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Research Article

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Responses of Soil Properties and Crop Productivity to Peat- Fertilizers in Russia

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ABSTRACT

Peat reserves of the Russian Federation are estimated at more than 170.0 billion tons, it makes more than one-third of the world resources. The use of peat as a component for the preparation of composts is an important factor in increasing the productivity of agricultural ecosystems. During two cycles of four-course crop rotation 'potatoes – barley – annual grasses – winter wheat', we studied the influence of lowland peat, composted peat-poultry manure, cattle manure, their combined application with mineral fertilizers on soil physicochemical properties, nitrifying and cellulosolytic activity of soil and productivity of crop rotation. Application of cattle manure and composted peat-poultry manure contributes to the increase in the content of humus in soil by 0.07-0.16%, when combined with mineral fertilizers – by 0.14-0.22%, respectively. On average, the highest yield was noted in the variants with cattle manure and composted peat-poultry manure – 10.75-12.13 t ha $^{-1}$ of grain units (g.u.), while in the check (without fertilizers) it was 8.03 g.u. (t ha $^{-1}$). That is why peat is more profitable to use in the form of composts, especially as a component of composted peat-poultry manure.

Key words: *Peat, Composted Peat-Poultry Manure, Mineral Fertilizers, Sod-Podzol Soil, Crop Rotation Productivity.*

INTRODUCTION

Organic fertilizers, including those based on peat, play an important role in increasing soil fertility, crop yields and improving their quality [1-3].

Peat belongs to the renewable natural resources and it is of great importance concerning the solution of the problem connected with the conservation and improvement of soil fertility [4, 5]. It should be noted that peat bogs are unique natural formations that play an important role in ensuring the ecological balance of the natural environment. That is why the development of peat deposits is to be carried out taking into account the landscape, hydrological, geochemical, biological, and climatic functions of peat bogs [6-9]. Ignorance of these factors can lead to the reduction in biodiversity, decrease in the productivity of adjacent cultivated lands, and increase in the scale of peat fires [10].

The total area of peat lands in the world makes 3.9 million km², but only 0.1% of these lands (5000 km²) are industrially used. Annually, 25 million tons of peat are dug out, on average, in the world, Russia accounted for only 5% of this quantity [11]. In Russia, bogs and marshlands containing peat occupy 21% of the territory. Peat resources are located in 57.4 thousand deposits with the total area of 50.8 million hectares and are estimated at more than 170.0 billion tons [12, 13].

The use of organic fertilizers is one of the key factors in increasing the soil fertility due to the process of improving physicochemical and biological properties of the soil [14-17]. The long-term experiments have shown that the application of organic fertilizers, due to the improvement of soil nutrient status, increases the yield of agricultural crops and improves the quality of crop production [18, 19].

It is well-known that the biological activity increases due to the embedding of organic matter into the soil. As a result, there is an increase in the bioaccessibility of nutrients both out of soil and out of applied organic/mineral fertilizers [20, 21].

Unfortunately, the wrong cultivation with unilateral application of mineral fertilizers influences negatively the microbiocenosis of soil. The enzyme activity of soil decreases [22-25].

In Russia, long-term field experiments mainly study the efficiency of cattle manure. This paper is aimed to study the effectiveness of peat-based fertilizers, their effect on the physicochemical properties of soil, microbiological activity and crop yield using the spatial-temporal analysis.

MATERIALS AND METHODS

Site description and experimental design

The studies were conducted in the experimental field of the All-Russian Research Institute of Organic Fertilizers and Peat (Sudogda district, Vladimir region, Russia) in 2009-2016 during two cycles of the four-course grain-crop rotation. The alternation of crops was the following one: potatoes – barley – annual grasses (Vetch-oat mixture) – winter wheat. The object of the study was the sod-podzol sandy loam soil, formed on the red-brown clay loam mantle (according to IUSS Working Group WRB – Umbric Albelubisoils, 2015) [26]. The average annual air temperature in the Sudogda district of the Vladimir region is 3.9°C. The sum of biologically active temperatures is 2000-2100°C. The annual amount of precipitation is 560-590 mm. During the greater period of the studies the meteorological conditions were close to the average annual observations. The only exception was 2010, characterized by arid conditions.

The following types of organic fertilization practices (FP) were used: manure of cattle (CM), lowland peat (P), and composted peat-poultry manure (PPC). Organic fertilizers were applied before the plowing of soil under potatoes once every four years in the first and second crop rotation within 8 years. The doses of organic fertilizers, containing peat, were equivalent to the amount of nitrogen applied with CM – 200 kg N ha $^{-1}$ that was considered to be a standard in the experiment. Taking into account the content of nitrogen, the average doses of organic fertilizers, applied to potatoes, amounted to (t ha $^{-1}$): CM – 52.6, P – 58.7, PPC – 27.5. The experiment studied their effect on potatoes and aftereffect on barley, vetch-oat mixture and winter wheat both in their pure form and in combination with mineral fertilizers.

The doses of mineral fertilizers depended on the content of total phosphorus and potassium in the organic fertilizers. The doses were not more than 280 kg N ha $^{-1}$ (N280), 200 kg P ha $^{-1}$ (P200), 320 kg K ha $^{-1}$ (K320) per one crop rotation (Table 1).

Table 1. The NPK balance (kg ha^{-1})

Variant	Applied			Leaching			Balance, + -		
	N	P	K	N	P	K	N	P	K
I rotation									
1. WF[a]	-	-	-	89,1	22,4	54,4	-89,1	-22,4	-54,4
2. CM[b]	200,0	79,4	166,0	156,0	36,6	129,5	44,0	42,8	36,5
3. P[c]	200,0	41,0	33,2	102,0	30,8	99,6	98,0	8,9	-66,4
4. PPC[d]	200,0	69,8	86,3	158,0	45,3	132,0	42,0	41,9	-45,7
5. CM + N_{80}PK	280,0	87,2	265,6	238,0	49,3	181,8	42,0	37,9	83,8
6. P + N_{80}PK	280,0	87,2	265,6	135,0	37,7	120,4	145,0	49,7	145,3
7. PPC + N_{80}PK	280,0	87,2	265,6	183,0	49,7	176,0	97,0	37,5	89,6
II rotation									
1. WF	-	-	-	150,0	39,4	126,2	-150,0	-39,4	-126,2
2. CM	200,0	57,6	96,3	180,0	48,8	161,9	20,0	8,7	-65,6
3. P	200,0	20,9	29,9	132,0	40,5	120,4	68,0	-19,5	-90,5
4. PPC	200,0	74,6	57,3	183,0	51,4	164,3	17,0	23,1	-102,1

5. CM + N_{80}PK	280,0	87,2	265,6	216,0	61,0	201,7	64,0	26,2	63,9
6. P + N_{80}PK	280,0	87,2	265,6	190,0	52,3	180,9	90,0	34,9	84,7
7. PPC + N_{80}PK	280,0	87,2	265,6	227,0	64,5	222,4	53,0	22,7	43,2
Average for 2 rotations									
1. WF	-	-	-	119,6	30,9	90,3	-119,6	30,9	-90,3
2. CM	200,0	68,5	131,1	168,0	42,7	145,7	32,0	25,7	-14,5
3. P	200,0	31,0	31,5	117,0	35,6	110,0	83,0	-4,7	-78,4
4. PPC	200,0	72,2	71,8	170,5	48,4	148,2	29,5	23,8	-76,4
5. CM + N_{80}PK	280,0	87,2	265,6	227,0	55,2	191,7	53,0	32,0	73,9
6. P + N_{80}PK	280,0	87,2	265,6	162,5	45,0	150,6	117,5	42,2	115,0
7. PPC + N_{80}PK	280,0	87,2	265,6	205,0	57,1	199,2	75,0	30,1	66,4

Note:
[a]Check – variant without fertilizer (WF);
[b]Manure of cattle (CM);
[c]Peat (P);
[d]Composted peat-poultry manure (PPC).

Ammonium nitrate (NH_4NO_3), triple superphosphate [$Ca(H_2PO_4)_2 \cdot H_2O$] and salt of potash (KCl) were applied prior to planting for the summer crops (potatoes, barley, vetch-oat mixture) and during the resumption of the spring growing season for winter wheat. Herbicides and fungicides were applied depending on weed pressure. The standard phytosanitary protection was applied according to integrated crop protection principles [27].

The layout of variants in the experience was systematic. The replication was threefold, the plot area was 48 m^2 (6 x 8).

The studies were conducted according to the following scheme: (1) check (variant without fertilizers), (2) CM, (3) P, (4) PPC, (5) CM + N80PK, (6) P + N80PK, (7) PPC + N80PK (Table 1).

Soil sampling and analyses

Soil samples were selected out of the plowing layer (0-20 cm) from each plot before the establishment of the experiment, then annually in the autumn after the harvesting of crops. The combined sample consisted of 20 individual ones taken with the hole borer. After drying, the soil was sieved through the screen with mesh diameter of 2 mm. Then it was analyzed according to the following methods: pH – with a potentiometer in the salt extract (1 mol l^{-1} KCl solution at the soil: solution ratio1: 2.5). The mobile compounds of phosphorus and potassium were extracted with the hydrochloric acid extract (0.2 mol l^{-1} HCl solution at the soil: solution ratio of 1: 5). The phosphorus content in the obtained extract was determined by the photometric analysis (a modification of the Denizhe method, based on the preparation of complex phosphoric acid compound with molybdenum oxides in the presence of tin chloride), the content of potassium – with a flame photometer. The content of soil organic carbon (SOC) was determined by the method of wet ashing of soil with the chromic mixture (0.4 M $K_2Cr_2O_7$ в H_2SO_4 diluted with water at the ratio 1: 1). The SOC content was converted to the total humus using the coefficient of 1.724, suggesting that humus contains 58% of SOC [28].

Soil biological properties

The selection of soil samples for the study of nitrifying ability was carried out in late June-early July in case of each cultivated crop. The cellulosolytic activity of the soil was determined by the «application» method. For this purpose, the linen cloth was placed into the plowing layer for two months (June, July). According to the decrease in the linen cloth mass, converted to %, we judged about the intensity of fiber destruction.

To determine the mobilized fraction of nitrogen using the Kravkov method, the soil sample was kept in the thermostat at the temperature of 28 °C and the capillary humidity of 60% within 12 days [29]. The nitrifying ability was calculated in the following way: [(mg N-NO_3 kg^{-1} soil)/(14 days × 24 h)]. The results demonstrating the effect of fertilizers on biological properties of the soil were obtained within the second crop rotation.

Data analyses

To assess the total productivity of crop rotation 'potatoes – barley – annual grasses – winter wheat' the crop yields were converted to grain units (t ha^{-1} of g. u.). To do it, the following conversion factors were used: for winter wheat, barley – 1.0, potatoes – 0.25, annual grasses – 0.14. An increase in the crop yields concerning various types of fertilizers is calculated with respect to the absolute check (without fertilizers). The balance of nutrients was determined as the difference between the intake of N, P and K with fertilizers (kg ha^{-1}) and their leaching with the crop of cultivated crops [30].

The statistical analysis of the results was carried out using STATVIUA.EXE. The essential difference between the variants was determined using the LSD criterion, the ONE-WAY ANOVA of variants. At the same time the differences between the variants were considered significant at $p < 0.05$. The agricultural payback of fertilizers (payment) was determined as an increase in the yield with respect to the check (kg ha^{-1} of g. u.) from 1 kg of NPK applied with fertilizer [31, 32].

RESULTS

Soil physicochemical properties

Before the establishment of the experiment, the soil of the experimental site was characterized by a slightly acid reaction of the soil medium (pH 5.22-5.42), and the content of the mobile forms of phosphorus and potassium varied insignificantly ($p < 0.05$). The content of humus ranged on average from 0.93 to 1.01% (Fig.1).

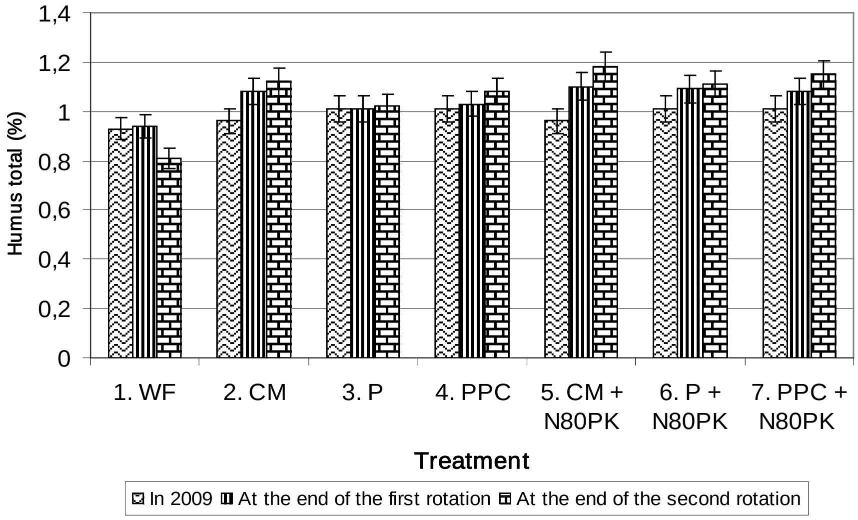

Fig. 1. Dynamics of humus content in the plowing layer (0-20 cm) before the establishment of the experiment in 2009 and after the 1st and 2nd crop rotations

After the first rotation, the total humus content in the soil by the application of PPC and P was similar to the check (without fertilizers), in case of the application of CM and all types of organic fertilizers together with $N_{80}PK$ – significantly higher by 0.14-0.16%.

Humus content at the end of the second crop rotation ranged on average from 1.02% (P) to 1.18% (CM + $N_{80}PK$) (Fig.1), indicating the overall significant effect of the FP ($p < 0.001$). Without fertilizer its content decreased from 0.93 to 0.81%. The effects of FP and FP + $N_{80}PK$ application rates were significant ($p < 0.05$) for the soil pH, P_{mobile}, K_{mobile} (Table 2). At the same time the use of P in its pure form reduced the content of P_{mobile} and K_{mobile} in comparison with the original one , and also promoted the acidification of soil, especially in case of combined application with $N_{80}PK$ (by 0.53 pH). The application of PPC + $N_{80}PK$ ($F > F_{05}$) significantly influenced the improvement of soil physicochemical properties.

Table 2: The effect of the application of fertilizers on the agrochemical properties of sod-podzol sandy loam soil (0-20 cm).

Treatment	P mobile, mg kg^{-1}					K mobile, mg kg^{-1}					pH_{KCl}				
	1*	2*	3*	4*	5*	1*	2*	3*	4*	5*	1*	2*	3*	4*	5*
1. WF	72,4	76,3	64,5	67,1	65,4	96,3	91,3	87,2	83,0	83,0	5.22	5.07	4.97	5,02	5,00
2. CM	78,0	71,1	68,0	78,5	75,0	99,6	107,9	107,9	103,8	96,3	5.30	5.30	5.30	5.20	5.31
3. P	65,4	72,4	64,1	70,6	57,6	91,3	95,5	91,3	88,8	87,2	5.41	5.54	5.38	5.35	5.35
4. PPC	70,2	124,3	107,7	102,0	86,8	93,0	116,2	112,1	103,8	99,6	5.42	5.62	5.65	5.68	5.52
5. CM + $N_{80}PK$	78,0	96,4	79,4	91,1	80,2	99,6	111,2	127,8	115,4	122,8	5.31	5.32	5.25	5.11	5.02
6. P + $N_{80}PK$	65,4	91,1	82,0	87,2	78,5	91,3	124,5	122,8	111,2	107,9	5.44	5.05	5.12	5.16	4.91

7. PPC + $N_{80}PK$	70,2	149,1	165,2	144,8	95,9	93,0	117,9	122,8	116,2	116,2	5.41	5.73	5.56	5.7	5.40
LSD_{05}	n.s.	7,4	3,1	4,8	4,8	n.s.	n.s.	3,3	3,3	3,3	n.s.	0.11	0.11	0.12	0.11

Note:

1* Before the establishment of the experiment in 2009; 2* Direct action; 3* The 1st year of aftereffect; 4* The 2-year of aftereffect; 5* The 3rd year of aftereffect.

Nitrifying and cellulosolytic activity of soil

Taking into account the given data (Fig. 2), it can be noted that the soil nitrifying activity is significantly influenced by the crop cultivated within the crop rotation.

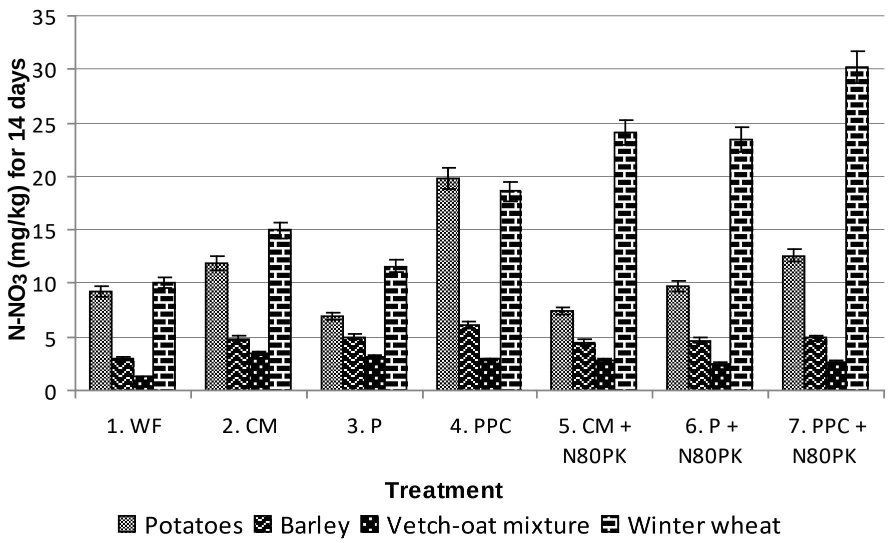

Fig. 2. Nitrification ability of sod-podzol sandy loam soil in the plowing layer (0-20 cm) of 'potatoes-barley-vetch-oat mixture-winter wheat' rotation.

In CM, P and WF variants it is 9.2-15.0 mg $N\text{-}NO_3$ kg^{-1} soil/14 days. The combined application of organic and mineral fertilizers (CM + $N_{80}PK$, P + $N_{80}PK$, PPC + $N_{80}PK$) 1.6-2 times increases the nitrifying activity under winter wheat in comparison with the unilateral application of CM, P and PPC (the relative error between the variants is significant in case of $p < 0.05$).

The cellulosolytic activity of soil increases significantly when fertilizers are applied under potatoes (Fig. 3).

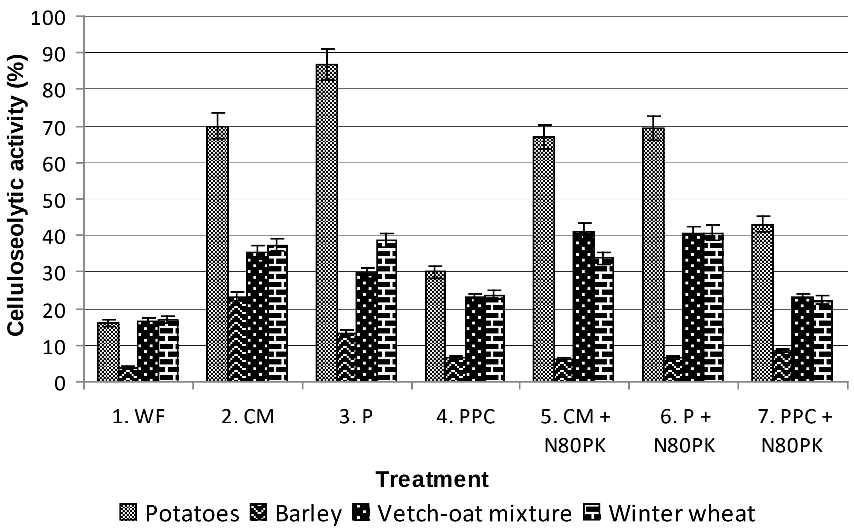

Fig. 3. The effect of organic fertilizers based on peat on celluloseolytic activity of soil in the plowing layer (0-20 cm) of crop rotation

The degree of the linen cloth decomposition by the application of CM, P and CM + CM + $N_{80}PK$, P + $N_{80}PK$ amounts to 67-87% (at $p < 0.05$), at 16% in the WF variant. In the 1st-3rd years of the aftereffect, the tendency of decay of cellulolytic activity is observed. The fact of the low decomposition degree of the linen cloth in case of barley cultivation is especially remarkable. In all probability, it is connected with the biological peculiarities of rhizosphere microorganisms in this crop.

Crop yields

The relative yields of different crops (t ha $^{-1}$ of g. u.) during the entire experimental period are reported in Table 3.

Table 3. Average productivity per crop type for 2 rotations, t ha $^{-1}$ of grain units

Crop FP:	WF	CM		P		PPC		LSD_{05}
NPK:	0	0	NPK	0	NPK	0	NPK	
Potatoes	3.24	4.65	6.50	4.19	5.20	5.50	6.48	0.74
Barley	0.84	1.58	2.22	1.00	1.76	1.68	2.25	0.44
Vetch-oat mixture	1.76	1.90	2.36	1.84	2.41	2.21	2.61	0.40
Winter wheat	2.19	2.62	3.24	2.22	3.16	2.74	3.26	0.36
Crop yields: (on average For 2 rotations)	8.03	10.75	14.32	9.25	12.53	12.13	14.60	1.91
(average for the year)	2.01	2.69	3.58	2.31	3.13	3.03	3.65	0.49

LSD of p-value<0.01;

The combined application of $N_{80}PK$ with the studied organic fertilizers contributed to an increase in the relative crop yield by 20-35% for almost all the crops ($p < 0.001$). The lowest yield of grain units on average within 2 rotations was noted in the check (without fertilizers) – 8.03 t ha $^{-1}$. Among the FP the lowest relative yield was observed in case of the application of P in pure form. The maximum productivity of crop rotation was obtained by applying CM and PPC combined with $N_{80}PK$ – 14.32-14.60 t ha $^{-1}$ of g. u.

DISCUSSION

Influence of fertilization practices on soil nitrifying and cellulosolytic activity

The process of conducting studies on the influence of application of organic fertilizers based on peat makes it possible to study the regularities of the effect of fertilizers on the yield of agricultural crops and on the change in effective soil fertility [33].

The influence of the studied factors was noticeably manifested in such indicators of the soil biological state as nitrifying and cellulolytic activity. The nitrification capacity reflects not only the soil ability to store up nitrate nitrogen due to the acidification of the reduced mineral forms, but also the intensity of the current mineralization of the organic matter [34]. During the cycle of crop rotation the nitrifying ability of sod-podzol sandy loam soil in the topsoil depended on the type of organic fertilizers, their combination with mineral ones, and soil moisture at the time of determination. Within the first year of the action of fertilizers, the highest values of the indicator were noted in the variant with PPC (19.8 mg $N\text{-}NO_3$ / kg / 14 days), within the first and second year of aftereffect they were almost equal (4.8-6.1 mg $N\text{-}NO_3$ / kg / 14 days), but they exceeded the values obtained in the check (3.0) (Fig. 2).

During the cycle of the crop rotation, the soil cellulosolytic activity also depended on the type of fertilizers applied (Fig. 3). Thus, the greatest degree of cellulose decomposition was observed when peat and manure were used both in pure form and with NPK during all years of the studies. It is apparently connected with the fact that due to the application of manure and peat the soil got twice as much physical mass of organic fertilizers (Fig. 3).

Influence on soil physicochemical properties

The application of the studied fertilizers had a different effect on the agrochemical properties of sod-podzol sandy loam soil within the crop rotation: it influenced the content of mobile phosphorus, exchange potassium, pH_{KCL} and total humus (Tabl.2, Fig. 1). Thus, the content of mobile phosphorus in the variant with manure, decreasing during the rotation, reaches its previous level by the end of the rotation. The greatest decrease in the content of mobile phosphorus was noted in the variant with peat, it amounted to 7.8 mg kg $^{-1}$ of soil in comparison with the initial one. In the variant with the use of PPC, the content of mobile phosphorus increased noticeably during one crop rotation. By the end of the rotation, it decreased but it was by 16.6 mg kg $^{-1}$ higher in comparison with the initial one. The effect of manure and peat with the additional application of mineral fertilizers on the content of mobile phosphorus became almost equal, an increase of 2.6-13.1 mg kg $^{-1}$ of soil was noted. In the check, there was a decrease of 7.0 mg kg $^{-1}$. The variant with PPC + NPK is also remarkable. The content of mobile phosphorus increased during the rotation, by its end, it decreased but the growth in the content in comparison with the initial content of mobile phosphorus amounted to 25.7 mg kg $^{-1}$ of soil (Table 2).

The content of exchangeable potassium in the soil in variants without NPK by the end of rotation in the check and in the variants with manure and peat decreased in comparison with the initial one: in the check the decrease amounted to 13.3 mg kg $^{-1}$; by the application of manure and peat – 3.3-4.1 mg kg $^{-1}$. The increase in the content of exchange potassium was noted in the variant with PPC and amounted to 6.6 mg kg $^{-1}$. The combination of organic and mineral fertilizers contributed to the conservation of the exchangeable potassium reserves. Its increase amounted to 16.6-23.2 mg kg $^{-1}$.

On average, the pH value decreased by 0.06 units during one crop rotation in case of the application of peat in pure form; at the decrease in the check (without fertilizers) by 0.22 pH. In the variants with manure and composted peat-poultry manure compost pH values remained at the same level, the application of these fertilizers did not have an acidifying effect on the soil. In the variants with applied mineral fertilizers, the decrease by 0.30-0.53 units in pH_{KCL}values was noted when using manure and peat (Table 2).

The combination of organic and mineral fertilizers contributed to the rise in mineral nitrogen reserves in the plowing layer during the tillering period – the time of ear formation of winter wheat, when plants consumed much nitrogen. Subsequently, it positively influenced the formation of the grain crop [35].

The application of fertilizers based on peat had a multidirectional effect on the content of total humus in the plowing layer (Fig. 1). So, on average, during one crop rotation the loss of humus was noted in the soil of the check and in the variant with peat. It amounted to 5-13% relative to the original content. In the variants with manure and PPC, an increase in total humus content was noted, in the variant with CM, it was the highest; the rise amounted to16%, in the variant with PPC – 6.9%. The combination of organic and mineral fertilizers contributed to the increase in humus content by 9.9-22%, depending on the type of fertilizer. The greatest increase was also noted in the variant with CM (Fig. 1). The studies show that the content of humus (SOC) increases significantly by the application of organic fertilizers in comparison with mineral ones [36].

The effect of fertilizer systems on the productivity of crop rotation

In case of applying organic fertilizers, the highest total productivity of crop rotation within two cycles, on average, was noted in the variant with PPC. It amounted to 12.13 t ha $^{-1}$ of g.u., while in the check (without fertilizers), it was 8.03 g.u. (t ha $^{-1}$) (Tabl. 3). According to the background of mineral fertilizers, in all variants of the experiment, the productivity of crops was higher in comparison with the check and organic fertilizer system. The greatest increases were obtained in the variants with CM and with PPC – 11.08-11.36 t ha $^{-1}$ of g.u.

Among the used types of fertilizers, PPC had the longest effect. The experiment results showed that, on average, within two cycles of crop rotation, in case of using organic fertilizers without mineral ones, we obtained additionally from 1.21 to 4.07 t ha $^{-1}$ of g.u. or 0.3-1.02 t ha $^{-1}$ of g.u.per year. In combination with mineral fertilizers, the level of increase was much higher – from 4.47 to 6.7 t ha $^{-1}$ of g.u., or 1.12-1.69 t ha $^{-1}$ of g.u. per year (Table 3). The total NPK content was taken to the optimum level, the average annual application of nutrients within the grain-crop rotation was N70P21.8K66.4.

The payback of 1 kg of nutrients by the application of organic fertilizers in pure form on average within two rotations amounted to 4.65 (P) -11.92 (PPC) kg of g.u. In combination with mineral fertilizers, this indicator increased to 7.11 P+N_{80}PK) -10.38 (PPC+N_{80}PK) kg of g.u. The largest payment for 1 kg of NPK, applied with fertilizers, was noted in the variant with PPC both in its pure form and at NPK background: it amounted to 11.92 and 10.38 kg of g.u.

The payment for 1 ton of peat (kg of g.u.) was 2 times lower compared to CM (43 kg of g.u.), that was taken as a standard in the experiment. The application of 1 ton of PPC was the most profitable and ensured the production of 148 kg of g.u. Therefore, peat is more profitable to be uses in the composted form, especially as a part of PPC.

At the end of the first crop rotation in the variants with manure and manure + NPK, we obtained a positive balance of biophile elements, some of them were not used by crop yields and remained to reproduce the soil fertility (Tabl. 1). In the variant with CM, 445.4 kg ha $^{-1}$ of NPK was applied, the leaching with the crop of four crop varieties amounted to 322.1 kg ha $^{-1}$, in the variant CM + N_{80}PK an even more positive balance was noted – 632.8 kg ha $^{-1}$ was applied, the leaching was 469.1 kg ha $^{-1}$ of NPK. In the variants with peat and PPC, a negative balance concerning potassium – 66.4 and 45.7 kg ha $^{-1}$ respectively was noted. The greatest negative balance, but concerning all nutrient elements, was noted in the check – 165.9 kg ha $^{-1}$ of NPK. The variants with the combined application of organic and mineral fertilizers significantly exceed the variants with organic fertilizers in pure form, the balance concerning nutrient elements was positive. By the application of 632.8 kg ha $^{-1}$ of NPK, the leaching amounted to 293.1-469.1 kg ha $^{-1}$. In addition, according to a number of authors, there was an increase in the weight of postcut-root residues containing significant amounts of P and K [37].

At the end of the second crop rotation, the negative balance concerning potassium was noted in the variants with organic fertilizers. It varied from 65.6 (CM) to 90.5 kg ha $^{-1}$ in the variant with peat; the same situation is observed concerning phosphorus –19.5 kg ha $^{-1}$, with a sharper negative balance of nutrients in check – 315.6 kg ha $^{-1}$ of NPK (Tabl. 1). This can be explained by the fact that during the second crop rotation, the amount of nutrients, applied with organic fertilizers, was lower, while the crop productivity was comparatively equal [38]. It also indicates the instability of sod-podzol sandy loam soil fertility. The positive NPK balance was obtained in case of the combination of organic and mineral fertilizers. In the variant with peat, it amounted to 209.6 kg ha $^{-1}$; in the variant with CM –154.1 kg ha $^{-1}$; in case of PPC – 118.9 kg ha $^{-1}$.

CONCLUSION

The application of organic fertilizers based on peat in the grain-crop rotation on the sod-podzol sandy loam soil contributed to the optimization of agrochemical and biological properties of the soil. As a result, it influenced the increase in the productivity of crops cultivated within the grain-crop rotation. The greatest increase in the total productivity of crop rotation (during two rotations on average), by the use of organic fertilizers applied in equal doses concerning nitrogen, was noted in the variant with PPC. It amounted to 12.13 t ha $^{-1}$ of g.u., at 8.03 t ha $^{-1}$ of g.u. in the check. According to the background of mineral fertilizers, in all variants of the experiment, the productivity of crops was higher on average by 12-35% in comparison with the organic fertilization system.

The combination of organic fertilizers based on peat and mineral fertilizers contributed to the conservation of reserves of mobile phosphorus, exchange potassium and total humus in the plowing layer of sod-podzol sandy loam soil. It was achieved by the positive balance concerning nitrogen, phosphorus and potassium in all rotations of crop rotation.

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