Agronomy Research **22**(3), 1241–1253, 2024
https://doi.org/10.15159/AR.24.099

Study of the influence of different organic fertilizers on soil agrochemical parameters in hazelnut plantations in Ukrainian Southern Steppe

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Received: July 29th, 2024; Accepted: September 19th, 2024; Published: November 14th, 2024

Abstract. The effect of different origin organic fertilizers on agrochemical indicators of typical medium-humic chernozem in hazelnut plantings in the conditions of Ukrainian Southern Steppe was studied. There were used cattle manure, chicken droppings, Biofertilizer No. 1 (the combination of sewage sludge, winter wheat straw, phosphate-mobilizing bacteria *Microbacterium barkeri*), Biofertilizer No. 2 (the combination of sewage sludge, sunflower seed husks, phosphate-mobilizing bacteria *Microbacterium barkeri*), and native sewage sludge in the study. It was found that different origin organic fertilizers effected on the main agrochemical soil indicators increasing. The content of easy hydrolyzable nitrogen in soil increased from 84.0 mg kg^{-1} in control up to 98.0 mg kg^{-1} in the tests, mobile phosphorus - consequently from 138.75 mg kg^{-1} in control to 306.30 mg kg^{-1} in the tests, and potassium from 108.40 mg kg^{-1} in control to 166.90 mg kg^{-1}. In addition, the organic matter content increasing from 3.76% (control) to 4.18% (tests) in the soil was detected. The express biosensor analysis of the fertilized soil showed a variation of the average ecotoxicity indicator from 0.92 to 1.41 which could be classified as a "low" common pollution level. It also detected an elevated zinc content in soil samples fertilized by Biofertilizer No. 1 and native sewage sludge. It proves that organic fertilizers based on sewage sludge applying can allow for overcoming the zinc deficit in Ukrainian soils. The advantages of Biofertilizers No. 1 and No. 2 were identified in respect to other studied organic fertilizers. New biofertilizers using allows soil nutrient content increasing, soil biological activity enhancement, which resulting in improvement in crop yield, and environmental enhancement.

Key words: easy hydrolysable nitrogen, biofertilizers, cattle manure, soil, organic matter, mobile potassium and phosphorus.

INTRODUCTION

The Ukrainian economy current state requires environment improvement and new approaches searching for solving the problem of food security maintenance. The need for plant products is not fully satisfied, therefore, the search of new raw materials sources, identification and selection of useful properties, as well as opportunities in usage increasing are the important and urgent problems (Satina & Mazur, 2019). Among the promising plants of the natural and cultivated flora, the special place is occupied by nut-bearing plant of *Corylus* L. genus - the hazelnut *Corylus domestica* (Kosenko et al., 2019).

A hazelnut culture grows well in different parts of Ukraine (Satina & Mazur, 2019). The Ukrainian soil and climatic conditions are fully satisfying the requirements of hazelnut in temperature and photoperiod. The most of other conditions are regulated by agrotechnical measures (Kosenko et al., 2019; Ayyildiz et al., 2023).

A hazelnut harvest is affected by specific climatic conditions, type and nutrient content of soil as well as using of agrotechnical methods (pruning, weeding). The factor variations resulting from different reasons are directly affect the harvesting (Ustaoglu & Karaca, 2014; Bekele et al., 2019; An et al., 2020; Gamayunova et al., 2020; Vinci et al., 2023).

The main component of soil organic matter is the organic carbon. About 45% of mineral soils in Europe have a low or very low soil organic carbon content (0–2%), and 45% have a medium content (2–6%) (Gardi et al., 2012). 85–90% of organic matter is represented by humus, which is formed at the stage of a small biological cycle of matter and energy.

In the most cases, the reserves of soil organic carbon and their dynamics are estimated for the upper most active soil layer (0–30 cm) (Dmytruk & Demyd, 2019). However, there is a vision of organic matter content (dynamics) evaluation in the soil profile in general in the global context. This approach, in particular, was chosen by the '4 ppm' initiative (Minasny et. al., 2017).

Ukrainian lands have lost 30% of humus over the past 130 years. The average NPK removal by yield is 130–180 kg ha^{-1} (Baliuk et al., 2012).

The content of humus in the soil arable layer is 3.14% on average in Ukraine, and through zones: Polissia - 2.24%, Forest-steppe - 3.19%, Steppe - 3.40% (Baliuk et al., 2021). Thus, it is necessary to look for opportunities for applying of alternative types of organic fertilizers, as the organic matter and humus contents in Ukrainian soils are constantly decreasing as a result of agricultural operation (Skrylnyk et al., 2019; Kravchenko, 2020).

The material basis of soil fertility consists of three main groups of factors: the agrochemical, the agrophysical and the biological. Their effect on the crop yield is determined by nutrients and moisture reserves in the soil, the reaction of the soil solution, the organic matter content, physical and biological activity.

The soils in the Odesa Raion of Ukraine are very diverse, and the organic matter content of in each type of soil is different. The state of soil fertility in the region can be evaluated by the concentration of organic matter (Zhantalai, 2012; Golubchenko et al., 2019) as hazelnut is very demanding on soil fertility. It grows well and bear on deep humus soils with a pH of 5–7, and the hazelnut productivity grown on infertile, insufficiently fertilized soils is low.

Biological origin nitrogen and phosphorus in soil are kept mainly in humus. Plants use only mineral (most soluble) forms of nitrogen and phosphorus for nutrition, which had got to the soil solution after humus mineralization. This contributes to the transition power elements fixed in soil organic matter into available form (Baliuk et al., 2016).

It is worth to remark that the major nutrient element for Ukrainian soil-climatic zones of Ukraine, including Odesa Raion, is nitrogen. As it is most common limiting nutrient in Ukrainian crop farming, so its rate of application is the biggest (Zaitsev et al., 2023).

The additional carbon application into the soil as a part of a manure helps to regulate the soil nitrogen-carbon balance by replenishing of carbon and nitrogen available form for microorganisms. This leads to the content of humus increasing in the soil top layer (Dmytruk & Demyd, 2019).

The phosphorus is the second by importance element for plant mineral nutrition. Its mineral forms content in ordinary chernozem prevail the organic phosphorus. Therefore, phosphorus mineral forms play the main role in phosphorus nutrition of plants. The phosphate balance in the soil solution can be affected by several factors: the solid phase phosphate composition, the adsorption and desorption processes, the synthesis and decomposition of organic and mineral compounds, the plants interaction, and the vital activity of microorganisms (Hasan et al., 2016).

The potassium, besides the calcium and magnesium, plays an important role in the plants ammonium nutrition, supporting required level of plant metabolism, in particular, at the initial stage of growth.

Different organic fertilizers affect differently on soil parameters differently due to their origin. The main organic fertilizer used in Ukrainian agriculture is manure. It contains about 25% dry matter and about 75% water, 0.5% nitrogen, 0.25% phosphorus, 0.6% potassium and 0.35% calcium. In addition, manure contains a large number of microorganisms (1 t contains 10–15 kg of living microbial cells). Manure has an integrated effect on soil and plants too. It enriches the soil with useful microorganisms, which increases nitrogen fixation and intensifies other microbiological processes. Manure also increases the carbon dioxide concentration in soil and ground air and reduces soil acidity. Its systematic use increases the humus and total nitrogen content in the soil improves soil structure, and contributes to better absorption and retention of moisture.

Chicken droppings are a fast-acting organic fertilizer, which is used to feed crops. It contains 0.7–1.9% nitrogen, 1.5–2.0% P2O5, 0.8–1.0% K2O and 2.4% CaO. The nutrients are in a form available to plants. Chicken droppings are closer to mineral fertilizers than manure in terms of their effect on the crop. At the same time, its effect is higher than mineral fertilizers, due to the nitrogen a part of which is contained in organic form, therefore it is gradually absorbed by plants.

Sewage sludge is produced by treating municipal wastewater in wastewater treatment plants. Fresh sludge moisture content is about 97%. Therefore, different techniques of drying, such as natural drying on sludge beds and mechanical dewatering on vacuum filters, are needed to decrease it. Sewage sludge from municipal wastewater treatment plants is characterized by a significant content of organic matter, macro- and microelements, and biologically active substances (Chew et al., 2019). In terms of total nutrient content (NPK), the sludge is comparable to traditional organic fertilizers and can increase soil fertility. They have a positive effect on the soil microbiological state by adjusting the composition of microbial groupings in the plant root spheres.

The effect of sewage sludge based organic fertilizers on soil parameters has been already studied (Jamil et al., 2006; Cardoso et al., 2022; Marin & Rusănescu, 2023), but such fertilizers manufacturing by composting them with phosphate-mobilizing bacteria suspension inoculation and their effect on soil agrochemical indicators has been poorly investigated yet.

Thus, the study was aimed at determining the main agrochemical indicators of the soil after the application of biofertilizers based on sewage sludge as well as the standard organic fertilizers in hazelnut plantations in Ukrainian Southern Steppe conditions and confirming their role in soil fertility increasing and environment restoring.

MATERIALS AND METHODS

On-farm research was carried out during 2021–2022 on the base of Engineering and Technological Institute 'Biotekhnika' of NAAS in Tsebrykovo (Rozdilna Raion, Odesa Oblast, Ukraine; 47°8′47″N 30°6′27″E), which location belongs to Ukrainian Southern Steppe. Various organic fertilizers were introduced into the soil under hazelnut plants while setting in May 2021. The rate of introduction was 5 kg per plant (in dry weight). The fertilizer-treated soil samples were taken in October 2021 and in August 2022 and analysed.

The Italian hazelnut plant variety of Tonda di Giffoni (2 years old seedlings) with 4 m × 4 m planting system was used in the experiments. The soil preparation for planting and the cultivation technology were generally accepted according to the methodology of conducting on-farm research with fruit and nut crops (Yeshchenko et al., 2005). The methodology includes preparation of soil for hazelnut planting, plot layout, digging pits in autumn to air the soil, and seedlings planting in spring. The organic fertilizers were added to the pits in spring in the amount calculated by the total nitrogen content. The fertilizers were mixed well with the soil. Seedlings were planted in pits one at a time, placing the root neck at soil surface level. The optimum soil moisture (75–80%) is ensured by irrigation. The seedbeds were covered with dry soil. The seedlings were grown in uncomfortable growing conditions after planting, forcing the root system to develop by seeking water and nutrients. Watering was less frequent but more prolonged. Circle around the hazelnut plants were kept under fall fallow, systematically loosening the soil to a depth of 6 cm to 8 cm (Yeshchenko et al., 2005).

The experiments design was:

- Test 1 – Control (soil without fertilizers);
- Test 2 – Cattle manure;
- Test 3 – Chicken droppings;
- Test 4 – Biofertilizer No. 1;
- Test 5 – Biofertilizer No. 2;
- Test 6 – Native sewage sludge.

There were no chemical fertilizers used as the additional control.

The Biofertilizer No. 1 was the combination of sewage sludge, winter wheat straw, and phosphate-mobilizing bacteria *Microbacterium barkeri* LP-1. The Biofertilizer No. 2 was consisted of sewage sludge, sunflower seed husks, and *Microbacterium barkeri* LP-1. Both biofertilizer types were developed at Engineering and Technological

Institute 'Biotekhnika' of NAAS (Krutyakova et al., 2021). The sewage sludge origin was Odesa biological treatment plant 'Pivdenna'.

Agrochemical indicators of all organic fertilizers used in the experiments are shown in Table 1.

Table 1. Agrochemical indicators of all organic fertilizers used in the experiments

Organic fertilizers	Dry matter, %	Organic matter, %	Total carbon, %	General forms, g kg^{-1}		
				P	K	N
Native sewage sludge	80.68	19.3	11.2	9.8	3.31	31.0
Biofertilizer No. 1	71.96	20.7	12	9.6	3.84	22.4
Biofertilizer No. 2	54.26	31.1	18	19.0	9.84	37.5
Cattle manure	61.0	59	30.1	2.55	2.2	1.72
Chicken droppings	47.0	57	30.2	1.8	0.5	1.9

Each organic fertilizer was introduced under three hazelnut plants. which maintained the triple replication of the experiment. The topography of the area under the hazelnut plantation was flat. The soil was ordinary medium-humus chernozem, which included humus (3.67%), easy hydrolyzed nitrogen (14.2 mg kg^{-1}), mobile forms of phosphorus (52.4 mg kg^{-1}), and potassium (61.2 mg kg^{-1}). The soil pH (aqueous) was 7.4.

The weather conditions while the experiment was:

– average monthly temperature 10.4 °C which is slightly less than the standard climatic norm of 10.5 °C in 2021;
– average monthly temperature 11.3 °C in 2022
– average air humidity 77% in 2021;
– average air humidity 54% in 2022.

The period with a temperature above 5 °C lasted 122 days in 2021, and 124 in 2022. The average monthly air humidity during the period of active vegetation in 2021 variated from 79% to 87%. The minimum of 65% was in September. These indicators in 2022 were 53% and 52% with the minimum of 37% in July.

The weather conditions of 2021 and 2022 differed not only by temperature, but also by the amount and distribution of precipitation. The maximum amount of precipitation during 2021 the hazelnut growing season was observed in June (104.0 mm), and in July (145.3 mm), and the minimum was fallen in September (6.6 mm) and in October (11.4 mm). The lowest amount of precipitation was marked in July (18.3 mm) and in October (10 mm), and the highest one was in August (101.7 mm) in 2022.

Thus, 2021 weather conditions were slightly differed from the standard climate norms, except for the amount of precipitation. Their standard climatic norm is 500 mm, and the amount of precipitation in 2021 exceeded it by 47.3%. Another matter was observed in 2022. The amount of precipitation was 305.4 mm, which is almost 1.6 times less than the standard climatic norm (500 mm), and 93% of precipitation fallen during the growing season.

The soil agrochemical indicators were analysed for the samples of each organic fertilizer taken in 2021 and 2022 consequently (Giacometti, 2013) The samples study was made at Testing Center of the Volyn Branch of the State Institution 'State Ground Protection' of the Ministry of Agrarian Policy and Food of Ukraine. Standard techniques described in Ukrainian National Standards (DSTU) and International Standards were used for the determination of agrochemical soil parameters. An easy hydrolyzed nitrogen was evaluated by the method of soil organic compounds hydrolysis by alkali solution, and further titration by Vitriol Acid solution (DSTU 7863:2015). Mobile compounds of phosphorus potassium were determined by photometric measurements (DSTU 4114:2002). Determination of pH was made according to international standard (ISO 10390:2021). An organic matter analysis was based on the thermal method of its determination by comparing of initial sample weight with one after ignition residue (DSTU 4289:2004). The soil was sampled by square method by sampling pipe (DSTU 4287:2004) and prepared for analysis by standard techniques (ISO 11464:2006; ISO 10381-2:2002).

The express biosensor analysis of the environmental objects (soil) pollution level by the ecotoxicity indicator was carried out at the Ovcharenko, F.D. Institute of Biocolloidal Chemistry of National Academy Sciences of Ukraine (Rieznichenko et al., 2015). Biosensor analytical systems provide the determination of pollutants that are toxic to living systems, while traditional methods only allow determining the total content of a substance without taking into account its biological toxicity (Rajkumar et al., 2017). Bioluminescence analysis is based on determining changes in the intensity of bacterial strains bioluminescence - components of sensor elements, compared to the control, affected by pollutants present in the sample (Rieznichenko et al., 2015).

The ecotoxicity indicator was used for the soil integral pollution level determination. It was evaluated as the ratio of the bacteria bioluminescence intensity upon contact with the test sample to the bacteria bioluminescence intensity upon contact with the reference (control) sample (reference soil/water):

$$E = \frac{I_n}{I_e} \tag{1}$$

where E – ecotoxicity indicator; I_n – bacteria bioluminescence intensity upon contact with the test sample, photon/sec.; I_e – bacteria bioluminescence intensity upon contact with the control sample, photon/sec.

Risk ranges were evaluated as:

- low (0.6…0.9) < E < (1.1…1.5);
- medium (0.4…0.6) < E < (1.5…1.7);
- high (0.2…0.4) < E < (1.7…2.0).

The bacteria bioluminescence intensity was evaluated by bioluminometer HIDEX (Finland).

RESULTS AND DISCUSSION

Odesa District natural conditions are favorable for various agricultural crops cultivation. The main natural wealth of the region is the land resources. They are mainly represented by chernozem soils with high natural fertility. Chernozem soils form region’s high agro-industrial (agricultural) potential in combination with a warm steppe climate.

The soil agrochemical indicators of fertilizer-treated soil samples taken in October 2021 are presented in Table 2.

Table 2. The agrochemical indicators of fertilizer-treated soil samples (2021)

Agrochemical indicator	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Easy hydrolysable nitrogen, mg kg^{-1}	61.44	74.66	96.12	72.09	68.76	65.78
Mobile compounds of phosphorus, mg kg^{-1}	171.58	293.18	208.96	249.44	232.33	198.38
Mobile compounds of potassium, mg kg^{-1}	123.60	164.70	125.20	118.70	144.40	133.20
Water solution, pH	8.00	8.10	8.30	8.30	8.30	8.20
Organic matter, %	3.86	3.86	3.86	4.05	3.86	3.86

As one can see from the Table 1, tested soils were characterized by very low concentration of easy hydrolysable nitrogen 61.44 mg kg^{-1} (Test 1) - 96.12 mg kg^{-1} (Test 3). However, the content of mobile phosphorus was very high 171.58 mg kg^{-1} (Test 1) - 293.18 mg kg^{-1} (Test 2). The mobile potassium concentration was medium in all tests and variated from 123.60 mg kg^{-1} (Test 1) to 164.70 mg kg^{-1} (Test 2). The tested soil pH was medium alkaline in Test 1, and strongly alkaline for other tests. Almost all tested soils had an increased level of organic matter availability (3.86%), and its content in the sample of Test 4 was high (4.05%).

The soil agrochemical indicators of fertilizer-treated soil samples taken in August 2022 are presented in Table 3.

Table 3. The agrochemical indicators of fertilizer-treated soil samples (2022)

Agrochemical indicator	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Easy hydrolysable nitrogen, mg kg^{-1}	84.00	98.00	91.00	98.00	91.00	84.00
Mobile compounds of phosphorus, mg kg^{-1}	138.75	306.30	245.05	292.00	204.05	174.75
Mobile compounds of potassium, mg kg^{-1}	108.40	166.90	134.50	140.70	130.90	112.00
Water solution, pH	8.02	8.06	8.30	8.04	8.14	8.08
Organic matter, %	3.76	3.80	3.86	4.18	4.09	3.78

Obtained data showed that, the concentration of easy hydrolysable nitrogen in 2022 was a shade higher than ones in 2021 but still very low 84.0 mg kg^{-1} (Tests 1, 6) - 98.0 mg kg^{-1} (Test 4). The mobile phosphorus concentration kept very high 138.75 mg kg^{-1} (Test 1) - 306.30 mg kg^{-1} (Test 2). and the mobile potassium concentration kept medium 108.40 mg kg^{-1} (Test 1) - 166.90 mg kg^{-1} (Test 2). The pH level increasing was observed. All soil samples became strongly alkaline 8.02 (Test 1) - 8.14 (Test 5). The organic matter content mostly showed an increased (Tests 1–3, 6) and high availability (Tests 4, 5).

Thus, we can conclude that organic fertilizers using led to mobile NPK content common enhancement in the soil. It confirms the role of organic fertilizers in hazelnut plantings nutrition optimization. At the same time, the pH level tended to decrease, which could be the basis of soil nutrient ability increasing (Neina, 2019; Wang et al., 2019).

The comparison of easy hydrolysed nitrogen content variations in fertilizer-treated soil samples in 2021 and 2022 is shown on Fig. 1. It can be seen that the nitrogen concentration increased in the most of tests, and its value in fertilized soil was higher than in control. The results confirms that organic fertilizers can be the source of easy hydrolysed nitrogen besides root and surface plant residues.

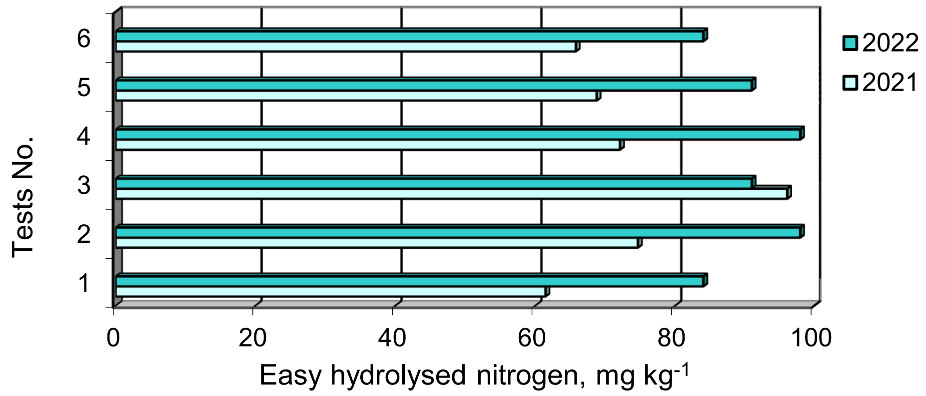

Figure 1. Easy hydrolysed nitrogen content in soil treated by various organic fertilizers: Test 1 – Control (soil without fertilizers); Test 2 – Cattle manure; Test 3 – Chicken droppings; Test 4 – Biofertilizer No. 1; Test 5 – Biofertilizer No. 2; Test 6 – Native sewage sludge.

The study showed that mobile phosphorus content also changed significantly under the influence of organic fertilizers (Fig. 2). This is the nutrition element in Ukrainian Steppe zone soils, which has the greatest impact on the crops yield and quality without distinction of the soil degradation type (Stakhiv & Shvartau, 2008).

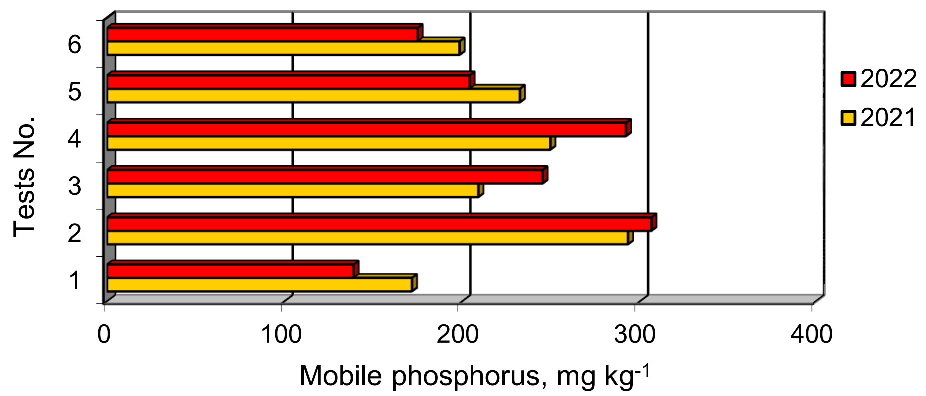

Figure 2. Mobile phosphorus content in soil treated by various organic fertilizers: Test 1 – Control (soil without fertilizers); Test 2 – Cattle manure; Test 3 – Chicken droppings; Test 4 – Biofertilizer No. 1; Test 5 – Biofertilizer No. 2; Test 6 – Native sewage sludge.

As is commonly known, agricultural crops remove a significant amount of potassium from the soil for crop formation (Gospodarenko et al., 2013, Jan & Hussan, 2022). Mobile potassium is absorbed from the soil. Therefore, the formation of its reserves in the soil is an important aspect of further crops productivity increasing and their larger harvesting in the future. The mobile potassium content depends on a number of factors, the most important of which are the rate of fertilization, the intensity of the potassium balance in the fertilizer-soil-plant system, soil physico-chemical properties, and the crop rotation structure.

Negative balance of mobile potassium was formed in all tests (Fig. 3). However, its concentration in fertilizer-treated soil samples (Tests 2–6) was higher than in control (Test 1) in 2021 and 2022 alike. This can be explained by the lag in the processes of the potassium transition into non-exchangeable forms.

As one can see from Fig. 3, the highest content of mobile potassium of 166.90 mg kg^{-1} was obtained by cattle manure using (Test 2). This can be explained by manure effect on soil properties. As the organic matter content increased, as the mobile potassium content enhanced due to its accumulation in the soil.

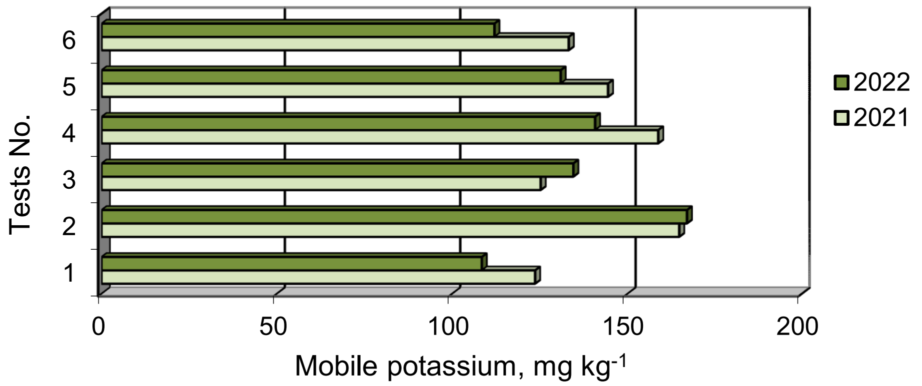

Figure 3. Mobile potassium content in soil treated by various organic fertilizers: Test 1 – Control (soil without fertilizers); Test 2 – Cattle manure; Test 3 – Chicken droppings; Test 4 – Biofertilizer No. 1; Test 5 – Biofertilizer No. 2; Test 6 – Native sewage sludge.

The organic matter content in fertilizer-treated soil samples taken in 2021 and 2022 is shown on Fig. 4. The diagram analysis revealed that the increasing of organic matter content in 2021 was obtained only in the case of Biofertilizer No. 1 applying (Test 4) at 1.16% in comparison to the control. However, the organic matter content increasing in 2022 was registered for both biofertilizers based on sewage sludge. Biofertilizer No. 1 and No. 2 exceeded control at 0.42% and 0.33% consequently. This can be explained by the gain of soil biological activity (Krutyakova et al., 2021; Kuht et al., 2023).

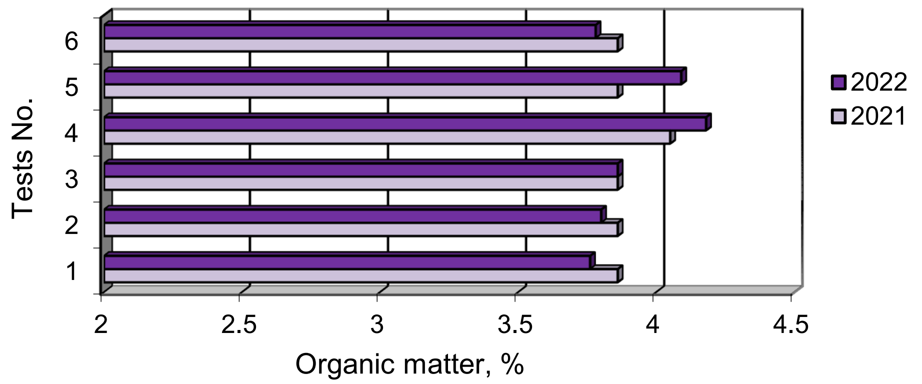

Figure 4. Organic matter content in soil treated by various organic fertilizers: Test 1 – Control (soil without fertilizers); Test 2 – Cattle manure; Test 3 – Chicken droppings; Test 4 – Biofertilizer No. 1; Test 5 – Biofertilizer No. 2; Test 6 – Native sewage sludge.

The diagrams analysis (Figs 1–4) indicated that all types of organic fertilizers benefited the soil. These results could be verified by ones obtained by other researchers (Fan et al., 2023; Krutyakova et al., 2021; Wang et al., 2019). At the same time, fertilizers based on sewage sludge resulted in comparable or even increased values of the main soil agrochemical indicators in comparison with the most common organic fertilizer (cattle manure). Thus, Biofertilizers No. 1 and No. 2 could be successful applied for soil fertility increasing in cultivation of hazelnut, as well as other crops. That indicates a great potential of sewage sludge based organic fertilizers for agriculture (Mota et al., 2021; Abdoli, 2022; Marin & Rusănescu, 2023).

The ecotoxicity analysis of soil was made for the determining of soil pollution by organic fertilizers using (Table 4). The ecotoxicity indicator was determined by three sensor elements, based on various bacteria with bioluminescence properties: CE 1 (*Vibrio fisheri*). CE 2 (*Alcaligenes eutrophus 1239*), and CE 3 (*Pseudomonas fragi* T2(5)).

Table 4. The ecotoxicity of the soil treated by various organic fertilizers in hazelnut plants cultivation

Test No.	Soil samples	The ecotoxicity indicator E, relative units				Common level of soilecotoxicity (pollution)
		CE1	CE2	CE3	Average	
1	Control	1.22	0.97	0.96	1.05	low
2	Cattle manure	0.84	1.09	0.82	0.92	low
3	Chicken droppings	1.00	1.05	1.49	1.18	low
4	Biofertilizer No. 1	0.98	1.16	2.10	1.41	low
5	Biofertilizer No. 2	1.13	1.19	0.79	1.04	low
6	Native sewage sludge	1.00	0.83	1.71	1.41	low

As it is clear from the Table 3, the average value of ecotoxicity indicator was less than 1.5 for all samples. That gave an opportunity to classify the soil ecotoxicity common level as 'low' (Rieznichenko et al., 2015). However, the indicator of native sewage sludge and Biofertilizer No. 1 evaluated by CE3 sensor referred it to the less favourable ranges middle or even high.

That could be explained by the sensors' specific response. CE1 and CE2 sensors' responses characterize the integral sample pollution. Therefore, ecotoxicity indicator E evaluated by CE1, and CE2 sensors does not differ much for all tests, as the integral pollution level was low.

At the same time, CE3 sensor response is characterized by sensitivity to zinc. Biofertilizer No. 1 and native sewage sludge samples contained elevated zinc content, and ecotoxicity indicator E, evaluated by CE3 sensor was higher for these two samples than others. However, elevated zinc content in Biofertilizer No. 1 and native sewage sludge was not affected on their integral pollution level.

It should be noted that agricultural crops have a zinc deficit as almost 60% of Ukrainian soils are depleted on this micronutrient (Makarenko et al., 2021). Thus, its evaluated content in organic fertilizers should benefit soils. However, the problem requires further studies.

CONCLUSIONS

The investigation of the impact of various organic fertilizers on soil agrochemical indicators in hazelnut plantings in the conditions of Ukrainian Southern Steppe was made. It was found, that all organic fertilizer types could be applied for benefit the soil.

New organic fertilizers based on sewage sludge allow gaining comparable value of soil nutrition by the main agrochemical indicators with the most popular organic fertilizer - the cattle manure. That is very important, because of cattle livestock reduction in Ukraine and respective necessity of new organic fertilized sources search.

Sewage sludge using as this source could solve several problems simultaneously, as such organic fertilizers making is the way for urban sewage sludge environmentally safe disposing. As it was confirmed by our study, even native sewage sludge applying for hazelnut planting fertilize led to very low pollution of soil. Therefore, new biofertilizers based on sewage sludge could be very promising for crops cultivation.

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