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# Use Of Phosphorus Fertilizers On Irrigated Light Chestnut Soil In The South-East Of Kazakhstan

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**Abstract**:

The article presents the results of long-term studies carried out in long-term experiments on the study of the fertilization system of sugar beet in the beet crop rotation and with its permanent cultivation on irrigated light chestnut soil. It is shown that with long-term (57-58 years) and systematic use of phosphorus fertilizers against the background of nitrogen-potassium (NK) fertilizers in the soil, background with different levels of phosphorus supply in the arable and subsoil layers are created. Single, one-and-a-half, double norms of phosphorus fertilizers, systematically applied in crop rotation and with permanent cultivation of sugar beets, not only increase the content of mobile phosphorus in the arable layer, respectively, to 49.0; 51.9; 59.0 mg/kg of soil, but also the content of the sum of loosely bound and different basic phosphates ($CaP_I$ + $CaP_{II}$), the nearest reserves of phosphorus available to plants in crop rotation and in monoculture conditions. Changes in the nutrient regime of the soil affect the chemical composition of cultivated crops, in particular, sugar beet, and the dynamics of biomass accumulation. Accordingly, the yield of sugar beet increases to 53.3-57.7 t/ha in crop rotation and up to 50.3-56.1 t/ha in monoculture with a simultaneous increase in sugar content up to 16.0-16.7% and total sugar harvest with 1 ha of crops.

**Keywords**: phosphorus, nitrogen, potash fertilizers, levels of phosphorus supply, mobile phosphorus, crop rotation, monoculture, yield, sugar content, loosely bound, different basic phosphates, sugar harvest per hectare, nitrogen content, potassium phosphorus in plants, NPK yield removal.

## 1. Introduction

Sugar beet is one of the most important crops in agriculture. Roots rich in carbohydrates were the main raw material for sugar production for the population.

Sugar beet is a priority crop for the irrigated zone of the south and south-east of the Republic of Kazakhstan, because the soil, bioclimatic and production potential of the region corresponds to its capabilities and characteristics of growth and development.

Analysis of the state of sugar beet production in the republic in recent years shows that the sown area by 2014 decreased to 1.17 thousand ha, with a yield at the level of 150-200 dt/ha, although today there is a tendency to an increase in its crops and an increase in yield root crops. With the annual demand of the Republic for sugar amounting to 560 thousand tons, in 2009 only 23.2 thousand tons of white sugar, or 6% of its total production, was produced from domestic raw materials, the rest (94%) was obtained from raw sugar imported from other countries. According to food safety requirements, the share of sugar production from domestic raw materials must be at least 20%.

By the way, in Kazakhstan the sown area of factory sugar beet in the 90s reached 80 thousand ha, which provided 20-25% of the needs of the republic's population in sugar. The experience of cultivation of sugar beet over the past years has shown that in the republic it is possible to obtain stable yields of at least 400 dt/ha on irrigation and 200-250 dt/ha on dry land. Sugar beet is a labor-intensive and high-cost crop, and at the same time its production is economically profitable. It is also of great agrotechnical importance as a precursor in clearing fields from weeds and maintaining soil fertility [1-3,4].

However, during the crisis years, the beet growing and sugar industry suffered greatly, specialized large commercial farms collapsed, their material and technical base was thoroughly undermined, seed farms and some sugar factories ceased to function.

Sugar supply to the population of the republic should be solved by increasing its productivity and breeding new highly productive varieties and hybrids of sugar beet. The breeding process of creating new competitive varieties and hybrids of sugar beet is constantly being improved.

The main soils of the Almaty region are light chestnut, the thickness of the humus horizon does not exceed 50-60 cm, the humus content ranges from 1.5 to 2.5%, total nitrogen - from 0.11 to 0.18%; ordinary serozem soils with a humus horizon of 35 to 50 cm contain significantly less humus (1.0-1.5%) and total nitrogen (0.09-0.14%).

In the Taldykorgan area of the region, serozem, light chestnut and meadow serozem soils prevail. A special place is occupied by low-carbonate serozem soils of the Alakol Valley, which, along with an insignificant thickness of the humus horizon (25-30 cm) and a low humus content (0.8-1.3%), total nitrogen (0.03-0.08%) on a small depth (from 30 cm and deeper, and sometimes from the surface) are underlain by facette deposits [5,6,7].

The territory of the foothill plains is dissected by a network of large and small rivers - the main sources of irrigation.

Thus, the soil and climatic conditions of the region are quite favorable for the cultivation of all crops of the sugar beet crop rotation.

The solution to the problem of regulating the phosphate regime is associated with determining the level to which it is advisable to increase the content of soluble phosphates depending on the type of soil, the content of natural phosphorus, the peculiarities of its absorption and fixation in the soil, the composition of cultivated crops and other indicators [8,9,10].

The study of these issues is necessary to determine the need for phosphate fertilizers, methods of their application, as well as the terms and time that will be required to create optimal phosphate levels [11,12,13].

When determining it, it is necessary to consider the specific requirements of crops to soil conditions, therefore, the concept of an optimal level can be attributed to a single crop or a group of homogeneous crops.

As many researchers note, doses and ratios of nutrients established for crops in short-term experiments, with long-term systematic use in crop rotation, often do not give the effect that was obtained with a single application [14,15,16].

The results of many studies have shown that mineral fertilizers have a significant effect not only on the gross phosphorus content in the soil, but also on the transformation of their group and fractional composition, which is confirmed by our studies conducted on light chestnut soil under irrigation conditions.

## 2. Materials and methods

The territory of the stationary of the Kazakh Research Institute of Agriculture and Plant Growing, where the field experiment with sugar beets was carried out, is located at the foot of the mountain ranges of the Ili Alatau at an altitude of 700-800 m above sea level. The soil cover of the experimental site is represented by piedmont light chestnut soils. The parent rocks are loess-like loams deeply underlain by pebble deposits. Groundwater occurs at a depth of 10 m or more.

The light chestnut soils of the experimental site have a well-developed profile: the humus horizon ($A_{II}$ + $A_I$) is structured, weakly compacted, therefore it is quite favorable for the cultivation of many agricultural crops. The content of humus is 2.27-2.35%, gross forms of nitrogen 0.171-0.182%, phosphorus 0.200-0.210% and potassium 1.62-1.75%. The content of mobile forms of nutrients in the plow horizon was respectively: 23.1-24.8; 20.2-27 and potassium 424-455 mg/kg of soil.

The tasks were solved by laying cuts and trenches in key areas on various types of soils in arable and virgin lands (chernozems, dark chestnut and light chestnut) of the vertical zoning of the Ili Alatau, as well as on the site of a field experiment with an eight-field beet crop rotation and permanent sowing of sugar beet, laid down in 1961-1962.

In just 57 years, under permanent crops of sugar beet on light chestnut soil, the following have been introduced:

Single dose of phosphorus - $N_{5600}P_{3360}K_{3360}$;

One-and-a-half dose - $N_{5600}P_{5040}K_{3360}$;

Double dose - $N_{5600}P_{6720}K_{3360}$.

Experience scheme:

1. Without fertilizers (control).
2. NK background.
3. NK+$P_1$ (single dose).
4. NK+$P_{1,5}$ (one-and-a-half dose).
5. NK+$P_2$ (double dose).
6. NPK + 60t manure

The experiment was repeated 4 times, the plot area was 216 $m^2$. Urea (46% of r.a.) was used as nitrogen fertilizers, double superphosphate (47% of r.a.), and potassium fertilizers - potassium chloride (60% of r.a.). The annually applied phosphorus fertilizers are: a single dose of phosphorus 90 kg/ha, one-and-a-half - 135 kg/ha and double doses of 180 kg/ha.

The agrochemical properties of the studied soils (humus, NPK content, pH, etc.) were determined by generally accepted classical methods; the total content of organic phosphates - by the Meta method as modified by Ginzburg; the composition of mineral phosphorus according to Ginzburg-Lebedeva; mobile phosphates - according to the Machigin method.

Chemical analyzes of soils and plants were carried out in the laboratories of the Department of Soil Science and Agrochemistry of the Kazakh National Agrarian University, the Kazakh Research Institute of Soil Science and Agrochemistry named after U.Uspanov, Kazakh Research Institute of Agriculture and Plant Growing and Soil Institute named after V.Dokuchayev (Moscow).

A long-term stationary experience was laid in 1961 on the basis of 8-full beet crop rotation with the following crop rotation: 1,2-alfalfa, 3,4,5-sugar beet, 6-winter wheat, 7-sugar beet, 8-winter wheat + alfalfa.

The initial agrochemical characteristics were as follows: the humus content in the 0-20 cm layer was 2.6%, total nitrogen 0.205%, total phosphorus 0.221%, hydrolyzable nitrogen 110-118 mg, mobile phosphorus (according to Machigin) 24 mg/kg, and exchangeable potassium 465 mg/kg, $CO_2$ content - 3.0-4.3%, solid residue 0.08-0.089%.

In subsequent rotations, until now, the structure of the crop rotation has undergone changes - the corn crop was introduced, the share of sugar beet in the crop rotation changed, additional variants of species, doses and ratios of fertilizers were imposed.

For comparison, in 1962 the culture of permanent sowing of sugar beet - "monoculture" was introduced.

Phosphate fertilizers were applied under the sugar beet at the rate of a single norm of 60-120 kg r.a. depending on the predecessor, with permanent sowing 90 kg r.a., then 60 kg.

So, in just 57 years, under the permanent sowing of sugar beets on light chestnut soil, the following was introduced: with a single norm - $P_{3360}$ kg, with a one-and-a-half norm - $P_{5040}$, with a double norm - $P_{6720}$ kg/ha of fertilizers.

**Research results and discussion**

The results of studies in long-term experiments have shown the dynamics of soil fertility depending on the use of fertilizers both for crops of beet crop rotation, and with permanent cultivation of sugar beets.

So, from Table 1 it can be seen that with long-term use of fertilizers, there is a slight decrease in the absorption capacity of the bases relative to the control (without fertilizers) variant.

**Table 1.** Composition absorbed bases of the soils of the experimental site (sugar beet monoculture, harvesting, 2019)

| № | Variants of the experiment | Depth, cm | Absorbed bases, mg-eq/% | | | | Absorption capacity, mg-eq per 100 g of soil |
|---|---|---|---|---|---|---|---|
| | | | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | |
| 1 | Control | 0-20 | 11,39<br>70,3 | 3,47<br>21,4 | 0,70<br>4,3 | 0,64<br>4,0 | 16,20 |
| | | 20-40 | 10,89<br>74,2 | 2,48<br>16,9 | 0,63<br>4,3 | 0,68<br>4,6 | 14,68 |
| 2 | NK | 0-20 | 10,89<br>73,7 | 2,48<br>16,8 | 0,68<br>4,6 | 0,72<br>4,9 | 14,77 |
| | | 20-40 | 10,89<br>74,2 | 2,48<br>16,9 | 0,64<br>4,3 | 0,67<br>4,6 | 14,68 |
| 3 | NK+$P_1$ | 0-20 | 10,40<br>70,1 | 2,97<br>20,0 | 0,67<br>4,5 | 0,79<br>5,4 | 14,83 |
| | | 20-40 | 11,88<br>81,5 | 1,49<br>10,3 | 0,53<br>3,6 | 0,67<br>4,6 | 14,57 |
| 4 | NK+ $P_{1,5}$ | 0-20 | 10,40<br>68,3 | 3,47<br>22,8 | 0,64<br>4,2 | 0,71<br>4,7 | 15,22 |
| | | 20-40 | 9,41<br>58,6 | 4,95<br>30,8 | 0,72<br>4,5 | 0,99<br>6,1 | 16,07 |
| 5 | NPK+60 t of manure | 0-20 | 10,40<br>70,0 | 2,97<br>20,0 | 0,75<br>5,1 | 0,73<br>4,9 | 14,85 |
| | | 20-40 | 10,89<br>76,1 | 2,48<br>17,3 | 0,47<br>3,3 | 0,47<br>3,3 | 14,31 |

At the same time, in the composition of absorbed bases on fertilized variants, the relative content of $Ca_{II}$ is higher than $Mg_{II}$. So, with the ratio of $Ca_{II}$ and $Mg_{II}$ in the control variant equal to 70.3% and 21.4% in the arable layer of the soil, in the nitrogen-potassium variant (NK), it is 73.7 and 16.8%, respectively.

An even more noticeable predominance of calcium over magnesium is observed sub-arable layer of the soil.

An exception is the variant with one-and-a-half norm of phosphorus ($P_{1,5}$ against the background of NK (NK+$P_{1,5}$) where the magnesium content in the arable and sub-arable layer is higher than in other variants and the ratio of $Ca_{II}$ to $Mg_{II}$ was 68.3% and 22.8% in the top layer, and in the bottom, respectively 58.6% and 30.8%.

From Table 1 it can be seen that the content of Na and K is less subject to fluctuations and their amount is practically the same. So the Na content varies according to the variants within the range of 0.53-0.75 mg-eq, which is from the absorption capacity of 3.6-5.1%. The K content also changes insignificantly, 0.47-0.99 mg-eq, respectively 3.3-6.1% of the absorption capacity.

**Table 2.** Dynamics of agrochemical indicators of light chestnut soil with long-term use of fertilizers for sugar beet in crop rotation and monoculture

| Variants of the experiment | Depth, cm | Gross forms , % | | | | |
|---|---|---|---|---|---|---|
| | | Nitrogen | Phosphorus | Potassium | pH | $CO_2$, % |
| CROP ROTATION OF SUGAR BEET, 2019 | | | | | | |
| Var-1, F1, w/f | 0-20 | 0,140 | 0,200 | 2,437 | 8,52 | 2,87 |
| Var-1, F1, w/f | 20-40 | 0,098 | 0,200 | 2,562 | 8,39 | 2,77 |
| Var-4, F1, NK | 0-20 | 0,168 | 0,212 | 2,687 | 8,36 | 2,67 |
| Var-4, F1, NK | 20-40 | 0,154 | 0,212 | 2,625 | 8,30 | 2,73 |
| Var-5, F1, NK+$P_1$ | 0-20 | 0,168 | 0,212 | 2,687 | 8,31 | 2,63 |
| Var-5, F1, NK+$P_1$ | 20-40 | 0,154 | 0,188 | 2,562 | 8,25 | 2,67 |
| Var-7, F1, NK+$P_{1,5}$ | 0-20 | 0,140 | 0,212 | 2,625 | 8,39 | 2,81 |
| Var-7, F1, NK+$P_{1,5}$ | 20-40 | 0,168 | 0,212 | 2,687 | 8,40 | 2,56 |
| Var-11, F1, NPK+60 t of manure | 0-20 | 0,154 | 0,212 | 2,625 | 8,57 | 2,52 |
| Var-11, F1, NPK+60 t of manure | 20-40 | 0,140 | 0,212 | 2,687 | 8,36 | 3,09 |
| Var-16, F1, NK+$P_2$ | 0-20 | 0,154 | 0,176 | 2,625 | 8,44 | 3,19 |
| Var-16, F1, NK+$P_2$ | 20-40 | 0,112 | 0,200 | 2,562 | 8,45 | 4,14 |
| MONOCULTURE OF SUGAR BEET, 2019 | | | | | | |
| Var-1, F1, w/f | 0-20 | 0,112 | 0,224 | 2,812 | 8,59 | 3,26 |
| Var-1, F1, w/f | 20-40 | 0,112 | 0,224 | 2,812 | 8,50 | 3,31 |
| Var-4, F1, NK | 0-20 | 0,126 | 0,224 | 2,687 | 8,44 | 2,06 |
| Var-4, F1, NK | 20-40 | 0,098 | 0,212 | 2,562 | 8,50 | 3,96 |
| Var-5, F1, NK+$P_1$ | 0-20 | 0,084 | 0,240 | 2,500 | 8,41 | 3,75 |
| Var-5, F1, NK+$P_1$ | 20-40 | 0,084 | 0,224 | 2,375 | 8,50 | 403 |
| Var-7, F1, NK+$P_{1,5}$ | 0-20 | 0,112 | 0,224 | 2,437 | 8,52 | 3,96 |
| Var-7, F1, NK+$P_{1,5}$ | 20-40 | 0,126 | 0,224 | 2,500 | 8,56 | 3,83 |
| Var-10, F1, NPK+60 t of manure | 0-20 | 0,126 | 0,200 | 2,250 | 8,46 | 3,41 |
| Var-10, F1, NPK+60 t of | 20-40 | 0,070 | 0,176 | 2,312 | 8,50 | 2,74 |

| | | | | | | |
|---|---|---|---|---|---|---|
| manure | | | | | | |

Long-term use of fertilizers has had some effect on the gross content of basic nutrients (NPK).

So, from Table 2 it can be seen that with long-term application of nitrogen-potassium fertilizers under the crops of beet crop rotation, the gross nitrogen content was 0.168% in the arable layer and 0.154% in the sub-arable layer, while in the control variant their values were 0.140 and 0.098%, respectively.

The application of additional phosphorus fertilizers at a single and one-and-a-half norm also contributed to maintaining the nitrogen content at a higher level - 0.168-0.154 and 0.140-0.168%, respectively. With a double norm of phosphorus (NK-$P_2$) and additional manure application of 60 t/ha, the gross nitrogen content decreased slightly, especially in the sub-arable layer.

The table shows that the gross phosphorus content slightly increases with fertilization (0.2120% relative to the control variant 0.200%).

As for the gross potassium content, the application of fertilizers (NK, NPK) contributes to some increase in it (2.62-2.68%) relative to the control variant (2.44-2.56%), but its clear pattern is not observed.

Determination of pH shows that long-term use of mineral fertilizers creates mainly a weakly alkaline medium in light chestnut soil.

The determination of $CO_2$ showed the presence of carbonates in the light chestnut soil from the surface and fertilizers did not significantly affect their value.

Table 2 shows that with permanent cultivation of sugar beet, along with a decrease in organic matter in the soil, there is a decrease in the total amount of nitrogen in comparison with the sowing of sugar beet in the crop rotation.

So, in the control variant, the content of total nitrogen was 0.112% in the arable soil layer, while in the crop rotation field it was 0.140%.

Even the application of nitrogen fertilizers (NK) did not increase the total nitrogen content to the level in the crop rotation field.

The application of phosphorus fertilizers not only increased, but to some extent contributed to a decrease in gross nitrogen in the arable layer of soil.

Therefore, it can be noted that with permanent cultivation, along with a decrease in the amount of organic matter, the content of total nitrogen in the upper layers of the soil decreases.

As for the gross phosphorus, it can be seen from the table that with the long-term use of arable land in monoculture, its amount in the arable and sub-arable layers of the light chestnut soil is noticeably higher than in the crop rotation fields, where, along with sugar beets, crops are cultivated no less than it consuming phosphorus (alfalfa, corn, winter wheat).

So, in the control variant under permanent sugar beet, the content of gross phosphorus was 0.224 in the 0-20 cm layer and 0.224 in the 20-40 cm layer, on the fertilized variants it fluctuated within the same range of 0.224-0.240%, while it was noted above in the variant in the crop rotation field, it fluctuated within 0.176-0.200-0.217%.

The amount of total potassium in the soil in the variants of its monoculture is slightly higher than in the crop rotation field under the sowing of sugar beet.

The table shows that the soil on the variants of the experiment with a weakly alkaline reaction and application to fertilizers only slightly reduces the value of these indicators, especially with permanent sowing of sugar beet.

There is no clear influence of fertilizers on the amount of carbonates, although in general, the value of $CO_2$ in the crop rotation field, as can be seen from the table, is slightly higher than in the sowing of monoculture of sugar beet.

Of no small importance in plant nutrition are mineral phosphates of various basicity, which are extracted from the soil stepwise (fraction) with various solvents (salts and acids).

The study of the fractional composition of phosphates of light chestnut soil by the Ginzburg-Lebedeva method showed that long-term and systematic application of phosphorus fertilizers in crop rotation and on permanent crops of sugar beet led to an increase in the content of the amount of "active phosphates". The amount of loosely bound ($Ca\text{-}P_I$), different basic ($Ca\text{-}P_{II}$) and calcium phosphates increased not only in absolute, but also in relative terms to gross phosphorus. So, in the crop rotation under the sowing of sugar beet in the phase of 5-6 leaves (0-20 cm layer) on fertilized variants: a single phosphorus norm ($P_{90}$) increases the content of loosely bound ($Ca\text{-}P_I$) and different basic ($Ca\text{-}P_{II}$) to 89 and 265 mg/kg or 6.7 and 19.9% of the total phosphate fraction. The one-and-a-half norm ($P_{135}$) increased to 104 and 296 mg/kg 7.4 and 21.1%, respectively (Table 3).

On permanent crops of sugar beet in the arable layer of soil in the phase of 5-6 leaves, the content of loosely bound ($Ca\text{-}P_I$) and different basic ($Ca\text{-}P_{II}$) phosphates on the variant of a single norm ($P_{90}$) of phosphorus fertilizers was 94.0 and 279.0 mg/kg or 6.8 and 20.3%, one-and-a-half norm ($P_{135}$) 106.0 and 297.0 mg/kg or 7.5 and 20.9%, and in the variant where NPK + 60 t of manure was used 102.0 and 285 mg/kg or 7.3 and 20.4%, respectively.

These indicators in 0-20 cm of soil on the control and background variants (NK) in the crop rotation 25-34 mg/kg and 223-233 mg/kg did not exceed the indicators on permanent crops of sugar beet 32-40 mg/kg and 238-245 mg/kg of soil (Tables 3, 4).

If the first two fractions of mineral phosphates ($Ca\text{-}P_I + Ca\text{-}P_{II}$) play an important role in plant nutrition and their dynamics during the growing season of sugar beet can change from spring to autumn, then the content and dynamics of highly basic ($Ca\text{-}P_{III}$) mineral phosphates remains at the beginning growing season is unchanged and, in the autumn (when determining the harvesting of beets), their content may increase, which is mainly due to the transition of readily soluble forms of phosphorus into hardly soluble two and three calcium salts, which are deposited in the soil. Their number is always higher than the first two factions.

So, in light chestnut soil in crop rotation, on crops of sugar beet in the phase of 5-6 leaves, the amount of highly basic phosphates in the 0-20 cm soil layer increased on fertilized variants from single, one-and-a-half and double norms of phosphorus to 821-835-846 mg/kg of soil, respectively, while in the control and background variants (NK) it was 785 and 795 mg/kg (Table 3).

In permanent crops, these indicators are as follows: single - 846 mg/kg, one-and-a-half phosphorus norm - 857 mg/kg of soil, on the control and NK variants 788 and 808 mg/kg (Table 4).

Thus, long-term and systematic use of phosphorus fertilizers increases the content of total phosphorus in the soil. Determination of the fractional composition of mineral phosphates in crop rotation and on permanent crops of sugar beet showed that the content of the most soluble fractions of calcium phosphates (Ca-$P_I$ + Ca-$P_{II}$) and highly basic fractions of calcium (Ca-$P_{III}$) increased from long-term and systematic use of single, one-and-a-half and double norms of phosphorus. By harvesting sugar beet, the content of the first two fractions decreases, and the content of highly basic calcium fractions increases, which is explained by the fact that the first fractions of loosely bound and different basic forms of phosphates are used to create a biological yield, while an increase in highly basic forms of mineral phosphates occurs due to the transition of readily soluble to a difficult-to-access form. The content of phosphates of one-and-a-half oxides in light chestnut soil is 8-11% of the total mineral phosphates of the soil and practically changes little.

The formation of the phosphate regime of the soil and its maintenance at an optimal level is achieved mainly through the application of phosphorus fertilizers.

**Table 3.** Composition and content of mineral phosphates depending on the long-term use of fertilizers on sugar beet crops in crop rotation (phase of 5-6 leaves, 2018)

| Soil | Depth of the layer, cm | Mobile phosphorus, mg/kg | Fractions of mineral phosphates, mg/kg | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | | | Ca-$P_I$ | Ca-$P_{II}$ | Al-P | Fe-P | Ca-$P_{III}$ | |
| Control (w/f) | 0-20 | 20,7 | 25,0 | 223 | 45 | 90 | 785 | 1168 |
| | 20-40 | 15,9 | 22,0 | 217 | 43 | 98 | 776 | 1156 |
| NK-background | 0-20 | 23,7 | 34,0 | 233 | 48 | 96 | 795 | 1206 |
| | 20-40 | 22,6 | 30,0 | 226 | 45 | 100 | 802 | 1203 |
| NK+$P_1$ (single norm) | 0-20 | 49,0 | 89,0 | 265 | 56 | 100 | 821 | 1331 |
| | 20-40 | 36,2 | 78,0 | 257 | 62 | 97 | 825 | 1319 |
| NK+$P_{1,5}$ (one-and-a-half norm) | 0-20 | 51,9 | 97,0 | 289 | 58 | 98 | 835 | 1377 |
| | 20-40 | 38,3 | 91,0 | 275 | 61 | 101 | 841 | 1369 |
| NK+$P_2$ (double norm) | 0-20 | 59,0 | 104,0 | 296 | 60 | 96 | 846 | 1402 |
| | 20-40 | 39,1 | 95,0 | 287 | 63 | 99 | 853 | 1397 |
| NPK+60 t of manure | 0-20 | 58,3 | 98,0 | 274 | 59 | 97 | 830 | 1358 |
| | 20-40 | 45,2 | 91,0 | 260 | 61 | 98 | 836 | 1346 |

**Table 4.** Composition and content of mineral phosphates, depending on the long-term use of fertilizers on crops of permanent sugar beet (phase of 5-6 leaves, 2018)

| Soil | Depth of | Mobile | Fractions of mineral phosphates, mg/kg | Total |
|---|---|---|---|---|

| | the layer, cm | phosphorus, mg/kg | Ca-$P_I$ | Ca-$P_{II}$ | Al-P | Fe-P | Ca-$P_{III}$ | |
|---|---|---|---|---|---|---|---|---|
| Control (w/f) | 0-20 | 44,0 | 32,0 | 238 | 48 | 92 | 788 | 1198 |
| | 20-40 | 39,0 | 28,0 | 233 | 46 | 97 | 783 | 1187 |
| NK-background | 0-20 | 46,2 | 40,0 | 245 | 50 | 98 | 808 | 1241 |
| | 20-40 | 41,7 | 35,0 | 238 | 49 | 102 | 818 | 1247 |
| NK+$P_1$ (single norm) | 0-20 | 55,9 | 94,0 | 279 | 58 | 98 | 846 | 1375 |
| | 20-40 | 47,1 | 82,0 | 272 | 62 | 94 | 853 | 1363 |
| NK+$P_{1,5}$ (one-and-a-half norm) | 0-20 | 56,4 | 106,0 | 297 | 62 | 100 | 857 | 1422 |
| | 20-40 | 50,6 | 95,0 | 206 | 60 | 105 | 864 | 1410 |
| NK+$P_2$ (double norm) | 0-20 | 58,6 | 102 | 285 | 61 | 99 | 852 | 1399 |
| | 20-40 | 41,7 | 95 | 272 | 62 | 102 | 859 | 1390 |

Long-term use of fertilizers in crop rotation causes significant changes in the physicochemical properties of the soil, its biological activity and nutrient regime.

Possessing a high reactivity, phosphorus actively participates in various soil processes, causing the appearance of various phosphorus compounds, both mineral and organic.

The fertilizer phosphorus applied into the soil is transformed, as a result of which its mobility changes over time. Therefore, it is of interest to observe the long-term dynamics of various forms of phosphates with long-term and systematic use of phosphorus fertilizers.

As noted above, with long-term use of phosphorus fertilizers in the arable and sub-arable layers of soil, not only the amount of mobile phosphorus increases, but also the total amount of mineral phosphorus, in which, first of all, the content of calcium mono- and diphosphates increases - the closest reserve of phosphates available to plants.

**Table 5.** Dynamics of mobile forms of npk under sowing of sugar beet

| Variants of the experiment | Depth, cm | Mobile forms, mg/kg | | |
|---|---|---|---|---|
| | | $N_{л.г.}$ | $P_2O_5$ | $K_2O$ |
| SUGAR BEET MONOCULTURE harvesting, 2019 | | | | |
| Var-1, F1, w/f | 0-20 | 28,0 | 49 | 520 |
| Var-1, F1, w/f | 20-40 | 30,8 | 53 | 540 |
| Var-4, F1, NK | 0-20 | 33,6 | 55 | 570 |
| Var-4, F1, NK | 20-40 | 36,4 | 46 | 570 |
| Var-5, F1, NK+$P_1$ | 0-20 | 47,6 | 63 | 660 |
| Var-5, F1, NK+$P_1$ | 20-40 | 50,4 | 46 | 590 |

| | | | | |
|---|---|---|---|---|
| Var-7, F1, NK+$P_{1,5}$ | 0-20 | 39,2 | 59 | 630 |
| Var-7, F1, NK+$P_{1,5}$ | 20-40 | 42,0 | 70 | 750 |
| Var-10, F1, NPK+60 t of manure | 0-20 | 33,6 | 36 | 570 |
| Var-10, F1, NPK+60 t of manure | 20-40 | 28,0 | 18 | 420 |
| SUGAR BEET CROP ROTATION harvesting, 2019 | | | | |
| Var-1, F1, w/f | 0-20 | 33,6 | 32 | 710 |
| Var-1, F1, w/f | 20-40 | 36,4 | 32 | 630 |
| Var-4,F1, NK | 0-20 | 64,4 | 42 | 500 |
| Var-4, F1, NK | 20-40 | 61,6 | 49 | 480 |
| Var-5, F1, NK+$P_1$ | 0-20 | 61,6 | 63 | 500 |
| Var-5, F1, NK+$P_1$ | 20-40 | 56,0 | 56 | 500 |
| Var-7, F1, NK+$P_{1,5}$ | 0-20 | 50,4 | 32 | 440 |
| Var-7, F1, NK+$P_{1,5}$ | 20-40 | 53,2 | 20 | 380 |
| Var-11, F1, NPK+60 t of manure | 0-20 | 64,4 | 42 | 630 |
| Var-11, F1, NPK+60 t of manure | 20-40 | 38,8 | 29 | 440 |
| Var-16, F1, NK+$P_2$ | 0-20 | 30,8 | 53 | 690 |
| Var-16, F1, NK+$P_2$ | 20-40 | 33,6 | 42 | 610 |

From Table 5, it can be seen the noticeable dynamics of the mobile forms of the main nutritional elements.

So, on the variants with fertilization under sugar beet in the crop rotation, the content of easily hydrolyzed nitrogen in the arable and sub-arable layers of light chestnut soil ranged from 50.4-64.4 mg/kg, the exception was the variant with a double norm of phosphorus fertilizers (NK-$P_2$) where nitrogen was only 30.8-33.6 mg, almost as in the control variant - 33.6-36.4 mg/kg of soil.

Table 5 also shows that the content of easily hydrolyzable nitrogen in the same period under the sowing of sugar beet with its permanent cultivation in all variants is noticeably lower relative to the crop rotation field, and ranged from 28.0-30.8 mg in the control to 33.6-50.4 mg/kg on fertilized variants. Apparently, a greater accumulation of organic matter under crops of crop rotation is affected, if not during monoculture.

Determination of mobile phosphorus showed its high content during this harvesting period. So in the crop rotation field under sugar beet in the control variant, its value was 32.0 mg/kg. On variants with fertilization, its content varied within 32.0-63.0 mg/kg.

The content of mobile phosphorus is even higher during this period under the permanent sowing of sugar beet. So, in the control variant, its content was 49.0-53.0 mg/kg and even higher in the variants with fertilization, with the exception of the variant with the application of manure. The table shows that in terms of the content of exchangeable potassium, the soil is highly supplied in all variants of the experiment, and the dependence on fertilizers is not observed, its amount is more subject to seasonal changes.

Fertilizers, having a positive effect on the nutrient regime of the soil, contributed to an increase in the productivity of sugar beet starting from the early periods of the growing season of plants.

So from Table 6 it can be seen that already from the first growing periods (4 pairs of leaves) the influence of fertilizers on the growth of sugar beet biomass is noticeable.

The application of nitrogen-potassium fertilizers contributed to the formation of dry biomass of beets 0.25 t/ha, while its value in the control (without fertilizers) variant was 0.15 t/ha, while the tops were 2 times higher in the control (0.19 t/ha versus 0.1 t/ha), while the difference in root biomass during this period was insignificant (0.06 versus 0.05 t/ha).

A noticeable effect of phosphorus fertilizers on the growth of sugar beet biomass is observed already from the initial growing season.

Thus, the application of a single and one-and-a-half norms of phosphorus fertilizers in the initial period had almost the same effect on the biomass of beets, increasing its relative to the control by more than two times (0.32 t/ha versus 0.15 t/ha). The same effect is exerted by the application of manure (40 t/ha) against the background of nitrogen-potassium fertilizers (0.35 t/ha).

It is interesting to note during this period the ratio of the biomass of the tops to the biomass of the roots. If it was 2.0 in the control variant, then in the nitrogen-potassium variant it was 3.2, i.e. the biomass of tops significantly prevailed over the weight of the root, while the application of phosphorus fertilizers and manure against the background of NK significantly reduced this ratio (2.2-2.6).

**Table 6.** Influence of fertilizers on the accumulation of dry biomass of sugar beet

| № | Variants of the fertilizers | I term (4 pairs of leaves) | | | | II term (harvesting) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total biomass | Including | | | Total biomass | Including | | |
| | | t/ha | Tops, t/ha | t/ha | Top of root | t/ha | Tops, t/ha | roots | Top of root |
| 1 | Control | 0,15 | 0,1 | 0,05 | 2,0 | 9,4 | 2,7 | 6,7 | 0,4 |
| 2 | NK | 0,25 | 0,19 | 0,06 | 3,2 | 10,4 | 3,1 | 7,3 | 0,4 |
| 3 | NK+$P_1$ | 0,32 | 0,23 | 0,09 | 2,6 | 17,5 | 5,9 | 11,6 | 0,5 |
| 4 | NK+$P_{1,5}$ | 0,32 | 0,22 | 0,10 | 2,2 | 17,9 | 5,4 | 12,5 | 0,4 |
| 5 | NPK+40 t of manure | 0,35 | 0,25 | 0,10 | 2,5 | 18,8 | 6,1 | 12,7 | 0,5 |

The effect of fertilizers on the biomass is manifested during the entire growing season of sugar beet, up to the period of its harvesting.

So, from Table 6 it can be seen that the total dry biomass during the harvesting period was 9.4 t/ha and its component of tops 2.7 t/ha and roots 6.7 t/ha.

On the variant with the application of only nitrogen-potassium fertilizers (NK), the excess is insignificant - 10.4 t/ha and, accordingly, tops of 3.1 t/ha and roots - 7.3 t/ha. The dry biomass of beets noticeably increases in variants where phosphorus fertilizers (P, $P_{1.5}$) and manure are additionally applied against the background of NK, and the amount of total biomass fluctuated within 17.5-18.8 t/ha, which is almost twice higher than in the control variant.

It should be noted that by the end of the beet growing season, the harvesting period in all variants, the dry root biomass significantly prevails over the biomass of the tops and the ratio of tops to root, in contrast to the beginning of the growing season, is significantly lower than unity.

So, on the control variant, it was 0.4 t/ha and roots 6.7 t/ha, and on the NK variant - with a leaf biomass of 3.1 t/ha and 7.3 roots their ratio was also 0.4.

It is interesting to note that, in contrast to the initial periods of the growing season, the ratio of tops/root in the variants with fertilization by the end of the growing season is the same as in the control variant - 0.4-0.5.

**Table 7.** Influence of phosphorus fertilizers on the content of n, p, k in beet plants, 2019

| Variant of the experiment | Tops | | | Roots | | |
|---|---|---|---|---|---|---|
| | N | P | K | N | P | K |
| Crop rotation | | | | | | |
| Control | 3,25 | 0,51 | 4,62 | 0,56 | 0,12 | 1,07 |
| NK+1,5P | 4,03 | 0,57 | 4,08 | 0,56 | 0,17 | 1,07 |
| NPK+manure | 4,20 | 0,60 | 4,08 | 0,67 | 0,17 | 1,34 |
| NK+2P | 4,23 | 0,59 | 4,35 | 0,67 | 0,19 | 1,34 |
| Field – M | | | | | | |
| Control | 3,10 | 0,38 | 4,82 | 0,56 | 0,11 | 1,34 |
| NK | 3,37 | 0,43 | 4,95 | 0,57 | 0,11 | 1,47 |
| NPK | 3,19 | 0,50 | 3,95 | 0,74 | 0,19 | 1,67 |
| NK+1,5P | 3,25 | 0,63 | 4,22 | 0,77 | 0,19 | 1,54 |
| NPK+manure | 3,36 | 0,64 | 4,95 | 0,66 | 0,16 | 1,68 |

Table 7 shows that even by the end of the growing season, the nitrogen content in the tops of sugar beets is high, and amounted to 3.25% in the control variant of the crop rotation field, while in the fertilized variants it was even higher - 4.03-4.23%. The phosphorus content in the leaves ranged from 0.51% in the control to 0.57-0.60% in the fertilized variants. As for potassium, its content in the leaves is quite high - 4.62% in the control variant, and even slightly lower in the fertilized variants - 4.08-4.35%.

As it is known, by the end of the growing season, the supply of basic elements to the roots stops and their minimum content is observed. Thus, the nitrogen content in the root ranged from 0.56% in the control to 0.67% in the variants with fertilization. The phosphorus content in the root was low and fluctuated within the range of 0.12-0.19%, and the potassium content was slightly higher than 1.34% in the variants fertilized with phosphorus than in the control - 1.07%.

The same table shows that the regularities of the dynamics of the content of nitrogen, phosphorus and potassium in sugar beet plants cultivated by a permanent crop, depending on fertilizers, are almost the same as in the field of crop rotation.

So, the nitrogen content in the tops ranged from 3.10 in the control variant to 3.19-3.37% for fertilized ones, the phosphorus content from 0.38 to 0.43-0.64%, and potassium from 4.82 to 4.95%.

The amount of nitrogen, phosphorus and potassium in the root also varies depending on fertilizers: nitrogen 0.56-0.77%, phosphorus 0.11-0.19, potassium 1.34-1.68%.

Determination of the yield of the main nutrients by the crop (biomass) of sugar beet showed that it takes out a fairly large amount of nitrogen and potassium with the harvest (Table 8).

So, in the crop rotation field, sugar beet with dry biomass of root crops of 7.3 t/ha yields 41.0 kg of nitrogen, 9.0 kg of phosphorus and 78 kg of potassium, while with dry biomass of tops of 2.0 t/ha, respectively 66.4 kg of nitrogen, 10.0 kg of phosphorus and 94.0 kg of potassium, and in total, the total mass of nitrogen 107.0 kg, phosphorus 19.0 kg and potassium 172.0 kg/ha.

The application of fertilizers, increasing the biomass of sugar beets and the content of nutrients in them, contribute to their significant yield by the crop. So the application of NK+1.5P increases the nitrogen yield by almost one-and-a-half times (167 kg versus 107 kg) relative to the control variant. The same picture is for the removal of $P_2O_5$ (33.0 kg versus 19.0 kg) and $K_2O$ (215.0 kg versus 172.0 kg). The takeaway is even higher on the variants with the application of NK+2P and NPK + manure 60 t/ha.

Table 8 shows that the same pattern is observed for fertilizer variants on crops of permanent cultivation of sugar beet.

**Table 8.** Yield of nutrients by beet plants (tops + roots), 2019

| Variant of the experiment | Dry matter, t/ha | | Nitrogen yield, kg/ha | | | $P_2O_5$ yield, kg/ha | | |
|---|---|---|---|---|---|---|---|---|
| | roots | tops | roots | tops | total | roots | tops | total |
| Field 8 | | | | | | | | |
| Control | 7293 | 2042 | 41 | 66,4 | 107 | 9,0 | 10,0 | 19,0 |
| NK+1,5P | 9882 | 2766 | 55 | 112 | 167 | 17,0 | 16,0 | 33,0 |
| NPK+manure | 11061 | 3310 | 74 | 139 | 213 | 19,0 | 20,0 | 39,0 |
| NK+2P | 16000 | 5600 | 107 | 237 | 344 | 30,0 | 33,0 | 63,0 |
| | | | | | | | | |

| Field – M | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | tops | roots | | tops | roots | |
| Control | 6696 | 2663 | 82,0 | 38 | 120 | 10,0 | 7,0 | 17,0 |
| NK | 7344 | 3117 | 105,0 | 42 | 147 | 13,0 | 8,0 | 21,0 |
| NPK | 11599 | 5982 | 194,0 | 86 | 280 | 30,0 | 22,0 | 52,0 |
| NK+1,5P | 12528 | 5400 | 178,0 | 97 | 275 | 35,0 | 24,0 | 59,0 |
| NPK+manure | 12744 | 6073 | 204 | 84 | 288 | 39,0 | 20,0 | 59,0 |
| | | | | | | | | |
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**Table 9.** Influence of fertilizers on the productivity of sugar beet in crop rotation and permanent cultivation

| № | Variants of the experiment | Mobile phosphorus, 0-20 cm average for 2 years | | Yield, t/ha | | | Average yield increase over 2 years | Sugar content, % | | | Sugar harvest, t/ha | | | Increase from sugar fertilizer, t/ha |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2018 | 2019 | Average for 2 years | | 2018 | 2019 | Average for 2 years | 2018 | 2019 | Average for 2 years | |
| CROP ROTATION | | | | | | | | | | | | | | |
| 1 | Control w/f | 26,3 | | 19,7 | 31,5 | 25,6 | - | 15,0 | 15,4 | 15,2 | 2,9 | 4,8 | 3,80 | - |
| 2 | NK-background | 32,8 | | 27,7 | 33,0 | 30,3 | 4,7 | 16,0 | 15,8 | 15,9 | 4,4 | 5,3 | 4,80 | 1,0 |
| 3 | NK+$P_1$ | 56,0 | | 53,3 | 50,4 | 51,7 | 26,1 | 16,4 | 16,5 | 16,5 | 8,7 | 8,3 | 8,5 | 4,7 |
| 4 | NK+$P_{1,5}$ | 51,9 | | 57,7 | 56,8 | 57,2 | 31,6 | 16,6 | 16,9 | 16,8 | 9,6 | 9,5 | 9,6 | 5,8 |
| 5 | NK+$P_2$ | 56,0 | | 56, | 55, | 55,9 | 30,3 | 16, | 16, | 16,6 | 9,3 | 9,2 | 9,3 | 5,5 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2 | 6 | | | 6 | 5 | | | | | |
| 6 | NPK+60 t of manure | 50,1 | | 61,4 | 73,7 | 67,6 | 42,0 | 16,7 | 16,4 | 16,5 | 10,2 | 12,2 | 11,2 | 7,4 |
| | $LSD_{095}$ t/ha | | | 3,5 | | | | | | | | | | |
| | P, % | | | 4,6 | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| With permanent cultivation | | | | | | | | | | | | | | |
| 1 | Control w/f | 45,0 | | 31,3 | 32,0 | 31,5 | - | 15,9 | 15,3 | 15,6 | 4,9 | 4,9 | 4,9 | - |
| 2 | NK-background | 48,0 | | 32,7 | 34,0 | 33,3 | 1,8 | 15,8 | 15,9 | 15,9 | 5,2 | 5,4 | 5,3 | 0,4 |
| 3 | $NK+P_1$ | 58,9 | | 50,3 | 53,7 | 52,0 | 20,5 | 16,3 | 16,5 | 16,4 | 8,2 | 8,8 | 8,5 | 3,6 |
| 4 | $NK+P_{1,5}$ | 58,0 | | 56,1 | 58,0 | 57,0 | 25,5 | 16,4 | 16,8 | 16,6 | 9,2 | 9,6 | 9,4 | 4,5 |
| 5 | NPK+60 t of manure | 48,0 | | 57,6 | 59,0 | 58,3 | 26,8 | 16,6 | 16,6 | 16,6 | 9,6 | 9,8 | 9,7 | 4,8 |
| | $LSD_{095}$ t/ha | | | 2,47 | | | | | | | | | | |
| | P, % | | | 3,8 | | | | | | | | | | |
| | | | | | | | | | | | | | | |

The level of crop yields is the main criterion for assessing the effectiveness of fertilizer use. Studies carried out for a long time by different researchers show that the productivity of agricultural crops, in particular sugar beets, is determined by the parameters of soil fertility, types of crop rotation and the conditions of their mineral nutrition.

The results of our research show that the productivity of sugar beet both in crop rotation and in permanent crops depended on the level of soil phosphate fund (Table 9).

In the control variant (without fertilizers), the yield of sugar beet roots cultivated in the crop rotation averaged 25.6 t/ha over two years.

In the baseline variant (NK), the beet yield was 30.3 t/ha and the yield increase relative to the control variant was only 4.7 t/ha.

In the variant where a single norm of phosphorus is applied for a long time against a nitrogen-potassium background, respectively, the yield of beet roots is 51.7 t/ha and a significant increase was obtained relative to the control variant (26.1 t/ha), which is 101%.

One-and-a-half norm of phosphorus fertilization, which has been used for a long time in crop rotation against the background of nitrogen-potash (NK), provided a root yield of up to 57.2 t/ha with a corresponding yield increase of 31.6 t/ha, which is almost 1.3 times higher than the yield on the control variant.

With an increase in the norm of phosphorus fertilization (double norm), the yield was 55.9 t/ha, and an increase of 30.3 t/ha. The maximum yield of sugar beet roots is 67.6 t/ha, an increase of 42.0 t/ha is provided for the variant where NPK+60 t of manure were used (Table 9).

The same pattern for the yield of sugar beet root crops is observed with its permanent cultivation (Table 9).

It should be noted that in the control variant with monoculture, as noted above, the soil is well provided with mobile phosphorus, the yield of root crops was 31.5 t/ha, in the background variant where the mobile phosphorus was 48.0, the yield increases to 33.3 t/ha and an increase did not exceed 1.8 t/ha. Improving the conditions of phosphorus nutrition with the application of $P_{1,5}$, $P_{2,0}$ contributed to a sharp increase in the yield of root crops to 52.0 and 57.0 t/ha, the increments ranged from 20.5-25.5 dt/ha. The maximum yield of 58.3 t/ha of sugar beet root crops was ensured by the application of NPK+60 t of manure, the increase was 26.8 t/ha (Table 9).

Thus, the maximum yields of sugar beet root crops of the order of 56.0-57.0 t/ha both in crop rotation and on permanent crops are ensured with the application of a one-and-a-half dose of phosphorus fertilizers against the background of NK. The combined application of complete mineral fertilizer (NPK) and 60 tons of manure only slightly exceeds this value on a monoculture and quite noticeably (67.6) under crop rotation conditions, that is, a certain part of the plant's need for phosphorus is replenished with organic compounds of manure phosphorus.

Fertilizers influenced not only the size of the yield of root crops, but also the quality indicators, in particular the sugar content of the roots.

Table 9 shows that with the sugar content of the roots on average for two years on the control variant 15.2%, the sugar harvest from 1 ha was 3.85 t/ha.

In the background nitrogen-potassium variant, the sugar content in the roots was 15.9% and the additional sugar harvest from fertilizers was 4.85 t/ha.

Phosphorus fertilizers, applied against the background of nitrogen-potassium fertilizers, contributed to an increase in the sugar content of the roots to 16.4-16.8%, and the harvest of sugar per hectare ranged from 8.5 tons at a single phosphorus norm to 9 at one-and-a-half and 9.3 tons at double norm. And the maximum sugar harvest was noted for the NPK+60 t manure variant - 11.2 t/ha.

Table 9 also shows that the increase in sugar harvest per hectare from phosphorus fertilizers ranged from 4.7-7.4 t/ha, i.e. exceeded the sugar harvest in the control variant by almost two and a half times.

With permanent sowing of sugar beet, the sugar content of the roots in the control (without fertilizers) and nitrogen-potassium variants (NK) is higher than in the conditions of crop rotation and amounted to 15.9 - 15.6% and a relatively high sugar harvest from 1 hectare is 4.9 -5.4 t/ha. With the application of phosphorus fertilizers, the sugar content in the roots is higher than in the control and was in the range of 16.4 - 16.6%, and the sugar harvest from 1 ha ranged from 8.8 t/ha at a single norm to 9.8 t/ha at application of NPK+60 tons of manure.

Increases in sugar harvest from the use of phosphorus fertilizers amounted to 3.6 - 4.5 t/ha, and from the combined use of NPK+60 t of manure - 4.8 t/ha.

## 3. Conclusion

Thus, phosphorus fertilizers, with long-term use both in crop rotation and in permanent cultivation of sugar beets, affect soil fertility indicators, in particular, an increase in the content of mobile phosphorus and the nearest reserves of phosphates available to plants, which ultimately affects an increase in the yield of roots and sugar content, and on the total harvest of sugar per unit area. In addition, it is proposed that when calculating fertilizer norms for subsequent crops in crop rotations, the level of soil provided with mobile forms of phosphorus should be considered.

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