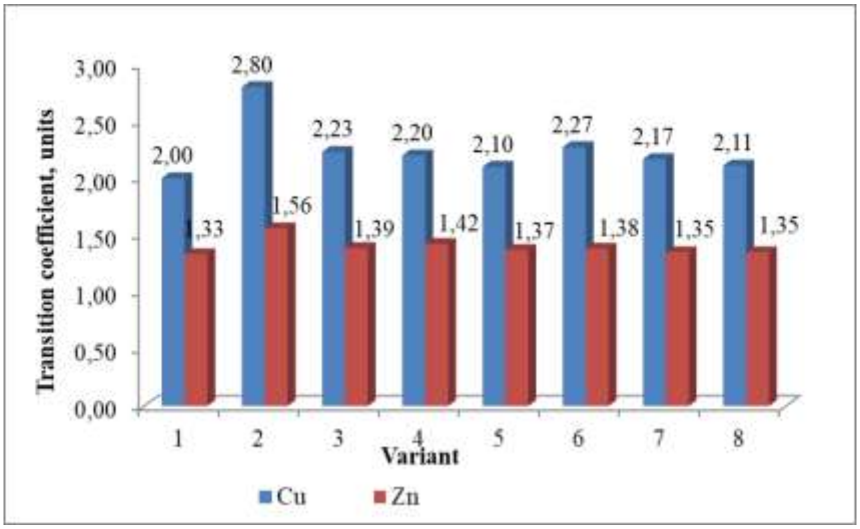

Fig. (2). The intensity of metals-microelements transition to the carrot roots of under the influence of fertilizers.
1. Without fertilizers (control); 2. $N_{100}P_{60}K_{120}$; 3. Muck – 18 t/ha; 4. FF – 5.5 t/ha; 5. FF – 5.5 t/ha + Azoter; 6. FF – 5.5 t/ha + Azoter + N_{30}; 7. FF – 11 t/ha; 8. Azoter + N_{30}.

Table 3. The effect of FF and Microbiological Preparation on the Content of Mobile Compounds of Heavy Metals in the Dark Gray Podzolic Soil (soil layer 0-20 cm).

Variant	Pb	Cd	Cu	Zn
Without fertilizers (control)	0.24	0.05	0.17	1.06
$N_{90}P_{60}K_{90}$	0.29	0.07	0.18	1.25
Cattle manure – 16.5 t/ha	0.19	0.04	0.20	1.33
FF – 5 t/ha	0.21	0.05	0.17	1.15
FF – 5 t/ha + Azoter	0.19	0.04	0.18	1.16
FF – 5 t/ha + Azoter + N_{25}	0.23	0.06	0.19	1.18
FF – 10 t/ha	0.20	0.05	0.19	1.27
Azoter + N_{25}	0.21	0.05	0.16	1.13
SSD_{05}	0.01	0.01	0.02	0.06
MCL (Fatieiev & Samokhvalova, 2012)	6.0	0.7	3.0	23.0

mg/kg, with the additional application of N_{30} – 0.25 mg/kg, which is 0.03 and 0.07 mg/kg higher, respectively than on control. During soil treatment with the formulation against the background of nitrogen fertilizers, no significant changes in the concentration of copper in the products were observed (the content was 0.19 mg/kg, in the case without fertilizers – 0.18 mg/kg).

With the application of 11 t/ha FF, the zinc content in the products was 1.62 mg/kg, which was 0.58 mg/kg higher than the control. The integrated application of 5.5 t/ha of FF and microbiological preparation increased the zinc content in the roots of table carrots by 0.33 mg/kg, with the application of nitrogen fertilizers – by 0.41 mg / kg. After application of the formulation on the background of N_{30}, the zinc content exceeded the control by 0.08 mg/kg.

The coefficient of Cu transition to the roots of table carrots with the application of 11 t/ha FF separately was 2.17 units, with the use of 5.5 t/ha FF in combination with a microbiological preparation – 2.10 and 2.27 units (in the version with the use of N_{30}), which exceeded the control indicator by 0.17; 0.10 and 0.27 units (Fig. **2**). During the treatment of the soil with the formulation against the background of nitrogen fertilizers, the Tc value was 2.11 units, against 2.00 units in the control. This indicates that the use of FF and microbiological preparation for different fertilizer systems provides an increase in the intensity of copper translocation to the resulting product.

The supply of zinc to the root crops of table carrots resulting from FF and microbiological preparation was slightly less intense compared to copper, but the transition factor of the element increased relative to the control by 0.02-0.05 units depending on the option (see Fig. **2**).

In the dark gray podzolic soil there is a similar trend in the accumulation of heavy metals as the effect of fertilizers, as in sod-slightly podzolic soil (Table **3**). The most intensive accumulation of plumbum is characteristic of the mineral ferti-

Table 4. The Content of Heavy Metals (Trace Metals) in the Heads of Cabbage Under Fertilizer Application.

Variant	Pb	Cd	Cu	Zn
Without fertilizers (control)	0.06	0.012	0.31	1.57
$N_{90}P_{60}K_{90}$	0.09	0.022	0.45	1.98
Cattle manure – 16.5 t/ha	0.04	0.011	0.43	2.05
FF – 5 t/ha	0.04	0.009	0.35	1.78
FF – 5 t/ha + Azoter	0.03	0.008	0.36	1.75
FF – 5 t/ha + Azoter + N_{25}	0.05	0.011	0.38	1.82
FF – 10 t/ha	0.04	0.010	0.39	2.00
Azoter+ N_{25}	0.04	0.008	0.32	1.68
SSD_{05}	0.01	0.01	0.03	0.11
MCL [22]	0.50	0.03	5.0	10.0

lizer system: the content of Pb compared to the control increased by 0.05 mg/kg, Cd – by 0.02 mg/kg.

The application of 10 t/ha FF helped to reduce the plumbum content in the dark gray podzolic soil relative to the control by 0.04 mg/kg, its integrated application of 5 t/ha with the Azoter formulation – by 0.05 mg/kg (with additional application of N_{25} – by 0.01 mg/kg), the use of the latter on the background of nitrogen fertilizers – by 0.03 mg/kg.

The content of cadmium in the soil during the application of 10 t/ha FF and after application of the microbiological preparation on the background of N_{25} compared to the control remained intact and amounted to 0.05 mg/kg. With the joint application of 5 t/ha FF and the formulation there was a decrease in the content of Cd compared to the fertilizers-free by 0.01 mg/kg, with additional application of nitrogen fertilizers – an increase of 0.01 mg/kg.

The content of Cu in the dark gray podzolic soil for the application of 10 t/ha FF, as well as for the application of 5 t/ha FF in combination with the Azoter was 0.18-0.19 mg/kg, which did not significantly exceed the control value (0.17 mg/kg). The use of the formulation on the background of N_{25} caused a decrease in copper content compared to the control by 0.01 mg/kg.

The application of 10 t/ha FF contributed to the increase of Zn content in dark gray podzolic soil compared to the control without fertilizers by 0.21 mg/kg, the application of 5 t/ha FF in combination with a microbiological preparation – by 0.10-0.12 mg/kg. During tillage with Azoter on the background of N_{25}, the zinc content was 1.13 mg/kg, which was also significantly (0.07 mg/kg) higher than the option without fertilizers.

According to the results of studies to determine the content of heavy metals in cabbage heads, a decrease in plumbum content compared to control without fertilizers: for 10 t/ha FF and for soil treatment with nitrogen fertilizers – by 0.02 mg/kg, for integrated application of 5 t/ha of FF and the formulation – by 0.03 and 0.01 mg/kg with additional application of N_{25} (Table **4**).

The content of cadmium in the heads of cabbage during tillage with Azoter on the background of N_{25} and under the effect of its integrated application with 5 t/ha FF, compared with the control without fertilizers decreased by 0.04 mg/kg. The application of 10 t/ha FF caused a decrease in the content of the element relative to the control by 0.02 mg/kg.

The lowest value of the coefficient of transition of plumbum from the soil to the heads of cabbage (0.16 units) is characteristic of the combined application of 5 t/ha FF and microbiological preparation (Tc on the control was 0.25 units) (Fig. **3**). A decrease in the intensity of Pb translocation to the product was observed with the introduction of 10 t/ha FF, as well as with the use of the formulation on the background of N_{25}: the transition factor decreased compared to the control by 0.05 and 0.06 units.

A significant increase in the content of trace metals in cabbage heads relative to the control was observed with the introduction of 10 t/ha FF, as well as with its integrated application of 5 t/ha with the Azoter formulation: Cu – by 0.05-0.08 mg/kg, Zn – at 0.18–0.43 mg/kg (see table **4**).

The coefficient of transition of copper to the heads of cabbage with the application of 10 t/ha FF compared to the control without fertilizers increased by 0.23 units, with the integrated use of 5 t/ha FF with Azoter – by 0.18 units, zinc – respectively by 0.09 and 0.03–0.06 units (Fig. **4**).

In general, it should be noted that the use of organic fermented fertilizer and the Azoter formulation in the fertilization systems of table carrots and white cabbage did not exceed the maximum concentration limit (MCL) of heavy metals in soil and products.

In addition to the ecological reasoning, the question of the economic efficiency of growing vegetable products is extremely important in modern conditions. According to our calculations, we found that the highest level of profitability of growing vegetable crops was obtained with the separate use of the Azoter formulation against the background of nitrogen fertilizers - 132.7% for growing table carrots and

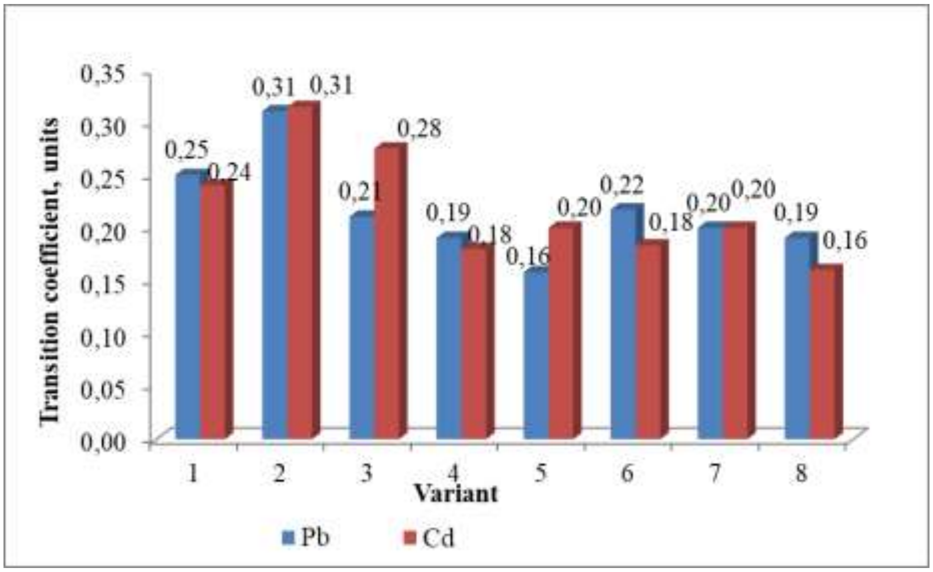

Fig. (3). The intensity of the transition of toxic metals to the heads of cabbage under different fertilizer systems.

1. Without fertilizers (control); 2. $N_{90}P_{60}K_{90}$; 3. Cattle manure – 16,5 t/ha; 4. FF – 5 t/ha; 5. FF – 5 t/ha + Azoter; 6. FF – 5 t/ha + Azoter + N_{25}; 7. FF – 10 t/ha; 8. Azoter + N_{25}.

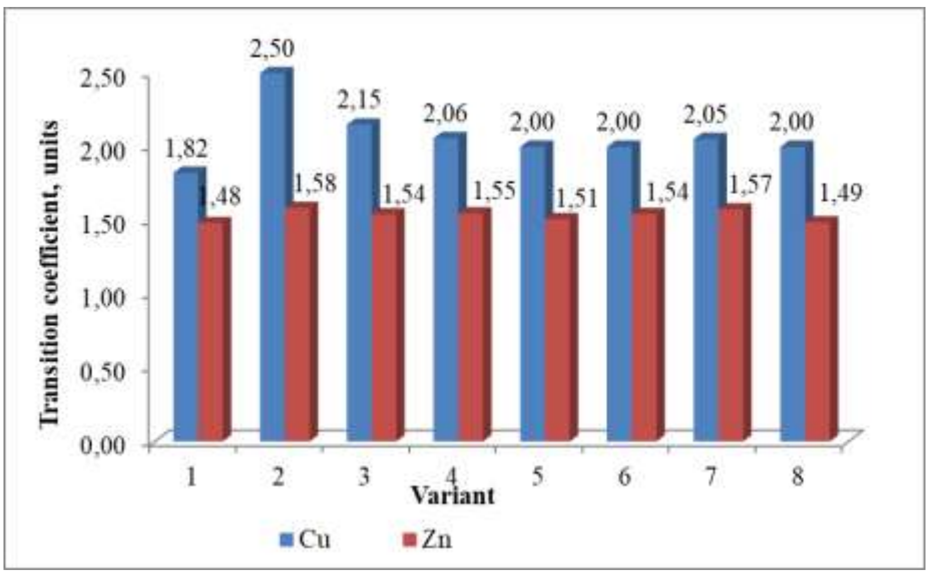

Fig. (4). The intensity of metals-microelements transition to cabbage heads under different fertilizer systems.

1. Without fertilizers (control); 2. $N_{90}P_{60}K_{90}$; 3. Cattle manure – 16,5 t/ha; 4. FF – 5 t/ha; 5.FF – 5 t/ha + Azoter; 6. FF – 5 t/ha + Azoter + N_{25}; 7. FF – 10 t/ha; 8. Azoter + N_{25}.

Table 5. Economic Efficiency of Using Ecologically Safe Fertilizers in Vegetable Crops Cultivation.

Variant	Yields, t per ha	Increase in net income, UAH hrn per ha	Profitability rate, %	Variant	Yields, t per ha	Increase in net income, UAH hrn per ha	Profitability rate, %
$N_{100}P_{60}K_{120}$	37.7	7359.1	58.3	$N_{90}P_{60}K_{90}$	43.9	6050.1	58.0
Muck-18 t/ha	37.2	4026.0	26.7	Cattle manure – 16.5 t/ha	43.0	3007.5	25.0
FF – 5.5 t/ha	31.9	1778.5	22.9	FF – 5 t/ha	37.9	479.0	7.5
FF – 5.5 t/ha + Azoter	35.9	5810.7	53.2	FF – 5 t/ha + Azoter	42.8	5009.8	51.6

FF – 5.5 t/ha + Azoter + N_{30}	36.2	5740.3	49.7	FF – 5 t/ha + Azoter + N_{25}	43.4	5294.5	51.0
FF – 11 t/ha	36.8	3077.0	20.1	FF – 10 t/ha	42.7	1498.0	11.5
Azoter + N_{30}	33.5	7082.0	132.7	Azoter+ N_{25}	38.6	4276.7	114.9

114.9% for growing white cabbage (Table **5**). With the integrated use of the preparation and organic fermented fertiliser, the level of profitability decreased to 51.0-53.2%, depending on the cultivated crop.

Fertilization systems with separate application of organic fermented fertilizer were the most cost-effective - the level of profitability was 20.1% and 11.5% for the cultivation of table carrots and white cabbage, respectively. Thus, taking into account the significant economic costs of using organic fermented fertilizers, their introduction in a complex with a microbiological preparation, due to the reduction of norms, is a promising measure to increase the economic efficiency of vegetable crop fertilization systems.

4. CONCLUSION

Therefore, according to the results of the study, it was found that the use of organic fermented fertilizer and microbiological preparation in different fertilizer systems provided a decrease in the intake of toxic metals – cadmium and plumbum, and increased content of trace elements – zinc and copper. Separate application of 11 t/ha FF, integrated application of 5.5 t/ha with the Azoter formulation, as well as tillage with the formulation on the background of N30 provided a decrease of the plumbum intake rate in carrot root crops compared to the control by 34; 42 and 26%, cadmium – by 7; 14 and 28%, and increase the intensity of copper translocation in to roots, respectively, by 9; 5 and 6%, zinc – by 2; 3 and 1%.

A similar trend was observed for the cultivation of white cabbage. The intensity of plumbum intake in cabbage heads with the introduction of 10 t/ha FF separately, 5 t/ha in combination with a microbiological preparation and after application of the preparation on the background of N_{25} decreased by 20, 36 and 24% respectively, cadmium – by 17; 17 and 34%, and the conversion factor of copper in the product increased by 26; 10 and 7%, zinc – by 6; 2 and 1%.

The decrease in the intake rate of toxic metals to vegetable products with the use of organic fermented fertilizers is due to the impact on their mobility in the soil. The fertilizer contains 60.0% of organic matter and 1.90% of calcium, which reduces the transition of these elements from the soil to plants, as a result of the formation of heavy metal ions of organo-mineral compounds of different nature.This phenomenon is confirmed by a number of studies in which it was noted that when studying the effectiveness of muck, cattlle manure, green manure and peat in equivalent norms, the mobility of plumbum decreased mostly under the influence of peat, which is a major component of organic fermented fertilizer (Lohynova, 2010).

The increase in the amount of microelements in the products due to the application of organic fermented fertilizer is due to the entry of a significant amount of them into the soil together with the fertilizer (copper content is 8.0 mg/kg, zinc – 22.5 mg / kg). In addition, Zn and Pb are characterized by an antagonistic effect (Christopher et al., 2020). Since the mechanism of absorption of these metals is the same, it is possible to assume that due to mutual competition zinc inhibited the absorption of plumbum, which led to an increase in its content in the product and, accordingly, a decrease in the toxic metal.

An effective agricultural technique for reducing the intensity of plumbum and cadmium in the product is the use of the Azoter formulation. This result is due to the ability of *Azotobacter* bacteria to form insoluble complexes with heavy metals, converting them into less toxic compounds by changing the valence of the elements and the removal by ion pump of cells (Zaiets et al., 2007). Scientists have noted that such properties of bacteria are manifested only in relation to toxic metals, in particular cadmium, plumbum and mercury (Jennifer et al., 2016). This, in turn, validates the translocation rate increase of trace metals (copper and zinc) to the produce.

The use of a microbiological preparation, in addition to reducing the intensity of heavy metals-toxicants entering the grown products, allows to significantly reduce economic costs in the technologies of growing vegetable crops. In particular, the use of a microbiological preparation against the background of starting doses of nitrogen ensures the profitability of growing table carrots at the level of 132.7%, white cabbage – 114.9%. The level of profitability of the integrated use of a microbiological preparation and organic fermented fertiliser for the cultivation of table carrots is 49.7–53.2%, white cabbage – 51.0–51.6%

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Received: June 25, 2023 Revised: June 30, 2023 Accepted: August 05, 2023

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