Influence of Long-term use of Phosphate Fertilizers on Accumulation of Various forms of Phosphates in Brown Soils and Influence of Levels of Available Phosphates on Crop Yield in Crop Rotation

Aigerim Meirambayevna Shibikeyeva[1], Rakhimzhan Yeleshevich Yeleshev[2], Sagynbay Kaldybayev[3] and Almagul Dzhumabekovna Malimbayeva[4]

Kazakh National Agrarian University, 8, Abai Street, Almaty, 050010, Kazakhstan, Russia.

DOI: http://dx.doi.org/10.13005/bbra/1641

(Received: 15 February 2015; accepted: 21 March 2015)

The article presents the 3-year results of studying the effect of the long-term use of phosphate fertilizers on the content and accumulation of various forms of phosphates in brown soils, and the influence of the levels of available phosphates on crop yields in crop rotation. We identified the levels of phosphate that can be used to optimize the nutrient status of dark-brown and light-brown soils of Kazakhstan with monitoring and regulating plants nutrition of studied crops that are cultivated in crop rotation.

Key words: Soil, fertilizer, crop rotation, humus, phosphorus, nitrogen, potassium, light-brown soils, dark-brown soils, mineral nitrogen, agile phosphorus, total phosphorus, organic phosphorus, mineral phosphorus, fractional composition of mineral phosphates, beet crop rotation, intensive vegetable crop rotation, soybeans, late cabbage.

Formation of soil phosphate regime and maintaining it at the optimal level is achieved mainly due to introduction of phosphate fertilizers. The well-known disadvantage of this method is a low share of phosphorus fertilizers fixation by plants due to phosphorus binding into poorly soluble forms. Attempts in numerous studies to solve the problem of low efficiency of phosphates in agriculture have not yet given the desired result. One of the existing reasons for this fact is the absence of systematic knowledge about the influence of various factors on the phosphate compounds in soil.

On the basis of the experimental results of research we managed to select four groups of processes affecting transformation of phosphates in soil: geochemical, biological, chemical and anthropogenic. Each of these groups has its own specifics and leads to rather peculiar manifestations of phosphorus compounds in soil.

Prolonged use of fertilizers in crop rotation causes significant changes in the physico-chemical properties of the soil, its biological activity and nutrient status. Phosphorus takes a special place in the issues of long-term use of fertilizers. This is caused by both great importance of this element for life of plants, and the specifics of its behavior in the soil. Due to its high reactivity, phosphorus is actively involved in various processes in soil, causing formation of various

* To whom all correspondence should be addressed.
E-mail: shm.aigerim@mail.ru

phosphorus compounds, both organic and mineral. Relatively low percentage of fertilizers fixation, especially in case of high dosage of phosphate fertilizers, contributes to its significant accumulation in soil.

When introduced into the soil, phosphorus transforms, therefore its mobility changes with time, so it is interesting to compare the dynamics of long-term use of various forms of phosphates with prolonged and systematic use of fertilizers, especially phosphorus.

Systematic long-term use of superphosphate in black soil, sod-podzol and dark gray soils changes the ratio between the mineral forms of phosphates in soil with increasing share of loosely bound phosphates and phosphate sesquioxides, mainly aluminophosphates. Phosphorus superphosphate transformation into restored-soluble and occluded phosphates that are inaccessible for plants is negligible (Nosko, 1982; Nosko, 1985).

So, in studies (Ginzburg, 1981; Gamzikov, Ilyin and Nazaryuk, 1989) in course of a long-term field experiment on poorly cultivated sod-podzol sandy soil, seasonal and long-term dynamics of agile phosphorus was determined by the process of transformation of the phosphates introduced into soil in stock at 300 and 600 kg/ha. Consequently, in case of using 300 kg of P_2O_5 per hectare, phosphates accumulation with annual introduction of phosphorus is slightly weaker. The long-term dynamics of agile phosphorus looks quite different against the background of P600, where mobile phosphates are fixed and transferred into a less soluble form.

In other studies (Kochergin, 1965), prolonged use fertilizers in slightly leached black soils contributed to significant accumulation of relatively freely soluble phosphates of alkaline and alkaline-earth metals in soil, increased the fraction of iron and aluminum phosphates, and considerably changed the share of high-basic calcium phosphates.

In other model and greenhouse experiments (Aderihin, 1970), on leached black soil and in the field - on typical black soil, the influence of increasing doses of monocalcium phosphate, manure, wheat and pea straw and $N_{60}P_{60}K_{60}$ on the content and fractional composition of organic phosphates was studied. It was found that the use of mineral and organic fertilizers increases with the total amount of organic phosphates and their individual fractions in the soil under the plants.

Subsequent works (Deriugin, Odintsova, 1978; Deriugin, 1974) showed data of a field experiment performed on sod-podzol loamy soil, when after introduction of superphosphate (total for 3 years – 1,080 kg/ha of P_2O_5), the content of iron and phosphate aluminum increased in the 0-30 cm layer of soil, as well as phosphorus soluble in 0.2 n. of HCl, and less loosely bound and water-soluble phosphate and calcium phosphate.

In stationary field experiments (Nikitishen, 1984), the influence of 55-year long-term and systematic use of manure and fertilizers on the reserve and forms of organic phosphorus compounds in black earth soil was studied. The results showed that the content of organophosphorus compounds in the first meter of soil increased.

Accumulation of residual phosphates with prolonged use of manure and mineral fertilizers was due to mineral and organic forms. Both in the years of introduction of phosphate fertilizers, and afterwards, the change in the content of organophosphates was not dependent on the type of the fertilizer. Accumulation and use of residual phosphates mainly influences the content of mineral phosphates, as compared to the organic ones. Phosphorus from the fertilizer transfers into all groups of mineral phosphates, from which phosphate fractions of Al-P and Ca-P are primarily used, and iron phosphates are used in the least.
Systematic introduction of phosphate fertilizers leads to a significant increase in soil phosphates agility. The main forms of the most agile compounds are phosphates extracted from 0.5 n. of NH_4F, 0.1 n. of NaOH and 0.5 n of H_2SO_4. An increase in norms of phosphate fertilizers contributes to an increase in the weight of the most agile compounds of phosphorus only to norms P_{90} and P_{120}. If P_{150} and P_{180} were used, mobile fractions of phosphorus did not increase (Eleshev, Malimbaeva, Shibikeyeva, 2014).

A significant portion of gross phosphorus reserves in soil are organophosphorus compounds. They play an important role in soil biochemical processes and ensure availability of phosphorus for plants in the process of mineralization. Studies of Eleshev R.E. (Eleshev, 1984; Eleshev, 1980) showed that soils of the foothill zone of the Zailiyskiy Alatau contain 0.15-0.16% of phosphorus. In the upper part of the humus profile of main types of soil, the total phosphorus amount ranges between 130 and 200 mg/100 g of phosphorus. Thus, gray earth contains 130-150 mg, brown earth - 187-200 mg/100 g of phosphorus and the total phosphorus reserves in one meter layer amount to 16-18 and 17-23 t/ha, respectively.

In the profile of all types of soil, total phosphorus content decreases with depth. However, different content of gross phosphorus in soils can be explained by the intensity of the soil-forming process, mineralogical and particle size distribution, the ability of the soil to absorb phosphate ions and by other factors.

MATERIALS AND METHODS

The main source of factual information is the data obtained in JSC KazAgroInnovation own research within the framework of the project of the Ministry of Agriculture of the Republic of Kazakhstan "Development of technologies for conservation and efficient reproduction of soil fertility and the criteria for evaluating their parameters."

In the soil samples the following was determined: total phosphorus - using the META method; organic phosphorus using the Lito-Chang-Jackson method; fractional composition of mineral phosphates using the Ginzburg-Lebedeva method; and agile phosphates using the Machigin method;

Main

Results of the research. This paper shows the data obtained after 3 years of studying the influence of long-term and systematic use of fertilizers on the content and accumulation of various forms of phosphates in irrigated dark-brown and light-brown soils.

The study was performed on the basis of the Kazakh Agriculture and Crop Production Research Institute in the conditions of the 7-field beet crop rotation founded in 1961 on light-brown soils, as well on the basis of the Kazakh Potato and Vegetable Production Research Institute in the conditions of the 4-field intensive vegetable crop rotation.

Crop rotation in beet crop rotation

1. Winter wheat + alfalfa
2. 2 years old alfalfa
3. 3 years old alfalfa
4. Sugar beet
5. Winter wheat
6. Soybeans
7. Grain maize

Crop rotation occurs in space and time. During the research, sugar beet, corn maize and soybeans (instead of beetroot) were cultivated. The total area of the plot was 7.2x30 cm = 216 m², 4 repetitions.

Phosphate fertilizers were introduced in the form of ammophos with the content of N - 12%, P_2O_5 - 46% of active material. Calurea was used as nitrogen fertilizer (46% of active material). In variant 2 (NK), calurea was used as nitrogen fertilizer (in autumn), in other variants, calurea was introduced with regards to the nitrogen introduced with ammophos. All fertilizers were introduced in the autumn into primarily cultivated soil, and potassium chloride was used as potassium fertilizer (60% of active material).

Crop rotation in case of 4-fields intensive vegetable crop rotation founded in 1992 on dark-brown soil:

1. White cabbage (late)
2. Cucumbers
3. Tomatoes
4. Root vegetables (carrots, beetroot).

Crop rotation occurs in space and time. Late cabbage was studied. The area of the experimental plots was 67.2 m2 (4.2 m x 16 m), with 4 repetitions.

Types of fertilizers introduced in intensive vegetable crop rotation: ammonium nitrate (34% of active material), double superphosphate (40% of active material), and potassium chloride (60% of active material). All kinds of fertilizers were introduced in early spring, 1.5-2 months before transplanting late cabbage.

Discussion of the results

In our studies, the content of the total phosphorus in the dark-brown soil in the original soil (top layer 0-40 cm) was 2,158 mg/kg. Long-term (over 20 years) use of dark-brown soils without fertilizer leads to soil depletion, so in the reference variant of intensive vegetable crop rotation, total phosphorus content in topsoil reduced to 2,039 mg/kg. In case of long-term (20 years) and systematic use of phosphate fertilizers in intensive vegetable crop rotation, gross content of phosphorus in soil increases. In the variant with single norms of phosphate fertilizers, where since 1992 the total of 1,050 kg/ha of phosphorus has been introduced, the content of total phosphorus increased to 2,291mg, when double norm was introduced (1,800 kg/ha), it increased to 2,335 mg, and when triple norm (2,550 kg/ha) was introduced, the total phosphorus content in the top 0-40 cm layer of soil increased up to 2,464 mg/kg.

In light-brown soils, original content of gross phosphorus was 2.056 mg/kg of soil. Long-term (over 50 years) and systematic use of light-brown soil without introducing fertilizers also reduces the gross content of phosphorus forms in the top 0-40 cm soil layer to 1,967 mg, as well as in the variant where only nitrogen-potassium fertilizers (NK) were introduced - to 1,983 mg. Prolonged use of increasing norms of phosphate fertilizers (single, sesquialteral and double norms of phosphorus) led to an increased content of gross phosphorus forms: introduction of a single norm (since 1961 in the total phosphorus amount of 2,980 kg/ha of active material) to 2,203 mg/kg, when a sesquialteral norm was introduced (4,065 mg/kg/ha of active material), it increased to 2,184 mg, and when a double norm (kg/ha of active material) was introduced, in increased to 2,133 mg/kg.

In plant nutrition, the most important role is played by organic and inorganic phosphates of soil, which are constantly present in soil in the process of turning into each other. Organic and mineral soil phosphates have various worth in mineral nutrition of plants. It is important to know the quantitative relationship of these groups of phosphates in the general reserve of soil. Organic phosphorus is the main part of the "working capital" of soil phosphates, and it can mineralize under certain conditions, enriching soil with mineral forms of phosphorus (Eleshev and Ivanov, 1990; Eleshev, 1983).

Development of soils leads to change of the ratio of organic and inorganic forms of phosphates.

Table 1 - Forms of phosphates in brown soils with long-term use of phosphate fertilizers in crop rotation

In the studied soil, mineral forms of phosphorus prevail over organic phosphates. The original content of organic phosphorus before

Table 1. Forms of phosphates in brown soils with long-term use of phosphate fertilizers in crop rotation

Variants of the experiment	Introduced P_2O_5 gg.kg/ ha	P_2O_5 in soil (0-40 cm): gross, mg/kg	organic		mineral		mineral phosphates acc. to Ginzburg- Lebedeva: Ca-P_I		Ca-P_{II}		Ca-P_{III}		(Al+Fe)P		sum of fractions
			mg/kg	%	mg/kg	%	1*	2**	1	2	1	2	1	2	
dark-brown soil, vegetable crop rotation															
Original background, 1992	0	2,158	660	30.6	1,448	69.4	23	2.5	120	13.5	643	71.5	113	12.5	899
Reference	0	2,039	571	28.0	1,468	72.0	22	2.2	131	13.2	695	70.0	146	14.6	994
$N_1 P_1 K_1$	1,050	2,291	738	32.2	1,553	67.8	83	5.6	322	22.0	872	59.4	191	13.1	1,468
$N_2 P_2 K_2$	1,800	2,335	765	32.8	1,570	67.2	112	7.0	346	21.3	955	58.7	212	13.0	1,625
$N_3 P_3 K_3$	2,550	2,464	770	31.3	1,694	68.7	137	8.2	356	21.3	963	58.0	209	12.5	1,665
light-brown soil, beet crop rotation															
Original background, 1961	0	2,056	583	28,3	1,473	71,7	10,0	0,9	282	25,5	742	67,1	71	6,5	1,105
Reference	0	1,967	515	26.2	1,452	73.8	14.5	1.4	223	22.2	700	70.0	68	6.4	1,006
NK	0	1,983	525	26.5	1,458	73.5	18.5	1.6	241	20.8	827	71.6	71	6.1	1,158
NPK	2,980	2,203	553	27.6	1,650	72.4	78	5.7	338	24.5	877	63.6	85	6.2	1,378
$NP_{1.5}K$	4,065	2,184	560	25.6	1,624	74.4	102	7.2	349	24.6	877	62.0	88	6.2	1,416
$NP_{2.0}K$	5,960	2,231	564	25.3	1,667	74.7	117	7.8	366	24.4	927	61.8	89	6.0	1,499

Note: 1 *- P_2O_5 mg/kg of soil; 2 ** -% of total mineral phosphates is quite different by reserves and absolute content of organic and inorganic phosphorus the experiment was 660 mg/kg, or 30.6% in dark-brown soil, and 583 mg/kg, or 28.3% of the gross amount in light-brown soil.

After 3 years of the research, the average content of organic phosphorus in dark-brown soil fertilized with single, double and triple norms of phosphorus fertilizer was as follows: 738, 765 and 770 mg/kg, respectively, which corresponds to 32.2%, 32.8% and 31.3% of the total phosphorus, with its content in the reference variant of 571 mg, or 28.0%. In case of long (over 20 years) and systematic introduction of phosphorus fertilizer, the content of organic phosphorus in vegetable crop rotation as a percentage ratio gradually decreased, but was higher than the initial level and the background variant, which should be considered as a positive fact (Malimbaeva, Yusupova, 2012).

In light-brown soil, after 3 years of the research, the average content of organic phosphorus both in fertilized and in the reference variants also decreased from the initial content in 1961. So, the initial content of organic phosphorus was 583 mg in the 0-40 cm layer in the reference and NK variants - 515 and 525 mg. In the variant with a single dosage of phosphorus (P_{90}) - 553, one-and-half (P_{135}) - 560 mg, and double (P_{180}) - 564 mg (Kaldybaev, Malimbaeva, Uteulina, 2014).

On the contrary, the content of mineral phosphorus in soil increases after the introduction of phosphorus fertilizers. Moreover, its percentage is higher than that of organophosphates both in dark-brown and in light-brown soil. However, in light-brown soil, the content from the gross amount of mineral phosphate is higher than that in the dark-brown soil; it seems to be due to the content

Table 2. Crop rotation yield with various levels of phosphorus nutrition (0-20 cm, mg/kg)

Variants of the experiment	Levels of P_2O_5 content, mg/kg of soil: Total of (Ca-P_2 +Ca-P_{22}) Sprin g	Autu mn	average for the growing season	Labile phosphorus spring	autumn	yield of crop average for the growing season	The average rotation cultures
			light-brown soil, sugar beet (2012, centner/ha)				
Reference	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-brown soil, corn maize, (average for 2 years 2012-2013, centners/ha)				
Reference	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-brown soil, soybean (2014, centners/ha)				
Reference	255	215	220-250	15.4	12.0	10-15	20-25
N	268	220	250-260	19.0	15.5	15-25	25-30
N	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
			Ddark-brown soil, late cabbage, (average for 3 years, t/ha)				
Reference	321	300	310-320	17.4	13.0	10-15	28-30
$N_1P_1K_1$	446	407	415-427	56.4	40.0	40-48	30-35
$N_2P_2K_2$	488	450	455-470	68.0	43.0	50-55	35-42
$N_3P_3K_3$	564	500	520-532	78.0	58.0	60-68	42-47

of organic matter in soil, where light-brown soils contain less organic substance compared with dark-brown soils.

Thus, introduction of increasing norms (from single to triple) of phosphorus fertilizers increased the content of its mineral form in dark-brown soil from 1,553 to 1,694 mg/kg, or from 67.8 to 68.7%. In the original background and in the reference variant, these figures were 1,448 or 69.4% and 1,468 or 72.0% mg/kg. In light-brown soil, these figures were as follows: in fertilized variants ($P_{90-135-180}$) from 1,650 to 1,667 mg, or from 72.4 to 74.7%, whereas in the original soil, before establishing beet rotation (1961) - 1,473, or 71.7%, and in the reference variant - 1,452 mg, or 73.8% and in the NK variant - 1,458 mg, or 73.5% (Ramazanova, Aitbaev, Kaldybaev and Malimbaeva, 2013).

Important in plant nutrition are mineral phosphates of varying alkalinity that are extracted from soil in steps (fractions) with various solvents (salts and acids).

Study of fractional composition of dark-brown soils by the method of Ginzburg - Lebedeva showed that long (over 20 years) and systematic introduction of phosphate fertilizers in dark-brown soil in vegetable crop rotation caused an increase in the content of the total of "active phosphates". The amount of loosely bound (Ca-P_{II}) and various alkaline (Ca-P) calcium phosphates increased not only in the absolute, but also in relative share of gross phosphorus.

Thus, in the dark-brown soil in the 0-40 cm soil layer on the original background and in the reference variant, the amount of loosely bound and variously alkaline phosphates was 143 and 153 mg, or 16.0 and 15.4% of the amount of "active" mineral phosphates, while after introduction within over 20 years of 1,050, 1,800 and 2,550 kg/ha of phosphorus, its amount increased to 405, 458 and 493 mg, or 27.6, 29.3 and 29.5%, respectively.

In light-brown soils of beet crop rotation, use of fertilizers, especially phosphorus, within over 50 years also increased the amount of mineral phosphates of various alkalinity groups. Thus, in the fertilized variants: single norm of phosphorus (P90), where from the start of the field experiment (1961), 2,980 kg/ha of active material phosphorus was introduced, the content of the sum of loosely bound variously alkaline mineral phosphates increased to 416, or 30.2% of the amount of phosphate fractions. Sesquialteral norm (P_{135}), where the total of 4,065 kg/ha of active material has been introduced, increased to 451 mg, or 31.8%, double norms (P_{180}), where the total of 5,960 kg/ha of active material has been introduced, increased to 493 mg, or 32.2%.

If the first two fractions of mineral phosphate (Ca-P_I + Ca-P_{II}) play an important role in plant nutrition, and their dynamics during the crops growing season can vary from spring to autumn, the content and dynamics of highly alkaline mineral phosphates remains unchanged in the early growing season and in the autumn (when crops are harvested), their content may increase, apparently due to the transition of readily soluble phosphorus into di- and tri-calcium soluble salts which settle in soil. Their percentage is always higher than that of the first two fractions.

Thus, in dark-brown soil in the vegetable crop rotation, the number of highly alkaline phosphate (Ca-P_{III}) increased in the fertilized variants as compared to the single, double and triple norms of phosphorus to 872 - 955 - 963 mg, or decreased in relative terms, as compared to the initial (71, 5%) and the reference variant (70.0%) to 59.4, 58.7 and 58.0% due to use of 1,050, 1,800 and 2,550 kg/ha of phosphate fertilizers in the period between 1992 and 2014.

In light-brown soils, these figures are as follows: single, sesquialteral norm of phosphorus - 877 mg, double norm - 927 mg, or 63.6, 62.0 and 61.8 %, respectively. In the original soil - 742, or 67.1%, and the reference and NK variants - 700 and 727 mg, or 70.0 and 68.7%.

The amount of phosphates of sesquioxides in brown soils increased in quantity, but their relative amount from the total sum of mineral phosphates remained practically unchanged. So, the quantitative content in fertilized variants in dark-brown soil increased from 113 to 212 mg, or 13.1 and 12.5 %, in the light-brown soils - from 85 to 89 mg, or 6.2 and 6.0%.

When phosphate fertilizer is introduced in the amount exceeding the amount of phosphorus removed by plants of cultivated crops, soils feature improvement in phosphate nutrition regime, which is caused by accumulation of residual forms of phosphates. When the optimal level of their content is reached, ensuring the obtaining of the maximum yield of crops, the yield increases from adding extra phosphates drops. To optimize dosage of phosphate fertilizers, it is necessary to know the level of available phosphorus and soluble fractions of mineral phosphates that may ensure the highest yields of crops.

Analysis and grouping of data from field experiments on irrigated brown soils with sugar beet, corn maize, soybeans and late cabbage show a direct correlation between indicators of phosphate regime of soils and crop yields to a certain limit exceeding which no longer has a positive effect (Table 2).

On light-brown soil, when the content of agile phosphorus in the reference variant is more than 15 mg/kg, and the sum of soluble fraction of mineral phosphates is over 340 mg/kg of soil, the average yield of sugar beet is 85-100 centners/ha (Table 2). The highest yield of sugar beet roots (480-490 centners/ha) can be achieved in the variant with a double dosage of phosphorus (P180), with seasonal mean content of agile phosphorus in soil of over 45 mg/ kg and that of soluble phosphates

When the content of agile phosphorus in the reference variant is 10-15 mg/kg and the amount of soluble fractions of mineral phosphates is 250255 mg/kg, the average yield of corn maize for 2 years of the study may be 60-85 centners/ha. In the variant where the amount of loosely bound and variously alkaline groups of mineral phosphates is 470-480 mg/kg, and that of agile phosphorus - 45-50 mg/ kg, corn maize yield was 110-125 centners/ ha. According to the data obtained from the experiment, an increase in the content of agile phosphorus of over <50 mg/kg and in the amount of soluble fractions of 510-515 mg/kg due to long-term and systematic introduction of double (P120) dose of phosphorus does not increase the yield of corn maize.

Yield of soybean (35-40 centners/ha) is the most authentic in the variant with a sesquialteral dosage of phosphorus (P90), where the seasonal mean phosphorus content in light-brown soil is 45-50, and the amount of phosphates in the first two groups is 440-480 mg/kg.

Vegetables are very demanding to the food regime of the soil, especially to phosphorus content in the soil (the amount of nutrients is to be higher than that for other groups of crops). The maximum average yield of late cabbage heads (42-47 t/ha) cultivated in intensive vegetable crop rotation on irrigated dark-brown soil was obtained with the average per season content of 60-68 mg of agile phosphorus and the amount of soluble fractions of 520-532 mg/kg soil, when a triple dose (P_{90}) of phosphorus fertilizer was introduced. In the reference variant, when the content of agile phosphorus in soil was 10-15 mg, and the total of soluble phosphates was 310-320 for vegetable crops, particularly for cabbage, it is considered to be low and affects the yield of cabbage heads, where it was 28-30 t/ha.

DISCUSSION

1. The most effective variant with the reliable increase in sugar beet yield (450-480 centners/ha) can be obtained by introducing a sesquialteral dose of phosphorus fertilizer (P_{135}) with average seasonal mean content of agile phosphorus in soil of 40-45 mg, and the total of the first two groups of mineral phosphates of 410-440 mg/kg.
2. The cultivation of maize in crop rotation,the content of agile phosphorus must be maintained at 45-50 mg/kg, and the amount of soluble fractions of mineral phosphates in the range between 470 and 480 mg/kg, which will provide the yield of corn maize of more than 110 centners/ha.
3. Yield of soybean (35-40 centners/ha) is the most authentic in the variant with a sesquialteral dosage of phosphorus (P90), where the seasonal mean phosphorus content in lightbrown soil is 45-50, and the amount of phosphates the first two groups is 440-480 mg/kg.
4. However, the most reliable option, where a perceptible increase in the yield due to introduction of fertilizers is obtained, is the variant where the yield of cabbage heads is 35-42 t/ha, with the content of available phosphorus in the range between 50 and 55 mg and the amount of soluble phosphate fractions is 455-470 mg/kg.

CONCLUSION

The established levels of phosphate can be used to optimize the nutrient status of dark-brown and light-brown soils of the South-East of Kazakhstan with monitoring and regulation of plants nutrition of studied crops that are cultivated in crop rotation.

ACKNOWLEDGMENTS

The authors express their gratitude for publication of these research results. This article was prepared within the framework of the project of JSC ”KazAgroInnovation” of the Ministry of Agriculture of the Republic of Kazakhstan.

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