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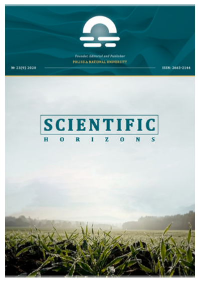

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The effectiveness of forms of mineral fertilisers and productivity of winter wheat on grey-meadow soils of Kyrgyzstan

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Abstract. Fertilisation of winter wheat is necessary to provide the crop with nutrients for optimal growth, development, and formation of the crop. However, the effectiveness of fertilisers may depend on their shape, soil conditions, and climate. The purpose of the study is to examine the effectiveness of using various forms of mineral fertilisers on the formation of productivity of winter wheat on grey-meadow soils of Kyrgyzstan. In 2019-2021, field experiment was conducted in the Educational-experimental Farm of the Kyrgyz National Agrarian University, named after K.I. Skryabin to achieve this

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goal. As a result of the study, it was identified that the formation of high yields of winter wheat is closely related to the use of nitrogen-containing fertilisers in crop rotation, which contributes to the accumulation of nitrate nitrogen in the soil. The substantial effect of ammonium nitrate and granulated superphosphate on the nitrogen regime of the soil was also noted. The concentration of carbon-ammonium-soluble phosphates is determined by the actions of ammonium sulphate, ammonium nitrate, and all forms of phosphorus fertilisers, but no special changes in the phosphate regime of the soil under the influence of forms of phosphorus fertilisers were identified. However, when using complex fertilisers, a slight accumulation of mobile phosphorus in the soil was noted. The introduction of ammonium nitrate ensures the yield of winter wheat grain at the level of 56 centner/ha, ammonium sulphate – 53.1 centner/ha. granulated superphosphate provided the highest level of winter wheat yield – 55.5 centner/ha and the highest increase in yield against the background of nitrogen-potassium nutrition – 8.7 centner/ha. Therefore, for winter wheat, after rowed precursors, it is preferable to apply ammonium nitrate from nitrogen forms of fertilisers. As an alternative to it – ammonium sulphate or urea, from phosphorus forms of fertilisers – granular superphosphate. The practical importance of the results of the study allows for developing more effective methods of using fertilisers and increasing the productivity of grain crops on grey-meadow soils of Kyrgyzstan and in other regions with similar soil and climatic conditions

Keywords: nitrate nitrogen; carbon-ammonium-soluble phosphorus; crop rotation; agriculture; macronutrients

INTRODUCTION

Winter wheat needs a certain amount of nutrients for normal growth and development. Complex fertilisers should be balanced in nitrogen, phosphorus, potassium, and other necessary trace elements. In addition, in the issue of optimising the nutrition conditions of winter wheat, an important place belongs to the scientifically based choice of the best forms of mineral fertilisers (Wen *et al.,* 2020). The investigation of the effectiveness of forms of mineral fertilisers and their impact on the productivity of winter wheat on grey-meadow soils of Kyrgyzstan is urgent for several reasons. Firstly, grey-earth-meadow soils are one of the main types of soils in Kyrgyzstan, and winter wheat is one of the main agricultural crops. Secondly, the use of mineral fertilisers is one of the main methods of increasing the yield of grain crops, including winter wheat. However, to achieve maximum effect, it is necessary to choose the right forms of fertilisers and their dosage (Aziz *et al.,* 2020).

Scientific studies show that the use of mineral fertilisers can increase the productivity of winter wheat. Thus, V. Vona *et al.* (2022) identified that the use of ammonium nitrate against the background of phosphorus-potassium nutrition led to an increase in the yield of winter wheat grain by 12% compared to using phosphorus-potassium fertilisers alone. According to the study by K. Muydinov *et al.* (2021), conducted in Uzbekistan, the right combination of different types of fertilisers can lead to an even higher yield of winter wheat grain. For example, a study conducted in the Andijan region showed that the use of a complex fertiliser containing nitrogen, phosphorus, and potassium, combined with micro-fertilisers, increased the yield of wheat grain by 50-60% compared to the control without fertilisers.

L. Liang *et al.* (2021) believe that some forms of fertilisers may be more effective on certain types of soils than on others. For example, in areas with low nitrogen content in the soil, the use of ammonium nitrate may be the most effective, while on soils with high nitrogen content, it is better to use more balanced forms of fertilisers, such as carbamide or amophoska. In addition, some forms of fertilisers, such as potash fertilisers, can be especially useful on soils with low potassium content. B.U. Suleymenov *et al.* (2019) also indicate that combining different types of fertilisers can increase soil nutrition and improve its structure, which contributes to better plant growth and development. In addition, according to A.A. Shpedt *et al.* (2021), proper application of mineral fertilisers can increase the quality of winter wheat grain. Mineral fertilisers contain nutrients necessary for the plant, such as nitrogen, phosphorus, potassium, magnesium, and other trace elements that play an important role in the formation and development of wheat grain and can improve its quality.

However, it should be considered that the effectiveness of the use of mineral fertilisers may depend on many factors, such as climatic conditions, soil composition, wheat varieties used, and fertiliser dosages. Therefore, to achieve maximum productivity of winter wheat, it is necessary to consider all these factors. It is important to note that in Kyrgyzstan today the production does not have scientifically based recommendations on the use of more effective forms of nitrogen, phosphorus, and complex fertilisers for winter wheat. In this regard, a comparative assessment of the effect of various forms of mineral fertilisers for winter wheat on grey-meadow soils is quite relevant and has great scientific importance, is of particular interest for practice.

The purpose of the study is to examine the effectiveness of various forms of mineral fertilisers on the formation of winter wheat yields. The following tasks were set and implemented to achieve this goal: analyse the effect of forms of mineral fertilisers on the content of nitrate nitrogen in grey-meadow soil, the effect of forms of phosphorus fertilisers on the content of carbon-ammonium-soluble phosphates in the soil, and examine the productivity of winter wheat grains.

MATERIALS AND METHODS

A field experiment was conducted to examine the effect of mineral fertilisers on the productivity of winter wheat in 2019-2021. The venue is the experimental field of the Educational-experimental Farm of the Kyrgyz National Agrarian University, named after K.I.Skryabin. The study was conducted on grey-earth meadow soils of Kyrgyzstan, which are characterised by an average content of humus, carbonates, and alkalinity. The content of humus in the arable soil layer is 2.3%, the content of gross nitrogen – 0.18%, phosphorus – 0.2, and potassium – 3.05%, mobile forms of phosphorus – 2.8 mg per 100 g of soil, the amount of exchangeable potassium – 52.2 mg per 100 g of soil. The pH value of the soil is 8.5. Since climatic factors are of substantial importance for the formation of the winter wheat harvest, it is necessary to note that the Educational-experimental Farm of the Kyrgyz National Agrarian University, named after K.I. Skryabin is located in the northern part of the republic in the Chui River basin. The zone is irrigated, characterised by a dry continental climate, with hot summers and relatively cold winters. During the study, depending on the prevailing conditions of the year, vegetation irrigation was conducted in the tubing phase and during the grain filling period with an irrigation rate of 700-800 m^3/ha of water per hectare.

The study of the effectiveness of forms of mineral fertilisers for winter wheat was conducted in an eight-field crop rotation with the following alternation of crops: spring barley + alfalfa, winter wheat, corn, winter wheat, corn, winter wheat. The annual fertiliser rate (NPK) was $N_{90}P_{90}K_{30}$. The following forms of fertilisers were examined in the experiment: ammonium nitrate (N_{an}) – 34% N, urea (N_u) – 46% N, ammonium sulphate (N_{as}) – 21.7% N, urea formaldehyde fertiliser (UFF) (N_{UFF}) – 37.7% N, granulated superphosphate (P_{gs}) – 19.5% P_2O_5, double superphosphate (P_{ds}) – 40.2% P_2O_5, fluorinated phosphate (P_{fp}) – 31.5% P_2O_5, ammophos (AM) – 11.2% N, 42.5% P_2O_5, ammonium phosphate (AMP) – 5.6% N, 44% P_2O_5 and potassium chloride K_c – 57% K_2O. Therewith, P15 in rows – control. Fertilisers were applied in fractions: under winter ploughing, in rows during sowing, and in top dressing. The variants of the experiment had a fourfold repetition, the arrangement of plots in the experiment was multi-row-stepped. The total area of the plots – 201.6 m^2 (length – 24 m, width – 8.4 m), accounting – 84 m^2 (length – 20 m, width – 4.2 m).

Nitrate nitrogen was determined in a fresh sample using an ion-selective electrode on an EK-74 device. Mobile phosphorus was analysed in dry samples in a 1% carbon-ammonium extract by the Machigin method in the modification of the Central Agrochemical Agricultural Service Institute on the photo-electrocolorimeter KFK-2 (GOST 26205-91). Harvesting was conducted using a plot-by-plot direct combining with the weighing of bunker grain from the accounting area. In addition, the study analysed the influence of forms of mineral fertilisers on the content of nitrate nitrogen in the soil and the influence of forms of phosphorus fertilisers on the content of carbon-ammonium-soluble phosphates in the soil and examined the productivity of winter wheat, which was formed under the influence of the introduction of mineral fertilisers. All experiments were repeated three times for each variant of the experiment. The obtained results were processed for reliability using the MANOVA multivariate method of variance analysis using Microsoft Excel software and the Statistica 10 software package. Differences in the results obtained are possible at the importance level $P \leq 0.05$ according to the Student's criterion.

RESULTS

As a result of the study, it was identified that when using highly soluble forms of nitrogen fertilisers, such as ammonium sulphate, ammonium nitrate, and urea, the content of nitrate nitrogen in the soil increases markedly in relation to the background, although there are no special differences between them (Table 1).

Table 1. *Influence of forms of mineral fertilisers on the content of nitrate nitrogen in the soil, mg per 100 g of soil (average for 2019-2021)*

Variant	Soil layer (cm)	Phases of development of winter wheat					Average for the growing season
		Tillering	Stem elongation	Earing	Milky-waxy ripeness	Full ripeness	
P_{15} in rows (control)	0-25	2.9	2	1.8	1.9	1.3	2
	25-50	2.4	1.5	1.5	0.7	0.6	1.3
	50-75	2.7	1.9	0.4	0.4	0.5	1.2
	75-100	1.7	2.1	0.2	1	0.5	1.1
	average	2.4	1.9	1	1	0.7	1.4
$P_{gs}K_c$ (background)	0-25	3.7	2.9	2	1.2	1.2	2.2
	25-50	2.5	1.4	0.6	0.5	1.4	1.3
	50-75	1.3	1.6	1.1	1.5	0.7	1.3
	75-100	2	1.7	1.3	1.5	0.7	1.4
	average	2.4	1.9	1.3	1.2	1	1.6
Background+N_{an}	0-25	3.7	3.5	2.9	1.3	1.4	2.6
	25-50	3.1	2.9	1.9	1.6	1.8	2

Table 1, Continued

Variant	Soil layer (cm)	Phases of development of winter wheat					Average for the growing season
		Tillering	Stem elongation	Earing	Milky-waxy ripeness	Full ripeness	
Background+N_{an}	50-75	4.5	2.3	2.3	2.5	1.3	2.6
	75-100	3.5	3.2.	2.6	1.6	1	2.3
	average	3.7	3.1	2.5	1.7	1.4	2.4
Background+N_u	0-25	3.5	3	2.8	2.1	2.6	2.8
	25-50	3.3	2.8	1.1	1.1	1.6	1.8
	50-75	2.6	2.9	2.7	0.8	1.1	2
	75-100	2.7	4	1	0.8	0.5	1.8
	average	3.6	3.8	1	1.2	1.5	2.3
Background+N_{as}	0-25	3.9	3.4	2.5	1.7	2.5	2.8
	25-50	2.7	2.4	1.9	1.2	1.1	1.9
	50-75	3.4	3.2.	1.9	1.9	1.3	2.3
	75-100	2.1	3.5	2.8	1.9	1.3	2.3
	average	3	3.1	2.3	1.7	1.6	2.3
Background+N_{UFF}	0-25	4.3	5.1	3.6	3.1	3.1	3.8
	25-50	4	3.9	2.2	2.8	2.1	3
	50-75	3.5	2.7	3	1.5	1.5	2.4
	75-100	2.8	2	2.9	1.7	1.5	2.2
	average	3.7	3.9	2.9	2.3	2.1	2.8
$N_{an}K_c$ (background)	0-25	3.6	3.6	2.3	4.5	4.2	3.6
	25-50	4.4	3.1	2.6	4.7	2.8	3.5
	50-75	5.5	2.1	2.2	4.3	2.4	3.3
	75-100	4.2	4.3	3.9	3.6	1.5	3.5
	average	4.4	3.2.	2.8	4.3	2.7	3.5
Background+P_{gs}	0-25	4	3.8	3.2.	3.2.	3.5	3.5
	25-50	3.5	2.8	2.6	2.8	2.6	2.9
	50-75	3	2.9	2.5	2.5	2.7	2.7
	75-100	2.4	2.2	2.1	2.5	2.5	2.3
	average	3.2.	2.9	2.6	2.8	2.8	2.9
Background+P_{ds}	0-25	3.1	3.8	3	3.7	3.8	3.5
	25-50	3.5	2.3	2	3.5	2.6	2.8
	50-75	2.6	2	1.9	2.4	2.5	2.3
	75-100	2.8	3.4	1.8	2.3	1.8	2.4
	average	3	3.2.	2.2	2.9	2.7	2.7
Background+P_{fp}	0-25	4.5	4	2.8	2.1	2.3	3.1
	25-50	3.5	3.8	2.7	1.8	2.3	3
	50-75	3	2.3	1.7	2.1	2.1	2.3
	75-100	4.1	1.5	1.4	1.8	1.5	2.1
	average	3.9	2.3	2.2	1.9	2.1	2.6
K_c+NP_{am}	0-25	-5.4	4.7	3.4	1.7	2	3.5
	25-50	5.9	3.6	3.7	2.2	2.1	3.5
	50-75	3.5	3.7	2.2	2.1	1.6	2.6
	75-100	3.3	3.3	2.1	2.4	1.7	2.6
	average	4.6	3.8	2.9	2.1	2	3.1
K_c+NP_{amp}	0-25	5.6	5.7	3.4	3.2.	3.6	4.3
	25-50	5.5	4.3	2.5	3.1	2.4	3.6
	50-75	4.1	3.3	1.4	2.6	3.2.	2.9
	75-100	4.1	1.3	1.6	2.7	2.4	2.4
	average	4.9	2.7	2.2	2.8	2.9	3.3

Note: *N_{an} – ammonium nitrate; N_u – urea; N_{as} – ammonium sulphate; UFF – urea-formaldehyde fertiliser; P_{gs} – granulated superphosphate; P_{ds} – double superphosphate; P_{fp} – fluorinated phosphate; AM – ammophos; AMP – ammonium phosphate; K_c – potassium chloride*
Source: *compiled by the authors*

When applying a urea-formaldehyde fertiliser, in which nitrogen is in the form of slightly soluble compounds, a tendency to increase the content of nitrates is observed. This is due to the fact that urea in such fertilisers is presented in the form of poorly soluble compounds that gradually turn into ammonia and other nitrogen compounds, and with their relatively low removal by agricultural crops, which contributes to the accumulation of nitrates in the soil. In the course of investigating the influence of forms of phosphorus fertilisers on the content of nitrate nitrogen in the soil, a rather substantial accumulation of nitrogen-potassium background (without phosphorus) and a decrease in the content of nitrates under the action of phosphorus fertilisers was established. The accumulation of nitrate nitrogen is associated with the weak use of nitrate nitrogen by plants, due to the absence of phosphorus in the composition of the fertiliser. A decrease in the nitrate content under the action of phosphoric fertilisers is associated with an increase in crop yields, as a result of which the absorption of nitrates from the soil increases to create an additional crop. Therewith, there is almost the same content of nitrate nitrogen in the soil, regardless of the forms of phosphorus fertilisers used, and when applying complex fertilisers such as ammophos and ammophosphate, a slight increase was noted. The content of available phosphorus compounds in the soil may depend on the amount and forms of mineral fertilisers used since phosphorus is one of the main elements of plant nutrition and its availability to plants can substantially affect their growth and development. The results obtained indicate that there are no substantial changes in the phosphate regime of the soil under the influence of forms of nitrogen fertilisers. This is due to the fact that nitrogen and phosphorus are different elements of plant nutrition, which have different ways of absorption and movement in the soil (Table 2).

Table 2. *Influence of forms of phosphorus fertilisers on the content of carbon-ammonium-soluble phosphates in the soil, mg per 100 g of soil (average for 2019-2021)*

Variant	Soil layer (cm)	Phases of development of winter wheat					Average for the growing season
		Tillering	Stem elongation	Earing	Milky-waxy ripeness	Full ripeness	
P_{15} in rows (control)	0-25	2.2	2.3	2.9	2.5	1.9	2.4
	25-50	1.1	2	1.6	1.5	1.2	1.5
	50-75	0.7	1.1	0.9	0.9	1	0.9
	75-100	0.7	0.2	0.9	0.7	0.8	0.7
	average	1.2	1.4	1.6	1.4	1.2	1.4
$P_{gs}K_c$ (background)	0-25	2.9	3.8	4	3.2.	3.4	3.5
	25-50	1.6	1.8	1.5	1.7	2	1.7
	50-75	0.8	1.6	0.9	1.2	0.9	1.1
	75-100	0.7	0.8	0.9	0.9	0.8	0.8
	average	1.5	2	1.8	1.8	1.8	1.8
Background+N_{an}	0-25	3.4	3.6	2.6	2.7	2.5	3
	25-50	1.5	2.6	1.6	1.7	1.5	1.8
	50-75	0.7	0.7	1.1	1.2	0.9	0.9
	75-100	0.7	0.6	1	1	0.7	0.8
	average	1.6	1.9	1.6	1.6	1.4	1.6
Background+N_u	0-25	4.2	3.9	3.4	3.8	3.7	3.4
	25-50	1.7	1.3	1.4	1.9	1.8	1.6
	50-75	1	0.9	0.9	1.4	1.2	1.1
	75-100	0.8	0.7	0.9	0.9	0.9	0.8
	average	1.9	1.7	1.6	1.9	1.9	1.7
Background+N_{as}	0-25	3.6	3.4	3.3	3	3.5	3.4
	25-50	2.7	1.5	1.4	1.6	1.8	1.8
	50-75	0.9	1.2	0.9	1.5	0.8	1.1
	75-100	0.8	0.7	1	0.9	0.7	0.8
	average	2	1.7	1.7	1.8	1.7	1.8
Background+N_{UFF}	0-25	3.4	3.8	4.3	3.6	3.6	3.7
	25-50	1.6	2.3	2.3	1.9	2.2	2.1
	50-75	1.1	1.1	1	1.2	1.2	1.1
	75-100	1	0.8	0.9	1	1	0.9
	average	1.8	2	2.1	1.9	2	1.9

Table 2, Continued

Variant	Soil layer (cm)	Phases of development of winter wheat					Average for the growing season
		Tillering	Stem elongation	Earing	Milky-waxy ripeness	Full ripeness	
$N_{an}K_c$ (background)	0-25	2.5	2.8	2.6	2.5	1.8	2
	25-50	1.8	1.7	1.5	1.2	1.2	1.5
	50-75	0.9	1.4	1	0.8	0.9	1
	75-100	0.6	0.7	0.8	0.7	0.8	0.7
	average	1.5	1.9	1.5	1.3	1.2	1.4
Background+P_{gs}	0-25	3.5	4.4	4.3	3.6	2.6	3.7
	25-50	1.2	1.9	1.8	2	1.4	1.7
	50-75	1	1.2	0.9	0.9	0.9	1
	75-100	0.7	1.1	0.8	0.9	0.8	0.9
	average	1.6	2.2	2	1.9	1.4	1.8
Background+P_{ds}	0-25	3.5	4.3	3.6	3.6	3.7	3.7
	25-50	2.2	2.9	2	1.9	2.1	2.2
	50-75	1.1	1.3	1	1.2	1.2	1.2
	75-100	0.8	0.9	0.9	0.9	0.9	0.9
	average	1.9	2.3	1.9	1.9	1.9	2
Background+P_{fp}	0-25	3.7	3.3	3.1	2.3	3.2.	3.1
	25-50	2.5	1.7	1.6	1.2	2.2	1.8
	50-75	0.9	1.1	1	0.8	1	0.9
	75-100	0.8	0.9	0.8	0.8	0.8	0.8
	average	2	1.7	1.6	1.3	1.8	1.7
K_c+NP_{am}	0-25	5.3	5.9	4.7	4.8	5.5	5.2
	25-50	3.3	2.9	2.9	3.7	3.5	3.2.
	50-75	1.9	1.3	1.2	2.2	1	1.5
	75-100	1.1	0.9	0.9	1.2	0.9	1
	average	2.9	2.7	2.4	3	2.7	2.7
K_c+NP_{amp}	0-25	5.1	5.6	4.4	4.5	5	4.8
	25-50	3	2.5	2.7	3.3	3.2.	2.8
	50-75	1.5	1.1	1	2	1	1.3
	75-100	1	0.8	0.9	1.1	0.9	0.9
	average	2.6	2.5	2.2	2.7	2.5	2.5

Note: *N_{an} – ammonium nitrate; N_u – urea; N_{as} – ammonium sulphate; UFF – urea-formaldehyde fertiliser; P_{gs} – granulated superphosphate; P_{ds} – double superphosphate; P_{fp} – fluorinated phosphate; AM – ammophos; AMP – ammonium phosphate; K_c – potassium chloride*
Source: *compiled by the authors*

The influence of forms of nitrogen fertilisers on the phosphate regime of the soil may be insubstantial. However, when using large doses of fertilisers, including both nitrogen and phosphorus, competition may arise between these elements for absorption by plants, which may lead to a change in the phosphate regime of the soil. Therefore, when applying mineral fertilisers, it is necessary to consider not only the amount and forms of fertilisers, but also their ratio, and the properties and condition of the soil. It was also identified that the introduction of phosphorus fertilisers against the background of nitrogen-potassium nutrition is accompanied by an increase in the content of carbon-ammonium-soluble phosphates in the soil. However, there are no substantial changes in the accumulation of mobile phosphorus under the influence of phosphorus-containing fertiliser. Therewith, the least accumulation of mobile phosphorus occurs when using fluorinated phosphate due to the absence of water-soluble phosphorus in its composition. Complex fertilisers have a more substantial effect on the phosphate regime of the soil than fertilisers containing only one element of nutrition. This is due to the fact that when using complex fertilisers containing, for example, both nitrogen and phosphorus, there is a more rational use of these nutrients by plants. Nitrogen and phosphorus in such fertilisers are in optimal ratios, which helps to improve their interaction in the soil and increase accessibility for plants. In addition, complex fertilisers may contain phosphates that are more readily available to plants than other forms of phosphorus contained, for example, in organic fertilisers. This can lead to an increase in the content of available phosphorus compounds in the soil and improve its availability to plants. The food regime created by the use of various forms of mineral fertilisers affected the productivity of winter wheat. Thus, the unequal effect of the examined forms of nitrogen fertilisers on the yield of winter wheat grain has been established. The most positive effect was provided by water-soluble forms of nitrogen fertilisers, among which ammonium nitrate stands out in value and importance, which provided 56 centner/ha of grain, which is 8.8 centner/ha more than the background. Ammonium sulphate is slightly inferior to it – 53.1 c/ha. The lowest grain yield increases in relation to the phosphorus-potassium background were obtained using urea 4 centner/ha and urea-formaldehyde form of fertiliser – 1.1 centner/ha (Table 3).

Table 3. *Influence of forms of mineral fertilisers on the yield of winter wheat, kg/ha*

Variant	Year			Average for 2019-2021	Increase, centner/ha	
	2019	2020	2021		to control	to the background
P_{15} in rows (control)	37.8	44.6	42.2	41.5	-	-
$P_{gs}K_c$ (background)	39.2	53.5	49.1	47.2	5.7	-
Background+N_{an}	45.7	60.9	61.4	56	14.5	8.8
Background+N_u	41.3	55.6	56.9	51.2	9.7	4
Background+N_{as}	43.5	57.9	58.1	53.1	11.6	5.9
Background+N_{UFF}	40.2	55.1	49.5	48.3	6.8	1.1
$N_{an}K_c$ (background)	38.1	51.3	51.1	46.8	5.3	-
Background+P_{gs}	46.7	58.9	60.9	55.5	14	8.7
Background+P_{ds}	40.1	54.9	54.8	49.9	8.4	3.1
Background+P_{fp}	42.3	57.7	55.9	52	10.5	5.2
K_c+NP_{am}	42.9	56.6	58.5	52.7	11.2	-
K_c+NP_{amp}	39.4	53.1	54.9	49.1	7.6	-
S_x, %	4.1	3.3	3.5			
HCP_{095}, centner/ha	4.7	4.2	4.4			

Note: *N_{an} – ammonium nitrate; N_u – urea; N_{as} – ammonium sulphate; UFF – urea-formaldehyde fertiliser; P_{gs} – granulated superphosphate; P_{ds} – double superphosphate; P_{fp} – fluorinated phosphate; AM – ammophos; AMP – ammonium phosphate; K_c – potassium chloride*
Source: *compiled by the authors*

Among the forms of phosphorus fertilisers, the most preferred position in terms of their effect on the yield of winter wheat grain is granulated superphosphate. Its use as a phosphorus fertiliser provided the highest level of winter wheat yield – 55.5 centner/ha and the highest increase in yield against the background of nitrogen-potassium nutrition – 8.7 centner/ha. The introduction of fluorinated phosphate slightly reduces this indicator to 5.2 c/ha. The weakest effect on the formation of the yield of winter wheat was observed in double superphosphate, with which the increase in crop yield against the background is only 3.1 centner/ha. The predominant effect of granulated superphosphate on the formation of a high yield of winter wheat grain is due to the presence in its composition of a concomitant component of gypsum, which has a reclamation effect on slightly alkaline soils. Thus, when using ammonium nitrate against the background of phosphorus-potassium nutrition, a larger yield of winter wheat grain is formed, and the introduction of granulated superphosphate provides a noticeable increase in the yield of winter wheat compared using other forms of phosphorus fertilisers.

DISCUSSION

The correct dietary regime is one of the important factors affecting the yield of agricultural crops, including winter wheat. Fertilisers are the main source of nutrients for plants, and their proper application helps to provide plants with the necessary nutrients for optimal growth and development. In addition, the nutritional regime of plants affects the presence of easily digestible forms of nitrogen and phosphorus in the soil, since plants absorb nutrients through the roots, and this, in turn, affects the composition of the soil. Plant nutrition conditions include factors such as the level and chemical composition of the soil, the use of fertilisers, harvesting, and crop rotation. The use of fertilisers containing nitrogen and phosphorus can increase the availability of these elements for plants, whereas harvesting without subsequent fertilisation can lead to soil depletion. Using crop rotations in farming can help preserve soil fertility and increase the availability of nutrients for plants (Chen *et al.,* 2019).

Studies by S. Tandy *et al.* (2021) and M.N. Ashraf *et al.* (2021) show that the application of only nitrogen and potash fertilisers without phosphorus can lead to the accumulation of nitrate nitrogen in the soil. This is due to the fact that potash fertilisers can increase the assimilation of nitrate nitrogen by plants, and nitrogen fertilisers can stimulate its accumulation in the soil. Therewith, phosphorus fertilisers can improve the absorption of other forms of nitrogen by plants, such as ammonium and amide, which do not accumulate in the soil in such large quantities as nitrate. Notably, the accumulation of nitrate nitrogen in the soil may be undesirable, as this can lead to contamination of groundwater and aquatic ecosystems and a decrease in the quality of agricultural products. Therefore, it is important to combine fertilisers correctly, consider the needs of crops and soil characteristics to achieve optimal results in agriculture. All this actualises the solution of the problem of nitrate accumulation in the soil in the context of modern agriculture.

K. Ibrahim *et al.* (2021) in their paper note that the introduction of phosphorus fertilisers against the background of nitrogen-potassium nutrition can reduce the content of carbon-ammonium-soluble phosphates in the soil and increase the availability of phosphorus for plants. In addition, N. Kokovic *et al.* (2021) believe that the use of fluorinated phosphate, which does not contain water-soluble phosphorus, can lead to the least accumulation of mobile phosphorus in the soil. Water-soluble phosphorus can quickly pass into the soil solution and become available to plants, but it can also be easily washed out of the soil by rainwater, which can lead to environmental pollution. Thus, the right combination of fertilisers, considering the needs of plants and soil characteristics, can substantially increase the productivity of crops and reduce fertiliser costs.

According to Q. Wu *et al.* (2020), different forms of fertilisers may have different effectiveness on different types of soil. For example, nitrogen fertilisers can be represented in various forms, such as ammonium nitrate, urea, or ammonium salts. Some of these forms may dissolve better in acidic soils, while others may be more effective on alkaline soils. In addition, low availability of phosphorus is often observed in acidic soils, which can reduce the effectiveness of the use of phosphorus fertilisers. Therefore, to ensure the best efficiency of the use of fertilisers, it is necessary to consider the type of soil and its chemical composition in each specific area, and recommendations for the use of fertilisers. This will help to use resources as efficiently as possible and achieve high crop yields with minimal environmental impact.

A study by M. Berca *et al.* (2017) shows that the use of ammophos can have a positive effect on the yield of winter wheat grain, but it will not necessarily have advantages over a mixture of fertilisers. Thus, the use of ammophos at a dosage of 120 kg/ha affected the increase in winter wheat grain yield by 7.6%, compared with the control group without fertilisers. However, a mixture of fertilisers containing nitrogen, phosphorus, and potassium, at a dosage of 100 kg/ha, also gave an increase in grain yield by 7.5%, which indicates that this fertiliser can be no less effective. In addition, according to J. Singh *et al.* (2013), the use of ammonium nitrate in combination with phosphorus-potassium fertiliser can lead to the formation of a higher yield of winter wheat grain than when using only phosphorus-potassium fertilisers, which was also identified in the course of the study.

Similar results were obtained in a study conducted by L. Prysiazhniuk *et al.* (2023), according to which, the use of ammonium nitrate against the background of phosphorus-potassium nutrition led to an increase in the yield of winter wheat grain by 5-10% compared to only using phosphorus-potassium fertilisers. Therewith, not only the quantity of the crop increases but also the quality of the grain – its size, weight, and protein content. M.B.H. Ros *et al.* (2020) also claim that ammonium nitrate is a nitrogen fertiliser that promotes accelerated plant growth and increases their yield. In addition, nitrogen is necessary for the formation of chlorophyll, which plays a key role in photosynthesis, and for the formation of proteins, which are an important element of grain. Granulated superphosphate has a substantial effect on the formation of winter wheat grain yield. It contains 19.5% of phosphoric acid, which is one of the most important macronutrients for plants, especially for winter wheat. Phosphorus contributes to the development of the root system, strengthening of the stem, grain formation, and improvement of its quality (Keller *et al.,* 2021). In addition, granulated superphosphate has good solubility, which allows it to quickly enter the plant and have a positive effect on its development. Due to the granular form of the fertiliser, its application is simplified, since it is evenly distributed in the soil, which ensures maximum efficiency (De Oliveira *et al.,* 2020).

The results obtained correspond to those of a study by H.S. Jat *et al.* (2019), indicating that the use of granulated superphosphate can have a positive effect on the formation of a high yield of winter wheat grain, contributing to an increase in yield by 5-15%, depending on the dose. In addition, a study conducted in the fields of Kazakhstan showed that the use of granulated superphosphate at a dosage of 30 kg/ha gave an increase in the yield of winter wheat grain by 8.6%, compared with the control variant without fertilisers (Buntic *et al.,* 2019). Similar results were obtained in studies conducted in Ukraine, according to which, the use of granulated superphosphate at a dosage of 60 kg/ha gave an increase in the yield of winter wheat grain by 13%, compared with the control option without fertilisers (Solodushko *et al.,* 2021).

Considering the mentioned studies, and the results obtained in this one, it can be argued that the use of complex fertilisers containing all three main macronutrients – nitrogen, phosphorus, and potassium, provides the greatest effectiveness of the impact on winter wheat and increases its yield. However, it is necessary to consider the characteristics of the soil and follow the recommendations on the dosage and method of fertilisation to minimise the negative impact on the environment.

CONCLUSIONS

Obtaining a high yield of winter wheat is closely related to the use of nitrogen-containing fertilisers in crop rotation, which contributes to the accumulation of nitrate nitrogen in the soil. The highest concentration of nitrate nitrogen under winter wheat was noted when using a urea-formaldehyde form of fertiliser, with a decrease in its content when using ammonium nitrate, urea, and ammonium sulphate. No substantial changes in the nitrate content under the influence of phosphorus-containing mineral fertilisers have been established. It is also important to note that complex fertilisers, compared with a mixture of separate fertilisers, slightly increase the content of nitrate nitrogen in the soil. In addition, the accumulation of carbon-ammonium-soluble phosphates in the soil increases under the influence of forms of phosphorus fertilisers, but no substantial differences in the content of mobile phosphorus in the soil were identified. However, the tendency of increasing the accumulation of carbon-ammonium-soluble phosphates during the application of complex fertilisers was established.

Thus, it can be stated that it is preferable to use ammonium nitrate for winter wheat in crop rotation after rowed precursors from nitrogen forms of fertilisers. As an alternative, ammonium sulphate can also be used, and in extreme cases, urea. The use of the urea-formaldehyde form of fertilisers in the conditions of grey-meadow soils is ineffective. The introduction of granular superphosphate is more effective among the forms of phosphorus fertilisers. The action of fluorinated phosphate and especially double superphosphate is less effective, but in the absence of superphosphate, they can also be used for application under winter wheat. Among the complex fertilisers, ammophos contributes to the formation of a higher yield of winter wheat than ammonium phosphate. It was also identified that ammonium nitrate ensured the yield of winter wheat grain at the level of 56 centner/ha, ammonium sulphate – 53.1 centner/ha. The use of granulated superphosphate as a phosphorus fertiliser provided the highest level of winter wheat yield – 55.5 centner/ha and the highest increase in yield against the background of nitrogen-potassium nutrition – 8.7 centner/ha. The weakest effect on the yield of winter wheat was observed in double superphosphate. Consequently, on the grey-earth-meadow soils of Kyrgyzstan, with the correct selection of forms of mineral fertilisers in the crop rotation after corn, it is possible to obtain a harvest of winter wheat grain of more than 55 centner/ha.

The practical importance of the research results lies in the possibility of developing more effective methods of using fertilisers and increasing the yield of grain crops on grey-meadow soils of Kyrgyzstan and in other regions with similar soil and climatic conditions. The prospect of further research is to examine the economic efficiency of using various forms of mineral fertilisers, which can help agricultural producers make more informed decisions about which fertilisers to use and in what doses.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Ефективність форм мінеральних добрив і продуктивність озимої пшениці на сіроземно-лучних ґрунтах Киргизстану

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Анотація. Удобрення озимої пшениці необхідне, щоб забезпечити культуру поживними речовинами для оптимального росту, розвитку та формування врожаю. Однак, ефективність добрив може залежати від їхньої форми, а також від ґрунтових умов і клімату. Мета роботи – вивчити ефективність застосування різних форм мінеральних добрив на формування продуктивності пшениці озимої на сіроземно-лучних ґрунтах Киргизстану. Для досягнення поставленої мети у 2019-2021 рр. проводили польовий дослід у Навчально-дослідному господарстві Киргизького національного аграрного університету ім. К.І. Скрябіна. У результаті дослідження встановлено, що формування високої врожайності пшениці озимої тісно пов'язане із застосуванням у сівозміні азотовмісних добрив, що сприяє накопиченню в ґрунті нітратного азоту. Також відмічено суттєву дію на азотний режим ґрунту аміачної селітри та суперфосфату простого гранульованого. Концентрація вуглеамонійрозчинних фосфатів визначається діями сульфату амонію, аміачної селітри та всіх форм фосфорних добрив, але особливих змін у фосфатному режимі ґрунту під впливом форм фосфорних добрив не виявлено. Однак за використання складних добрив відзначено незначне накопичення рухомого фосфору в ґрунті. Внесення аміачної селітри забезпечує врожайність зерна озимої пшениці на рівні 56 ц/га, сульфату амонію – 53,1 ц/га. Суперфосфат простий гранульований забезпечив найвищий рівень урожаю озимої пшениці – 55,5 ц/га та найвищу прибавку до врожаю на фоні азотно-калійного живлення – 8,7 ц/га. Отже, під озиму пшеницю після просапних попередників з азотних форм добрив краще вносити аміачну селітру, а як її альтернативу – сульфат амонію або сечовину, з фосфорних форм добрив – суперфосфат простий гранульований. Практична значущість результатів дослідження дає можливість розробити більш ефективні методи використання добрив і збільшення продуктивності зернових культур на сіроземно-лучних ґрунтах Киргизстану, а також в інших регіонах зі схожими ґрунтово-кліматичними умовами

Ключові слова: нітратний азот; вуглеамонійрозчинний фосфор; сівозміна; сільське господарство; макроелементи