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ЭФФЕКТИВНОСТЬ УДОБРЕНИЙ НА ПОСЕВАХ ПШЕНИЦЫ В СЕВЕРО-ЗАПАДНОЙ ЗОНЕ КУРГАНСКОЙ ОБЛАСТИ

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Представлены результаты длительного (1968–2021 гг.) эксперимента по применению удобрений за 10-ю и 11-ю ротации зернопарового севооборота на опытном поле Курганской области. Севооборот включал пар и три пшеницы. Эффективность удобрения различалась в зависимости от комбинации элементов питания, места пшеницы в севообороте и условий увлажнения периода вегетации. На тяжелосуглинистом выщелоченном черноземе опытного поля в этих ротациях проявилось умеренное действие фосфорного удобрения и высокое – азотного на посевах, удаленных от пара. Сочетание азотного и фосфорного удобрений давало более высокую прибавку урожайности. Азотное удобрение оказывало положительное влияние и на качество пшеницы, повышая содержание клейковины и массу 1000 зерен. С увеличением накопления клейковины в зерне пшеницы на фоне азотного удобрения повышалась повторяемость соответствия качества пшеницы требованиям к 3-му классу зерна. Проявилось действие удобрений и длительности их применения на агрохимические свойства почвы. Заметнее с применением удобрений повышалось содержание подвижных питательных веществ в почве, гумуса, общего содержания азота и фосфора, но при этом снизилось значение $pH_{сол}$. Высокая экономическая эффективность относилась к азотному удобрению, вносимому на второй и третьей пшенице после пара с окупаемостью 1 кг азота 12–19 кг зерна. Действие фосфорного удобрения было умеренным, поскольку содержание подвижного P_2O_5 в пахотном слое почвы оставалось высоким. Сильнее применение аммофоса влияло на урожайность пшеницы при хорошей обеспеченности растений азотом на первом посеве по пару.

Ключевые слова: северо-западная зона Курганской области, выщелоченный чернозем, состав удобрения, зернопаровой севооборот, урожайность пшеницы, качество зерна

FERTILIZER EFFICIENCY ON WHEAT CROPS IN THE NORTHWESTERN ZONE OF THE KURGAN REGION

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The results of long-term (1968-2021) experiment on the use of fertilizers for the 10th and 11th rotations of grain and fallow crop rotation in the experimental field of the Kurgan region are presented. Crop rotation included fallow and three crops of wheat. Fertilizer efficiency varied depending on the combination of the nutrients, the place of wheat in the rotation, and the moisture conditions of the growing season. Moderate effect of phosphorus fertilizer and high effect of nitrogen fertilizer on heavy loamy leached chernozem of the experimental field in these rotations was observed on the crops distant from the fallow. The combination of nitrogen and phosphorus fertilizers gave a higher yield increase. Nitrogen fertilizer also had a positive effect on the quality of wheat, increasing the gluten content and the thousand-kernel weight. With the increase of gluten accumulation in wheat grain against the background of nitrogen fertilizer, the repeatability of wheat quality compliance with the requirements for the 3rd class of grain increased. The effect of fertilizers and the duration of their application on the agrochemical properties of soil became visible. The content of mobile nutrients, humus, total nitrogen and phosphorus increased more noticeably with the use of fertilizers, but the pH_{salt} value decreased. High economic efficiency related to nitrogen fertilizer applied on the second and third wheat after fallow with a payback of 1 kg of nitrogen 12-19 kg of grain. The effect of phosphorus fertilizer was moderate, since the content of mobile P_2O_5 in the topsoil remained high. The use of ammophos had a stronger effect on the yield of wheat when the plants were well supplied with nitrogen in the first fallow crops.

Keywords: northwestern zone of the Kurgan region, leached chernozem, fertilizer composition, grain fallow crop rotation, wheat yield, grain quality

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INTROUCTION

Spring soft wheat is the main crop in the agriculture of the Kurgan region. Most of its plantings in the region are located on leached chernozem (black earth) and ordinary solonized soils. In chernozem soils, unlike other soil types, more nitrates accumulate, providing a favorable nitrogen regime for spring wheat. Among the two subtypes of chernozem, more nitrates form in ordinary solonized compared to the leached one.

With prolonged use of nitrogen fertilizers, not only does the amount of mobile nitrogen compounds in the soil increase, but the content of total nitrogen also changes, increasing by 4-16% [1]. The importance of clarifying the optimal doses of nitrogen fertilizer is justified by eliminating or reducing nitrogen losses through leaching into soil layers below the root-inhabited horizon. The action of nitrogen and phosphorus is closely linked. Adequate phosphorus supply in plants enhances the positive effect of nitrogen fertilizer [2–4].

In the Ural region, 50-60% of the soils in arable lands have a low content of mobile phosphorus [5, 6], necessitating the combined application of nitrogen and phosphorus fertilizers in such conditions. There is a sufficient amount of mobile potassium in the soils of the Kurgan region, but against the background of systematic application of nitrogen and phosphorus, the addition of potassium fertilizer brings a small additional increase in crop yields, especially in tilled crops. The efficiency of even optimal doses of fertilizers largely varies depending on the prevailing meteorological conditions[1–3] [7]. As noted by O.V. Melnikov and T.M. Mazhu-

[1]*Fatykhov I.Sh., Kolesnikova V.G., Korepanova E.V., Islamova C.M.* Environmental problems in agronomy // Modern agroindustrial complex - effective technologies: proceedings of the international scientific-practical conference dedicated to the 90th anniversary of V.M. Makarova (December 11-14, 2018). Izhevsk: Izhevsk State Agricultural Academy, 2019, Vol. 1, pp. 445-447.

[2]*Volkova L.V.* Yield of spring soft wheat and its relationship with the elements of productivity in different meteorological years // Agricultural Science Euro-North-East, 2016, No. 6, pp. 9-15.

[3]*Melnikov O.V., Mazhugo T.M.* Yield and grain quality of spring soft wheat varieties depending on growing conditions // Bulletin of the Kursk State Agricultural Academy, 2015, No 8, pp. 123-125.

go (see footnote 3), "crop yield is a result of a compromise between plant productivity and its resilience to adverse environmental conditions." By shifting the sowing date, there is an opportunity to adjust crop yields considering the distribution of precipitation and variability of other weather indicators based on long-term climatic data. There are instances when, under conditions of reduced solar activity, early sowing dates for wheat were advantageous, and during increased solar activity, late sowing[4] was beneficial.

Wheat grain yield and quality also vary in relation to other agronomic elements: selection of intensive type varieties [8], sowing of valuable or strong wheat [9], the place in the crop rotation, and the type of soil treatment. Regarding the influence on wheat yield, no-till and traditional farming converge in the steppe zones of many regions[5]. Fertilizers increase the amount of primary production and the total sum of plant residues, gradually increasing the humus content[6] due to this. Under the influence of fertilizers, the content of mobile nutrients in the soil increases, significantly improving plant nutrition conditions[7] [10].

MATERIAL AND METHODS

A long-term experiment was conducted at the experimental field of the Kurgan Agricultural Research Institute in the village of Maltsevo (Kurgan region) in three setups starting from 1968, 1969, and 1971. Initially, this department was known as the Shadrinsk Experimental Station, led by T.S. Maltsev for 35 years, followed by V.B. Sobyannin. Since 2010, the station has been annexed to the Kurgan Agricultural Research Institute, operating as the T.S. Maltsev Laboratory. For most of the years, the experiments were conducted by B.N. Sobyanin, P.Z. Sobyanina, V.B. Sobyanin, and O.B. Sobyanina, and from 2011 onwards by N.V. Ionina. From 2011, A.N. Kopylov led the research. The analysis of this experiment was performed by the authors of this article.

The experimental data studying fertilizers were published in 2019 in the "Agricultural chemistry" journal, where a summary of the results of the experiments with fertilizers from 1968 to 2017 was made [11]. The present article discusses the data obtained during the 10th and 11th rotations (2014-2021).

The soil type is heavy loamy leached chernozem. The crop rotation is expanded both spatially and temporally, meaning records were kept for the first to third wheat after fallow in three experimental fields. The agrochemical properties of the soil in the initial years of the experiment were as follows: humus across the three plots – 6.18-6.48-6.33%, total nitrogen – 0.308-0.314-0.339%, gross phosphorus – 0.145-0.118-0.153%, pH_{KCl} – 5.8-6.2, mobile P_2O_5 and K_2O according to Chirikov – 54-61 and 159-196 mg/kg of soil. The content of mobile phosphorus in the control began to increase from the 7th rotation due to systematic soil cultivation across plots, although each plot had a protective zone of 2.11 m on both sides. In the control during the 4th rotation, this indicator was maintained at the initial level of 54 mg/kg; in the 7th rotation (1999-2005) it equaled 74 mg/kg, and by 2011, it reached 93 mg/kg. Even against the backdrop of nitrogen-potassium fertilization, this value for the mentioned rotations changed from 43 to 60 mg/kg. Consequently, the usually well-manifested effect of fertilizers in the PK combination on wheat sowing after fallow, ranging from 2 to 5 centners of grain per hectare, was observed only in the 1st to 5th rotations. In the 6th and 8th rotations, the yield increase from PK on the first wheat decreased to 1.1-1.3 c/ha,

[4]*Vasilevsky V.D.* Response of soft spring wheat of different ripeness groups to sowing time in the southern forest-steppe of Western Siberia depending on solar // Modern agro-industrial complex - effective technologies: materials of the international scientific-practical conference dedicated to the 90th anniversary of V.M. Makarova (December 11-14, 2018). Izhevsk: Izhevsk State Agricultural Academy, 2019, Vol. 1, pp. 90-94.

[5]*Pasynkov A.V., Pasynkova E.N.* Method of tentative determination of crude gluten content in wheat grain// Modern agro-industrial complex - effective technologies: materials of the international scientific and practical conference dedicated to the 90th anniversary of V.M. Makarova (December 11-14, 2018). Izhevsk: Izhevsk State Agricultural Academy, 2019, Vol. 1, pp. 348-352.

[6]*Karpukhin M.Y., Grinets L.V.* Resource-saving technologies in the steppe zone of Northern Kazakhstan and their advantages and problems // Agrarian Bulletin of the Urals, 2016, No. 4, (146), pp. 13-17.

[7]*Sharkov I.N.* Humus and soil fertility management // Agrarian sector, 2016, No. 4 (38), pp. 126-135.

and in the 7th rotation, there was no addition. It was decided to suspend the use of phosphorus fertilizer for 8 years (2003-2010). After the hiatus, from 2011, phosphorus was applied locally with the SZ-3.6 seeder before sowing, unlike the previously used scattered uniform method. With localized application of phosphorus fertilizer in the 10th rotation, the yield increase from P_{20} on wheat after fallow amounted to 2.6 c/ha.

In the initial years, the crop rotation was five-field: fallow, two wheat crops, corn (oats since 1997), and wheat. From 2011, it became a four-field rotation: fallow and three wheat crops. The main soil treatment in the initial rotations was plowing, and from 2011, it became superficial. The plot area was 221 m² (34 × 6.5), with a registration plot of 68.4 m² (30 × 2.28), and the repetition of the variants was done four times.

The doses of all the nutrients varied. The tables show their average amount for 53 years of the experiment. The action of fertilizers was studied using the scheme: control (without fertilization), PK, NK, NPK. Nitrogen was applied in the form of ammonium nitrate, and phosphorus in the form of superphosphate. Potassium chloride was used in the experiment for 32 years (up to 2000). Afterwards, potassium had only a slight residual effect, as the K_2O content in the soil of the plot was high - 172-200 mg/kg.

In the 10th and 11th rotations, wheat varieties “Iset 45” and “Raduga” were sown. Sowing was carried out using the “Kuzbass” sowing complex to a depth of 6 cm at a rate of 4 million germinated grains per hectare. Sowing was done between May 25 and June 3, as the heavy loamy soil reached physical maturity and the air temperature rose to 15-17°C. The soil was rolled on the day of the sowing.

For plant care, a tank mixture of Explorer was used, l/ha: Oprichnik (0.4), Toptun (0.6), and the insecticide Aivengo (0.1). In the years of stem rust spread, the crop was sprayed with the fungicide Falcon. The harvest was collected directly using the Sampo-500 combine with a sample of grain taken to account for bunker mass moisture and impurity content.

In the grain-fallow crop rotation with plowing, droughts occurred 10 times over 24-26 years of wheat plantings. Over 7-8 years of grain-fallow crop rotation with surface treatment, it occurred once in 2021. The total precipitation for May-August during the analyzed period (2014-2021) averaged 192 mm, with fluctuations between 36 and 281 mm.

The purpose of the research was to continue studying the effects of fertilizer composition under changed agronomic and agrochemical conditions of wheat cultivation.

RESULTS AND DISCUSSION

Effect of fertilizers on wheat yield. The weather conditions in the 10th and 11th rotations for six sowings of the first wheat after fallow favored the formation of high yields five times. The exception was 2021 with a severe drought that lasted in May, June, and early July, which led to a decline in the yield of both unfertilized and fertilized wheat, previously ranging from 26-35 to 8-9 centners per hectare, respectively. Nitrogen was not applied to the first wheat, but its use in the following crop rotation fields had an aftereffect, which was positive only in 2019, explained by the heat deficiency in the previous year during fallow and also in May and June 2019. On the fertilized wheat after fallow, significant effects on yield were observed with the phosphorus-potassium and complete mineral fertilizer variants, with yield increases of 1.6 and 2.0 centners per hectare (see Table 1). The phosphorus action was low due to the aforementioned gradual increase in mobile P_2O_5 (according to Chirikov) on the experimental site. By 2011, it reached 93 mg/kg in the control, 62 mg/kg in the $N_{54}K_{16}$ variant, and 108 and 118 mg/kg in the phosphorus-fertilized backgrounds.

The yield of the second wheat after fallow decreased to 10-13 centners per hectare in some years, averaging 14.8 centners per hectare over 5 years of the 10th and 11th rotations. Yield improvement in this crop rotation field was ensured by nitrogen fertilizer and its combination with phosphorus, where the yield reached the level of the first wheat after fallow. In the final crop rotation field due to the drought of 2021, the lowest grain harvest was achieved - 5-12 centners per hectare. On average, over 5 years in the control, 13.4 centners per hectare were harvested. Nitrogen fertilizer had the strongest effect on yield in this field. However, increased weed infestation at the end of the rotation, even with fertilization, limited grain yield to 21.8 centners per hectare on the $N_{54}K_{16}$ background and 23.4 centners per hectare with the application of full mineral fertilizer (see Table 1).

Comparing the effectiveness of fertilizers over two experimental periods with different soil treatments showed that the pattern of the effect of different fertilizer compositions was consistent. For example, in the first wheat after fallow in the variants 1-4 (see variant names in Table 1), the yield during plowing was 21.0; 23.5; 21.8, and 23.0 c/ha, during the years with superficial treatment, it was 25.4; 27.4; 26.1, and 28.0 c/ha. For the second wheat, the yields were 11.5; 11.8; 16.1; 17.7 and 14.2; 16.2; 24.9; 27.8 c/ha, respectively. The yield and its increase were lower during the plowing years, as the first experiment period had more drought-affected years.

Effect of fertilizers on grain quality. The fertilizer had a positive effect on the quality of wheat grain. Without fertilization, in the conditions of the northwestern zone, it is not always possible to simultaneously increase both the yield of wheat and the protein content in the grain. Thus, in the 10th and 11th rotations, even for the first wheat after fallow, the grain quality met the requirements for the 3rd class in terms of gluten content only in 50% of the years. The nitrogen-potassium background in the first sowing after fallow increased the repeatability of the 3rd class to 67% of years. In the second and third sowings after fallow, without fertilization, the gluten content in wheat grain was significantly lower, but with the addition of nitrogen,

Табл. 1. Урожайность первой – третьей пшеницы после пара в 10–11-й ротациях, ц/га

Table 1. Yield of the first - third wheat after fallow in 10-11th rotations, c/ha

Year	Option				
	Control	$P_{27}K_{16}$	$A*N_{54}K_{16}$	$AN_{54}P_{27}K_{16}$	LSD_{05}, c/ha
First wheat after fallow					
2014	31,3	33,2	30,0	34,0	0,9
2015	32,9	34,8	30,2	34,8	2,2
2017	30,5	32,2	29,9	32,0	1,3
2018	28,0	30,0	28,4	30,3	1,1
2019	26,5	27,0	28,2	30,3	0,7
2021	8,1	9,4	8,0	8,1	1,5
Average	26,2	27,8	25,8	28,2	
+– to the control	–	1,6	–0,4	2,0	
Second wheat after fallow					
2015	20,1	23,8	31,4	32,4	2,1
2016	19,5	21,0	31,0	36,2	3,0
2018	10,4	10,7	15,9	17,8	2,7
2019	13,0	15,5	28,3	33,6	3,1
2020	11,0	11,1	18,9	19,3	4,2
Average	14,8	16,4	25,1	27,9	
+– to the control	–	1,6	10,3	13,1	
Third wheat after fallow					
2016	18,6	20,0	29,8	28,7	2,7
2017	16,9	18,0	27,6	29,6	2,5
2018	14,5	16,1	22,1	23,9	2,1
2020	11,6	11,0	19,3	22,2	2,9
2021	5,7	5,6	10,4	12,5	1,7
Average	13,4	14,1	21,8	23,4	
+– to the control	–	0,7	8,4	10,0	

Note. Nitrogen fertilizers were not applied to the first wheat, but their application in subsequent fields of the crop rotation had an aftereffect. Here and in Tables 2 and 6 A - aftereffect.

it increased by 5–11% in absolute terms. Phosphorus-potassium fertilizer slightly changed the gluten content in the grain (see Table 2).

For the unfertilized third wheat, only 2 out of 5 years marked a gluten level of no less than 23%. Against the background of fertilization, including nitrogen, a significant increase in gluten was detected for three years. The average increase compared to the control was 5-6% in absolute terms. The decrease in gluten content in the grain in 2016 and 2017 was due to achieving a sufficiently high yield. The plants' affliction with stem rust also mattered.

Another important quality trait of wheat is grain plumpness (weight of 1000 grains). Under the conditions of the experiment, this indicator varied by year and option from 24.4 to 42.7 g. The use of fertilizers had a positive effect on the weight of 1000 grains mainly in options with nitrogen, especially against the background of a complete mineral fertilizer $N_{54}P_{27}K_{16}$, by which the value increased by 2-4-6 g for the second and third wheat after fallow.

The impact of fertilizers on the agrochemical properties of the soil. The effect of fertilizers on many soil properties occurs slowly and gradually, so we should refer to the initial soil analysis results in the 1st rotation and compare them with the data obtained 30 years later in the 6th rotation. Even for such slowly changing soil properties as humus, the total of absorbed bases, gross nitrogen, and phosphorus content, the fertilizers had an impact. Over 30 years, the amount of mobile phosphorus increased noticeably, and soil acidity also increased (see Table 3).

The relationship between the variability of wheat yield for the 1st to 6th rotations and the humus content in each subsequent rotation is of interest. The sum of plant residues is directly determined by the yield level of crop rotation crops; we considered wheat yield. Straw has been left in the field since 1978 (with the introduction of

Табл. 2. Содержание клейковины в зерне первой – третьей пшеницы после пара в 10–11-й ротациях, %

Table 2. Gluten content in the grain of the first - third wheat after fallow in the 10th-11th rotations, %

Option	Year						Average	3rd grain class, % of years
	2014	2015	2017	2018	2019	2021		
First wheat after fallow								
Control	26,7	18,7	20,7	24,3	17,9	29,1	22,9	50
$P_{27}K_{16}$	27,0	19,5	20,0	24,5	17,4	28,9	22,9	50
$AN_{54}K_{16}$	28,0	19,0	23,0	23,0	19,6	28,8	23,6	67
$AN_{54}P_{27}K_{16}$	28,0	19,0	24,5	22,2	20,6	29,0	23,9	50
LSD_{05}, %							1,44	
Second wheat after fallow								
Option	2015	2016	2018	2019	2020			
Control	13,2	15,2	24,5	19,9	22,6		19,1	40
$P_{27}K_{16}$	14,0	14,0	24,5	22,3	20,0		19,0	20
$N_{54}K_{16}$	16,0	16,5	30,0	31,4	27,3		24,2	60
$N_{54}P_{27}K_{16}$	14,0	16,5	32,0	30,0	30,6		24,6	60
LSD_{05}, %							3,32	
Third wheat after fallow								
Option	2016	2017	2018	2020	2021			
Control	15,5	21,5	26,1	21,0	28,3		22,5	40
$P_{27}K_{16}$	16,0	22,0	29,4	23,2	26,0		23,3	60
$N_{54}K_{16}$	17,0	21,5	41,0	34,2	29,0		28,5	60
$N_{54}P_{27}K_{16}$	17,0	22,0	36,4	31,3	32,0		27,7	60
LSD_{05}, %							4,63	

the Sampo-500 combine). Soil analysis was conducted at the beginning of the rotation for each experimental setup. In this complex relationship, there isn't a complete match, but in most comparisons, an increase in humus content was found after the rotations with higher yields (see Table 4).

The calculations are made on average for three experimental setups. It is clear that after achieving yields within 18-22 tons/ha in the 1st rotation, the humus content in the 2nd was higher than in the 3rd after 16-20 tons/ha in the 2nd. The humus content increased even more significantly in the 4th rotation due to a larger amount of plant residues at a yield of 17-27 tons/ha. A decrease in productivity in the 4th rotation to 12-18 tons/ha led to a reduction in humus in the 5th rotation to 5.63-6.61% (see Table 4).

Even without considering the expected plant residues in the forecrop wheat field based on

Табл. 3. Изменение агрохимических показателей выщелоченного чернозема за 30 лет опыта в с. Мальцево (среднее по трем закладкам)

Table 3. Changes in agrochemical indicators of leached chernozem over 30 years of experience in the village of Maltsevo (average of three establishments)

Option	Humus, %	pH_{wat}	pH_{KCl}	Total nitrogen, %	Total phosphorus, %	Ca + Mg, mg-eq./100 g	P_2O_5, mg/100 g	K_2O, mg/100 g
1st rotation								
$N_0P_0K_0$	6,30	6,6	6,1	0,288	0,134	36,4	0,175	13,8
PK	6,57	6,6	6,0	0,292	0,135	36,4	0,177	13,8
NK	6,66	6,5	6,2	0,321	0,138	37,2	0,176	13,3
NPK	6,68	6,5	6,2	0,321	0,139	37,2	0,176	13,3
After 30 years, 6th rotation								
$N_0P_0K_0$	6,43	6,3	5,2	0,290	0,148	38,4	0,645	13,6
PK	7,28	6,2	5,2	0,346	0,170	39,0	1,456	13,9
NK	7,41	6,2	5,2	0,321	0,161	38,6	0,469	14,0
NPK	7,34	6,2	5,2	0,310	0,179	37,2	1,954	13,0

Note. P_2O_5 - according to Franceson, K_2O - according to Brovkina.

Табл. 4. Влияние колебаний продуктивности пшеницы по ротациям севооборота на изменчивость содержания гумуса в слое почвы 0–20 см

Table 4. The effect of fluctuations in wheat productivity by rotation of crop rotation on the variability of humus content in the soil layer 0-20 cm

Option	Rotation, years					
	1st	2nd	3rd	4th	5th	6th
	1968–1975	1974–1980	1979–1985	1984–1990	1989–1995	1994–2000
Wheat yield, c/ha						
Control	18,6	16,0	17,4	12,9	10,3	13,1
PK	19,6	17,2	18,7	14,2	12,1	13,9
NK	21,2	17,4	24,5	16,2	14,1	17,6
NPK	22,6	20,0	27,6	18,0	16,0	19,0
Humus content, %						
Option	2nd 1974–1977	3rd 1979–1981	4th 1984–1987	5th 1989–1992	6th 1994–1997	9th 2011
Control	6,72	6,24	6,55	5,63	6,43	6,90
PK	7,21	6,81	7,39	6,43	7,28	7,10
NK	7,12	6,72	7,84	6,61	7,41	7,10
NPK	6,86	6,85	7,39	6,30	7,34	7,33

the yield, the discussed relationship is evident. Since 1997, the yield of oats, which averaged 9-22-25 tons/ha in the 6th-8th rotations based on three experimental setups, has been significant for the sum of residues, so elevated values were noted in the 9th rotation in 2011.

The experiment extensively studied the content of mobile P_2O_5 in the soil using the Francesson method, which changed both over time and under the influence of fertilizers. These data are presented in Table 5 for the 1968 setup. The materials obtained annually for 37 years are divided into seven periods, with an average calculated for 2 years.

Annual application of phosphate fertilizer significantly enriched the soil with mobile phosphorus. Its content also increased in the variants without phosphorus, explained by the transfer of soil from one area to the adjacent ones during processing at the experimental site across the variants. Until 2011, autumn plowing, spring harrowing, and pre-sowing cultivation were carried out.

Economic efficiency of different fertilizer compositions. Are fertilizers profitable in the new agrotechnical and agrochemical conditions of the experiment? The payback of nitrogen and phosphorus should be at least 8-10 kg/kg. According to Table 6, phosphate feed efficiency with grain additions is below the norm. In contrast, the nitrogen payback significantly exceeded it and equaled 16-19 kg/kg for the second wheat after fallow and 12-15 for the third.

Calculations of payback in rubles also showed that the most profitable was the use of nitrogen fertilizer. In 2020, 2021, the price of 1 centner of nitrate was 1800 rubles, 3rd class grain 1600 rubles/ centner; the dose of N_{54} in the form of ammonium nitrate - 2772 rubles/ha, with the cost of application and harvesting of additional yield 4822 rubles/ha. Addition from nitrogen 8-10 c/ha at a price adjusted on the basis of repeatability of obtaining 3rd class grain costs 12,480-15,600 rubles/ha, i.e. high profit is obvious.

Regarding ammophos, it is important to decide whether to introduce it under wheat after fallow in the conditions that have developed in the experiment: a high content of mobile P_2O_5 and a small average grain increment - 1.6 c/ha. Currently, 1 centner of ammophos costs 5400-5700 rubles, the P_{27} dose is 2916-3078 rubles/ha, with costs for the application and harvesting of grain increment - 3966-4063 rubles/ha. An increase of 1.6 c/ha with a repeatability of 3rd class grain for 50% of the years is worth 2480 rubles/ha. Expenses for the purchase and application of fertilizer are not covered by the increase in the yield value. The best increment from phosphorus added to nitrogen (2.8 c/ha) is valued at 4368 rubles/ha, but this slightly exceeds the cost of ammophos. Consequently, as long as the elevated content of mobile phosphorus in the soil is maintained, the grain and fallow crop rotation can be satisfied with the use of only nitrogen fertilizers. When the content of mobile phosphorus decreases to 40-60 mg/kg of soil, it is necessary to apply expensive ammophos.

When considering the effects of phosphorus on the first wheat, a significant increment was noted: 11 times in 26 years of plowing (2-3 c/ha) and 6 times in the following 7 years with surface soil treatment (2-7 c/ha). When adding phosphorus to nitrogen on the second and third sowings after fallow, increments of 2-7 c/ha were noted 8 times during plowing years. After an 8-year

Табл. 5. Изменчивость содержания P_2O_5 по Францесону в слое почвы 0–20 см в течение 37 лет опыта, мг/100 г

Table 5. Variability of the content of P_2O_5 according to Franceson in the soil layer of 0-20 cm during 37 years of experience, mg/100 g

Option	Years						
	1969, 1970	1974, 1975	1979, 1980	1987, 1988	1993, 1994	1998, 1999	2003, 2005
Control	0,136	0,151	0,270	0,368	0,482	0,672	0,545
PK	0,170	0,314	0,492	0,815	1,137	1,703	1,186
NK	0,164	0,165	0,244	0,275	0,272	0,442	0,485
NPK	0,222	0,314	0,634	0,722	1,446	1,641	1,396
LSD_{05}				0,27			

Табл. 6. Окупаемость азота и фосфора по посевам яровой пшеницы в зернопаровом севообороте в 10-й и 11-й ротациях, кг/кг

Table 6. Nitrogen and phosphorus profitableness for spring wheat in the grain and fallow crop rotation in the 10th and 11th rotations, kg/kg

Wheat after fallow					
first		second		third	
Control	–	Control	–	Control	–
P_{27}AK	5,9	P_{27}AK	6,7	P_{27}AK	2,6
AN_{54}AK	–	N_{54}AK	19,4	N_{54}AK	15,6
$AN_{54}P_{27}$AK	2,4	$N_{54}P_{27}$AK	16,4	$N_{54}P_{27}$AK	12,3

break in the application of phosphorus, when it was introduced during the years of surface soil treatment, a yield increase of 2-5 tons/ha was obtained on the second crop 4 times in 7 years and 5 times in 8 years - 2-3 c/ha on the third. Considering the manifestation of higher increments than the average effects, you can switch to the application of a smaller dose (P_{15}) and introduce it during sowing, which will increase the increment and payback of phosphorus.

CONCLUSION

Studying the effectiveness of different fertilizer compositions on wheat sowing in a grain-fallow rotation in the 10th and 11th rotations on heavy loamy leached chernozem, rich in mobile phosphorus, in the northwestern zone of the Kurgan region showed that the primary factor in improving plant nutrition was the application of nitrogen fertilizer. The same trend characterized the action of different compositions earlier, on average, in the 1st-9th rotations of the grain-fallow rotation during the years of plowing. In the 10th and 11th rotations, nitrogen provided high increments on wheat sowings, distant from fallow – 8-10 and 10-13 c/ha in combination with phosphorus, respectively. The average effect of nitrogen for the 1st-9th rotations is lower - 6-7 c/ha, possibly due to the improvement of nutrition conditions directly from plowing, as well as the influence of frequent droughts. The yield increment from the application of phosphorus in the first sowing after fallow was low - 1.6 c/ha, but in the initial period of the experiment, while the soil was poorer in phosphorus, in some years there was a very high effect of phosphorus fertilizer with obtaining increments of wheat after fallow up to 7 c/ha. Later, both with plowing and surface soil treatment, the yield increment from phosphorus was limited on average to 2 c/ha, which meant a low payback of expensive phosphorus fertilizer. Considering the higher effects obtained from phosphorus in some years, you can switch to the application of a smaller dose (P_{15}) and introduce it during sowing. This can increase the increment and ensure a decent payback of phosphorus fertilizer. In the following fields, an increment from phosphorus was more often noted only against the background of nitrogen fertilizer.

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