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Study of the Qualitative State of Podzolized Black Soil in Short-Term Crop Rotations

Yaroslava Hryhoriv[1*], Uliana Karbivska[1], Oleg Turak[1], Yurii Chernevyi[1], Vasyl Oliinyk[1], Ihor Koliadzhyn[1], Andrii Savchyn[1], Pavlo Dmytryk[1], Victoria Gniezdilova[1], Nadiia Asanishvili[2]

[1] Vasyl Stefanyk Precarpathian National University, Shevchenko St., 57, Ivano-Frankivsk, 7601841, Ukraine

[2] National Scientific Center "Institute of Agriculture NAAS", 2-B Mashynobudivnykiv St, village Chabany, Fastiv district, Kyiv region, 08162, Ukraine

* Corresponding author's e-mail: hryhorivsl@gmail.com

ABSTRACT

Presented work long-term experiment research (2012–2022 in ongoing experiment) on podzolized black soil to study the effectiveness of the use of organic (manure, non-marketable part of the crop, siderate) and mineral fertilizing systems in short term crop rotation were presented. The positive influence impact of the use of organic fertilizers and non-marketable part of the crop on stabilizing the amount of humus, increasing the reserves of alkaline-hydrolyzed nitrogen, exchangeable mobile phosphorus and potassium forms compounds in the soil was established. Changes in the nutrient regime and agrochemical properties of podzolized black soil under different saturation of crop rotations with cultivated crops, grain crops and leguminous plants were shown. A significant impact on the agrochemical characteristics of the soil in short-term crop rotations under crops of both the organic-mineral fertilizer system and its predecessors was proven. It was established that the use of organic-mineral fertilizers (traditional organic-mineral fertilizer system) in crop rotation provides an increase in the content of nutrients in both arable and subarable layers of the soil, promotes an increase in the amount of crop residues, and, accordingly, harvest residues helps to increase the amount of crop residues, and provides a positive balance of nutrients under crops in crop rotation. The research materials are of practical importance for the implementation of nutrition optimization systems in short term crop rotations aimed at both sustainable increase of crop yields as well as maintenance and restoration of soil fertility.

Keywords: crop rotation, fertilizer system, humus, mobile phosphorus and potassium forms, alkaline hydrolyzed nitrogen.

INTRODUCTION

It is well known that the primary task of modern agriculture is to preserve and reproduce soil fertility, which is based on the formation of a favorable qualitative state of the soil and the achievement of its high productivity.

The structure of crop rotation and the fertilization system directly affect the achievement of high and stable yields of field agricultural plants. Under the current intensive conditions, the role of crop rotation in restoring soil fertility and protecting the surrounding environment as an organizational and functional model of the farming system in solving the main tasks as well as principles of its development to obtain high and sustainable crop productivity is increasing. In today's intensive conditions, the role of crop rotation in restoring soil fertility and protecting the environment as an organizational and functional model of the farming system is increasing in solving the main tasks and principles of agro-industrial development to obtain high and sustainable crop yields.The agrochemical and agrophysical indicators of soil fertility are primarily influenced by the of crop

rotation and the structure of sown areas, as well as the fertilization system of agricultural plants. For these reasons, one of the primary tasks of crop rotation as a biological factor in regulating fertility, in addition to maintaining and reducing productive humus reserves, is to optimize the content of nutrients, which primarily ensures the improvement of soil fertility [Kachmar O. et al., 2015; Hryhoriv Ya. et al., 2020]. After all, it was proven that these indicators can change depending on the type of crop rotation, the selection of crops grown in them, and the fertilizer system [Borivskyi et al., 2013; Hera O., 2014; Ivaniuk V., 2005; Shevchenko M. et al., 2015].

Today, the efficiency of the agricultural sector can be ensured through the use of modern advanced technologies. The standard of activity of such agricultural production should not only be the increase in the level of production, but also the desire to reduce its cost, maximize profits, well as conserve and reproduce natural resources [Saiko V., 1997].

The research of a number of foreign and domestic scientists indicates that the most effective way to increase the yield of crop rotation plants is to introduce elements of organic farming into fertilization mechanisms through the combined use of mineral fertilizers and crop residues well as the ploughing siderates of crop rotation [Zaryshniak A. et al., 2012; Polovyi V., 2007; Tsvei Y.. et al., 2013; Clive A., 1987].

It is worth noting that Russia's war against Ukraine has clearly defined the importance of Ukraine's agricultural producers in stabilizing the global food market. According to Mr. Strubenhoff: "At the moment we need more production, not less" [Strubenhoff H., 2022]. He and a number of scientists expressed the opinion that in the near future the world needs to expand the area of arable lands, which are mainly located in the tropics. However, these soils, despite their high natural fertility, these require additional expenses [Alexander P. et al., 2016; Gomiero T., 2016]. Or go the other way, Another way requires an annual increase in the yield of major crops, such as wheat, corn, rice, and soybeans by 2.5% yearly. This goal, according to Ray et al. will not be easy to achieve, as the current increase in yields of these plants crops is significantly lower than this goal [Ray et al., 2013]. The second factor is inherent in the efficient use of mineral fertilizers and other crop protection measures. The actions taken by farmers must be consistent with the basic principles intensification of sustainable agriculture, which refers to the efficient exploitation of the means of production, including fertilizers [Royal Society, 2009]. The term "competition for the harvest" in the modern international understanding refers to the crop yield productivity of the main unit of agricultural production, which, in fact, determines the fertility of the soil [Łukowiak R. et al., 2020].

Table 1. Scheme of the experiment to study the effect of productivity of short-term crop rotations, 2012-2022

Crop rotation field						Applied per 1 ha of crop rotation area			
	I	II	III	IV	V	Manure, t	kg of active substance		
							N	P_2O_5	K_2O
Crop rotation	Clover for two mowing	Winter wheat $N_{50}P_{50}K_{80}$	Sugar beets, manure 40 t/ha $N_{115}P_{90}K_{145}$	Maize on grains $N_{120}P_{100}K_{120}$	Barley + clover $N_{45}P_{45}K_{45}$	8	65	55	75
	Pea $N_{20}P_{45}K_{45}$	Winter wheat $N_{75}P_{50}K_{60}$	Sugar beets, manure 40 t/ha $N_{115}P_{90}K_{145}$	Barley + post-harvest crops * $N_{45}P_{45}K_{45}$	Maize on grains $N_{120}P_{80}K_{100}$	8	75	60	80
	Soybean $N_{20}P_{40}K_{40}$	Winter wheat $N_{75}P_{50}K_{60}$	Sugar beets, manure 40 t/ha $N_{115}P_{90}K_{145}$	Barley + post-harvest crops * $N_{45}P_{45}K_{45}$	Maize on grains $N_{120}P_{80}K_{100}$	8	75	60	80
	Soybean $N_{20}P_{40}K_{40}$	Winter wheat + post-harvest crops * $N_{75}P_{50}K_{60}$	Maize on grains manure 40 t/ha $N_{120}P_{100}K_{120}$	Maize for silage $N_{100}P_{40}K_{80}$	Sugar beets $N_{115}P_{90}K_{145}$	8	85	65	90
	Soybean $N_{20}P_{40}K_{40}$	Winter wheat + post-harvest crops * $N_{75}P_{50}K_{60}$	Soybean $N_{20}P_{40}K_{40}$	Maize for silage manure 40 t/ha $N_{100}P_{40}K_{80}$	Winter wheat $N_{70}P_{40}K_{60}$	8	55	45	55

MATERIALS AND METHODS

The experimental part of the scientific work was carried out on podzolized medium loamy black soil on the experimental field of the farm "Potochyshche" in Ivano-Frankivsk region (2012-2022). The soil of the experimental field is characterized as fertile with good agrophysical characteristics. Thus, at the beginning of the research, the following quality parameters in the topsoil were determined: humus (according to Tyurin) – 3.5%, salt pH – 6.2, hydrolytic acidity – 1.87 mg-eq/100 g, the amount of absorbed bases – 40.0 mg-eq. /100 g of soil (according to Kappen), easily hydrolyzable nitrogen (according to Kornfield) – 19.7 mg/100 g, mobile phosphorus and potassium (according to Chirikov) – 22.9 and 11 mg/100 g of soil. The study of the qualitative composition of podzolized chernozem was carried out in five five-field short-crop rotations with the combined application use of organic and mineral fertilizers (conventional organic-mineral fertilizer system (Table 1.)).

The total area of the stationary experiment is 2 hectares, the size of the plot in the crop rotation is 0.5 hectares. Sowing the area of the plot is 140 m^2, the accounting plot is 50 m^2. The arrangement of variants in the experiments was systematic, replicated three times. In the experiment, agricultural techniques for growing agricultural plants commonly used under the study conditions, except for the factors under study were used. In the experiment, varieties and hybrids of plants included in the State Register of Plant Varieties and Crops adapted for the growing conditions in the Forest-Steppe of Ukraine were sown.

The preparation and selection of soil samples for analysis was carried out in accordance with the generally accepted methods reported in scientific journals and in accordance with State standards of Ukraine.

RESULTS AND DISCUSSION

It is proven that the fertilizer system, as a crucial part of agricultural technology for growing crops, makes it possible to obtain consistently high, profitable crop yields while preserving and reproducing soil fertility. With the long-term application use organic and mineral fertilizers in crop rotation, most of the macro- and microelements enter the biological cycle. It is well known that without studying the balance of nutrient supply and consumption in the soil, it is impossible to control and influence the exchange in the "fertilizer-soil-plant" system [Chaban V. et al., 2014].

It was determined, showed that the balance of macronutrients in crop rotations was restored to varying degrees by the use of organic and mineral fertilizers (Table 2). These results are supported by the research of other scientists [Medvedev, V. et al., 2018; Nikitina, O., 2017] who determined that on typical, podzolic and leached black soil, the increase in the content of mobile potassium compounds was detected when potassium fertilizers are applied at a dose that compensates for its removal by 75% from the soil. This trend is also justified by the bioreplacement of potassium from the lower horizons of the soil and the parent rock.

It was found that the highest balance of easily hydrolyzed nitrogen was noted in crop rotations with the introduction of organic and mineral fertilizers and with one (86%) and two soybean fields (85%). At the same time, when applying only organic fertilizers, the nitrogen balance decreased to 55-56% in short-term crop rotations with one field of clover. It should be noted that in the studied crop rotations, there was no decrease in the content of easily hydrolyzed nitrogen in the soil, but on the contrary, its amount increased by 12–65 kg/ha per year.

Table 2. Balance of lightly hydrolyzed nitrogen in short-term crop rotations, 2012-2022 (kg/ha of crop rotation area)

The structure of sown areas, %					Balance item					
Grain crops	Hoed crops	Pulse crops			Total spending	Additions (with fertilizers, green manure, seeds, precipitation)	Difference between income and expenses	Balance intensity, %	Changes in the stock of total nitrogen in Soil (0–20 cm)	Nitrogen balance (or income from nitrogen fixation)
		Pea	Soybean	Clover						
60	40	-	-	20	178	105	-70	60	+55	+129
80	40	20	-	-	179	120	-56	69	+20	+79
80	40	-	20	-	181	120	-58	68	+20	+81
60	60	-	40	-	151	132	-20	87	+13	+30
80	20	-	40	-	125	105	-19	85	+13	+31

Scientists have proven that plant growth is the result of the action of about 20 elements that are essential in the soil. The biophysical properties of nutrients have been well studied and widely covered in textbooks and review articles [Marschner P., 2012; Benton Jones J., 2003; Wang Y., 2015]. However, not all of these elements are considered nutrients, but they all have a positive effect on crop productivity [White P. et al., 2010]. It was established, it was found that the content of mobile phosphorus is characterized by significant fluctuations over the years of experiment (Table 3). Surely, the soil fertility of each plot of the studied crop rotation has different characteristics. However, it should be noted that the content of mobile phosphorus varies significantly depending on the meteorological conditions of the years of the experiment, where soil moisture is a true regulator of single-substituted phosphate mobility.

In a short-term crop rotation, the reserves of mobile phosphorus compounds were determined by both the dose were determined by the dose of organic and mineral fertilizers, as well as by the crops' preceding and following crops' yields. It was found that they depended most of all on the use of the studied fertilizer systems. Thus, the applying of phosphorus with fertilizers in the amount of 55-65 kg per 1 ha of arable land ensures a deficit-free balance of phosphorus in the crop rotation and in the soil as a whole. Under organic-mineral fertilization systems in crop rotation, the soil phosphate reserve is represented by a large proportion of its mobile compounds, which forms a favorable environment for phosphate nutrition of crops. The obtained results were very similar to the patterns of N, P, and K accumulation during the growing season obtained in the late 20th century, which were carried out in the 1980s [Barraclough P., 1989].

The main sources of mobile potassium in the soil are mineral and organic fertilizers, and small amounts are supplied by precipitation as well as seeds; the main losses are the removal of potassium by the crops and the infiltration process [Hospodarenko H., 2019; Miroshnychenko M., 2010].

Scientists agree [Hospodarenko, H., 2019; Nikitina O., 2017; Tsvei Ya. et al., 2001] that the maximum effect on the content of mobile potassium in the soil is exerted by its physicochemical properties, potassium balance, potassium fertilizer application rates, crop rotation structure and the peculiarities of yield residues application the peculiarities of crop residues application. The minimal decrease in the content of mobile potassium in the case of low rates of potash fertilizers cannot be explained by the refusal to use them on chernozem soils. First of all, they should be used for potassium-philic plants in order to ensure a balanced mineral nutrition [Hospodarenko, H., 2019; Nikitina O., 2017; Tsvei Ya., 2015].

As a result of the conducted research, it was found that in short rotation crop rotations with 20% saturation with green legumes, the intensity of potassium balance under the organic-mineral fertilizer system was at the level of 191–198%. The increase in the reserves of mobile potassium compounds was due to the use of fertilizers, green manure and non-marketable products. At the same time, in the presence of 20% of clover for two mowing in the crop rotation, the potassium content in the soil decreased to 121–131% (Table 4).

Thus, the results of the research showed that under the conditions of the organic fertilization system, a decrease in the intensity of the potassium balance to 104–109% was observed in crop rotations with 20–40% filling of perennial leguminous plants, and with 60%, a deficit potassium balance was noted (-26 kg per 1 ha of crop rotation area).

Table 3. The balance of mobile phosphorus in short-term crop rotations, 2012-2022 (kg/ha of crop rotation area)

The structure of sown areas, %					Balance item					
Grain crops	Hoed crops	Pulse crops			Total spending	Additions (with fertilizers, green manure, seeds, precipitation)	Difference between income and expenses	Balance intensity, %	Changes in the stock of mobile phosphorus in soil (0–20 cm)	Mobile phosphorus balance
		Pea	Soybean	Clover						
60	40	-	-	20	49	38	-11	5	+28	-3
80	40	20	-	-	48	40	-9	55	+12	+19
80	40	-	20	-	50	40	-10	55	+12	+21
60	60	-	40	-	55	45	-8	56	+3	+23
80	20	-	40	-	45	35	-10	42	+3	+3

Table 4. Balance of mobile potassium in short-term crop rotations, 2012–2022 (kg/ha of crop rotation area)

The structure of sown areas, %					Balance item				
Grain crops	Hoed crops	Pulse crops			Total spending	Additions (with fertilizers, green manure, seeds, precipitation)	Difference between income and expenses	Balance intensity, %	Mobile potassium balance
		Pea	Soybean	Clover					
60	40	-	-	20	105	46	-59	35	+79
80	40	20	-	-	127	57	-70	49	+85
80	40	-	20	-	128	58	-70	47	+83
60	60	-	40	-	134	76	-58	58	+98
80	20	-	40	-	95	26	-68	22	-26

Table 5. Humus balance in in short-term crop rotations in the 0–20 cm soil layer, 2012–2022

The structure of sown areas, %					Applied per 1 ha of crop rotation area				Humus				
Grain crops	Hoed crops	Pulse crops			Manure, t	kg of active substance			%		Balance, ±		
		Clover	Pea	Soybean		N	P_2O_5	K_2O	At the end of the first rotation, 2010	At the end of the third rotation, 2018	in 10 years		per year
											%	t/ha	t/ha
60	40	20	-	-	8	65	55	75	3,14	3,64	+0.50	+12.8	+1.28
80	40	-	20	-	8	75	60	75	3,13	3,55	+0.42	+11.2	+1.12
80	40	-	-	20	8	75	60	75	3,21	3,50	+0.31	+8.2	+0.82
60	60	-	-	40	8	85	65	90	3,14	3,42	+0.28	+7.0	+0.71
80	20	-	-	40	8	55	45	55	3,13	3,46	+0.33	+8.8	+0.90

It was proven that the use of fertilizers can influence the quantitative and qualitative composition of humus. For example, with prolonged and systematic application of an organic-mineral fertilizer system, the content of organic substances in the soil increases significantly. The degree of accumulation of organic substances in the soil is determined by short-term crop rotation, the dose of organic fertilizers and soil and climatic properties of the zone [Kudria S., 2018].

In all studied crop rotations, a positive balance of humus was noted (Table 5). It was determined that in the crop rotation with the cultivation of hoed crops: sugar beets and maize for silage manure, with a parallel decrease in the share of pulse crops to 20%, led to an increase in the processes of humus mineralization, which in turn reduced its accumulation to 0.66 t/ha per year. The use of manure in such a short-term crop rotation in combination with mineral fertilizers reduced the humus content to 0.24 t/ha per year.

The results of the research have shown that the application of manure simultaneously with mineral fertilizers in grain-hoed crops rotations with 20% of pulse crops (peas or soybeans) ensures the accumulation of humus at the level of 0.71–1.12 t/ha per year.

It was found that the use of moderate doses of mineral fertilizers increases the mineralization of humus, which leads to a decrease in its reserves in the 0–30 cm layers of the soil.

Therefore, summarizing the results of this study, it can be seen that due to the crop rotation factor, it is possible to effectively influence the processes of humus formation, as well as the balance of organic matter and nutrients not only under certain plants, but also in the soil as a whole.

CONCLUSIONS

An increase of 11–65 kg/ha per year in the content of easily hydrolyzed nitrogen in the soil in all studied short-term crop rotations was found. It was determined that the growth of nitrogen due to nitrogen fixation by pulse crops was 30–157 kg/ha of crop rotation area. Thus, in crop rotations with clover (81–128 kg/ha), the maximum supply of biological nitrogen was observed.

It was determined that the reserves of mobile phosphorus compounds were usually determined depending on the dose of manure and mineral fertilizers. Thus, a positive balance of phosphorus was formed under the organic-mineral fertilizer

system in a short-term crop rotation with 20% of pulse crops (clover for two mowings, soybeans, and peas). Its intensity was in the range of 120–131%. In crop rotations with a content of 20–60% of perennial leguminous plants, a negative phosphorus balance of 3–15 kg per 1 ha of crop rotation area was observed after manure application.

It was noted that the increase in the reserves of mobile potassium compounds was due to the use of fertilizers, green manure and non-marketable part of the production. It was found that the intensity of the potassium balance was 104-198% in short-term crop rotations with 20–40% of pulse crops content with the application of organic and mineral fertilizers and manure.

According to the results of the conducted research, a positive balance of humus was established in all studied short-term crop rotations. Thus, an increase in the humus content in podzolic black soil by 1.28 t/ha per year was observed in a crop rotation with 60% of pulse crops in it and with the use of 8 t/ha of manure. Under these circumstances, the most favorable conditions for physicochemical processes were formed.

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