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ПИТАТЕЛЬНЫЙ РЕЖИМ ОРОШАЕМЫХ ЛУГОВО-ЧЕРНОЗЕМНЫХ ПОЧВ ПРИ ДЛИТЕЛЬНОМ ИНТЕНСИВНОМ ИСПОЛЬЗОВАНИИ

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Изучены закономерности фосфорного и калийного режима почв при совершенствовании агротехнологий орошаемого земледелия. Длительные исследования проходили в экспериментальном зернотравяном севообороте на орошаемой лугово-черноземной почве. Опытный участок расположен в южной лесостепи Омской области. Интенсивное использование орошаемой пашни при рациональном сочетании режимов влажности и минерального питания способствует получению максимальных урожаев кормовых и зерновых культур. Создание различных условий минерального питания за счет фонов с повышенной и высокой обеспеченностью подвижным фосфором с наложением на них разных вариантов агротехнологий позволило смоделировать возможные агроэкологические условия, формирующие контрастные показатели продуктивности культур. Сравнительная оценка эффективности различных агроприемов по выращиванию культур на орошаемом фоне свидетельствует, что приемы обработки почвы и предшественники не оказывали существенного влияния на содержание доступного фосфора в почве. Равновесное содержание подвижного фосфора при многолетнем отрицательном балансе изменилось незначительно. Систематическое внесение фосфорсодержащих удобрений заметно повысило фосфатный статус почвы. Однако адекватная оценка фосфатного состояния пахотных почв возможна при использовании нескольких диагностических индексов (методов). Длительное интенсивное использование орошаемой пашни снизило запасы легкообменного калия от 4 до 1–2 мг/100 г почвы в пахотном слое. Содержание обменного калия также снизилось почти в 2 раза, но почва остается в высоком и очень высоком классе обеспеченности им. Однако ряд показателей свидетельствует о нарастающем истощении ее наиболее подвижными фракциями почвенного калия. Более устойчивы запасы необменного калия, которые снизились за 40 лет примерно на 19%, и почва перешла в разряд с неустойчивой обеспеченностью.

Ключевые слова: чернозем, орошение, минеральное питание, фосфор, калий, удобрения

NUTRIENT REGIME OF IRRIGATED MEADOW-CHERNOZEM SOILS UNDER LONG-TERM INTENSIVE USE

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The patterns of phosphorus and potassium status of soils were studied given the improvement of agricultural technologies of irrigated agriculture. Long-term studies were carried out in an experimental grain-grass crop rotation on irrigated meadow-chernozem soil. The experimental plot is located in the southern forest-steppe of Omsk region. Intensive use of irrigated arable land with a rational combination of moisture and mineral nutrition regimes contributes to obtaining maximum yields of forage and grain crops. The creation of various conditions for mineral nutrition due to an increased and high supply of mobile phosphorus and with the application of different options of agricultural technologies made it possible to simulate possible agro-ecological conditions that form contrasting indices of crop productivity. A comparative assessment of the effectiveness of various agricultural approaches to growing crops under irrigation conditions indicates that soil cultivation techniques and forecrops did not significantly affect the content of available phosphorus in the soil. The equilibrium content of mobile phosphorus given a long-term negative balance changed insignificantly. The systematic application of phosphorus-containing fertilizers significantly increased the phosphate status of the soil. However, an adequate assessment of the phosphate status of arable soils is possible using several diagnostic indices (methods). Long-term intensive use of irrigated arable land has reduced the reserves of easily exchangeable potassium from 4 to 1–2 mg/100 g of soil in the arable layer. The content of exchangeable potassium has also decreased by almost 2 times, but the soil remains in a high and very high class of its availability. However, a number of indicators show its increasing depletion in the most mobile fractions of soil potassium. The reserves of non-exchangeable potassium are more stable, which have decreased by about 19% over 40 years, and the soil has passed into the category with an unstable supply.

Keywords: chernozem, irrigation, mineral nutrition, phosphorus, potassium, fertilizers

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INTRODUCTION

Long-term scientific and practical experience shows that the efficiency of irrigated agriculture increases with the introduction of organic and mineral fertilizers, as well as microelements. Irrigation creates prerequisites for the most effective use of fertilizers for all crops and on all soils. The main condition for obtaining the maximum effect of the application of fertilizers is the correct combination of irrigation regime and fertilizers.

An important sign of fertility is the phosphorus regime in soils. Purposeful regulation of its agrotechnical and reclamation methods affects the reserves of natural phosphorus compounds in soils in order to increase their mobility and accessibilty[1] [1–5].

It is well known that the optimal dose of phosphorus fertilizers is weakly dependent on the type of the soil. The pre-sowing application of $P_{10–15}$ is practically equally effective both on infertile soddy-podzolic soils and on typical and ordinary chernozems. There are practically no soils rich in phosphorus in nature, the level of dynamic equilibrium of phosphate systems of extensively used soils is at the border of low and medium values of phosphorus supply [6, 7].

Potassium as a nutrient is less studied than phosphorus, due to the fact that in arid conditions with low productivity and high potassium supply of the soil, the issue of using potash fertilizers is not as relevant as phosphorus fertilizers. The need for potassium increases due to the more intensive use of arable land with high pro-

[1]Kolbin S.A., Samokhvalova L.M., Prozorov A.S. The influence of the moisture conditions of the growing season on phosphorus removal by spring wheat in the forest-steppe of the Ob region // Soil resources of Siberia: challenges of the XXI century: materials of the All-Russian. scientific. Conf., dedicated to the 110th anniversary of R.V. Kovalev. Novosibirsk, 2017. P. 209–212.

ductivity and saturation of crop rotations with crops with a high removal of potassium from the soil [8–10].

The aim of the work is to study the patterns of the nutritive regime of soils while improving the agricultural technologies of irrigated agriculture.

MATERIALS AND METHODS

The experimental part of the work was carried out in stationary experiments laid down in 1977–1978 in two four-field crop rotations - grain-grass and fodder, combined since 1996 into one eight-field grain-grass crop rotation. The experimental site is located in the southern forest-steppe of the Omsk region.

The climate of the area is typically continental. The sum of the average monthly temperatures for a period> 10 ° C varies within the irrigation zone on average from 1900 to 2200 °. The amount of precipitation during the growing season is about 200 mm.

The soil is meadow-chernozemic, medium-thick, medium-humus, heavy loamy with a humus content in the 0–0.4 m layer of 6.0–6.5%, the thickness of the humus horizon "A" is 0.45 m. The reaction of the soil environment in the arable layer is neutral: pH_{water} - 7.0-7.2.

The soil moisture regime (background) was maintained by irrigation within narrow limits (WRC - 0.9–1.0 HB) in layers of 0.5–1.0 m, depending on the phase of development and biology of crops. The irrigation rate is mainly 300 m3 / ha.

Experiments are two- and three-factor. At the initial stage (from 1978 to 1985), they included four nutritional backgrounds: control (without fertilizers) and with fertilization based on an increase in yield (backgrounds I – III) and 4–5 variants of soil cultivation for fodder and grain crops. Due to the positive balance of phosphorus, backgrounds with increased and high content of phosphorus are created. At the second stage (1986–1995), four backgrounds in terms of the content of mobile phosphorus in the soil were combined with different seeding rates for crops and nitrogen fertilizers (1986–1990). Then (1991–1995), nitrogen fertilizers ($N_{0, 30, 60, 90}$) and micronutrients (Zn, Mo, Cu) were superimposed on these backgrounds. In addition, a spare application of manure of 40 t / ha (and without it) was carried out, as well as compensation for the removal of phosphorus within 10 years by the introduction of 60 kg ai / ha on backgrounds I – III.

From 1996 to 2020, the fundamental difference between the experimental schemes was the refusal to compensate for the removal of phosphorus and its positive balance by the background application of P_{60} with their further detailing by superimposing the variants with the introduction of phosphorus (P_{60}) and without it in combination with nitrogen ($N_{0, 30, 60, 90}$) with fertilizers, depending on the biology of crops.

The crops included in the crop rotation at different periods of the years have been: lucerne, fodder galega, awnless rump in single-species and mixed crops, biennial white and yellow sweet clover, annual legume-bluegrass mixtures for green fodder of the main and intermediate crops, for grain silage - for spring sowing, winter crops (rye, triticale), Sudanese grass of the main and post-cut crops, including mixed with vetch, fodder beans, panic grass of cut-down crops, sugar sorghum, cabbage, cereals and legumes.

Allocation of plots is systematic; their area is 360 m^2 (18 × 20 m). Repetition is three and four times. Watering was carried out by SSR-64 "Volzhanka". In the field experiments we used the appropriate serial tillage, sowing and harvesting equipment.

The organization of field experiments, observations, records and laboratory analyzes was carried out in accordance with the methodological manuals and guidelines generally accepted in agriculture and agrochemistry. These are guidelines for setting up field experiments and conducting field observations[2], methods for chemical analysis of the soils[3].

[2]Dospekhov B.A. Field experiment technique. Moscow: Kolos, 1979.416 p.

[3]Agrochemical methods of soil research: monograph. Moscow: Nauka, 1975.656 p.

The analysis of the content of mobile phosphorus by various methods and forms of potassium was carried out simultaneously in the original (archived) samples and modern soil in 2018 and 2019 respectively.

RESULTS AND DISCUSSION

The experience of conducting intensive agricultural production has shown that obtaining high yields is impossible without a radical improvement in the phosphate regime of soils.

A comparative assessment of the effectiveness of various agricultural practices for growing crops on an irrigated background indicates that soil cultivation techniques and predecessors did not significantly affect the content of available phosphorus in the soil.

The level of phosphorus nutrition was determined by the creation, due to a positive balance of backgrounds, with an increased, high and very high supply of $P_2 O_5$ and compensation of the removal by the introduction of phosphorus-containing fertilizers.

The level of mobile phosphorus in the control variants of experiments on meadow chernozem soil changed insignificantly, despite the long-term alienation of the element from the soil. At the same time, with the systematic application of phosphorus fertilizers, the content of mobile phosphorus increased significantly (see Table 1).

It can be assumed that the value of this indicator as a diagnostic parameter when monitoring the phosphate state of the soils in agrocenoses reflects the mode of accumulation of this element rather well and much worse - the scale of its consumption (removal) by crops. This indicates the advisability of the integrated use of several diagnostic indices for an adequate assessment of the phosphate state of arable soils.

Over the entire research period, taking into account the transformation of the experimental schemes while maintaining control and, to varying degrees, fertilized options, various amounts of mineral fertilizers, including phosphorus-containing ones, were introduced in fodder and grain-grass crop rotations. So, in the fodder crop rotation, taking into account the biology of the crops, over 40 years in the fertilized version, 2739 kg of ai / ha of nitrogen and 3288 kg of ai / ha of phosphorus were introduced, in the grain-grass - 3138 and 2796 kg of ai / ha, respectively. The annual dose of phosphorus in the fodder crop rotation was approximately 82 kg of ai / ha, in the grain-grass - about 70 kg of ai / ha. However, a significant annual removal of phosphorus with two- and three-mowing use of perennial grasses and two harvests of annual forage crops reduced the content of mobile forms of phosphorus in comparison with grain-grass crop rotation.

Табл. 1. Содержание фосфатов в почве при длительных полевых опытах (1978–2019 гг.)
Table 1. The content of phosphates in the soil of long-term field experiments (1978-2019)

Variant	Soil layer, m	Phosphorus content, mg / kg of the soil		
		according to Chirikov	according to Franceson	according to Karpinsky
Raw land (parent)	0–0,2	4,0	60,0	215
	0,2–0,4	2,7	51,9	193
Fodder crop rotation				
Without fertilizers	0–0,2	1,8	32,5	179
	0,2–0,4	0,8	24,2	168
NP	0–0,2	1,2	32,1	174
	0,2–0,4	0,6	25,4	170
Grain crop rotation				
Without fertilizers	0–0,2	1,6	30,3	170
	0,2–0,4	0,7	20,1	165
NP	0–0,2	1,1	30,7	169
	0,2–0,4	0,6	20,4	168
LSD_{05}		0,3	4.4	15

According to A.E. Kochergin[4], the most sensitive assessment of the phosphate state of the West Siberian soils is provided by the Franceson method. The stable content of easily exchangeable phosphorus in the upper layer of the control variants of meadow-chernozem soil in comparison with the initial content and a clear tendency of its corresponding increase in the underlying soil layers are obvious (see Table 1). The reason for this phenomenon can be both a relatively low mobility of phosphorus compounds in this soil, and their certain biogenic accumulation in the upper soil horizons during long-term cultivation of grasses, accompanied, possibly, by a slight increase in the degree of mobility of the available soil phosphate fractions. With the systematic use of phosphorus fertilizers, the level of readily mobile phosphorus in meadow chernozem soil significantly increased, indicating a high supply of available forms of this mineral element to crops.

The high buffering capacity of the meadow chernozem soil and its increased natural fertility contributed to the preservation of a certain level of phosphorus ions in the soil solution even with prolonged agricultural use. However, a significant decrease in the productivity of crops in extensive agrocenoses indicates that the soil possibilities are generally not unlimited.

Potassium is also an important element of plant mineral nutrition. It occupies a leading position among other biophilic elements in the removal of many agricultural crops, especially fodder crops, with the harvest. However, less attention is paid to the optimization of the potassium state of the soils in agrocenoses in comparison with nitrogen and phosphorus. The use of potash fertilizers in modern agriculture in Siberia is at a minimum. This approach is usually justified by the fact that the main arable soils contain rather high reserves of gross potassium and its mobile forms. However, it is often not taken into account that long-term intensive agricultural use of soil can affect soil potassium reserves, influencing the yield and quality of crop production [11].

Optimization of nitrogen-phosphorus nutrition of plants in experiments on meadow-chernozem soil contributed to a significant increase in the yield of forage and grain crops in relation to unfertilized options. At the same time, a significant additional removal of potassium with the crop was noted. The high initial reserves of potassium available to plants did not limit the potassium nutrition of crops, providing an increased removal of an element alienated by plants and the possibility of a long-term negative balance of potassium in agrocenoses.

The potassium fund of the soil is subdivided into four interrelated components (forms), based on the strength of the bond of certain groups of potassium cations with the solid phase of the soil: easily exchangeable potassium (soil solution), exchangeable, non-exchangeable, potassium of the mineral skeleton (structural). The first three forms determine the effective soil fertility with respect to potassium, which necessitates their quantitative and qualitative assessment when monitoring the soil potassium state of the soil [11, 12].

Due to its small absolute values, easily exchangeable potassium is rarely used to characterize the potassium state of arable soils, although the available data indicate a fairly close relationship of this indicator with productivity and its good diagnostic capabilities [12, 13]. The level of easily exchangeable potassium gives an idea of the degree of depletion of the soil, its ability to desorb the ions of this element into the soil solution.

The content of easily exchangeable potassium in the soil is a fairly universal index of the provision of crops with soil potassium. Under similar conditions of potassium nutrition of plants on different soils, the level of easily exchangeable potassium in them is approximately the same regardless of the absolute values of the content of other potassium forms in these soils. The gradations of the supply of potassium in the main arable soils of the Western Siberia according to the content of its easily exchangeable form in them were published earlier [12].

[4]Kochergin A.E. Phosphate soils fund and its availability to plants // Soils of Western Siberia and an increase of their fertility. Omsk: Omsk Agricultural Institute. 1984.P. 12-19.

The content of easily exchangeable potassium in the original soil was very high - 4.0 mg / 100 g in the 0–0.2 m layer and 2.7 mg / 100 g in the 0.2–0.4 m layer (see Table 2).

Long-term agricultural use of the soil in the control variant caused a significant decrease in the reserves of this form of potassium both in the arable layer and especially in the subsoil. The systematic use of mineral fertilizers in the NP variant contributed to an increase in crop productivity and, accordingly, a further decrease in the content of easily exchangeable potassium in the soil. The increased potassium fund of the meadow chernozem soil and the high buffering capacity of its potassium system made it possible for many years to maintain the intensity of the processes of potassium desorption into the soil solution at a sufficiently high level. However, over 40 years of experiments, the supply of the studied soil with easily exchangeable potassium decreased from very high (4 mg / 100 g of soil) to unstable (1–2 mg) in the arable layer of all variants and low (<1 mg per 100 g) in the subsoil. This circumstance testifies to the growing need of grown crops for additional potassium nutrition.

In the arable and subsoil layers, the content of exchangeable potassium has decreased over 40 years by almost 2 times from the initial (from 52-60 to 20-32 mg / 100 g), while remaining, nevertheless, in a high and very high class of availability according to standard gradations (see Table 2). However, the vector of changes in the potassium state of this soil is obvious, which makes it possible to predict its transition in the future to the class of supply with problematic potash nutrition of crops. The options "without fertilizers" and NP did not differ in the scale of the decrease in the content of exchangeable potassium. At the same time, it is possible to note a tendency for the intensification of this process in the grain-grass crop rotation in comparison with the forage one.

In the topsoil, over 40 years of the experiment, the content of non-exchangeable potassium decreased by 36–46 mg / 100 g of soil, which was approximately 19% of the original reserves. In the grain-grass crop rotation, the potassium reserves in the arable and subsoil layers of the soil were used more intensively than in the fodder (see Table 2). According to the proposed gradations [13], the studied heavy loamy soil was initially considered to be optimally provided with a non-exchangeable form of potassium (180–250 mg / 100 g). During the experiments, it passed into the category with an unstable supply (<180 mg).

Табл. 2. Калийное состояние лугово-черноземной почвы в длительном полевом опыте (1978–2018 гг.)

Table 2. Potassium state of meadow-chernozem soil in the long-term field experiment (1978–2018)

Variant	Soil layer, m	The content of forms of potassium, mg / 100 g of soil		
		Easily exchangeable potassium	Exchangeable potassium	Non-exchangeable potassium
Raw land (parent)	0–0,2	4,0	60,0	215
	0,2–0,4	2,7	51,9	193
Fodder crop rotation				
Without fertilizers	0–0,2	1,8	32,5	179
	0,2–0,4	0,8	24,2	168
NP	0–0,2	1,2	32,1	174
	0,2–0,4	0,6	25,4	170
Grain crop rotation				
Without fertilizers	0–0,2	1,6	30,3	170
	0,2–0,4	0,7	20,1	165
NP	0–0,2	1,1	30,7	169
	0,2–0,4	0,6	20,4	168
LSD_{05}		0,3	4.4	15

CONCLUSIONS

1. The content of mobile phosphorus in the control variants changes insignificantly during long-term alienation from the soil. Compensation of phosphorus removal from intensively used meadow chernozem soils and its positive balance reliably maintain the created optimal level of its content, without reducing either crop yields or soil fertility, which is equivalent to the full use of phosphates.

2. Long-term agricultural use of the soil in the control variants significantly reduced the reserves of easily exchangeable potassium. The content of exchangeable potassium has almost halved over 40 years, remaining in a high class of abundance. The meadow-chernozem soil is highly supplied with available potassium and, after 40 years of use, formally belongs to this category. However, a number of additional indicators demonstrate an increasing depletion of its most mobile fractions of soil potassium.

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