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The Effect of Available Phosphates on Yields of Vegetable and Beet Crop Rotations, their Bioenergetic and Economic Efficiency.

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ABSTRACT

The article presents data on the effect of the available phosphates on crop yields of vegetable and beet crop rotations and their economical efficiency. The highest yield of sugar beet (480-490 kg/ha, 2012) can be obtained applying a double dose rate of phosphorus (P_{180}) at seasonal average soil content of labile phosphorus more than 45 mg/kg and soluble phosphates more than 440 mg/kg of soil.
Keywords: soil, fertilizer, nitrogen, phosphorus, potassium, sugar beet, grain maize, late cabbage, crop rotation.

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INTRODUCTION

Soil is an integral component of the biosphere, performing important ecological functions, which are largely dependent on the extent of its cultivation. The level of soil fertility determines the stability and productivity of phytocoenozis, diverse and healthy wildlife. Therefore, the rational use of soils and protecting them against degradation is a critical task not only of agriculture, but also the state in general. Fertilizers are powerful means to influence the ecological functions of soil, crop production, as well as preservation and expanded reproduction of soil fertility.

It is well known that the effect of fertilizers on soil is quite multifaceted: they may have different effect on the reaction of environment in the soil, the absorption or expulsion of ions into the soil solution, the state of humus, biogenic elements, and microbiocenosis.

The phosphorus problem in agriculture is a highly relevant and still insufficiently developed both in Kazakhstan and some other countries. It includes the problems related to phosphorus forms in soils, ways of mobilizing it for assimilation by plants, as well as the study of the conditions for more rational application of phosphate fertilizers [8, 14, 15].

Phosphorus, as a nutrition element in the life cycle of plants, plays a significant role. Relative and absolute phosphorus content in the plant is several times smaller than, for example, nitrogen and potassium. However, in terms of physiological and biochemical functions, and even more, energy function, its share in the biological cycle is equivalent to the nitrogen. Mobilization of phosphorus from the soil and fertilizers in the amount of 25-35% gives rise to problem of management the phosphorus soil regime as part of the general problem of agricultural chemistry, namely the development of mineral nutrition management systems, as well as control of substance and energy flows in intense agrophytocenosis. Achievement of planned productivity of agrophytocenosis in contemporary conditions is rightly associated with significant scientific and technological progress in agriculture, the widespread use of scientific developments in the field of soil chemistry and plant nutrition.

Until recently, at the turn of the XX century, it was believed that phosphorus was the most studied element in agrochemical science. Without questioning this assertion in general, it should be mentioned, however, that the development of agricultural chemistry of phosphorus, especially in terms of its practical application, underwent and still is undergoing significant qualitative changes in accordance with the development of the productive forces. It evolves in parallel with the development of industries related to agricultural knowledge and theoretical foundations of other fundamental research that is subjected to the general course of the global socio-economic metamorphosis in Russia.

In Kazakhstan, the possibility of applying phosphate fertilizers began to be considered in the late 30s of the XX century. The first works of this period were the research works of scientists. Subsequently, the basic principles of the approach to effective application of phosphate fertilizers were summarized for sugar beet crop rotations in Ili Alatau irrigated zone [11, 2, 6, 7, 17, 5].

When applying phosphate fertilizer at the rates exceeding the amount of phosphorus, which can be removed by plant crops, soils show improvement in phosphate nutrition regime that is caused by the accumulation of residual forms of phosphates. At reaching the optimal level of their content, ensuring maximum yield of crops, yield increase by an additional application of phosphates plummets. To optimize the dose rate of phosphate fertilizers, it is necessary to know the available level of labile phosphorus and soluble fractions of mineral phosphates, which can ensure the achievement of highest yields of crops [9, 1, 3].

MATERIALS AND METHODS

Research was carried out at the site of Kazakh Agriculture and Crop Research Institute (KazNII) under the conditions of the 7-pole beet crop rotation on light-chestnut soils, as well as at the site of Kazakh Potato and Vegetable Research Institute under the conditions of the 4-pole intense vegetable crop rotation.

The area of the experimental plots was 67.2 m^2 (4.2 m x 16 m). The experiments were carried out at fourfold tier.

Types of fertilizers, applied in the crop rotation, included the following: ammonium nitrate (34% of application rate, a.r.), double acid phosphate (40% of a.r.), and potassium chloride (60% of a.r.). All kinds of fertilizers were applied in early spring period for 1.5-2 months.

RESEARCH RESULTS

The analysis and grouping of data on sugar beets, grain maize, soybean and late cabbage from field experiments on irrigated chestnut soils show a direct correlation between the indicators of soil phosphate regime and crop yields just to a certain limit, beyond which the positive effect disappears. In light-chestnut soils, where the content of labile phosphorus in the check was more than 15 mg/kg and the total soluble fractions of mineral phosphates was 340 mg/kg of soil, the average yield of sugar beet was an average of 85-100 kg/ha. The highest yield of sugar beets (480-490 kg/ha) can be obtained applying a double dose rate of phosphorus (P_{180}) at seasonal average soil content of labile phosphorus more than 45 mg/kg of soil and soluble phosphates more than 440 mg/kg. The most effective option with reliable yield increase of sugar beet (450-480 kg/ha) can be obtained by applying one and a half dose rate of phosphorus fertilizer (P_{135}) at the seasonal soil content of labile phosphorus in amount of 40-45 mg and the first two groups of mineral phosphates in amount of 410-440 mg/kg of soil.

Table 1: Crops yield at different levels of phosphorus nutrition (0-20 cm, mg/kg)

Test options	Concentration level of P_2O_5 mg/kg in soil						The average yield of crop rotation
	Sum ($Ca\text{-}P_I + Ca\text{-}P_{II}$)			Labile phosphorus			
	Spring	Fall	The average during the vegetation	Spring	Fall	The average during the vegetation	
	Light-chestnut soil, sugar beets, hundredweight/ha (2012)						
Control	260	235	<340	16.5	12.0	<15	85-100
NK	262	250	340-375	20.0	17.5	15-25	110-120
NPK	385	410	375-400	43.3	28.4	35-40	400-450
$NP_{1.5}K$	450	422	410-440	59.0	35.4	40-45	450-480
$NP_{2.0}K$	470	420	>440	61.0	40.0	>45	480-490
	Light-chestnut soil, grain maize, hundredweight/ha (average per two years, 2012-2013)						
Control	274	235	250-255	17.4	12.0	10-15	60-85
NK	277	250	260-264	20.2	15.5	15-20	85-95
NPK	445	410	425-428	41.3	28.4	32-35	95-110
$NP_{1.5}K$	500	452	470-480	57.0	35.4	42-46	110-125
$NP_{2.0}K$	540	489	510-515	64.0	40.0	<50	125-130
	Light-chestnut soil, soybean, hundredweight/ha (2014)						
Control	255	215	220-250	15.4	12.0	10-15	20-25
NK	268	220	250-260	19.0	15.5	15-25	25-30
NPK	390	425	410-420	40.5	27.5	25-35	30-35
$NP_{1.5}K$	480	445	440-480	55.0	30.7	45-50	35-40
$NP_{2.0}K$	550	500	500-520	60.0	35.0	<50	40-42
	Dark-chestnut soil, late cabbage, hundredweight/ha (average per three years, 2012-2014)						
Control	321	300	310-320	17.4	13.0	10-15	28-30
NK	446	407	415-427	56.4	40.0	40-48	30-35
NPK	488	450	455-470	68.0	43.0	50-55	35-42
$NP_{1.5}K$	564	500	520-532	78.0	58.0	60-68	42-47

When the content of labile phosphorus in the check was 10-15 mg/kg and the total amount of soluble fractions of mineral phosphates was 250-255 mg/kg of soil, the average yield of grain maize for 2 years of the study amounts on average to 60-85 hundredweight/ha. In the option, where the content of loosely bound groups and various-based mineral phosphates was 470-480 mg/kg and labile phosphorus was 45-50 mg/kg, the grain maize yield was 110-125 kg/ha. According to test data, the increase in the content of labile phosphorus to a value not exceeding 50 mg/kg and the total amount of soluble fractions to 510-515 mg/kg through the long-term and systematic application of double dose rate of phosphorus (P_{120}) does not result in increase of grain maize yield (Table 1).

Therefore, when cultivating grain maize in the crop rotation, the labile phosphorus content must be maintained at the level of 45-50 mg/kg, whereas the total amount of soluble fractions of mineral phosphates should be kept within the range of 470-480 mg/kg that will provide the yield of more than 110 kg/ha of grain maize.

Most reliable yield of soybean (35-40 t/ha) can be obtained at one and a half dose rate of phosphorus (P_{90}), where the seasonal average phosphorus content in the light-chestnut soil was 45-50 and the amount of phosphates of the first two groups was 440-480 mg/kg of soil.

Vegetable crops are very demanding to the soil nutrition regime, especially phosphorus content in the soil (at that, the amount of nutrients should be higher than for other groups of crops). The maximum average yield of late cabbage (42-47 t/ha), cultivated in intense vegetable crop rotation on irrigated dark chestnut soil was obtained at the average seasonal content of labile phosphorus of 60-68 mg and the total amount of soluble fractions of 520-532 mg/kg of soil, when applying a triple dose rate (P_{90}) of phosphorus fertilizer. However, the most reliable option, showing a perceptible increase in the crops yield due to the application of fertilizers, was obtained in cabbage crops, which amounted to 35-42 t/ha at the content of labile phosphorus within the range of 50-55 mg and variation of the total amount of soluble phosphate fractions within the range 455-470 mg/kg of soil. In the check for vegetable crops and particularly for cabbage, the content of the labile phosphorus in the soil was 10-15 mg and the total amount of soluble phosphates was 310-320 that is considered low; though such low content affected the yield of cabbage, which amounted to 28-30 t/ha.

The established levels of phosphates content may be used in the optimization of nutrient status of dark chestnut and light chestnut soils of Kazakhstan, when monitoring and controlling nutrition of studied plants, cultivated in crop rotations.

Bioenergy efficiency of mineral fertilizers in intense vegetable crop rotation is rather important. Aggravation of the energy situation in the world has resulted in increased interest to energy issues of the economy, including agriculture, which is the main and single source of country's foodstuff.

Calculations of energy efficiency give a more objective and long-term view on the fertilizers effectiveness than the economic evaluation. This is because, as mentioned above, the values of cost parameters change depending on the demand of market relations.

Crop production in agriculture is associated with non-renewable energy use, including the production of fertilizers. It is therefore important to develop and apply energy-saving agricultural technologies, making it possible to use less energy in crop production. This requires knowledge of the calculation basis of the energy efficiency of fertilizers application in advanced technologies.

The essence of the energy analysis is that all quantitative indicators, such as the actual increase in the agricultural crops yield due to application of fertilizers, as well as the cost of fertilizers application, are expressed in energy equivalent, i.e. joules. Joule (J) is a unit of energy, work and heat quantity in the International System of Units. Larger units of energy are 1 kilojoule (kJ)=10^3 J, gigajoule (GJ) = 10^9. Besides, J=0.2388 calories (Table 2).

In intense vegetable crop rotation, the energy content in the average yield increase of cabbages over 3 years of research on fertilized soils ranged from 8185-17806 MJ and depended on the application of a single, double or triple dose rates of fertilizers.

The energy content of the basic production increase of the studied crops in beet crop rotation on fertilized soils was as follows: sugar beet - 5266-111744 MJ (2012), grain maize - 14383-77971 MJ (2012-2013), and soybeans - 21901-30951 MJ (2014). The highest rates were obtained when applying one and a half and double dose rates of phosphorus fertilizer, whereas the energy content was the lowest, when the phosphorus fertilizer (NK) was not applied.

Table 2: The energy content and bioenergy efficiency of fertilizers

Test options	Crop yield increase hundred-weight/ha	Energy content, MJ	Energy consumption at application of fertilizers, MJ	Energy efficiency, units
Vegetable crops rotation, late cabbage, t/ha, average during 2012-2014				
Control	-			
$N_1 P_1 K_1$	50.0	8185	8072.0	1.01
$N_2 P_2 K_2$	106.0	16790	16146.0	1.04
$N_3 P_3 K_3$	140.0	17806	24219.0	0.74
Beets crop rotation, sugar beets, hundredweight/ha, 2012				
Control	-			
NK	18.0	5266	15192	0.35
NPK	370	94663	16326	5.80
$NP_{1.5}K$	398	101744	16893	6.02
$NP_{2.0}K$	360	111744	17905	6.20
Beets crop rotation, grain maize, hundredweight/ha, 2012-2013				
Control	-	-	-	-
NK	9.5	14383	16990	0.84
NPK	40.8	61771	17746	3.48
$NP_{1.5}K$	47.6	72066	18124	3.98
$NP_{2.0}K$	51.5	77971	18502	4.21
Beets crop rotation, soybean, hundredweight/ha, 2014				
Control	-	-	-	-
NK	12.1	21901	12660	1.73
NPK	14.5	26245	13416	1.96
$NP_{1.5}K$	17.0	30770	13794	2.23
$NP_{2.0}K$	17.1	30951	14172	2.18

In terms of total energy consumption on technology processes, the mineral fertilizers are characterized by the following values per one kg of active ingredient: nitrogenous fertilizers - 86.6 MJ, phosphate and potash fertilizers - 12.6 and 83.3 MJ respectively. Due to the higher energy consumption in the production of nitrogenous fertilizers, they have the lowest energy efficiency.

Energy consumption for the application of mineral fertilizers in intense vegetable crop rotation on cabbage (2012-2014) amounted to 8072 MJ at application of a single dose rate of fertilizer, while 16146 MJ at the double dose rate and 24219 MJ at the triple dose rate.

Similarly, in the beet crop rotation: for sugar beet (2012), when applying NK - 15192 MJ, at a single dose rate of phosphorus (P_{90}) -16326 MJ, at one and a half dose rate of phosphorus (P_{135}) - 16893 MJ, and at a double dose rate of phosphorus (P_{180}) - 17905 MJ; for grain maize (2012-2013): 16990, 17746, 18124 and 18502 MJ, respectively; and for soybeans (2014): 12660, 13416, 13794 and 14172 MJ, respectively.

The main indicator showing the energy efficiency of fertilizer application is the energy efficiency ratio. The energy efficiency ratio, greater than unity, indicates the efficient application of fertilizers.

Thus, energy efficiency in intense vegetable crop rotation of the late cabbage in fertilized soils was as follows: 1.01 and 1.04 units for single and double dose rates of fertilizers, respectively; while 0.74 units - for triple dose rate.

In the beet crop rotation, energy efficiency of the studied crops was higher. This is because sugar beets, grain maize and soybean are crops that contain more amount of dry basis. Thus, the energy efficiency of these crops amounted for 5.80-6.20 units. At that, sugar beet showed the best result, when applying the complete mineral fertilizer with a combination of different dose rates of phosphorus fertilizer, i.e. single (P_{90}), one and a half (P_{135}) and double dose rates (P_{180}); Grain maize showed the best results in terms of energy efficiency, namely 3.48-4.21 units, in the same options ($P_{60.90.120}$) as sugar beet; for soybeans the best options were those with one and a half and double dose rates of phosphorus ($R_{90,120}$), which provided 2.23 and 2.18 units, respectively.

To evaluate the application of mineral and organic fertilizers for agricultural crops, we also determine their economical efficiency.

The economic evaluation of fertilizers application is rather important. However, the prices on fertilizers and agricultural products vary depending on market conditions, so they can be considered only for short-range planning.

Key indicators of economic efficiency of different types of fertilizers include the net proceeds of their application and its derivatives, such as net income per one tenge of production costs and per unit of applied fertilizer, as well as profitability.

The efficiency of applied fertilizers depends on the farming standard. The higher the farming standard, the more efficient is the effect of applying fertilizers. Here crucial is general standard of farming, as well as peculiarities of agrotechniques, irrigation methods, irrigation regime and other factors.

Economic efficiency of fertilizers is quite high. In particular, mineral fertilizers applied to leading crops in the proper dose rate and combination, cover not only all the costs of their application in the first year, but also give a profit.

The most important point when evaluating agronomic and economic efficiency of fertilizers is the determination of crop increases due to fertilizers applied [16], [10], [12], [13], [5].

Calculations of economic efficiency in our experimental data have shown that the application of mineral fertilizers led to essential increase in crops, which depended on the dose rates of applied fertilizers (Table 3).

Table 3: Economic efficiency of the fertilizers application

Test options	Applied kg of NPK a.r.	Average crop yield, t/ha	Increase in crop	Payback per kg of NPK a.r. by product
Vegetable crops rotation, late cabbage, t/ha, average during 2012-2014				
Control	0	31.5	-	-
$N_1 P_1 K_1$	120	36.5	5.0	41.7
$N_2 P_2 K_2$	240	42.1	10.6	44.2
$N_3 P_3 K_3$	360	45.5	14.0	38.9
Beets crop rotation, sugar beets, hundredweight/ha, 2012				
Control	0	100	-	-
NK	180	118	18.0	10.0
NPK	270	470	370	137.0
$NP_{1.5}K$	315	498	398	126.3
$NP_{2.0}K$	360	460	360	100.0
Beets crop rotation, grain maize, hundredweight/ha, 2012-2013				
Control	0	88.0	-	-
NK	200	97.5	9.5	4.8
NPK	260	128.0	40.8	15.7
$NP_{1.5}K$	290	135.6	47.6	16.4
$NP_{2.0}K$	320	139.5	51.5	16.1
Beets crop rotation, soybean, hundredweight/ha, 2014				
Control	0	7.4	-	-
NK	150	19.5	12.1	8.1
NPK	210	21.9	14.5	7.0
$NP_{1.5}K$	240	24.2	17.0	7.1
$NP_{2.0}K$	270	24.5	17.1	6.3

Thus, the application of a single dose rate of fertilizers ($N_{60}P_{30}K_{30}$) gave an increase by 5.7 t/ha, the application of double dose rate of fertilizers ($N_{120}P_{60}K_{60}$) almost doubled the increase, which amounted to 10.2 t/ha, whereas triple dose rates ($N_{180}P_{90}K_{90}$) gave an increase of 12.4 t/ha.

The quantity of agricultural products, resulting from the application of fertilizers, is expressed as an increase of crop yields in kilograms per kg of NPK or per ton or organic fertilizers, and is calculated by dividing the difference between the crop yields obtained on fertilized and unfertilized plots per dose rate of fertilizer.

DISCUSSION

In our experiments, the return per kg of NPK a.r. by main products (cabbages) at application of a single dose rate of fertilizer was 41.7 kg, at double and triple dose rates the return amounted for 44.2 and 38.9 kg of basic products, respectively. The most effective option in intense vegetable crop rotation proved the one corresponding to the application of a double dose rate of fertilizer (N_2 P_2 K_2), where a return per kg of NPK a.r. by main products (cabbage) was on the average of 44.2 kg for the 3 years of the study.

When determining the return per kg of NPK a.r. by beet rotation crops (sugar beet, grain maize and soybeans) as main products, it is obvious that the most effective options for these crops are single and one and a half dose rates of phosphorus fertilizer. Thus, the return of one kg of NPK a.r by sugar beet for these options was 137 ($P_{1.0}$) and 126.3 ($P_{1.5}$) kg, grain maize - 15.7 and 16.4 kg, and soybeans - 7.0 and 7.1 kg, respectively. Thus, the calculation of economic efficiency was carried out only by summing the yield increase due to the application of fertilizer and return of one kg of NPK a.r. by main products, because prices for mineral fertilizers and agricultural products vary depending on market conditions, so they can be evaluated only for short-range planning.

In the last decade, along with traditional methods of evaluating the effectiveness (economic and agronomic) of agricultural production through labor and monetary indicators, increasingly important becomes the method of energy evaluation of modern agricultural technologies, which takes into account both the amount of energy, accumulated in agricultural products, and the energy consumed during their production.

Final part

The highest yield of sugar beet (480-490 kg/ha, 2012) can be obtained using a double dose rate of phosphorus (P_{180}) at seasonal average soil content of labile phosphorus more than 45 mg/kg and soluble phosphates more than 440 mg/kg of soil.

The most effective option with reliable yield increase of sugar beet (450-480 kg/ha) can be obtained by applying one and a half dose rate of phosphorus fertilizer (P_{135}) at the seasonal soil content of labile phosphorus in amount of 40-45 mg and the first two groups of mineral phosphates in amount of 410-440 mg/kg of soil.

In case, where the content of loosely bound groups and various-based mineral phosphates is 470-480 mg/kg and labile phosphorus is 45-50 mg/kg, the grain maize yield amounts for 110-125 kg/ha. According to test data, the increase in the content of labile phosphorus to a value not exceeding 50 mg/kg and the total amount of soluble fractions to 510-515 mg/kg due to long-term and systematic application of double dose rate of phosphorus (P_{120}) does not result in increase of grain maize yield (Table 1). Most reliable yield of soybean (35-40 t/ha) corresponds to application of one and a half dose rate of phosphorus (P_{90}), where the seasonal average phosphorus content in the light-chestnut soil is 45-50 and the amount of phosphates of the first two groups is 440-480 mg/kg of soil. The most reliable option, showing a perceptible increase in the crops yield due to the application of fertilizers was obtained in cabbage crops, which amounted to 35-42 t/ha. This was achieved at the content of labile phosphorus within the range of 50-55 mg and variation of the total amount of soluble phosphate fractions within the range 455-470 mg/kg of soil.

Single and double dose rates of fertilizers in intense vegetable crop rotation turned out to be energy efficient for late cabbage; energy efficiency ratio for these two options is greater than unit. Triple dose rate for late cabbage turned out to be more expensive to grow production unit.

In the tests, the return of one kg of NPK a.r. for cabbage within 3 years of the study was 41.7 kg when applying a single dose rate of fertilizer, and 44.2 and 38.9 kg at double and triple dose rates. The most efficient option was the one with the application of a double dose rate of fertilizer, where the return of one kg of NPK a.r. by cabbage averaged over 3 years of the study to 44.2 kg. Return of one kg of NPK a.r. by sugar beet (2012) in these options was 137 ($P_{1.0}$) and 126.3 kg ($P_{1.5}$), grain maize - 15.7 and 16.4 kg, and soybean - 7.0 and 7.1 kg, respectively. Single and double dose rates of fertilizers were turned out to be energy efficient for late cabbage; here the energy efficiency ratio is larger than unity. Thus, energy efficiency of the late cabbage was respectively 1.01 and 1.04 units at single and double dose rates of fertilizers, while 0.74 units at triple dose rate. In the beet crop rotation the following options have shown the best results: for sugar beet (2012) application of complete mineral fertilizer in combination with different dose rates of phosphorus fertilizer, i.e. single (P_{90}), one and a half (P_{135}) and double (P_{180}) resulted in 5.80-6.20 units; Grain maize (2012-2013) has shown the same best options ($P_{60.90.120}$) that corresponded to 3.48-4.21 units; while soybean (2014) proved the best results at one and a half and double dose rates of phosphorus ($P_{90.120}$) and amounted for 2.23 and 2.18 units, respectively.

CONCLUSIONS

In the beet crop rotation energy efficient options were those with complete application of mineral fertilizers in combination with different dose rates of phosphorus fertilizer. Thus, the calculation of economic efficiency was carried out only by summing the yield increase due to the application of fertilizer and return of one kg of NPK a.r. by main products, because prices for mineral fertilizers and agricultural products vary depending on market conditions, so they can be evaluated only for short-range planning.

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