Phosphorus fertilizer payment taking into account its long-term after-effect

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Abstract. When phosphorus and nitrogen fertilizers are used together, their interaction is positive. This relationship is expressed differently in different weather conditions. Its manifestation also depends on elements of culture cultivation technology. In order to optimize phosphorus nutrition, pre-determined doses of phosphorus are offered, sometimes highly overestimated, which should have a long-term follow-up. To control the content of mobile phosphorus, doses of phosphorus have been developed, which can increase the index of plant availability with this element by 10 mg/kg.

In a stationary experiment at the Central Experimental Field of the Kurgan NIISH, the effect of three doses of phosphorus-free nitrogen and combined with phosphorus fertilizer for 25 years and the further follow-up of phosphorus was evaluated. Phosphorus fertilizer was added for 25 years on the background of nitrogen in a dose of P40. Once the phosphorus fertilizer is discontinued, the duration of its follow-up is now 24 years.

1. Introduction

The effects of nitrogen and phosphorus fertilizers are closely related. Interaction of nitrogen and phosphorus fertilizers is indicated by V.I. Nikitishen and V.I. Lichko [1]. Their studies were carried out on grey forest soil in 9-Polish crop rotation with clover in one of the fields. Phosphorus and nitrogen fertilizers were tested separately and compared to nitrogen-phosphorus on barley cultivation in part of years the positive interaction of the above-mentioned fertilizers was particularly pronounced. Thus, in 1982, at a barley harvest of 18 c/ha in control, nitrogen gave an increase of 5.0 c/ha, phosphorus 2.5, nitrogen-phosphorus fertilizer 10.2. A similar pattern in 1990: 28.6 c/ha was obtained in the control, and the corresponding increases in c/ha were 3.7; –0.3 and 12.7. The average crop gain over 8 years from phosphorus addition to nitrogen was 5 c/ha. The results of the experience were greatly influenced by weather conditions.

The essential role of weather for the action of fertilizers is revealed in the experiments of V.G. Mineev et al. [2]. With a lack of moisture in May and the 1st half of June, during a period of high demand for phosphorus in plants, cereal yields declined dramatically and even increased doses of phosphorus were poorly used. At a reduced temperature at the beginning of the vegetation, the addition of phosphorus to the fertilizer significantly increased the grain harvest.

To regulate the phosphorus nutrition of plants, it is necessary to study phosphorus reserves in the soil. B.S. Nosko [3] for black plants of Ukraine leads to large fluctuations of gross phosphorus reserve in different zones – from 3.8 to 22.9 t/ha in a meter layer and from 0.98–2.17 in an arable layer. In this total reserve 26–62 % is organic phosphates and only 3.3–6.8 % mobile. In order to increase the mobile P₂O₅ content by 10 mg/kg, in his opinion, it is required in different dosage areas within the
P63-222. On average, in 1981–1985 the content of mobile P₂O₅ in the Ukrainian SSR in Polesje was in mg/kg 62, in forest steppe 81 and in steppe zone 73.

A. A. Christenko [4], discussing methods of determining mobile P₂O₅ in the soil, believes that they are quite rigid, because all extracts are acidic, and there is no such acidity in the soil.

Y.I. Kasitsky [5] notes the long-term use – for 7 years the dose of P90, on average per year in this experiment on carbonate blackness Kubani had to be P13. When compared to this follow-up, the effect of the newly introduced phosphorus became gradually higher. The author considers the optimal dose of phosphorus fertilizer to be unstable. It depends on the level of crop yield in a zone. The cost of increasing the P₂O₅ content by 10 mg/kg, according to him, for non-carbonate soils varies within the limits of P50–120.

For leached blackness, S.A. Shafran and N.A. Kirpichnikov [6] call a sufficiently high required amount of phosphorus to increase the P₂O₅ content by 10 mg/kg – P100-110. The authors cite the change in the balance of nutrients in the farming of Russia in two periods of 25 years. In 1976–1990 years the balance on nitrogen and phosphorus was positive and was 20 and 35 kg/ha, on potassium negative (~17). In 1991–2015, due to the decrease in the use of fertilizers for all three food cells, it became negative (~56, –12 and –76 kg/ha).

The concomitant technology of crop cultivation, in particular the soil treatment system, is important for the development of the efficiency of phosphorus input. Scientists of Western Siberia V.E. Sineshlykov and G.I. Tkchenko [7] in 30 years of experience have noticed that the content of phosphorus in the soil during the growing period has increased differently depending on the soil treatment. In case of deep irrevocable treatment it increased by 70 %, against the background of minimum soil treatment by 41 % and in case of ploughing by 22 %. The effect of phosphorus fertilizer (P120 on the rotation of 4-Polish grain crop rotation) on all types of soil treatment was close. Thus, in the 1st field, respectively, three types of soil treatment, wheat yields increased from 29–30 in control to 36 c/ha. In the following field N60 was added, crops in control and against the background of fertilization during plowing 17.8 and 33.4 c/ha, recalibration – 15.5 and 32.9 and at minimum – 15.0 and 31.9. In the last field of crop rotation, N90 was added to phosphorus. In this field crop rotation was respectively c/ha: 11.9 and 27.9; 10.1 and 26.0; 10.1 and 25.8. Yield in control and against the background of fertilization at replacement of ploughing by other types of soil treatment decreased by 1 c/ha on the 1st crop and by 1–2 c/ha in the 2nd and 3rd crops.

For the black soils of the Volga region, optimal doses of fertilizers have been established for different levels of soil availability with mobile phosphorus and nitrate nitrogen content inside each of the phosphorus levels. Recommended doses are given by cultures and subtypes of chernozem [8]. Based on the results of zone experiments, it was found that phosphorus reserves in the soil increase with the transition of zones from north to south and from west to east [9]. Yield of spring wheat on the background of nitrogen with improvement of soil supply with mobile phosphorus increases 1.6–2.6 times [10]. The optimal P₂O₅ content in some studies is clearly overestimated. For example, in the work of D.M. Alekseyeva, it is recommended to achieve a content of up to 100–180 mg/kg for black volumes of different zones of Ukraine [11]. According to Tambovsky NIISH, all three elevated levels of P₅O₅ were taken: 96, 122 and 157 mg/kg. As a result, on the 5th year of experience, the fertilizer N40P40K40 acted moderately, and at the 3rd level did not produce significant crop increases [12].

The Kurgan region stands out among other regions of Russia with low content of mobile phosphorus in the soil of the arable land, but phosphorus fertilizers have been used in very small volumes for the last 20 years. The literature shows that due to the expansion of the use of phosphorus fertilizers in the non-chernozem zone, the proportion of ration with low and very low content of available phosphorus decreased from 51.9 % in 1971 to 21.7 % in 2010 [13].

In the Kurgan region, such a positive effect was also observed. Thus, in the 1st round (1966–1972) in swallow there were 74 % of mobile phosphorus-poor soils and by 1995–1999 due to the application of fertilizers their share decreased to 40 %. Further, by 2016, due to the decrease in the use of fertilizers, especially phosphorus, low and very low reserves of mobile phosphorus in the soil were noted by 62 % of the arable land [14]. In the 1980s, up to 50 kg of NPK was used per hectare in the
Kurgan region, and in 2016–2018 – about 14–15 kg/ha, mainly nitrogen. How much the efficiency of one nitrogen fertilizer on phosphorus-poor soils is reduced is shown by the results of the tests of the Kurgan NIISH, where the effect of adding phosphorus fertilizer to nitrogen in its action and after action is determined.

2. Technique
The research was carried out in the Kurgan Research Institute of Agriculture – a branch of FSBNU UrFANZ UrO RAS – in laboratories of agro-chemistry and agriculture within the framework of the State Task of the Ministry of Science and Higher Education on the direction 142 of the Program of FNI of State Academies of Sciences on the topic "Improve the system of adaptive-landscape for the generation of agricultural Diversification of crop rotations, integrated plant protection, biologization, preservation and enhancement of soil fertility and development of information and analytical complex of computer programs and databases providing innovative management of the farming system».

Stationary experiment on the topic: "Composition of fertilizer and doses of nitrogen in grain-mineral crop rotation" was laid down by the Head in the laboratory of Agro-Chemistry V.I. Volynkin in 1971 year. Place of Experience – Central Experimental Field of Kurgan NIISH (village Garden). From 1993 to 2019 years the contractor of research was O.V. Volynkins. The experience was in two stages. The crop rotation corn-wheat-wheat-oats was first put four-floor grain-cultivating. For 25 years the research was carried out in crop rotation with annual ploughing, and for the next 24 years on permanent wheat on stubble as such agrophon spread in farming of the Kurgan region.

During the laying down of experiment, the selection of doses of fertilizers was based on the results of short-term experiments. For phosphorus background a dose of P40 was taken in the form of double superphosphate, nitrogen was introduced in the form of ammonium nitrate, potassium – potassium chloride, it was used only under corn. The dose of phosphorus was clearly overstated, as subsequent studies have shown. Further experiments with testing different doses of phosphorus proved that it is sufficient to add P15–20 to the rows during planting [8]. However, experience with 25 years of overpricing provided important information. The total amount of phosphorus P1000 was followed for 24 years.

During the years of growing permanent wheat, stubble sowing was carried out by stubble seeder CKH-2.1 with cultivating paw opener. Area of division in m²: total 270 (6 x 45), account 99 (2.2 x 45). The repetition of the variants is three times. Grain crops were taken into account by "Sampo-500" combine with sampling to determine moisture and purity of grain bunker mass. Maize was removed by manual skewing from an area of 14 m², the plants weighed and their humidity determined.

During the years of crop rotation in the experience sown wheat Saratovsky 29 and Saratovsky 39, as well as varieties of selection of Kurgan NIISH Vera, Shadrinsky, later – Omskaya 18. The varieties of oats are Golden Rain and Skakun. Corn hybrids – Moldavian 215CB, Bemo 181CB, Collective 100TB, Vir-42. On the seed of permanent wheat were used varieties of local selection: resistant to stem rust variety Tertsia and since 2012 year Zauralochna.

Soil – leached chernozem, low-power low-humus medium loamy with content of humus in soil layer 0–20 cm 4.5 %, pH2O 6.2–6.4, pHKcl initial 6.2, currently 5.3–5.6 in control and 4.8–5.3 against the background of N60P20. Content of mobile compounds on the background without fertilizers in mg/kg: P2O5 40 (low), K2O 250–350 (high). With the use of P40 in the crop rotation, the P2O5 content increased to 100–110 mg/kg, and in the years of taking into account the following effects of the P1000, this value gradually decreased to 90–80–70 mg/kg. In 21–24 years by 2016–2019 the content of P2O5 became 55–62 mg/kg.

3. Results and discussion
The use in crop rotation of three doses of one nitrogen on low-P2O5 content chernozem indicated weak fertilizer action in these variants (1–2 c/ha, g. e.). At the same time, it was impractical to increase the average nitrogen dose by crop rotation from N25 to N50-75. Even in the wet years, when the growth of wheat, oats and maize from nitrogen increased to 3–4 c/ha of grain units, from nitrogen-phosphorus
fertilizer under such conditions the increase doubled to 6–8 c/ha. In the experiment, nitrogen doses were studied in combinations: N, NP, NPK. The after-effect was studied since 1996 in NPK variants, and in a combination of NP since 2008 year P20 has been added for comparison.

Since exchange potassium in the soil at the test contains 250–350 mg/kg, the action and subsequent action are P40K40 referred to as P40. In addition, potassium was introduced only under corn. This is also justified by the fact that during the years of action of fertilizers in crop rotation grain increases in variants of NP and NPK were very close. In the 2nd stage of the experiment, when examining the after-effect of phosphorus on permanent wheat, one nitrogen fertilizer also gave an increase significantly less than in combination with the background of the after-effect (A) of phosphorus in NA*PK (*A = after-effect) variants (table 1).

The average increase of phosphorus in relation to N20–40–60 backgrounds was 1.4–2.7–3.4 c/ha, respectively. Over 49 years of experience from the action and follow-up of phosphorus, the total yield increase was 3.5–6.3–7.8 c/ha z. e. Due to this, the payback of phosphorus increased 1.8–2.2 times. In both the action and the subsequent action of the phosphorus fertilizer, the association of the phosphorus effect with the nitrogen dose is seen. From the same dose of phosphorus P40 in the crop rotation as the nitrogen dose increased from N25 to N50–75, the increase increased significantly. This pattern was also clear during the years of the follow-up of phosphorus fertilizer. Therefore payment of P40 taking into account a phosphorus after-effect in kg/kg increased with 8.8 at the 1st dose of nitrogen up to 15.8–19.5 at following two.

The level of significant increases due to phosphorus action and follow-up was most dependent on the humidification conditions of the growing period. Nevertheless, the role of the nitrogen dose as well as the degree of mitigation of the follow-up is also evident. Thus, the proportion of significant crop growth over the two periods of experience as the nitrogen dose increased varied from 60 to 76 and 80 % in the years of phosphorus action and from 43 to 70–71 % in the 24 years of its follow-up.

The division of 24 years into groups of 6 years showed the progress of phosphorus follow-up. Such analysis helps to follow the gradual weakening of phosphorus follow-up. The growing conditions and nitrogen dose were of great importance. In the 1st and 2nd six-year increases were higher. Here and hydrothermal coefficient (GTC) for May-August more than one. In the 3rd period three dry years were repeated with a GTCs of 0.3–0.7, so the increases are lower.

**Table 1. The Action and aftereffect of phosphorus fertilizer**

| Years of action and aftereffect P40K40 | Indicator | Dose in crop rotation |
|---------------------------------------|-----------|-----------------------|
|                                       |           | N25 | N50 | N75 |
| Action in crop rotation, 25 years, 1971–1995 | Addition from one nitrogen to control, where yield 15.6 c/ha g. u. | 1.4 | 1.6 | 1.4 |
|                                       | Increase from addition to nitrogen P40K40 | 2.1 | 3.6 | 4.4 |
|                                       | Frequency of significant increase from P40K40, % at years | 60 | 76 | 84 |
|                                       | Payment of phosphorus P40*, kg/kg | 5.3 | 9.0 | 11.0 |
|                                       | Nitrogen Dose on permanent wheat on stubble | N20 | N40 | N60 |
| Action of nitrogen on permanent wheat on stubble and after-effect of R40K40, 24 years, 1996–2019 | Increase from one nitrogen to control, where yield 10.3c/ha g.u. | 2.0 | 2.4 | 2.5 |
|                                       | Increase from addition to nitrogen P40K40 | 1.4 | 2.7 | 3.4 |
|                                       | Frequency of significant increase from P40K40, % at years | 43 | 70 | 70 |
|                                       | The amount of annual increases from the action and after-effect P40*, c/ha g. u. | 3.5 | 6.3 | 7.8 |
|                                       | Payment P40 for 49 years, kg/kg | 8.8 | 15.8 | 19.5 |

Notes:* the effect of fertilizer in the crop rotation in combinations of NP and NPK was close, due to which the payback was calculated to P40.

For the last 6 years, despite the GTCs of 0.98, the harvest increase of permanent wheat on an eddih has become even lower, indicating a weakening of phosphorus after-effect (table 2). Conclusion is confirmed by gradual decline of P05 content in soil layer 0–20 cm against this background from initial level of 110 mg/kg to 90–80–70–62. It can be observed that in the last two six years, the previously manifested interaction of phosphorus with nitrogen dose has become less clear.
It is more reasonable to conclude on the time frame for the necessary resumption of phosphorus use by more than one experiment. In parallel studies on phosphorus doses, optimal doses of phosphorus for application to wheat-P15–20 have been established. The after-effect of phosphorus is still evident, but it is obvious that this effect is weakened.

It is more reasonable to conclude on the time frame for the necessary resumption of phosphorus use by more than one experiment. In parallel studies on phosphorus doses, optimal doses of phosphorus for application to wheat-P15–20 have been established. In these experiments there are variants, according to which the terms of attenuation of the following action of previously applied fertilizers are determined. In experiments in 1971 in four-floor grain-fallow crop rotation followed the after-effect of three sums of phosphorus P240–360–720, added in half in two years at 1971 and 1975. In one of the bookmarks of the experience, the attenuation of the P240 of the 1st dose did not occur in the 27th year [16].

During this time, the average amount of phosphorus per year was P9. At the same average value, the P9 of P360 ceased to be felt on the 39th year of experience and the P720 – on the 45th with an average annual amount P16.

Another tab of this crop rotation has similar results. Post-action attenuation P240–360–720 observed in the 34–34–44th years of experience with average annual amounts of P7–10–16 phosphorus. Excluding years with fallow in terms of the number of crops in crop rotation, the duration of follow-up for P240–360–720 at two tabs of experiment was 20–25; 25–29 and 33–34. According to several experiments, the moment when it is necessary to use new portions of phosphorus fertilizer is more reliable. It turned out that if the average annual amount of phosphorus is reduced to P15–17, the conditions of phosphorus feeding of wheat should be improved by resuming the annual introduction of phosphorus in doses of P15–20 locally.

It is important to observe the content of mobile P2O5 in the soil layer 0–20 cm on different agrophones. The data in the sternal wheat test for 11 years showed that in the control this value was

### Table 2. The increase from nitrogen in combination with the aftereffect of phosphorus and from the aftereffect of phosphorus on permanent wheat in sixth anniversary, c/ha

| Years | 6 years – 1996–2001 | 6 years – 2002–2007 | 6 years – 2008–2013 | 6 years – 2014–2019 |
|-------|---------------------|---------------------|---------------------|---------------------|
| GTK₅₈ | 1.13                | 1.04                | 0.71                | 0.98                |
| Crop in control, c/ha | 8.6 | 10.7 | 9.5 | 10.0 |
| N*A | **AP** | N | AP | N | AP | N | AP |
| N20 | 4.6 | 1.7 | 3.4 | 1.0 | 3.1 | 1.6 | 2.7 | 1.5 |
| N40 | 7.1 | 3.0 | 6.3 | 3.2 | 4.2 | 2.6 | 3.9 | 2.0 |
| N60 | 7.9 | 4.6 | 7.6 | 4.8 | 4.1 | 2.8 | 4.0 | 1.5 |
| HCP₅₀ | 1.9–4.2 | 1.6 | 1.5–2.8 | 1.3 | 1.2–3.2 | 1.1 | 1.3–3.2 | 0.9 |

* A – aftereffect. **Including.

In order to determine the average annual amount of phosphorus applied at the moment of the subsequent effect weakening, the sum of its introduction is divided by the number of years passed by this moment. In the experience discussed in this article dividing the P1000 by 49 years of experience is on average P20 per year.

Mitigation of the after-effect is also apparent when comparing these variants using a nitrogen-phosphorus fertilizer, not shown in the tables. Briefly, in the transition in 1996 from 25 years of crop rotation to permanent wheat, the first 12 years of phosphorus after-effect were observed in combinations of NP and NPK. With respect to unilateral nitrogen use, it was significant and on average equal. Since 2008, against the background of the N20–60P20 variants was 1–2 c/ha higher. Since 2017 year, the excess of phosphorus action over after-effect by 1–2 c/ha has also been evident in P20 with a dose N20.
maintained at the average level in mg/kg 48 with variations in years from 39 to 64, with addition of nitrogen alone the discussed indicator decreased to 41 with variation within 35–50, against the background of the follow-up of phosphorus fertilizer – 60 with variations from 48 to 67. When nitrogen and phosphorus were added together, the mobile P₂O₅ content was 80 mg/kg, ranging from 73 to 90.

On the basis of the results shown in the article, as well as parallel experiments with phosphorus fertilizers V.I. Volynkin adjusted the Chirikov scale on the soil layer 0–20 cm for local conditions. In mg/kg the levels of mobile phosphorus presence are as follows: very low – up to 20, low – 20–45, medium – 46–60, increased – 61–80 and high – more than 80. On the background of P₂O₅ content 60–80 mg/kg for the permanent sowing of wheat in the central zone of the Kurgan region, the optimal nitrogen dose is in the range N40–50, since an additional increase in grain increase with an increase in the dose from N40 to N60 on the phosphorus background was observed only in wet years.

4. Conclusion

The studies showed the close interaction of phosphorus fertilizer with the dose of nitrogen, which was pronounced both in the 1st stage of the experience in crop rotation and in the 2nd period – in the more rigid technology of cultivation of permanent wheat along the sternum. During both the of-action and after-effect, the same amount of phosphorus P1000 was used more fully with increasing nitrogen dose. Duration of after-effect of previously applied superphosphate depends on total dose of its introduction.

Considering the results of parallel experiment with grain-fallow crop rotation for the compared amounts of phosphorus added P240–360–720 the duration of their after-effect in two experiment tabs was 27-34 years in the variant P240, 34–39 – P360 and 44–45 – P720. Excluding years with fallow by the number of crops in the crop rotation, the duration of after-effect for P240–360–720 equaled 20–25; 25–29 and 33–34.

It turned out that when reducing to P15–17 the amount of previously introduced fertilizer, it is necessary to improve conditions of phosphorus nutrition of plants. In the experience with permanent wheat, the P1000’s after-effect for 24 years was still evident.

A reliable reference point in the application of phosphorus fertilizer is the content of mobile P₂O₅ in the soil layer 0–20 cm. The correction of the Chirikov scale for local conditions specifies the conditions for the necessary use of superphosphate or ammonophos. When reducing its content from 90–70 mg/kg to 50, it is necessary to use phosphorus fertilizer again.

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