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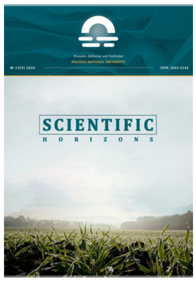

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Restoration of soil fertility and improvement of phytosanitary condition of soil in short rotation of crops in Polissia of Ukraine

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Abstract. With the intensification of agricultural land use and changes in natural conditions, soil quality in Ukraine is deteriorating, with a decrease in humus content, the average annual loss of which is about 0.6 t/ha. Therefore, its reproduction is now becoming increasingly important through the use of organic raw materials and the introduction of legumes into the crop rotation, which leads to a partial replacement of nitrogen from mineral fertilisers with biological nitrogen. The purpose of this study

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was to find ways to provide the topsoil with organic residues, develop soil microflora, and improve the activity of nitrogen-fixing bacteria in a short grain legume crop rotation. The study was conducted in 2019-2023 using the following methods: visual – to determine the stages of organogenesis; field – to determine the interaction of abiotic factors; physiological – to determine the symbiotic fixation of atmospheric nitrogen. It was found that due to mineralisation of organic residues of legume crop rotation, the amount of macro- and microelements in the soil layers 0-10 cm, 10-20 cm, and 20-30 cm increased by 45.1-46.9-43.1 mg/kg, respectively. It was found that saturation of short crop rotation by 50% with legumes, straw residues, and green manure contributed to the reduction of pathogenic microorganisms and the growth of suppressive ones. It was found that in a short rotation of crops, 10.3 t/ha of organic matter in the form of stubble and root residues, straw and green manure enters the soil, which contributed to the cultivation of environmentally friendly agricultural products with the restoration of soil fertility. The biological activity of the soil during the growing season in the layer of 10-20 cm reached 47.4%, and the content of alkaline hydrolysed nitrogen in the rhizosphere of the root system increased by 43.9 mg/kg. The value of the study lies in the fact that the introduction of short organic crop rotations in farms of various forms of ownership is an innovative approach to providing light grey soils with organic raw materials, restoring and maintaining their fertility, improving their phytosanitary condition, promoting biodiversity, achieving environmental sustainability and high yields

Keywords: crop rotation; crop residues; green manure; biological activity; soil; phytopathogens

INTRODUCTION

To obtain high and sustainable crop yields in the Polissia region of Ukraine, all elements of cultivation technology must be aimed at preserving and restoring soil fertility through the accumulation of organic residues and the formation of humus, which improves the water-physical, thermal, and agrochemical properties of the soil, increases its absorption capacity and buffering capacity, and optimises its phytosanitary condition and nutritional status.

In the system of modern intensive crop production, increasing importance is gained by the scientific research on restoring soil fertility and its biological activity, where the main component is the biological cycle of substances and soil microorganisms; investigation of soil biological activity in short legume crop rotations using post-harvest residues and green manure, establishing the processes of organic matter transformation and improving soil fertility in the biodynamic processes of humus formation (Adamchuk *et al.*, 2019; Kliuchevych *et al.*, 2020).

To provide the soil with organic raw materials, it is necessary to introduce scientifically based soil conservation crop rotations, including the expansion of perennial legumes and pulses, and the use of organic fertilisers. According to M. Torbati *et al.* (2021), the tendency to increase the volume of mineral fertilisers and pesticides, reduce soil fertility, and over-compact it is a cause for concern. There is a positive trend towards an increase in the volume of crop by-products (stubble and root residues, straw) and post-harvest green manure crops. Generally, applying 4-6 t/ha of straw and using 11-12 t/ha of green manure is equivalent to applying 12 t/ha of organic fertiliser.

Soil biological activity is the principal indicator of monitoring the intensity of organic residue decomposition, providing scientific justification and assessment of the impact of organic and mineral fertilisers on their use in managing the growth process and developing intensive elements of the technology for growing environmentally friendly crops. Determining the biological activity of the soil helps to optimise the regime of soil restoration and preservation of its fertility. The conventional practice was to use long-lasting energy crops and pesticides to ensure high yields. However, this approach led to a decrease in soil fertility, loss of beneficial mycoflora, and, as a result, the accumulation of pathogens of various aetiologies and environmental pollution.

Currently, the humus content in the ploughed soils of Ukraine's Polissia region, according to their particle size distribution, is insufficient to optimise the root layer in terms of agrophysical and agrochemical properties. Therefore, the search for ways to reproduce the soil organic matter, control and maintenance of the optimum humus status is extremely relevant. Normal humus recovery requires organic matter contained in crop residues. That is why the purpose of this study was to find ways to provide the topsoil with organic residues, develop soil microflora, and improve the activity of nitrogen-fixing bacteria in a short grain legume crop rotation.

As a result of non-compliance with scientifically based farming systems, the natural soil fertility of agricultural land is declining (the humus content of Ukrainian soils has decreased by 20%). The main reason for these negative changes is the lack of organic fertiliser application. The widespread use of mineral fertilisers and chemical plant protection products against pests has increased the threat of chemical degradation and pesticide contamination of crop production (Richard *et al.*, 2022). The main challenge of transitioning to biological farming is to ensure enhanced reproduction of soil fertility and increase crop yields. It is noted that organic fertilisers are particularly important on light sod-podzolic soils (Lisovyi *et al.*, 2021).

Crop rotation, the use of by-products and green manure positively affect the ecological state of the soil and are essential elements of agriculture to improve soil fertility, provide and preserve moisture, microbiological processes and increase crop yields (Pisarenko & Pisarenko, 2022; Voitovyk, 2023). In the research of E.G. Degodyuk *et al*. (2019), the use of straw of predecessors shows a deterioration in the nitrogen regime, immobilisation of mobile forms of nitrogen occurs during humification of organic residues (straw), which have a low nitrogen content. The use of green manure in the form of fodder radish activates the nitrification process.

The green manure incorporated into the soil before sowing is only 25% decomposed and provides energy for nitrogen-fixing microorganisms during the growing season. Green manuring of soil with a short growing season (fodder radish) suppresses weeds in maize crops, improves microbiological processes, phytosanitary condition of the soil, and activates the destruction of organic raw materials. Chaika *et al*. (2019) report an increase in sugar beet yield after vetch-oat mixture and fodder radish by 5.0-5.7 t/ha. The combined use of green fertilisers and straw creates optimal conditions for the decomposition of organic raw materials, as it occurs at a carbon to nitrogen (C:N) ratio of 20-25:1 and provides a high humification factor. Therefore, nitrogen fertilisation is not recommended under such conditions (Sydletsky *et al.*, 2021).

V.F. Petrychenko and V.V. Lykhochvor (2020) believe that the phytosanitary condition of the soil in agriculture plays an important role in ensuring plant health, resistance to pests, and increasing yields. I.V. Honcharuk *et al*. (2020) believe that biological farming, as the main environment for plant growth and development, is a factor in the phytosanitary regime of the soil-plant system when saturated with crops with similar biological characteristics. Placing crops in such rotations helps to restore soil fertility and improves the phytosanitary condition of crops. Thus, considering the relevance of the scientific research, the purpose of this study was to identify ways to restore the fertility of nutrient-poor soil in short rotation of crops, improve its phytosanitary condition to obtain high and sustainable crop yields.

MATERIALS AND METHODS

The study was conducted in a stationary short grain-legume crop rotation with saturation of cereals and legumes (50 + 50) in the conditions of the educational and research field of Polissia National University during 2019-2023. The soil is grey forest light loam.

A four-field crop rotation scheme:

1. Perennial grasses for one mowing (clover).
2. Winter wheat using nutritious residues and green manure (fodder radish).
3. Soybeans using leaf and stem mass for fertiliser.
4. Barley with clover undersowing.

The system of using crop residues and green manure:

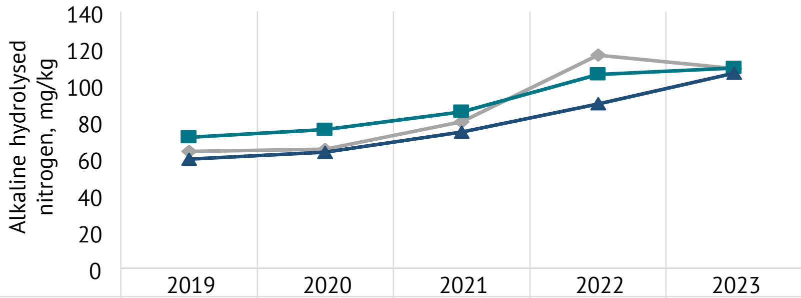
1. Biological control (root and stem residues).
2. Root and stem residues + chopped straw.
3. Root and stem residues + green manure.
4. Root and stem residues + straw + green man ure.

The experiments were replicated four times, with a sowing plot of 39.6 (3.6×11) m² and a trial plot of 25 (2.5×10) m². The experiments were conducted following the methodology and organisation of scientific research (Yevtushenko & Khizhnyak, 2019). Agrochemical analyses of the soil were conducted in the measuring laboratory of the Educational and Research Centre of Ecology and Environmental Protection of Polissia National University (certificate of conformity of the measurement system according to the requirements of DSTU ISO 10012:2005 (2007).

Humus content was determined according to Tyurin's DSTU 4289:2004 (2005); hydrolysable nitrogen content was determined according to the Kornfield method (DSTU 7863:2015, 2016); mobile phosphorus and exchangeable potassium content was determined according to Kirsanov (DSTU 4405:2005, 2006). The biological activity of the soil was determined by the application method, the degree of decomposition of linen fabric in the soil layer 0-20 cm. The application method – the specified weight of linen fabric was embedded in the soil to a depth of 20 cm, and the degree of cellulose decomposition was determined after 45 days. The species composition of micromycetes was analysed according to generally accepted methods (Azam *et al.*, 2020; Dignam *et al.*, 2022; Kara & Soylu, 2023). Experimental studies of plants (both cultivated and wild), including the collection of plant material, were following the institutional, national, or international guidelines. The study adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

It was established that in the system "cereals without the use of straw by-products", a positive humus balance can be achieved only if the structure of sown areas is at least 20-21%. In the legume-grain system, a positive humus balance is achieved only when straw and fertiliser are used on 25-30% of the sown area. The deficit-free use of humus can be overcome only if the crop rotation is saturated with cereals with the use of straw and fertilisers of at least 55-60%. A noticeable humus formation was found: the maximum increase in humus was observed in the 0-10 cm soil layer compared to the initial content (1.0-1.1%). Straw in combination with green fertilisers decomposes slowly in the soil without polluting it with high concentrations of nitrate nitrogen, promotes the development of soil fauna, increases the viability of bacteria, earthworms, and other living soil organisms, and improves the biological activity of the soil. The formation of alkaline hydrolysed nitrogen in the soil layer of 10-20 cm increased by 43.9 mg/kg over the years of research and amounted to 109.2 mg/kg, and at a depth of 20-30 cm – 106.4 mg/kg (Fig. 1).

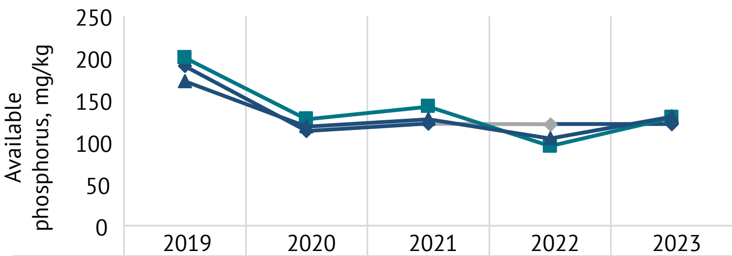


	2019	2020	2021	2022	2023
0-10	63.7	64.9	79.8	116.2	108.8
10-20	71.4	75.6	85.4	105.7	109.2
20-30	59.5	63.3	74.2	89.6	106.4

***Figure 1**. Dynamics of alkaline hydrolysed nitrogen supply in a short grain-legume crop rotation depending on the use of crop residues and green manure*
***Source:** compiled by the authors of this study*

In the soil layer of 10-20 cm, the accumulation and storage of productive moisture, improvement of soil porosity, which contributed to the processes of nitrification of nitrogen, and intensification of biological activity of decomposition of cellulose, hemicellulose, and other organic compounds were detected. With deep incorporation of organic matter (20-30 cm), anaerobic mineralisation processes were observed, accompanied by the release of low molecular weight fatty acids, which in large quantities adversely affect the vegetation of cereal crops, the process of decomposition of organic matter in the soil proceeds towards humification. Due to the mineralisation of organic residues, straw, green manure containing macro- and microelements, their amount in organic short rotation of crops increases by 45.1 mg/kg in the 0-10 cm soil layer, by 46.9 mg/kg at a depth of 10-20 cm, and by 43.1 mg/kg at 20-30 cm. Furthermore, organic residues contain a significant amount of nitrogen-free substances: glucose – 33-75%, hemicellulose – 21-22%, and lignin – 18-22%.

Phosphorus is of great importance in the decomposition of nutrients (straw, stubble, root system), as it plays an active role in the development of microorganisms and cellular metabolism. The main source of phosphorus in the soil is its content and reserves, depending on the particle size distribution of the soil and its humus content. Light grey sandy loam soils are poor in total phosphorus. The state of phosphate in the soil is influenced by organic matter, non-commodity products, soil moisture, and temperature. Insufficient availability of phosphorus reserves in the soil is conditioned by poor diffusion of phosphate ions in the soil. The relatively low utilisation rate of phosphate fertilisers in the first year of application (10-15%) is due not only to the transition of phosphates into unavailable forms, but also to their limited availability to the root system. With the introduction of organic matter and its mineralisation, available phosphorus (119.3-126.5 mg/kg) accumulates in the soil layer of 10-30 cm (Fig. 2) and is used to feed crops in crop rotation by 35-40%.



	2019	2020	2021	2022	2023
0-10	190	112.8	121.4	120.8	120.9
10-20	200	127	141.7	94.8	128.6
20-30	172	118	126.9	103.8	129.9

***Figure 2**. Dynamics of exchangeable phosphorus supply in a short grain-legume crop rotation depending on the use of crop residues and green manure*
***Source:** compiled by the authors of this study*

Potassium has a positive effect on reducing the damage to plants by fungal pathogens, thickens the wall cells. The potassium content in the 10-20 cm soil layer did not change and ranged within 144-149 mg/kg (Fig. 3).

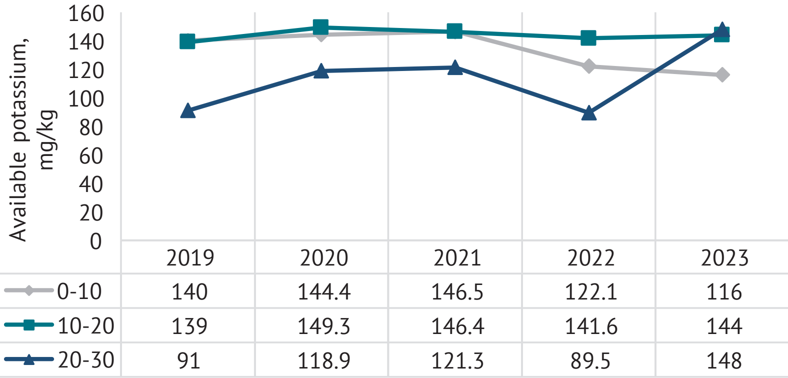


***Figure 3**. Dynamics of potassium availability in a short grain-legume crop rotation depending on the use of crop residues and green manure*
***Source:** compiled by the authors of this study*

The mineralised potassium in organic matter is quickly transferred to the soil solution and becomes available for plant nutrition. In a short grain legume crop rotation with 10.3 t/ha of organic residues, it is not washed off and accumulates in the upper soil layers. Potassium from mineral salts in the soil solution is the best source of plant nutrition. Organic residues and green fertilisers are re-integrated into the mineral and organic plant nutrition cycle to form the next phytomass. The combination of organic residues with green manure prevents the leaching of mobile elements and their removal by groundwater, and promotes the development of soil fauna, increases the activity of bacteria and earthworms, which help improve the agrochemical and physical properties of the soil.

The findings of the study established the frequency of isolation of soil microbial communities in organic short rotation of crops (Table 1). Among them, pathogenic species (from the genera *Fusarium* spp., *Alternaria* spp., *Cladosporium* spp., *Pythium* spp.) and suppressive species (*Trichoderma* spp., *Aspergillus* spp., *Penicillum* spp., *Mucor* spp., *Rhizopus* spp.) were identified.

***Table 1**. Frequency of soil microbial isolation in organic short rotation of crops*

Micromycetes	Isolation frequency, %				
	2019	2020	2021	2022	2023
Pathogenic micromycetes					
Fusarium spp.	18.0	13.0	15.0	12.0	11.0
Alternaria spp.	12.0	9.0	10.0	6.0	4.0
Cladosporium spp.	7.0	5.0	3.0	4.0	5.0
Pythium spp.	5.0	7.0	2.0	6.0	4.0
Suppressive micromycetes					
Trichoderma spp.	12.0	16.0	14.0	19.0	20.0
Aspergillus spp.	19.0	18.0	23.0	16.0	21.0
Penicillum spp.	17.0	19.0	17.0	21.0	19.0
Mucor spp.	8.0	10.0	7.0	12.0	10.0
Rhizopus spp.	2.0	3.0	9.0	4.0	6.0

***Source:** compiled by the authors of this study*

It was found that throughout all the years, the study of 50% saturation of short rotation of crops with legumes (clover, soybean), residues of straw, and green manure contributes to the reduction of pathogenic microorganisms – the causative agents of diseases of the root system of plants in the soil and the growth of the development of suppressive micromycetes, especially *Trichoderma* spp., *Penicillum* spp., *Mucor* spp. It is the optimum selection of crops in a short organic legume crop rotation that promotes the development of trophic relationships, depriving plant pathogens of a constant source of food, which reduces their numbers. Furthermore, legumes secrete substances with natural antifungal properties, which reduces the development of phytopathogen infestation and improves soil biological activity (Table 2).

Table 2. Biological activity of light grey soil and crop yields of short rotation of crops, average for 2019-2023

Organic substance	Biological activity, %	Yield, t/ha		
		winter wheat	soybean	barley
Stubble and root residues	28.2	5.6	2.2	2.9
Stubble and root residues + straw	33.4	6.1	2.4	3.2
Stubble, root residues + green manure	42.2	7.2	2.7	3.8
Stubble, root residues + straw + green manure	47.4	7.6	3.0	4.0
LSD_{05}		0.6	0.44	0.15

Source: *compiled by the authors of this study*

The vital activity of cellulose-degrading microorganisms depends on the introduction of organic matter. The biological activity of the soil during the growing season was within 28.2-47.4%. During warming up and optimum soil moisture in the variant with the incorporation of crop residues and green manure (fodder radish), the intensity of fibre decomposition increased and reached a maximum of 42.2-47.4% in the 10-20 cm soil layer. In the surface layer at 0-10 cm, without incorporating straw and post-harvest green manure, the biological activity of the soil was only 28.2%. Thus, during the period of macrostages (BBCH 10-61, cotyledons fully opened – the beginning of flowering), the cellulosic acidity of flax fabric decomposition was 47.4%.

It was found that harvesting and chopping straw into pieces of 2.5-4.5 cm and embedding them in the soil to a depth of 10-12 cm contributed to the decomposition of straw by 5.2% faster compared to the biological control. Microorganisms that carry out mineralisation require two main elements: carbon and nitrogen, with a ratio of 10-12:1 in the soil. The low coefficient of humus formation by the ratio of N:C ratio in straw was 1:86, and the potential for humification stayed high. When straw and green mass were used, the N:C ratio was within 1:21, optimum conditions for humus formation were created, and biological activity reached 47.4%. It was found that in the short rotation of crops, on average, over the years of research, 10.5 t/ha of by-products were received, consisting of stubble and root residues (straw and green manure), which ensured a yield of winter wheat of 5.6 t/ha, soybeans of 3.0 t/ha, and spring barley of 4.0 t/ha (Table 3).

Table 1. Crop yields in short rotation of crops depending on the supply of organic raw materials and nitrogen of biological origin, average for 2019-2023

Short rotation of crops	Yield, t/ha	Dry matter, t/ha				Nitrogen, kg/ha		
		stubble and root residues	straw	green manure	total	organic matter	biologically fixed	total
Clover	4.7	3.0	4.7	-	7.7	98.0	60.0	158.0
Winter wheat + by-products + green manure	5.6	6.7	8.4	4.2	19.3	16.8	-	16.8
Soybeans + by-products	3.0	2.6	4.5	-	7.1	13.6	85.0	98.6
Barley with clover undersowing	4.0	4.0	3.8	-	7.8	36.0	60.2	96.2
Total	-	16.3	21.4	4.2	41.9	164.4	205.2	369.6
Per 1 ha of crop rotation area	-	4.0	5.3	1.0	10.3	41.1	51.3	92.4

Source: *compiled by the authors of this study*

The combination of straw and green manure created conditions for a uniform acceleration of humification and accumulation of nutrients in the topsoil, specifically nitrogen, and increased their efficiency when using green manure by 14.0-15.2%. Organic residues and green fertilisers were reintroduced into the plant nutrition cycle to form new phytomass. The combination of organic residues with green manure prevents the leaching of mobile elements and their removal by groundwater, promotes the development of the soil fraction, and improves the agrophysical properties of the soil.

The present study showed that the use of green manure and the introduction of legumes (clover, soybeans) into short rotation of crops activates soil nitrogen-fixing bacteria, increases the supply of symbiotic atmospheric nitrogen, and improves biological activity. The humified nutrients are not washed out, bind to the soil, and take part in the nutrition of crop rotation plants. V. Oliynyk (2019) argues that perennial grasses and cereals are of exceptional importance in improving the humus condition of the soil. The optimum parameters of sod-podzolic clay-sandy soils are 1.4-1.6%, and sandy loam soils – 1.6-1.8%. In fact, the humus content in ploughed soils is between 0.6-1.0%.

According to S.P. Tanchyk *et al*. (2019), S.I. Kudrya (2020), predecessors, their rotation, and the use of crop residues are important for improving soil fertility. However, the researchers do not indicate what the structure of crops should be in crop rotations on light grey soils, unlike the present study. However, in Ukraine, only 0.5 t/ha of manure is applied. To restore the fertility of light grey soils, it is necessary to return non-commodity products to the soil and introduce crop rotations with legumes saturated within 50%, which is equivalent to the application of manure. The content of alkaline-hydrolysed nitrogen in the 10-20 cm soil layer reaches 109 mg/kg, and potassium – 148 mg/kg. V.V. Gangur and V.M. Sakhatska (2019) state that the most intensive microbiological processes occur after manure application (50 t/ha), both separately and in combination with mineral fertilisers, with glucose destruction reaching 59-61%.

In studies by D. Porodzinsky (2020) and V. Kyrychenko (2020), it took 5-7 years for the soil to restore fertility functions. To accelerate the decomposition of cellulose and lignin, live strains of cellulose-degrading bacteria (destructors) should be used. According to our observations, after harvesting stubble and root residues, the complete decomposition of linen fabric took place within 3.5 years. M. Kara and E. Soylu (2023), S. Stankevich *et al*. (2020) highlight the evidence that providing the topsoil with organic residues increases the growth of fungi and bacteria that decompose cellulose, which increases cellulose-degrading activity in the 10-20 cm soil layer. M. Torbati *et al*. (2021) note that soil acts as the main nutrient medium for plant growth and development, but at the same time it can also be a carrier of harmful microorganisms that contribute to the spread of plant diseases. The main groups of phytopathogenic microorganisms in soil include bacteria (genera *Agrobacterium*, *Ervinia*), fungi (genera *Fusarium* spp., *Alternaria* spp., *Cladosporium* spp.), nematodes, etc. However, the researchers did not conduct studies in short rotation of crops on light grey soils and did not indicate the structure of pathogenic and suppressive microflora in the soil.

Thus, in this context, a short organic crop rotation is a promising solution that helps to create optimum conditions for the development of plants and beneficial microorganisms-antagonists, improves the phytosanitary condition of the soil and increases its fertility.

CONCLUSIONS

A short four-field grain and legume crop rotation with perennial legumes and legumes (50%) and cereals (50%) ensures the supply of 10.3 t/ha of organic matter to the soil in the form of stubble root residues, straw and green manure, which contributes to the cultivation of environmentally friendly agricultural products and the restoration of soil fertility. It was found that with the introduction of organic substances and their mineralisation in the soil layer of 10-30 cm, the formation of alkaline hydrolysed nitrogen increased to 109.2 mg/kg, the accumulation of available phosphorus increased to 119.3-126.5 mg/kg, and the potassium content did not change and was within 144-149 mg/kg.

Saturation of the short rotation of crops by 50% with legumes (contributes to the reduction of pathogenic microorganisms in the soil and the growth of the development of suppressive micromycetes: *Trichoderma* spp., *Penicillum* spp., *Mucor* spp. It was found that the biological activity in the soil layer of 10-20 cm of legume crop rotation after planting crop residues and green manure during the growing season reaches 47.4%. With by-products in the soil (10.5 t/ha), the short rotation of crops yielded 5.6 t/ha of winter wheat, 3.0 t/ha of soybeans and 4.0 t/ha of barley. Further research will be aimed at investigating and implementing innovative approaches to restoring and preserving soil fertility, increasing biodiversity, and using effective microorganisms to generate sustainable and high crop yields.

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None.

CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Відновлення родючості та покращення фітосанітарного стану ґрунту в короткоротаційній сівозміні Полісся України

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Анотація. За інтенсифікації використання сільськогосподарських земель і зміни природних умов якість ґрунтів в Україні погіршується, зменшується вміст гумусу, середньорічні втрати якого становлять близько 0,6 т/га. Тому наразі набуває актуальності його відтворення за рахунок застосування обсягів органічної сировини та введення у сівозміну зернобобових культур, що зумовлює часткову заміну азоту з мінеральних добрив на біологічний. Метою дослідження було пошук шляхів забезпечення орного шару ґрунту органічними рештками, розвитком ґрунтової мікрофлори, покращення діяльності азотфіксуючих бактерій короткоротаційної зернобобової сівозміни. Дослідження проводили впродовж 2019-2023 років, користуючись методами: візуальний – визначення етапів органогенезу; польовий – взаємодія абіотичних чинників; фізіологічний – визначення симбіотичної фіксації азоту атмосфери. Встановлено, що за рахунок мінералізації органічних рештків зернобобової сівозміни збільшувалася кількість макро- і мікроелементів у шарах ґрунту 0-10, 10-20 та 20-30 см відповідно на: 45,1-46,9-43,1 мг/кг. Було досліджено, що насичення короткоротаційної сівозміни на 50 % бобовими культурами, залишками соломи та сидератами сприяло зменшенню патогенних мікроорганізмів і зростанню розвитку супресивних. Установлено, що в короткоротаційній сівозміні в ґрунт надходить 10,3 т/га органічної речовини у вигляді стерньових і кореневих рештків, соломи та сидератів, що сприяло вирощуванню екологічно безпечної сільськогосподарської продукції з відновленням родючості ґрунту. Біологічна активність ґрунту за період вегетації в шарі 10-20 см досягала 47,4 %, а вміст лужногідролізованого азоту в ризосфері кореневої системи збільшувався на 43,9 мг/кг. Цінність наукових досліджень полягає в тому, що впровадження в господарствах різних форм власності короткоротаційних органічних сівозмін є інноваційним підходом у забезпеченні ясно-сірих ґрунтів органічною сировиною, відтворенні і підтриманні його родючості, покращенні фітосанітарного стану, сприянні збільшенню біологічної різноманітності, досягненні екологічної стійкості та високої врожайності

Ключові слова: сівозміна; поживні рештки; сидерати; біологічна активність; ґрунт; фітопатогени