Removal and utilization coefficient of mineral fertilizers under various phosphate supply conditions

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Abstract. This study examines the effectiveness of mineral fertilizers, particularly phosphorus, in the cultivation of winter wheat varieties "Alekseyevich" and "Bezostaya 100" under various phosphate supply conditions in the meadow-gray soils of the Samarkand region. It was observed that the nutrient removal by both varieties increased with the rise in phosphate supply levels, fertilizer rates, and ratios. The highest nutrient removal was recorded in the low-phosphate supply background, whereas further increases in phosphate supply led to a decrease in removal. As nutrient removal increased, the utilization coefficient concurrently decreased. The relationship between these variables follows the linear regression equation y=a-bx, demonstrating a strong correlation. Specifically, for the "Alekseyevich" variety, the coefficients at very low, low, and medium phosphate supply levels were -0.99, -0.99, and -0.98, respectively. For the "Bezostaya 100" variety, these values were -0.98, -0.99, and -0.99, respectively.

1 Introduction

It is crucial that fertilizer application systems are developed not for general agricultural crops, but rather by taking into account the specific characteristics of a particular variety under diverse soil and climatic conditions. This approach allows for a more rational use of mineral fertilizers and more accurately reveals the yield and quality indicators of the variety [3].

Cultivating agricultural crops for long periods without fertilization leads to a sharp decrease in the amount of mobile phosphorus in the soil. This is due to the removal of phosphorus by crops and its only partial return to the soil through plant residues and a fraction of the applied fertilizers. Furthermore, the uptake of applied phosphorus by plants remains low. The phosphorus utilization coefficient for winter wheat from mineral fertilizers is approximately 25%, while for crop rotation systems, it can reach up to 40%. Conversely, extensive data exists regarding the increase in mobile phosphorus content in soils regularly treated with phosphatic fertilizers [1, 2].

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The balance method for calculating fertilizer rates is based on utilization coefficients, considering the removal of nutrients from both the soil and fertilizers by plants [4]. Due to the fact that utilization coefficients vary significantly under different soil-climatic conditions and are influenced by various factors, this method has not been recommended for planning mineral fertilizer use in recent years. In calculations, it is essential to consider prospective indicators, such as removal competence and standards [5].

In the southern zone of the Amur region, applying a nitrogen fertilizer rate of 30 kg/ha in wheat cultivation led to a 14-22% increase in nitrogen utilization coefficients in accordance with different phosphate supply levels: low (27-35 mg/kg), medium (37-50 mg/kg), and high (55-95 mg/kg). Applying a uniform nitrogen rate of N30 across varying phosphate supplies resulted in an increase in nutrient removal and utilization coefficients by 33%, 60%, and 83%, respectively [6].

One of the primary contemporary challenges is achieving high and high-quality yields of agricultural crops, including winter wheat, while simultaneously enhancing soil fertility. The meadow-gray soils of the Samarkand region vary in their phosphorus supply, making the study of the effectiveness of mineral fertilizers, particularly phosphorus, highly relevant in these conditions. The scientific significance of this research lies in identifying optimal mineral fertilizer rates and ratios: for very low phosphate supply, a ratio of 1.0:0.8:0.6 (N210P170K126); for low supply, a ratio of 1.0:0.7:0.5 (N180P125K90); and for medium supply, a ratio of 1.0:0.6:0.4 (N150P90K60 kg/ha).

With the reduction of mineral fertilizer ratios and rates due to the increase in natural soil phosphate supply, grain quality indicators improved in both winter wheat varieties. While nutrient removal increased, the fertilizer utilization coefficient decreased. From a practical standpoint, the highest phosphorus utilization coefficients achieved were 13.0% and 14.4% for the "Alekseyevich" and "Bezostaya 100" varieties, respectively, in light-colored gray soils, and 13.3% and 15.0% in meadow-gray soil conditions.

2 Materials and Methods

Field experiments were conducted under the conditions of irrigated meadow-gray soils in the Samarkand region, characterized by varying levels of mobile phosphorus content. Field and laboratory studies were carried out based on standard methods accepted in agrochemistry, and the obtained data were subjected to dispersive, correlational, and regressive analysis according to B.A.Dospekhov [7]. The objects of research included meadow-gray soils with different levels of mobile phosphorus supply, winter wheat varieties "Alekseyevich" and "Bezostaya 100", and mineral fertilizers: ammonium nitrate NH_4NO_3 (N – 34.5%), simple superphosphate - $Ca(H_2PO_4)_2$ * H_2O + $CaSO_4$ (19–20 % P_2O_5), and potassium chloride - KCl (56% K_2O).

The field experiments consisted of 3 backgrounds based on the soil's mobile phosphorus supply, with 4 variants and 4 replications. The total area of each experimental plot was 100,8 m^2, with a harvestable (accountable) area of 50 m^2. Plant and soil analyses were performed using standard methodologies generally accepted in agrochemistry and soil science.

3 Results and discussion

In the first year of our research (2020), conducted under the conditions of irrigated meadow-gray soils in the Akdarya district, the phosphorus utilization coefficient for the "Alekseyevich" variety of winter wheat reached its maximum at 13.3% in the variant with very low phosphate supply when N150P120K90 was applied. However, as mineral

fertilizer rates increased, the utilization coefficient concurrently decreased. In the background with low phosphate supply, the highest phosphorus utilization coefficient was 12,9% in the variant where N150P105K75 was applied. In contrast, this figure was 11,5% in the N180P125K90 variant and 10,1% in the N210P145K105 variant, confirming that the utilization coefficient decreases as the fertilizer rate increases within this specific background.

It was observed that while the utilization coefficients for nitrogen, phosphorus, and potassium fertilizers slightly increased with the rise in phosphate supply levels, they decreased as the overall mineral fertilizer rates were increased (Table 1).

Table 1. Nutrient removal and utilization coefficient of mineral fertilizers under various phosphate supply conditions (Akdarya district, "Alekseyevich" variety, 2020).

Background (Soil P status)	Variants	Yield (s/ha)	Yield increase over control (s/ha)	Nutrient removal from mineral fertilizers (kg)			Utilization coefficient (%)		
				N	P	K	N	P	K
Background I (Very Low)	Control (Unfertilized)	37.50	0	0	0	0	0	0	0
	N_{150} P_{120} K_{90}	59.70	22.20	66.8	15.9	46.2	44.5	13.3	51.3
	N_{180} P_{145} K_{108}	62.40	24.90	78.1	17.1	52.8	43.4	11.8	48.9
	N_{210} P_{170} K_{126}	67.10	29.60	89.2	17.8	58.9	42.5	10.5	46.7
Background II (Low)	Control (Unfertilized)	39.00	0	0	0	0	0	0	0
	N_{150} P_{105} K_{75}	62.00	23.00	69.4	13.5	44.7	46.3	12.9	59.6
	N_{180} P_{125} K_{90}	66.60	27.60	80.8	14.4	51.5	44.9	11.5	57.2
	N_{210} P_{145} K_{105}	69.00	30.00	91.2	14.7	57.1	43.4	10.1	54.4
Background III (Medium)	Control (Unfertilized)	40.70	0	0	0	0	0	0	0
	N_{150} P_{90} K_{60}	6620	25.50	71.4	11.2	40.7	47.6	12.4	67.8
	N_{180} P_{110} K_{72}	67.50	26.80	81.1	12	47.3	45.1	10.9	65.7
	N_{210} P_{130} K_{84}	70.10	29.40	91.1	12.7	53.2	43.4	9.8	63.3

The utilization coefficients of mineral fertilizers applied to the "Bezostaya 100" variety of winter wheat under the conditions of the Akdarya district are presented in Table 2. According to the data, the phosphorus utilization coefficient for the "Bezostaya 100" variety was higher than that of the "Alekseyevich" variety. Specifically, the highest utilization coefficient was recorded at 15.0% in the variant with very low phosphate supply where N150P120K90 kg/ha was applied. In subsequent variants, the utilization coefficients decreased to 13,3% for N180P145K108 kg/ha and 12,1% for N210P170K126 kg/ha. The lowest indicator was observed under medium phosphate supply conditions, reaching 10.3% in the variant where N210P130K84 kg/ha was applied (Table 2).

Table 2. Nutrient removal and utilization coefficient of mineral fertilizers under various phosphate supply conditions (Akdarya district, "Bezostaya 100" variety, 2020).

Background (Soil P status)	Variants	Yield (s/ha)	Yield increase over control (s/ha)	Nutrient removal from mineral fertilizers (kg)			Utilization coefficient (%)		
				N	P	K	N	P	K
Background I (Very Low)	Control (Unfertilized)	48.40	0	0	0	0	0	0	0
	N150 P120 K90	77.80	29.40	69.0	18.0	48.3	46.0	15.0	53.7
	N180 P145 K108	82.45	34.05	81.5	19.3	54.7	45.3	13.3	50.6
	N210 P170 K126	89.20	40.80	94.1	20.5	59.7	44.8	12.1	47.4

Background II (Low)	Control (Unfertilized)	51.00	0	0	0	0	0	0	0
	N150 P105 K75	80.60	29.60	71.4	14.7	45.3	47.6	14	60.4
	N180 P125 K90	86.70	35.70	83.5	15.8	51.1	46.4	12.7	56.8
	N210 P145 K105	91.20	40.20	94.4	16.8	55.1	45	11.6	52.4
Background III (Medium)	Control (Unfertilized)	53.50	0	0	0	0	0	0	0
	N150 P90 K60	85.10	31.60	75.6	12.2	39.1	50.4	13.6	65.2
	N180 P110 K72	88.40	34.90	83.8	13.3	44.3	46.5	12.1	61.5
	N210 P130 K84	92.70	39.20	89.5	13.5	48.2	42.6	10.3	57.4

Under the conditions of meadow-gray soils in the Akdarya district, a consistent decrease in fertilizer utilization coefficients was observed in both varieties as mineral fertilizer rates increased throughout the research years.

In the meadow-gray soils of the Akdarya district with varying phosphate supply levels, the relationship between mineral fertilizer rates/ratios and the phosphorus utilization coefficients of "Alekseyevich" and "Bezostaya 100" winter wheat varieties followed the linear regression equation y = a - bx. The correlation between these variables was found to be highly significant (strong). Specifically, for the "Alekseyevich" variety, the correlation coefficients at very low, low, and medium phosphate supply levels were -0.99, -0.99, and -0.98, respectively. For the "Bezostaya 100" variety, these values were -0.98, -0.99, and -0.99, respectively (Table 3).

Table 3. Relationship between mineral fertilizer rates/ratios and phosphorus utilization coefficients (Akdarya district, meadow-gray soil).

Background (Soil P status)	Variants	Alekseyevich" variety		Bezostaya 100" variety	
		regression equation	correlation coefficient	regression equation	correlation coefficient
Background I (Very Low)	N_{150} P_{120} K_{90}	Y=1.4-14.7x	r= -0.99	Y=1.4-16.4x	r= -0.98
	N_{180} P_{145} K_{108}				
	N_{210} P_{170} K_{126}				
Background II (Low)	N_{150} P_{105} K_{75}	Y=1.4-14.3x	r= -0.99	Y=1.2-15.2x	r= -0.99
	N_{180} P_{125} K_{90}				
	N_{210} P_{145} K_{105}				
Background III (Medium)	N_{150} P_{90} K_{60}	Y=1.3-13.6x	r= -0.98	Y=1.6-15.3x	r= -0.99
	N_{180} P_{110} K_{72}				
	N_{210} P_{130} K_{84}				

Under the conditions of meadow-gray soils, it was observed that the fertilizer utilization coefficients for the "Bezostaya 100" variety were slightly higher than those for the "Alekseyevich" variety. Furthermore, the utilization coefficients decreased as the phosphate supply levels increased. As crop yields increased, the removal of nutrients from both the soil and the applied mineral fertilizers also showed a corresponding increase.

4 Discussion

In the studies conducted by V.G. Sechev et al., the efficiency of fertilizer use in crop rotation fields is determined by the economic removal of nutrients from the crop yield. Its primary criterion is considered positive within the framework of stabilizing production processes. One of the critical indicators characterizing the mineral nutrition regime and the

effectiveness of fertilizer utilization during plant development is the uptake of nutrients relative to the applied amount [8].

According to S.N. Adrianov, under varying phosphate supply conditions in the ordinary gray soils of the Ili district, Almaty region—specifically a natural background (18–20 mg/kg) and an enhanced background (28–30 mg/kg)—the removal of nitrogen and phosphorus by winter wheat varies depending on fertilizer application and the soil's phosphate level. The application of nitrogen fertilizers increased nitrogen removal to 27–30 kg per unit of winter wheat yield, while phosphorus removal increased from 10.3 to 12.5\ kg/t in the natural background. As the phosphate supply increased to 28–30 mg/kg, the removal of nitrogen and phosphorus rose to 31.0 and 12.8 kg/t, respectively. The phosphorus balance was negative in the natural background but became positive in the high-phosphate background. Furthermore, while the nitrogen balance was positive with the application of nitrogen fertilizers, it became negative under high-phosphorus background conditions [9].

Research conducted in the Minsk region on moderately loamy podzolic soils examined the "Avgustin" winter wheat variety. Under a fertilization regime of N70+40+40P65K115, the crop achieved a yield of 60.5 c/ha, resulting in a nutrient extraction of 140 kg of Nitrogen (N), 62 kg of Phosphorus (P), and 62 kg of Potassium (K) from the soil. In comparison, an alternative approach utilizing N70+40+40P55K70 supplemented with 3 t/ha of straw and 20 kg of N via UAN (liquid fertilizer) enhanced the yield to 62.6 c/ha. In this scenario, the total NPK removal was recorded at 157 kg, 54 kg, and 63 kg/ha, respectively [10].

Similarly, studies in the Voronezh region on typical chernozem soils with average humus content analyzed the "Krastal" variety. In the unfertilized control group, the total nutrient uptake (including primary and secondary products) was 77.9 kg N, 28.1 kg P, and 43.4 kg K. Application of mineral fertilizers significantly increased these figures: At a dose of N30P30K30, uptake reached 92.4, 33.7, and 57.6 kg. With N50P50K50, values rose to 99.8, 39.0, and 63.1 kg.

The most intensive regime (N60P60K60 + N30+30+30) resulted in a removal of 111.1 kg N, 39.1 kg P, and 64.3 kg K. Furthermore, data from five additional wheat varieties confirmed a consistent upward trend in nutrient consumption relative to fertilizer application [11].

The data obtained in our studies align with the findings of the aforementioned researchers; however, certain variations were observed attributable to soil and climatic conditions, specific varietal characteristics, types of mineral fertilizers applied, and the initial nutrient levels of the soil.

5 Conclusion

In conclusion, under the conditions of meadow-gray soils in the Samarkand region with varying phosphate supply levels, nutrient removal in both winter wheat varieties increased as mineral fertilizer rates rose. Specifically, for the "Alekseyevich" variety under very low phosphate supply conditions, increasing fertilizer rates led to an increase in nutrient removal of nitrogen by 66.8–89.2 kg/ha, phosphorus by 15.9–17.8 kg/ha, and potassium by 46.2–58.9 kg/ha. In the low phosphate supply background, these values were 69.4–91.2, 13.56–14.7, and 44.7–57.1 kg/ha, respectively. Under medium phosphate supply, nitrogen removal ranged from 71.4–91.1, phosphorus from 11.2–12.7, and potassium from 40.7–83.2 kg/ha. The highest nutrient removal was observed in the low phosphate supply background. A similar trend was recorded for the "Bezostaya 100" variety.

As mineral fertilizer rates increased across different phosphate supply levels, the utilization coefficients of the applied mineral fertilizers, particularly phosphorus, showed a

downward trend. In very low phosphate supply meadow-gray soils, the highest utilization coefficients were achieved in the variant where N150P120K90 kg/ha was applied, reaching 13.3% for "Alekseyevich" and 15.0% for "Bezostaya 100". The utilization coefficient decreased with the further increase of both soil phosphate supply and mineral fertilizer rates. It was statistically proven that the correlation between increasing mineral fertilizer rates and the phosphorus utilization coefficient follows an inverse linear regression equation, demonstrating a high density of relationship (strong correlation).

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