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The Content of Various Forms of Phosphorus in Leached Chernozem Due To Application of Fertilizer Systems

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Abstract

Soil fertility is in a constant dynamic change: with intensive use of agricultural lands, the decrease of nutrients is observed therein, being the reason of the soils degradation [1]. On the leached chernozem of the Stavropol Upland, the influence of fertilizer systems based on various principles on agrochemical indices of soil fertility, including the content of phosphorus forms in soil, has been studied. The long-term use of phosphorus-containing mineral fertilizers promotes the increase of loosely bound phosphates, aluminophosphates, iron phosphates, multibase calcium phosphates in 0-20 and 20-40 cm soil layers.

Keywords: mobile phosphorus, aluminophosphates, iron phosphates, leached chernozem, fertilizer system, soil properties, soil nutrient status.

INTRODUCTION

Phosphorus is one of the important elements in plant nutrition. After organic matter and nitrogen, phosphorus is often the scarcest element in the growth of agricultural crops. A considerable part of the available soil phosphorus is present in organic matter [2]. When the organic matter is exhausted by intensive soil cultivation, erosion, and with the yield removal - the phosphorus deficiency becomes an actual problem. In practice, phosphorus-containing fertilizers help meeting the need of plants in phosphorus. Nowadays, when we are striving for zero tillage, it may be necessary to increase a number of phosphorus fertilizers to meet the needs of more intensive crop rotation and the organic matter restoration [3].

The research objective was to study the effectiveness of fertilizer systems in the pea - winter wheat - spring rape rotation link on the leached chernozem of the Stavropol Upland. One of the main tasks of studying this issue by the research method was to assess the effect of the systematic application of fertilizer systems on the content of phosphorus forms in the meter profile of leached chernozem.

METHODS

The place of the field research was the stationary experiment of the Agrochemistry and Agriculture Departments located on the territory of the experimental station of the Stavropol State Agrarian University. The stationary experiment is included in the geographical network of experiments with fertilizers and is registered in the register of certificates of long-term experiments of the Geonetwork of the All-Union Research University of the Russian Federation. The experimental field is located within the Stavropol Upland at an altitude of 500-550 m above the sea level. The relief of the territory represents an undulating plain, the mesorelief is a northern gentle slope with a steepness of about 1°. The soil of the experimental field - leached, powerful, low-humus, heavy loamy chernozem. Currently, leached chernozem is characterized by average values of humus content (5.2-5.9%), nitrification capacity (16-30 mg/kg), mobile phosphorus content (22-28 mg/kg according to Machigin), and by average value of potassium (240-290 mg/kg). The reaction of the soil solution in the upper soil horizons is neutral and is within the range of 6.1-6.8. According to the average long-term data, 550-650 mm of precipitation falls in the zone of experiments per year, including 450-470 mm during the active plant vegetation period. The sum of effective temperatures over the active vegetation period is 3,000-3,200 °C, and the hydrothermal index is 1.1-1.3.

The experiment is a single-factor one, deployed in time and space. The repetition of the experiment is three-factor one, the experimental scheme is constructed by the method of plots splitting, the total plot area is 108 m2, the width is 7.2 m, the length is 15 m, and the accounting area is 50 m2.

The following regional crop varieties were used in the research: Aksai leafless pea 5, Zernogradka 11 winter wheat, Forum spring rape.

The mineral fertilizers used in the experiment included: ammonium nitrate, granular superphosphate, potassium chloride, ammophos, nitroammophos, organic fertilizers were represented by straw of cultivated crops.

Table 1 - Fertilizer systems studied in the experiment

Crop sequence	Fertilizer system	Fertilizer application		
		Preplant	At seeding	Additional fertilization
Pea	Recommended	P_{30}	Nitragin + + $N_{10}P_{10}$	–
	Biologized	Straw 4.7 t/ha + N_{40}	Nitragin + + $N_{10}P_{10}$	–
	Estimated	$N_{22}P_{52}K_{22}$	Nitragin + + $N_{10}P_{10}$	–
Winter wheat	Recommended	$N_{30}P_{30}$	$N_{10}P_{10}$	N_{30}
	Biologized	Straw 2.4 t/ha + N_{20}	$N_{10}P_{10}$	N_{30}
	Estimated	$N_{58}P_{68}$	$N_{10}P_{10}$	N_{30}
Spring rape	Recommended	$N_{30}P_{40}K_{20}$	$N_{10}P_{10}$	–
	Biologized	Straw 5.3 t/ha + N_{40}	$N_{10}P_{10}$	–
	Estimated	$N_{50}P_{45}K_{20}$	$N_{10}P_{10}$	–

In the studied link of crop rotation (pea - winter wheat - spring rape) against the background of the 20-22 cm dumped tillage, relative to control (without fertilizers), the influence of the following fertilizer systems was studied (Table 1):

– recommended – with the saturation of the rotation link NPK 90 kg/ha, including N40P43,3K6,7 at a ratio of N:P:K=1:1.08:0.17 (with the crop rotation saturation NPK 115 kg/ha, including N50P58,75K6,15 at a ratio of N:P:K = 1:1.18:0.13 + 5 t/ha of organic fertilizers);

– biologized – with the saturation of the rotation link NPK 63.3 kg/ha, including N53,3P10,0K0 at a ratio of N:P:K= 1:0.19:0 + 4.1 t/ha of organic fertilizers (with the crop rotation saturation NPK 62.5 kg/ha, including N42,5P20K0 at a ratio of N:P:K = 1:0.47:0 + 8.2 t/ha of organic fertilizers);

– estimated–planned for the maximum crop yield of the crop rotation link (pea - 33 dt/ha, winter wheat - 60 dt/ha, spring rape - 22 dt/ha) with the saturation of the rotation link NPK 142.3 kg/ha, including N63,3P65K14 at a ratio of N:P:K=1:1.03:0.22 (with the crop rotation saturation NPK 167 kg/ha, including N75P73,5K11,5 at a ratio of N:P:K = 1:0.98:0.15 + 5 t/ha of organic fertilizers);

RESULTS.

The content of mobile phosphorus in the 0-20 cm soil layer.

Movable phosphorus is a part of the phosphates extracted from the soil by weakly acidic and slightly alkaline extracts that simulate the effect of the root system on the soil. It is conventionally assumed that the extracts dissolve the phosphates available to plants [4]. The moisture conditions during the years of research had significantly influenced the content of mobile phosphorus in the 0-20 cm layer of leached chernozem. Thus, sharp fluctuations in soil moisture in the plow layer can lead to an increase in the content of hardly soluble forms, and vice versa, the optimum moisture conditions contribute to the increase in mobile forms of phosphorus, the content of available phosphates was significantly higher than in dry periods.

The dynamics of mobile phosphorus in pea crops had the following sequence: its maximum number had been observed in all the experiment versions in the preplant period, and then it gradually decreased, reaching its minimum by the phase of full ripeness (Table 2).

Table 2 – **The effect of fertilizer systems on the dynamics of the content of mobile phosphorus (mg/kg) in a 0-20 cm layer of soil in pea crops**

Fertilizer system, A	Selection term, B				A, MSD_{05} = 2.2
	Before sowing	Stooling	Blossoming	Complete ripeness	
Control	19.3	18.2	16.3	15.5	17.3
Recommended	27.1	25.2	21.3	19.5	23.3
Biologized	22.5	19.8	18.3	17.1	19.4
Estimated	30.9	29.0	25.7	24.9	27.6
B, MSD 05 = 1.6	25.0	23.1	20.4	19.3	MSD05 = 3.8 Sx = 4.7

All fertilizer systems studied were significantly superior to the control by the content of mobile phosphorus. With an average of 17.3 mg/kg of soil in the control for three years, the use of the recommended and biologized fertilizer systems had increased this indicator by 6.0 and 2.1 mg/kg, respectively, and the estimated one - by 10.3 mg/kg compared to the natural agrochemical background.

Throughout the pea growing season, the systems studied significantly increased the content of mobile phosphorus, and the difference with the control was (mg/kg of soil): before sowing - 3.2-11.6; in the stooling phase - 1.6-10.8; in the blossoming phase - 2.0-9.4; and to full ripeness - 1.6-9.4 (Table 3).

The estimated system had an advantage over the biologized and recommended ones, but the provision of 0-20 cm of the leached chernozem layer on all nutrition backgrounds was characterized as an average one.

Dynamics of change in mobile phosphorus in the soil under winter wheat had the following nature (Table 3). The maximum phosphorus content on all nutrition backgrounds was noted before sowing, then the phosphorus content had a single course from the tillering phase - a steady decline with the attainment of the minimum values by the full ripeness phase.

Mineral phosphorus compounds are found in soils in the form of salts of calcium, magnesium, iron and aluminum, and orthophosphoric acid. The orthophosphates of alkali metals and ammonium are readily soluble in water. The monosubstituted calcium orthophosphate $Ca(H_2PO_4)_2 \cdot H_2O$ is also very soluble in water, and the disubstituted calcium orthophosphate $CaHPO_4 \cdot 2H_2O$ is much the worse soluble. The trisubstituted phosphates of bivalent and trivalent cations very poorly dissolve in the water. Phosphorus can be found in the soil in the minerals of apatite, phosphorite, vivianite, and in the absorbed state in the form of a phosphate anion. Mineral phosphates are the main source of phosphorus for plants. Phosphorus of organic compounds is digested after their mineralization. A weakly acid reaction (pH – 5.0-5.5) is the most favorable reaction of the medium for the assimilation of phosphate ions by plants [3].

We established that the recommended and estimated fertilizer systems were characterized by an increased consumption of mobile phosphorus, and the difference for the growing season was 9.8 and 12.3 mg/kg of soil. While the content of mobile phosphorus decreased by 8.9 mg/kg of soil on the control, on the biological fertilizer system it decreased by 6.7 mg/kg of soil.

The estimated fertilizer system contributed to a significant increase in the content of mobile phosphorus, not only in comparison with the control but also in comparison with other fertilizer systems studied in the experiment [5]. Moreover, the availability of mobile phosphorus in the version with the estimated system refers to the increased content, while in other versions - to the average one. The difference between the indicators of the recommended and biologized systems is insignificant: during the winter wheat vegetation, the advantage of the estimated fertilizer system was noted, and the difference in developmental phases was from 7.0 to 9.7 mg/kg of soil, depending on the fertilizer systems, the difference compared to the control was 13.8 mg/kg of soil, and compared with the biologized and recommended systems - 12 and 8.5 mg/kg of soil, respectively.

From the data provided in Table 4, it can be concluded that the phosphate content in the 0-20 cm soil layer substantially increased in all fertilizer systems in comparison with the control, but the content of mobile phosphorus in the soil under spring rape during the vegetation period had downward nature, with the achievement of its minimum to the phase of full ripeness.

On the recommended fertilizer system during the vegetation, the stock of mobile phosphates decreased by 9.6 mg/kg of soil, on the estimated system - by 12.0 mg/kg of soil, while on the biologized system the reduction in the element concentration was less significant - 4.2 mg/kg of soil.

Thus, the greatest content of P_2O_5 in the years of the experiments was noted in the versions with the estimated fertilizer systems, which was explained by the high saturation of 1 ha of the rotation link with phosphorus fertilizers for the planned yield of agricultural crops (Figure 1).

Table 3 – The effect of fertilizer systems on the dynamics of the content of mobile phosphorus (mg/kg) in a 0-20 cm layer of soil in winter wheat crops

Fertilizer system, A	Selection term, B					A, MSD_{05} = 2.8
	Before sowing	Stooling	Stem elongation	Heading	Complete ripeness	
Control	23.4	20.2	17.1	15.9	14.5	18.2
Recommended	28.7	26.1	23.3	20.3	18.9	23.5
Biologized	24.1	22.3	20.8	19.9	17.4	20.9
Estimated	38.2	35.8	30.9	29.1	25.9	32.0
B, MSD_{05} = 1,2	28.6	26.1	23.0	21.3	19.2	MSD_{05} = 4.0 Sx = 4.7

Table 4 – The effect of fertilizer systems on the dynamics of the content of mobile phosphorus (mg/kg) in a 0-20 cm layer of soil in spring rape crops

Fertilizer system, A	Selection term, B					A, MSD_{05} = 1.4
	Before sowing	Rosette	Budding	Blossoming	Complete ripeness	
Control	18.3	17.3	16.7	15.1	14.7	16.4
Recommended	25.6	19.9	18.7	18.2	16.0	19.7
Biologized	19.8	18.4	17.5	16.9	15.6	17.6
Estimated	28.3	22.6	21.2	20.8	16.3	21.8
B, MSD_{05} = 1,0	23.0	19.6	18.5	17.8	15.6	MSD05 = 2.5 S_x = 4.7

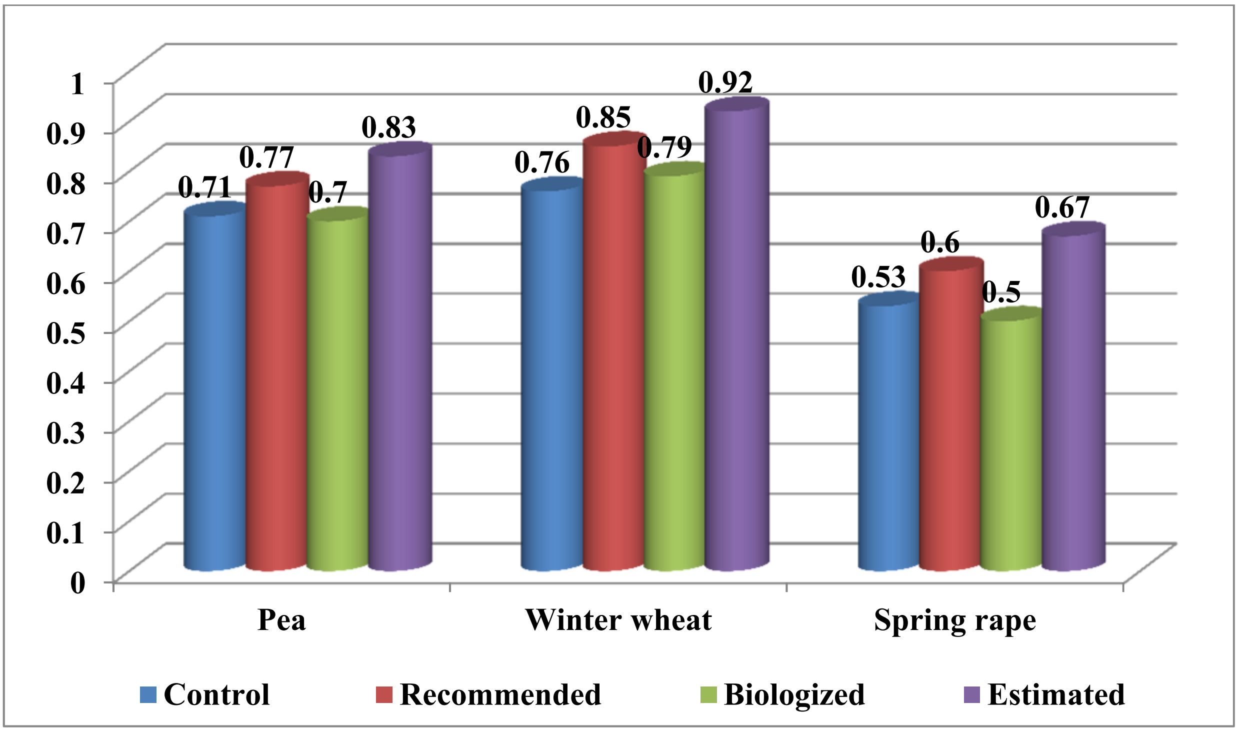

Figure 1 – The effect of fertilizer systems on the dynamics of the content of mobile phosphorus (mg/kg) in the 0-20 cm layer of leached chernozem

The average phosphorus content during the crop vegetation was 16.4 mg/kg of soil in control, in the versions with the recommended and biologized fertilizer systems - 19.7 and 17.6 mg/kg of soil, respectively, on the estimated one - 21.8 mg/kg of soil.

Based on the data shown in Figure 1, it can be concluded that the largest content of mobile phosphorus in the 0-20 cm soil layer was observed on winter wheat - 23.7 mg/kg of soil, compared to other crops that were inferior by 1.8 and 5 mg/kg of soil. The alternation of crop rotation links had an ambiguous effect on the content of mobile phosphorus in the 0-20 cm layer of leached chernozem. Therefore, while during the rotation period of the rotation link the concentration of mobile phosphorus decreased by 1.8 mg/kg of soil, on the fertilized background the difference was more significant: on recommended - 3.8 mg/kg; on biological - 3.3 mg/kg; on estimated - 10.2 mg/kg of soil.

On average, during the study period, the maximum mobile phosphorus content of 32 mg/kg of soil was observed in the versions with the use of the estimated fertilizer system, which is explained by the introduction of 73.5 kg/ha rate of application of mineral fertilizers phosphorus. The difference between the values of phosphorus content on the recommended and biologized systems was within the experiment error.

The dynamics of mobile phosphorus on all nutrition backgrounds had the same sequence – a steady decline throughout the whole vegetation period with the attainment of minimum values by full ripeness.

It should be noted that all fertilizer systems studied were characterized by an increased consumption of mobile phosphorus during crop vegetation - the difference with the preplant period was 3.6-5.6 mg/kg. At the same time, the content of mobile phosphorus decreased: under peas - by 1.9-5.7, under winter wheat - by 2.5-9.4, and under spring rape - by 3.4-7.4 mg/kg of soil.

The content of phosphorus forms in the meter soil profile

The total content of phosphorus in the soil varies from 0.01 to 0.3% and, first, depends on the mineralogical composition of the parent rocks. In addition, humus-rich soils contain more phosphorus (in the humus 1-2% P_2O_5). The minimum content of phosphorus was observed in sod-podzolic sandy soils, the maximum - in chernozem soils. The vital activity of plants causes biological accumulation of phosphorus in the upper horizons of soils [4]. In order to increase the crop yield of the crop rotation link, it is required to clearly separate the forms of nutrients, in particular, the phosphates consumed by the plants. The natural reserve of phosphates is determined by the nature of the soil-forming process and its content in the parent rocks [6]. The replenishment of phosphate in the soil occurs solely due to the introduction of phosphorus-containing fertilizers. Depending on the type of soil, its chemical composition, phosphorus, introduced into the soil, undergoes various transformations. The application of phosphorus-containing fertilizers increases the content of both gross phosphorus and its various mineral forms in the soil. The fractional composition changes toward increasing the iron and aluminum phosphates, and the latter, in turn, contribute to increasing the amount of available phosphorus and reducing the content of hardly soluble calcium phosphates. Poorly soluble phosphorus compounds are significantly accumulated mainly only on soils that are free from plants, since plants actively influence the formation of various fractions of phosphates.

With the regular application of organic fertilizers, the content of its mobile forms mainly increases, and they remain in an assimilated form for a long period.

Various fluctuations in the moisture regime of the soil toward desiccation lead to rearrangement of phosphorus forms and increase the amount of hardly soluble phosphates.

The mobility of phosphate forms and the increase of their availability for plants grow when phosphorus fertilizers are mixed with other types of mineral fertilizers, as well as organic matter. Data on the effect of the estimated fertilizer system on the dynamics of phosphate forms in leached chernozem are provided in Table 15.

The analysis of Table 15 leads to the conclusion that the content of almost all forms of recoverable phosphates in the meter soil profile with the estimated fertilizer system exceeds the parameters of the control.

Thus, the estimated fertilization system in the soil layer 0-10 cm in terms of the content of water-soluble phosphates exceeds the control indicator by 50%, and is 2 mg/kg of soil. In the following soil layer (11-20 cm), the content of water-soluble phosphates was not detected in the control, in contrast to the estimated fertilizer system (2 mg/kg). Down through the soil profile, water-soluble forms were absent both in the control and in the version with the estimated fertilizer system.

Table 5 – **The effect of the estimated fertilizer system on the dynamics of the content of phosphorus forms (mg/kg) in a 0-100 cm layer of soil in winter wheat crops**

Soil layer	Control					Estimated				
	Applied with fertilizers	Phosphorus fractions				Applied with fertilizers	Phosphorus fractions			
		Water soluble	Aluminum phosphates (Al-P)	Ferrum phosphates (Fe-P)	Calcium phosphates (Ca-P)		Water soluble	Aluminum phosphates (Al-P)	Ferrum phosphates (Fe-P)	Calcium phosphates (Ca-P)
0–10	0	1	88	142	89	mineral $N_{1720}P_{1944}K_{552}$ organic $(N_{1120}P_{560}K_{1024})$	2	104	165	105
11-20		0	76	127	73		2	85	150	87
21-40		0	112	237	134		0	134	252	151
41-60		0	81	225	102		0	96	238	114
61-80		0	64	189	96		0	73	192	104
81-100		0	55	157	87		0	62	158	94

The content of aluminophosphates with the estimated fertilizer system exceeded the control by 7-22 mg/kg of soil. Thus, the upper soil layer in the estimated system increased the aluminum phosphate content by 16 mg/kg, the soil layer of 11-20 cm provided an increase of 9 mg/kg, and in the soil layer 21-40 cm the increase was 22 mg/kg of soil. In the underlying layers, an increase in the content of aluminophosphates by 7-15 mg/kg of soil was also noted. It should be noted that the highest content of aluminum phosphates was observed in the upper, arable soil horizon.

In turn, the number of iron phosphates exceeded the content of aluminum phosphates twice, and in some layers - thrice, regardless of whether fertilizers were applied or not. The estimated fertilizer system increased the content of iron phosphates relative to the control by 1-23 mg/kg of soil.

The maximum increase in iron phosphates of 23 mg/kg was noted in the 0–10 and 11–20 cm soil layers. In the following soil layer (21-40 cm), the iron phosphate content decreased and was only 15 mg/kg of soil. A soil layer of 41-60 cm was characterized by an increase by 13 mg/kg in iron phosphates in the estimated system with respect to the control. In the lower layers of the soil, a slight increase in iron phosphates by 1-3 mg/kg was observed.

The content of calcium phosphate such as di-tri-octacalsium phosphate, apatite, and iron and aluminum phosphates reprecipitated in other extracts was 7-16 mg/kg higher in the estimated fertilizer system than that in the control. As in the previous three extracts, the maximum amount of the fraction, as well as the increase relative to the control was noted in the upper horizons of the soil. The highest increase (16 mg/kg soil) of hardly soluble phosphates was noted in the 0-10 cm soil layer. In the 11-20, 21-40 and 41 cm soil layers, the increase in the indicator of the estimated system relative to the control was approximately on the same level, i.e. 14, 17 and 12 mg/kg of soil. In deep soil layers, 61-80 and 81-100 cm, the increase in hard-to-reach calcium phosphates was insignificant, by 8 and 7 mg/kg of soil, respectively.

Thus, after analyzing the effect of fertilizer systems on the dynamics of phosphate forms on the leached chernozem, we came to the conclusion that the mineral fertilizers applied during three crop rotations contributed to the accumulation of fertilizer relative to the control (unapproved) version of practically all fractions of phosphorus in the estimated system. It should be specially noted that the main increase in the forms of phosphorus and their accumulation are noted in the upper layers of the soil, which, apparently, can be explained by the greater biomass of plants and the root system and as a consequence of root secretions. As studies have shown, hardly dissoluble phosphates of iron and calcium predominate, massively exceeding the water-soluble phosphates and phosphates of aluminum available for plants.

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