Панчук Т. В., Бордюжа І. П., Бордюжа Н. П., Мізерна Н. А., Носуля А. М.

УДК 631.85.031:635.21

CONTENT OF MOBILE PHOSPHORUS COMPOUNDS UNDER DIFFERENT METHODS AND RATES OF FERTILIZER APPLICATION DURING THE PERIOD OF THEIR ACTIVE CONSUMPTION BY POTATO PLANTS

T. V. PANCHUK, postgraduate student, https://orcid.org/0000-0003-2629-1427
ORCID: 0000-0003-2629-1427
E-mail: timur_panchuk@ukr.net
I. P. BORDIUZHA, PhD
https://orcid.org/0000-0002-5942-5877
E-mail: i_bordiuzha@nubip.edu.ua
N. P. BORDIUZHA, PhD, associate professor,
https://orcid.org/0000-0002-5482-2160
E-mail: n_borddiuzha@nubip.edu.ua
National of university of life and environmental sciences of Ukraine
N. A. MIZERNA, Deputy Head of the Department of Expertise on Excellence, Homogeneity and Stability of Plant Varieties, https://orcid.org/0000-0001-6213-5216
A. M. NOSULIA, senior research officer, https://orcid.org/0000-0002-2026-6733
Ukrainian Institute of Expertise of Plant Varieties

https://doi.org/10.31548/dopovidi5(105).2023.013

Abstract. *The article highlights the results of research on the influence of spread and local fertilization methods on the duration of localization, availability and migration of phosphorus compounds in the subsoil zone during the cultivation of seed potatoes. The research was conducted in a field experiment of the Department of Agrochemistry and Quality of Crop Production in the National University of Life and Environmental Sciences of Ukraine on the land use territory of Biotech LTD (Boryspil district, Kyiv region) during 2019-2022. FPK 8-24 was used as a pre-sowing fertilizer in the variant with a spreading method using a self-propelled sprayer Tecnoma Lazer 3000, and potassium chloride was applied using a John Deere 6195M unit and a spreader MVD 1000, followed by their incorporation with a Vaderstad Carrier CR 400 disk to a depth of 10 cm. Localized application was carried out by a unit consisting of a John Deere 8300 and a Peliper RV 3000 cultivator: phosphorus fertilizers (RKD 8-24) were applied with a tape (15 cm depth), and potash fertilizers were applied in a strip (10-12 cm width, 18-20 cm depth) (Bykin & Panchuk, 2021). Nitrogen fertilizers, as a background in all variants, were applied to the pre-sowing soil in the form of UAN-25 + S4, considering the nitrogen applied with FFR 8-24.*

The use of local fertilization allows to better optimize the nutrition of potato plants. During the period of active phosphorus consumption, a higher content of phosphorus compounds was observed in the variants where fertilizers were applied locally than in the variant where fertilizers were applied in a scattered manner. In particular, even with the application of a reduced rate of fertilizers ($P_{40}K_{90}$) locally on *the background of N_{150}, a higher content of phosphorus and potassium in the soil during the growing season was observed compared to the variant where the full rate of fertilizers ($P_{80}K_{180}$) was applied on the background of N_{150} by the scatter method.*

It was found that fertilizer localization provided a longer period of phosphorus availability in high concentrations. Also, the formation of concentration zones in deeper soil layers was noted, which were less affected by the negative effects of weather conditions and provided potato plants with this element even when the upper soil layers dried out.

***Key words**: phosphorus, local application, spreading application, localization, availability*

Relevance. Ukraine is one of the top 5 countries in the world in terms of potato production, which, in turn, is of great export importance and directly affects the country's food security. However, the average yield in recent years has reached only 14-16 t/ha. At the same time, in the advanced farms of Ukraine, due to the introduction of scientific developments into production, this figure was 30-40 t/ha. This trend shows that the potential of potato economic productivity in Ukraine is not fully utilized. Therefore, optimization of potato plant nutrition by improving and developing new methods of mineral fertilizer application is currently relevant and of great practical and theoretical importance. The analysis of scientific literature shows an insufficient level of study in this area, and especially little laboratory and field research has been conducted.

Analysis of recent research and publications. An important condition for the full growth and development of plants is the provision of phosphorus, which is especially important at the initial stage of vegetation and during the formation of tubers. Phosphorus is a component of such important compounds as phosphoproteins, nucleotides, phospholipids, nucleic acids, phosphorus esters of sugars involved in energy metabolism (NAD, ATP, FAD, etc.). Its deficiency can cause serious disruptions in biosynthesis, energy metabolism, and membrane function (Lambers, 2022). The application of phosphorus-containing fertilizers causes the accumulation of mineral and organic phosphorus compounds in the soil. To establish the optimal level of phosphate nutrition, it is necessary to determine the degree of phosphorus availability to plants from soil and fertilizers (Shevchenko, 2013). Its availability is influenced by adsorption, chemisorption, biological transformations, and other intra-soil processes. They are quite complex in nature, so the fixation of phosphorus in the soil depends on its type and chemical compounds. It has been established that many soils have a high absorption capacity for phosphorus from fertilizers. First, phosphorus is fixed in the application area, remaining in a soluble and accessible form for plants (about 25% of the applied amount). After the fertilizer is dissolved, a dynamic equilibrium is established between the solid phase of the soil and the soil solution. When phosphate ions are absorbed by the roots of potato plants, it is disturbed, which facilitates the transfer of new portions of phosphate from the soil to the soil solution. At the same time, the roots of potato plants mainly absorb phosphorus, which is located at no more than 2-2.5 mm. Therefore, even with the most powerful development of the root system, plants can only use phosphorus from a small volume of soil. Therefore, one of the most important indicators of soil fertility is the content of available forms of phosphorus. The supply of plants with sufficient amounts of these compounds depends on their reserves in the soil, the degree of phosphate mobility, weather conditions, particle size distribution, and other indicators that affect the consumption of phosphorus from soil and fertilizers (Bykin & Panchuk, 2021; Danyliuk, Vyslobodska & Vereshchak, 2003). The root system of potatoes can absorb phosphorus in the form of inorganic compounds. Soils with a neutral or acidic soil solution reaction contain phosphorus mainly in the form of dihydrogen phosphate ($H_2PO_4^-$), and in alkaline soils it is contained in the form of hydrophosphate (HPO_4^{2-}). In soil, phosphorus compounds are negatively charged, so they easily react with positively charged aluminum, iron, and calcium ions, which leads to the formation of insoluble compounds that are not available to plants. Their formation largely depends on the acidity of the soil (pH_{KCl}): at $pH < 6$, insoluble aluminum phosphates are formed; at $pH > 7$, insoluble calcium and iron phosphates are mainly formed (Jasim, A., Sharma, L. K., Zaeen, A., Bali, S.K., Buzza, A., & Alyokhin, A., 2020; Pavlichenko, 2021). In general, phosphorus in the soil is found mainly in the bound state, which causes its low concentration in the form of mobile forms. The main way phosphorus compounds reach plant roots is through diffusion, the rate of which depends on soil temperature and moisture. A decrease in soil temperature below 14°C inhibits diffusion, which can cause phosphorus deficiency even with its high content in the soil (Jasim, Sharma, Zaeen, Bali, Buzza & Alyokhin, 2020). The level of phosphorus uptake by plants is influenced not only by its content in the soil, but also by the availability of other nutrients. In potato nutrition, phosphorus is most important in the early stages of vegetation, during the period of rapid growth of vegetative mass, it, together with nitrogen, provides accelerated formation of the leaf apparatus of plants, thus determining the future yield. When potato plants are optimally supplied with this nutrient, seedlings appear earlier and the root system develops faster. Optimal phosphorus nutrition accelerates the development of potato plants, as well as tuberization processes, thereby shortening the growing season (Parkhuts, 2014; Kryzska & Potapenko, 2014). During the tuberization period, the supply of phosphorus to potato plants leads to the development of tubers of optimal size (Misgina, 2016). Phosphorus improves the physiological maturity of tubers, which contributes to the formation of a dense skin, and provides better resistance to mechanical damage during harvesting and transportation. It is also important for starch metabolism, so its application to potatoes is necessary even when the soil contains sufficient amounts of assimilable phosphorus (Ostrovsky & Ilchuk, 2003).

Mineral fertilizers are the best tool for increasing crop yields. Providing plants with the optimal amount of nutrients through their targeted use is one of the most important components of their cultivation technology. Fertilizers should be applied at a clearly defined time in optimal doses with their uniform distribution in the field. The effectiveness of mineral fertilizers directly depends on the methods and quality of their application. Traditionally, fertilizers are spread over the soil surface using spreaders. About 50% of the fertilizer granules are placed in the 0-15 cm soil layer, and a significant portion of them may be poorly accessible to plants. The reason for this is that the root system of potatoes develops and is located deeper than this layer during the growing season in search of moisture and nutrients (Bykin & Panchuk, 2021; Ponomarenko, Yaropud & Zozuliak, 2016). It is also important to note that climatic conditions in Ukraine are changing, and drought is a frequent meteorological phenomenon that provokes drying of the topsoil in which fertilizers are placed (Bykin & Panchuk, 2021). This increases the proportion of inaccessible nutrients for the root system, mainly due to inadequate particle size distribution. Quite often, when fertilizers are spread, there is an uneven distribution of fertilizers. In production conditions, it is even more difficult to maintain the required intervals between spreader passes without the use of special equipment, so the quality of fertilizer application is sharply reduced. The uneven distribution of nutrients in the soil causes uneven germination, development and maturation of plants, and ultimately, a shortfall in yield and a deterioration in its quality. When fertilizers are spread, the soil is compacted by machinery, which subsequently has a negative impact on the growth and development of potato plants. It has been found that up to 50% of the total area is subject to compaction (Bykin & Panchuk, 2021; Ponomarenko, Yaropud & Zozuliak, 2016). Increasing the availability of nutrients and reducing costs is only possible through fertilizer optimization. Therefore, one of the ways to improve potato nutrition and reduce nutrient losses, eliminate the negative impact of fertilizers on the environment, and obtain high, stable crop yields is to apply mineral fertilizers locally to the zone of plant root development (Bykin & Panchuk, 2021; Alyokhin, 2016). The use of localized fertilization technologies is an alternative to spreading fertilizers and has a number of advantages. Under such conditions, the level of nitrogen utilization increases by 10-15%, phosphorus by 5-10%, and potassium by 10-12%, which allows reducing fertilizer application rates by 25-30% (Bender & Vasylovych, 2016). Scientists identify the main factors that provide certain advantages to the local use of phosphate fertilizers: the impact of fertilizers on the soil is limited in the layer that is in direct contact with the fertilizer belt (Sparrow, Chapman, Parsley, Hardman & Cullen, 1992); the pH of the soil solution increases in the area of fertilizer application (Jin, Chen, Chen, Jiang, Hopkins, Zhang & Benavides, 2019); localization and reduction of the area of contact of phosphate fertilizers with the soil increases the mobility of phosphorus and increases its availability for potato plants (Rosen, Kelling, Stark & Porter, 2014); local application of fertilizers involves their placement in deeper soil layers that are better moistened even in drought, which in turn leads to a prolonged effect of fertilizers and better absorption by plants (Khmylevskyi, 2006). The intra-soil technology of their use allows adjusting the application of fertilizers according to the timing of application and, accordingly, the ontogeny of plants. The possibility of combining local fertilization with basic, pre-sowing and inter-row tillage, as well as sowing and planting, is not only an effective reserve for saving agricultural resources, but also prevents excessive soil compaction (Nukeshev, Eskhozhin, Lichman, Karaivanov, Zolotukhin & Syzdykov, 2016). The most common method of fertilizer placement is the belt method. It allows fertilizer belts to be placed at an optimal distance from the tubers. The application of mineral fertilizers in the spring and before sowing allows for several operations to be carried out simultaneously, which in turn reduces the energy intensity of the work (Zolotukhin, Lichman & Nukeshev, 2017). Many studies have shown that it is most effective to place fertilizer belts for continuous sowing crops and cereals at intervals of 15-30 cm, plowed under the row 5-10 cm deeper than the seeds to protect plant roots from burns (Novikov & Motorin, 2021). When applying fertilizers locally, they can be placed in layers to different depths, as well as combine liquid and solid forms. It has been established that the level of utilization of nutrients from fertilizers and soil is largely influenced by the moisture supply of plants. Placing fertilizers locally facilitates the search for nutrients and increases their absorption during the growing season, including during soil drought. The effectiveness of the local application method may depend on the granulometric composition and level of soil fertility and moisture availability, forms, types and rates of fertilizers, parameters of their placement in the soil, biological characteristics of crops, etc. The key feature of this fertilizer application method is the formation of zones in the topsoil with a high content of mobile forms of nutrients. The high concentration of salts in a small volume reduces the degree of nutrient fixation by the soil and reduces their loss. It was found that the degree of phosphorus fixation decreases with local application compared to scattered application. As a result, the period of its stay in the form available to plants is extended. The soil in contact with the fertilizer belt is capable of a sharp saturation with nutrients, which causes a change in the concentration of the soil solution and an increase in osmotic pressure. Such conditions inhibit the vital activity of microorganisms. This blocks the binding of nutrients and slows down the nitrification process (Bykin & Panchuk, 2021).

The aim of the research. To establish an effective method and rate of mineral fertilizer application that can optimize the nutrition of seed potato plants by changing the placement of mineral fertilizers and increasing the period of availability of phosphorus compounds in dark gray podzolic light loamy soil.

Materials and methods of research. Scientific research was conducted in a field experiment of the Department of Agrochemistry and Quality of Plant Production of the National University of Life Sciences of Ukraine on the territory of land use of Biotech LTD (Boryspil district, Kyiv region) during 2019-2022 according to the developed experimental scheme (Table 1).

1. Scheme of the field experiment to study the effectiveness of different methods and rates of fertilizer application, 2019-2021.

Serial number of the variant	Fertilizer application method and rate	
	spreading	local
1	$N_{150}P_{80}K_{180}$	-
2	N_{150}	$P_{80}K_{180}$
3	N_{150}	$P_{60}K_{135}$
4	N_{150}	$P_{40}K_{90}$

The area of the sown plot was 495 m^2, and the accounting plot was 312 m^2. The experiment was replicated 4 times. The placement of the variants was systematic. The soil of the experimental plot is dark gray podzolized coarse-loamy light loamy on loess. It was characterized by a slightly acidic reaction of the soil solution (5.48), a high degree of mobile phosphorus (246 mg/kg) and exchangeable potassium (224 mg/kg), an increased content of exchangeable magnesium (2.64 mg. equivalents/100 g), average calcium content (7.93 mg.equivalents/100 g), low content of mobile sulfur (3.64 mg/kg) and mineral nitrogen (14.5 mg/kg) (Bykin & Panchuk, 2021).

The following fertilizers were used in the research: UAN - 25: N content - 25%, S - 2.4% (TU U 24.1-00203826. 024-2002), FERT 8:24: N content - 8 %, P_2O_5 - 24 % (TU 2186-627-00209438-01), potassium chloride: K_2O content - 60 % (TU 2184-042-00209527-97), magnesium sulfate: MgO content - 16 % (TU 2141-073-00206457-2007), calcium nitrate: N content - 15.5 %, Ca - 19 % (TU U6-13441912.004-99).

The technology of growing table potatoes was adapted to the conditions of the Left-Bank Forest-Steppe of Ukraine and was carried out in accordance with the requirements of DSTU 4506:2005 "Food potatoes. Technology of cultivation. Main provisions". The predecessor was winter wheat. After harvesting, the crop residues were tilled to a depth of 5-6 cm with simultaneous sowing of oil radish as a green manure (seeding rate 30 kg/ha). In the autumn period, the soil was chiseled with a deep cultivator AGR-2.4 to a depth of 38-40 cm with a distance of 50 cm between the working bodies. Spring moisture closure was carried out using a Vaderstad Carrier CR400 disk harrow to a depth of 5-7 cm. Mineral fertilizers were applied according to the scheme of the experiment (Table 1).

FPK 8-24 was used as a pre-sowing fertilizer in the variant with a spreading method using a self-propelled sprayer Tecnoma Lazer 3000, and potassium chloride was applied using a John Deere 6195M unit and a spreader MVD 1000, followed by their incorporation with a Vaderstad Carrier CR 400 disk to a depth of 10 cm. Localized application was carried out by a unit consisting of a John Deere 8300 and a Peliper RV 3000 cultivator: phosphorus fertilizers (RKD 8-24) were applied with a tape (15 cm depth), and potash fertilizers were applied in a strip (10-12 cm width, 18-20 cm depth) (Bykin & Panchuk, 2021). Nitrogen fertilizers, as a background in all variants, were applied to the pre-sowing soil in the form of UAN - 25 + S4, taking into account the nitrogen applied with the FFR 8-24. Thus, in the variant with scattered application, the dose was N_{73}. In the variants with local application of P_{80} K_{180} - N_{73}; P_{60} K_{135} - N_{80}; P_{40} K_{90} - N_{87}. Before the formation of the ridges, $MgSO_4$ (50 kg/ha) and N_{35} in the form of UAN-25 + S_4 were applied with their subsequent working by the ridge forming agent, and N_{15} in the form of calcium nitrate was applied as a fertilizer. Planting of seed tubers was carried out in the first decade of May (John Deere 6195M tractor aggregated with Grimme GL 34KL) at the rate of 55 thousand tubers/ha to a depth of 7-9 cm with their pre-planting treatment with growth stimulants Gros 78 Rooter (1.5

l/t) and Ecoline Phosphite (K) (1 l/t) using an applicator on the inspection table (Bykin & Panchuk, 2022). The formation of ridges was carried out at the end of the third decade of May using a John Deere 6195M tractor and a Grimme GF 75-4 ridge-forming cutter.

Samples of soil and potato plants were taken at the following stages of growth and development: germination (BBCH-10), budding (BBCH-51-59), flowering (BBCH-60-69), "green berry" (BBCH-70-79), and technical maturity (BBCH-91-99). The selection and preparation of soil samples for analysis was carried out in accordance with DSTU ISO 10381-2:2004 and DSTU ISO 11464:2001. The content of mobile phosphorus compounds was determined by the Kirsanov method.

Results of the study and their discussion. Under the conditions of our experiment, in the germination phase under the spread fertilizer application ($P_{80}K_{180}$) on the background of N_{150}, the phosphorus content ranged from 129 to 392 mg/kg (Fig. 1). In the layer of 0-5 cm it was the highest and varied from 352 to 392 mg/kg. With increasing depth, the content of this element decreased, so that in the layer of 5-10 cm its content reached a level of 335 to 379 mg/kg. At a depth of 10-15 cm, it ranged from 160 to 311 mg/kg. With its further increase to 15-20 cm, it was in the range of 129-179 mg/kg. The high phosphorus content in the upper soil layers during the germination phase is due to the scattered application of fertilizers.

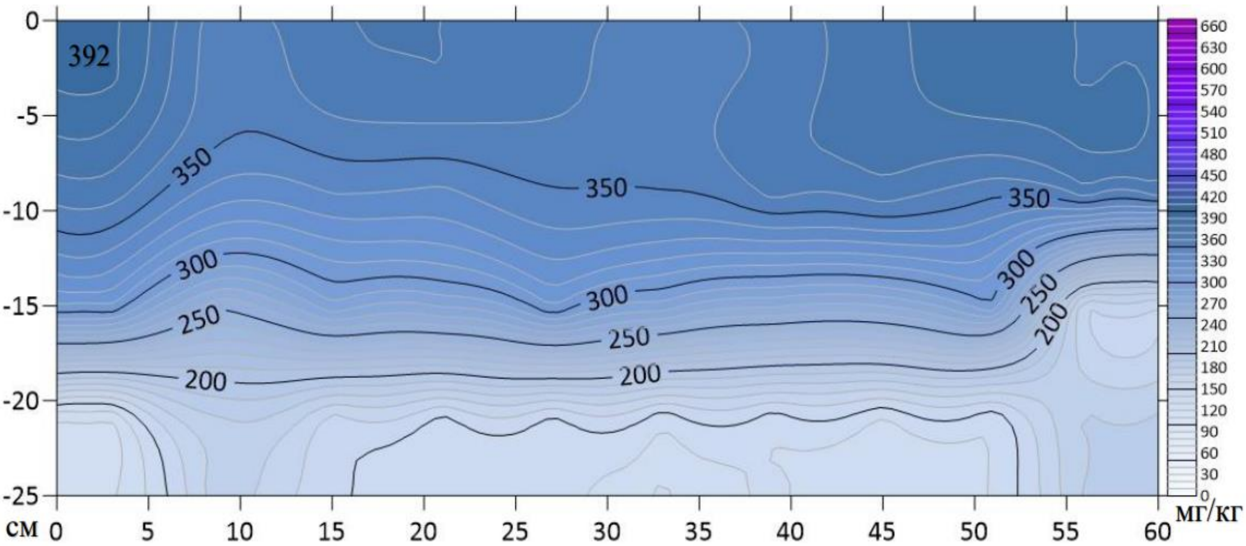

Fig. 1. Distribution of mobile phosphorus in the soil of the sub-soil zone in the germination phase under spread fertilization ($P_{80}K_{180}$) on the background of N_{150}, 2019-2021.

This method resulted in an uneven distribution of this element over the soil profile with different concentration zones in the soil, which is clearly seen in the above figure.

During this period, with local application ($P_{80}K_{180}$) on the background of N_{150}, the maximum phosphorus content in the application zone was 365 mg/kg (Fig. 2). According to our research, the main localization of phosphorus under this method and application rate was recorded at a depth of 10-12 cm with clear concentration zones of ≈ 300, 250 and 200 mg/kg.

Compared to the spreading method of applying a similar fertilizer rate, the zones with a content of ≈ 300 and 350 mg/kg were smaller. This is primarily due to the application method, as well as the fact that the fertilizers have not yet fully come into contact with the soil due to their localization. When applying a reduced rate by 25 % (P60K135) locally against the background of N150, the maximum phosphorus concentration in the fertilizer placement zone was 331 mg/kg (Fig. 3).

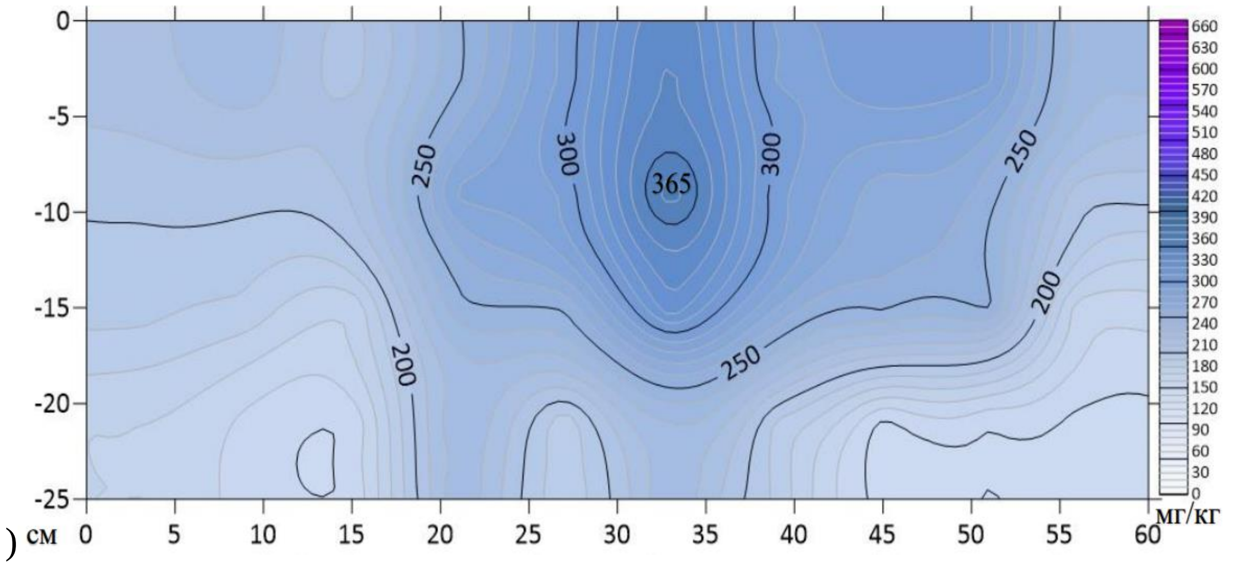

Fig. 2. Distribution of mobile phosphorus in the soil of the sub-soil zone in the germination phase under local fertilization ($P_{80}K_{180}$) on the background of N_{150}, 2019-2021.

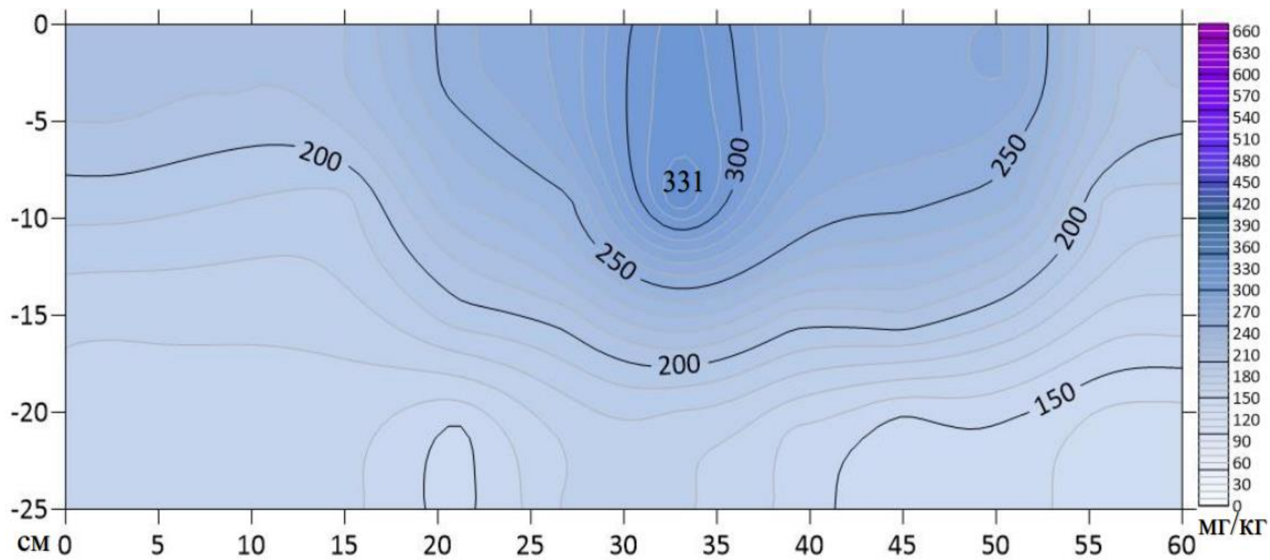

Fig. 3. Distribution of mobile phosphorus in the soil of the sub-soil zone in the germination phase under local fertilization (P60K135) on the background of N150, 2019-2021.

It is worth noting that the narrowing of the zones with a content of ≈ 200 and 250 mg/kg may also be due to a lower fertilizer rate compared to the above options.

Reducing the local rate by half to the level of $P_{40}K_{90}$ on the background of N_{150} caused the localization of phosphorus compounds at a depth of 10-12 cm, and the maximum content in the application zone was 290 mg/kg (Fig. 4). At this rate and method of application, the zones with concentrations of ≈ 250 mg/kg and ≈ 300 mg/kg were narrowed. At the same time, the zone with a phosphorus content of ≈ 200 mg/kg was the largest compared to the above variants where local fertilization was applied.

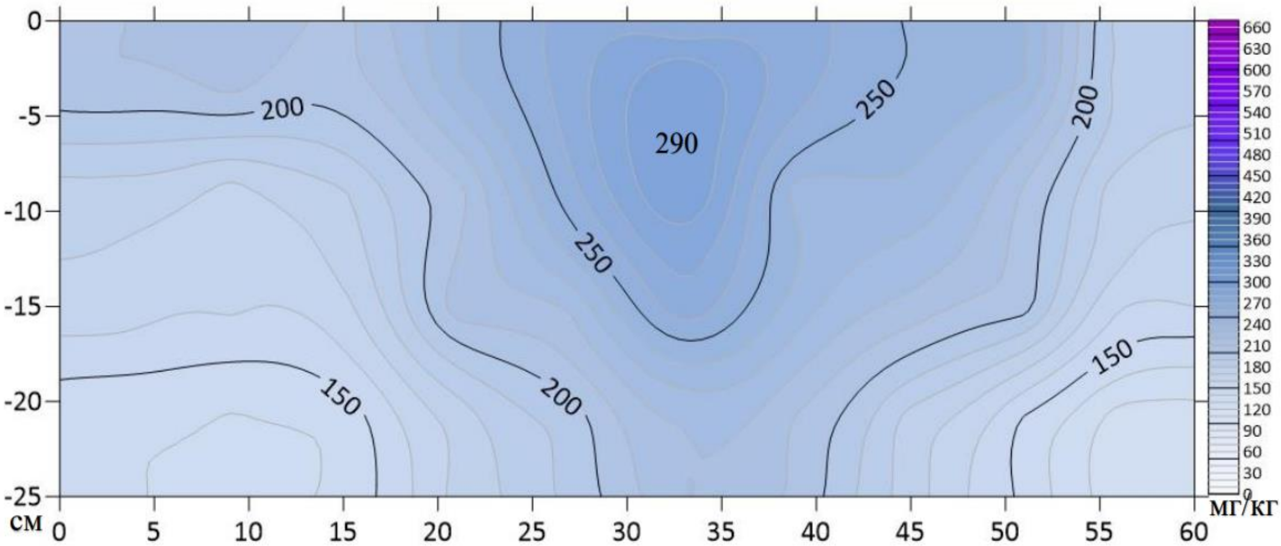

Fig. 4. Distribution of mobile phosphorus in the soil of the sub-soil zone in the germination phase under local fertilization ($P_{40}K_{90}$) on the background of N_{150}, 2019-2021.

This increase may be due to a lower rate of phosphorus fertilizers than in other variants, and when they encountered the soil under the influence of moisture, they reacted with the soil faster and more completely.

Thus, in the germination phase, the highest concentration of phosphorus was observed in the upper layers of the soil in the variant where fertilizers were applied in a scattered manner. At the same time, local application contributed to its localization at a depth of 10-15 cm, which helped to minimize the impact of weather conditions on its content and availability.

By the budding phase, the content of mobile phosphorus in the soil of the subsoil zone decreased. Under scattered fertilizer application ($P_{80}K_{180}$) on the background of N_{150} ranged from 119 to 291 mg/kg (Fig. 5).

Thus, in the 0-5 cm layer, its content ranged from 240 to 291 mg/kg. With an increase in depth to 5-10 cm, its amount decreased to 231-257 mg/kg. With a further increase in depth to a layer of 10-15 cm, its content decreased to the range of 135-238 mg/kg. At a depth of

15-20 cm, this figure continued to decline to the level of 119-168 mg/kg. Such a decrease in phosphorus content with depth is primarily due to its traditional application to the soil surface and incorporation into the 0-10 cm layer, as well as the low mobility of the element itself along the soil profile.

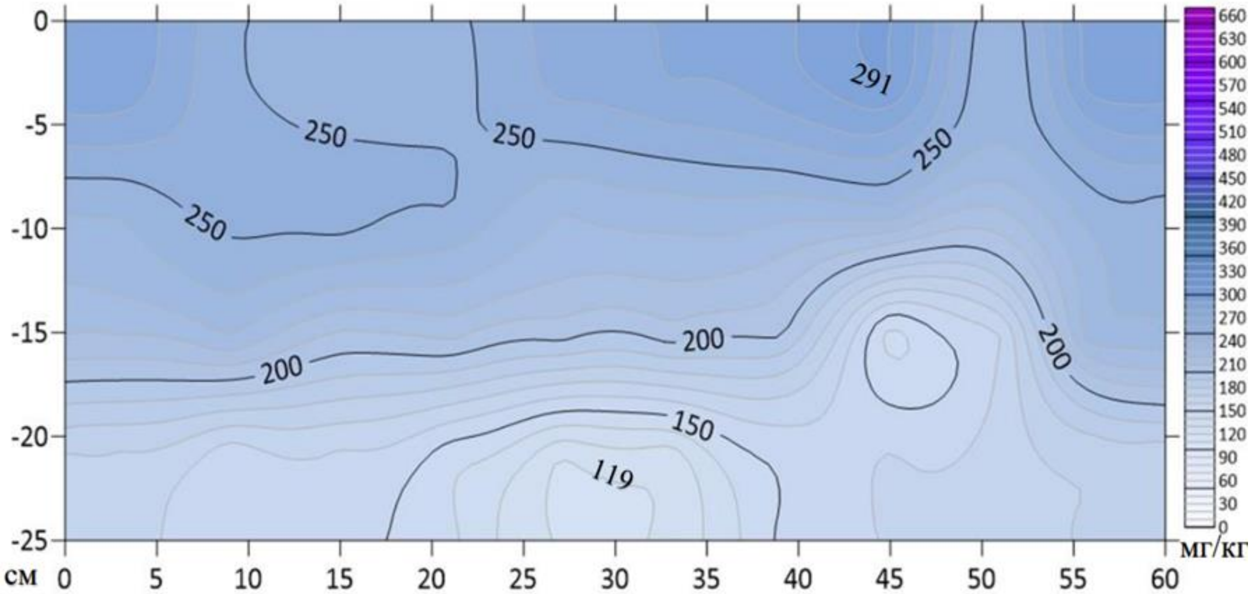

Fig. 5. Distribution of mobile phosphorus in the soil of the sub-soil zone in the budding phase under spread fertilization (P80K180) on the background of N150, 2019-2021.

With the local application of a similar rate of phosphorus and potassium fertilizers ($P_{80}K_{180}$) on the background of N_{150}, the content of mobile phosphorus in the root zone ranged from 353 to 115 mg/kg. Analyzing (Fig. 6), we can clearly distinguish the zone of phosphorus localization in the layer of 8-12 cm. The maximum content in the center of this zone was 353 mg/kg. It should also be noted that the concentration around the fertilizer placement zone was in the range of 200-250 mg/kg. Comparing this method of application with the spreading method, we can conclude that local placement of phosphate fertilizers creates a localization zone with a higher concentration in the soil. This can block the binding of phosphorus compounds and allow plants to receive this element in full for a longer period.

In the variant with local application of the norm reduced to $P_{60}K_{135}$ on the background of N_{150}, the zone of phosphorus localization with a content of about 250 mg/kg was smaller in size compared to the above variant. At the same time, in the center of this zone, the phosphorus concentration was higher than in the previous variant and amounted to 369 mg/kg (Fig. 7).

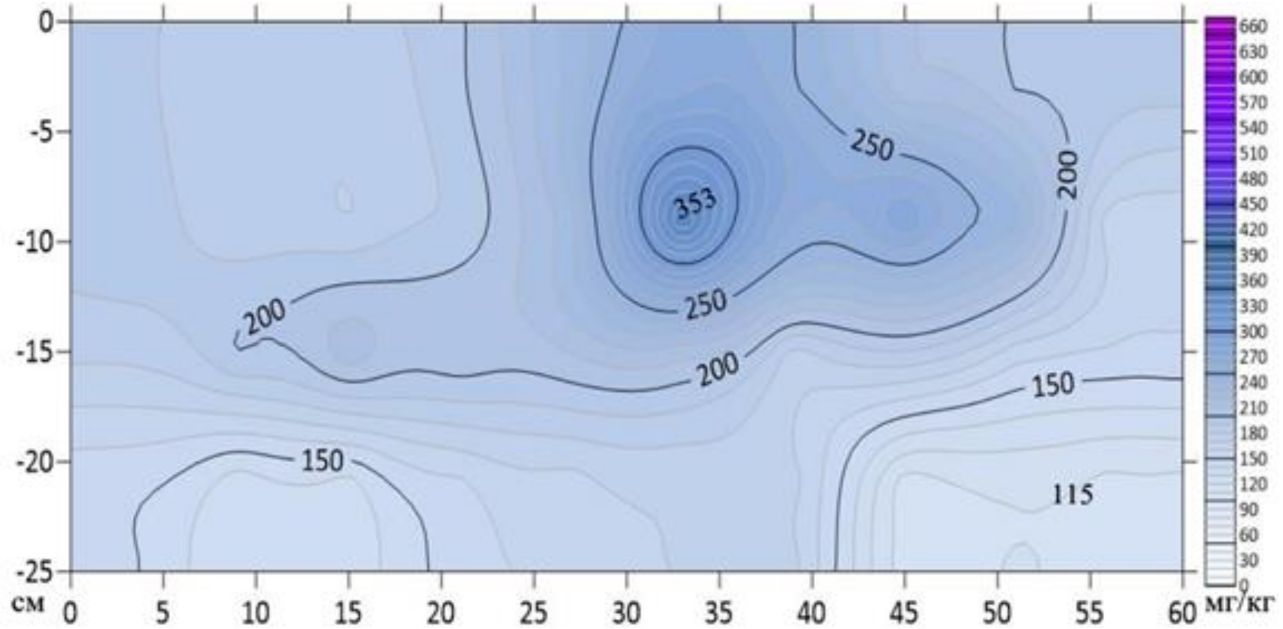

Fig. 6. Distribution of mobile phosphorus in the soil of the sub-soil zone in the budding phase under local fertilization (P80K180) on the background of N150, 2019-2021.

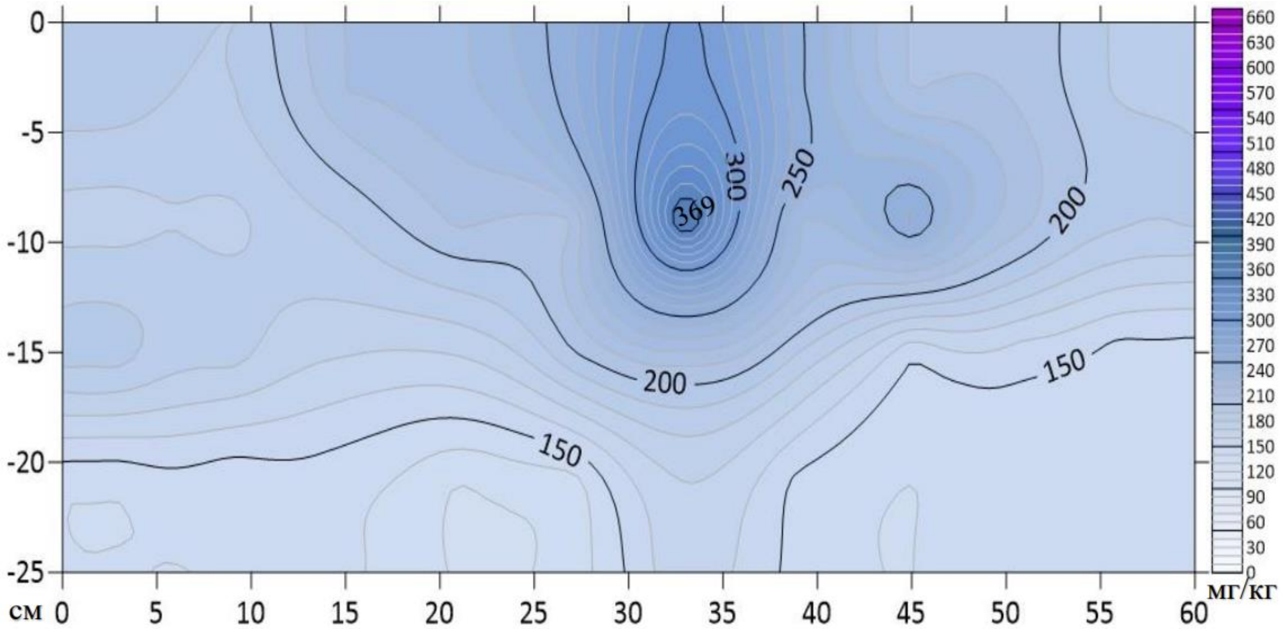

Fig. 7. Distribution of mobile phosphorus in the soil of the sub-soil zone in the budding phase under local fertilization (P60K135) on the background of N150, 2019-2021.

The increase in the content in the localization area compared to the variant where the full rate of phosphorus and potassium fertilizers was applied locally may have been due to lower phosphorus consumption by plants, as its content in leaves and roots was lower. It could also be due to lower phosphorus fixation by the soil.

Local application of a reduced by 50 % rate of phosphorus and potassium fertilizers ($P_{40}K_{90}$) on the background of N_{150} caused the phosphorus content in the subsoil zone to range from 108 to 346 mg/kg (Fig. 8). Analyzing the following indicators, it should be noted that at this rate of application, a localization zone with a content of more than 300 mg/kg was observed, and 346 mg/kg in the center.

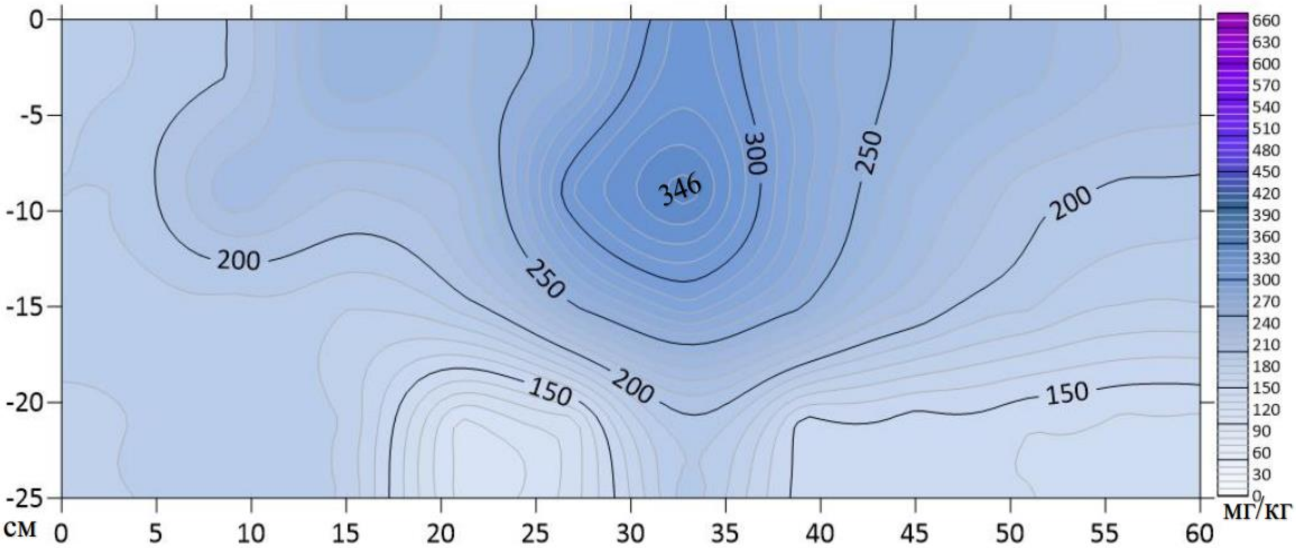

Fig. 8. Distribution of mobile phosphorus in the soil of the sub-soil zone in the budding phase under local fertilization ($P_{40}K_{90}$) on the background of N_{150}, 2019-2021.

Perhaps the expansion of the phosphorus zone compared to the above variants may be due to the rate of phosphorus applied from fertilizers, which reacted faster with the soil under the influence of moisture.

During the flowering period, optimal phosphorus nutrition ensures the formation of standard-sized tubers, which improves future yields. In this phase, under the spreading application of $P_{80}K_{180}$ on the background of N_{150}, the phosphorus concentration in the 0-5 cm layer decreased to 202-261 mg/kg compared to the budding phase (Fig. 9).

With an increase in depth to 5-10 cm, its content decreased to 183-241 mg/kg. In the layer of 10-15 cm, the concentration of this element ranged from 131 to 227 mg/kg, while at a depth of 15-20 cm it was in the range of 108-147 mg/kg. The uneven and layered distribution of phosphorus across the soil profile is primarily due to the scattered application of fertilizers and the way they are worked in. Reduction of zones with high concentration levels in the flowering phase may be due to the active consumption of this element by the plant to ensure optimal tuberization and crop formation.

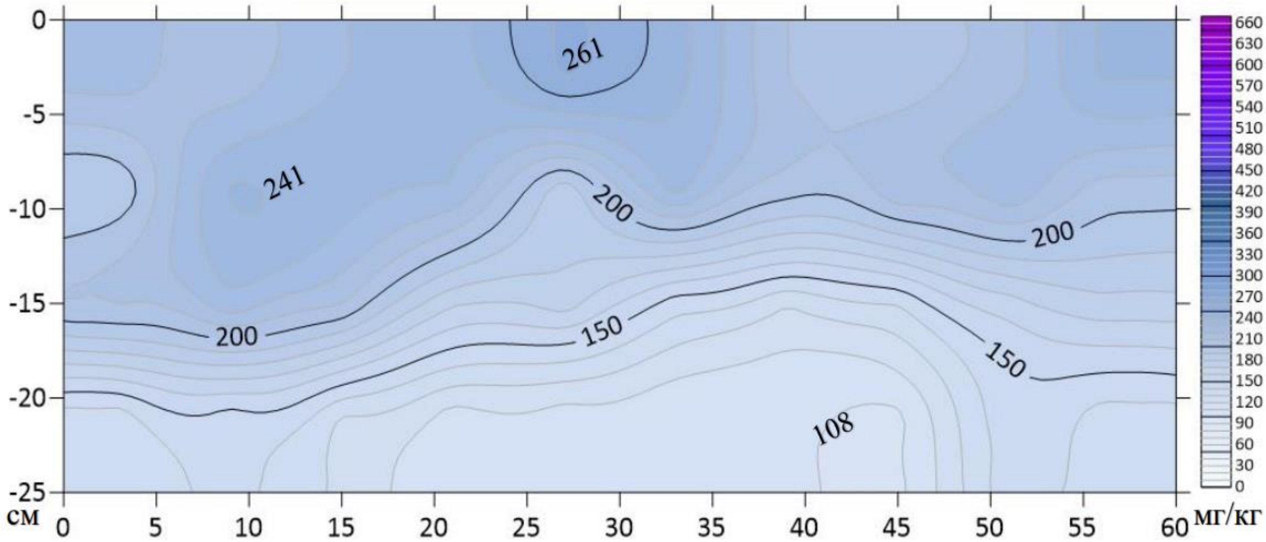

Fig. 9. Distribution of mobile phosphorus in the soil of the sub-soil zone in the flowering phase under spread fertilization (P80K180) on the background of N150, 2019-2021.

With the local application of $P_{80}K_{180}$ on the background of N_{150}, the concentration of phosphorus decreased by the flowering phase compared to the previous phase of vegetation (Fig. 10).

The maximum phosphorus content in the center of the application zone was 292 mg/kg, which is 61.9 mg/kg less compared to the budding phase. There was also a decrease in the zone with a concentration of ≈ 250 mg/kg.

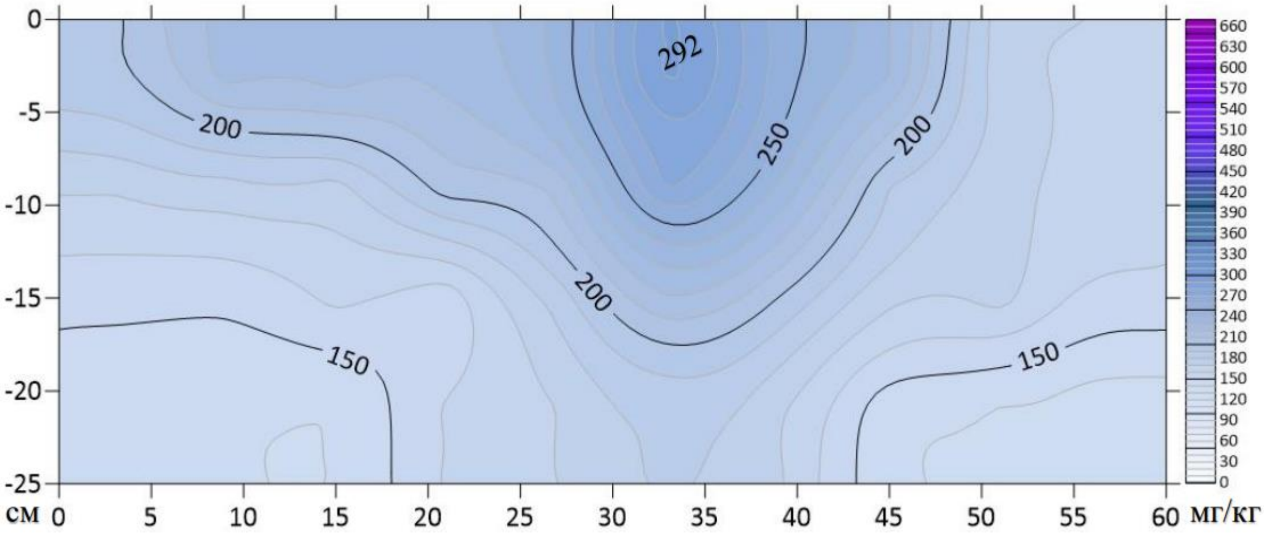

Fig. 10. Distribution of mobile phosphorus in the soil of the sub-soil zone in the flowering phase under local fertilization ($P_{80}K_{180}$) on the background of N_{150}, 2019-2021.

In the variant with local application of 25 % lower rate ($P_{60}K_{135}$) on the background of N_{150}, a decrease in phosphorus concentration was observed in the subsoil part of the soil profile (Fig. 11).

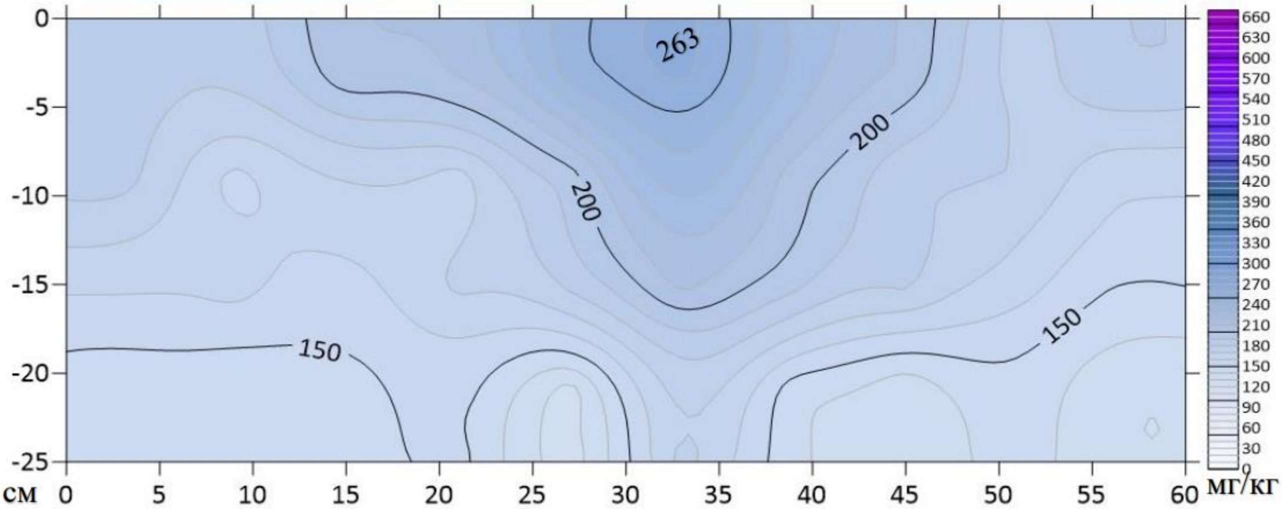

Fig. 11. Distribution of mobile phosphorus in the soil of the sub-soil zone in the flowering phase under local fertilization (P60K135) on the background of N150, 2019-2021.

In the flowering phase, in the variant where local application was applied at a rate reduced by 50 % ($P_{40}K_{90}$) on the background of N_{150}, a decrease in the concentration of phosphorus in the soil was also observed (Fig. 12).

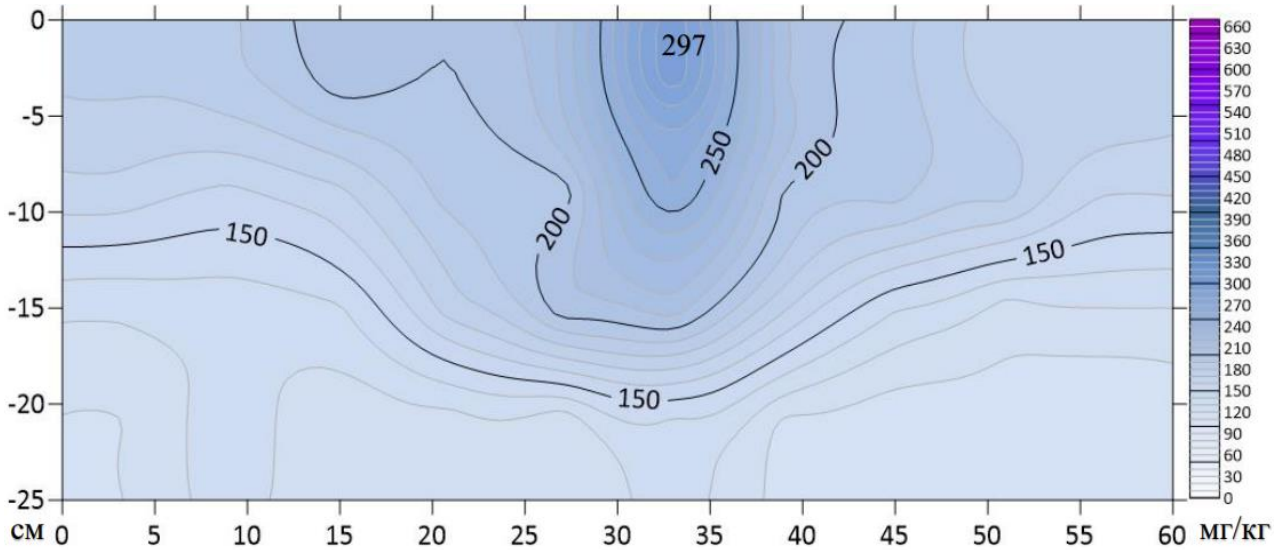

Fig. 12. Distribution of mobile phosphorus in the soil of the sub-soil zone in the flowering phase under local fertilization (P40K90) on the background of N150, 2019-2021.

Analyzing the above data, we can note the narrowing of phosphorus localization zones compared to the previous phase of growth and development. The maximum phosphorus content in the localization zone was 297 mg/kg, which is less than in the previous phase. The narrowing of the zones and the decrease in the content of mobile phosphorus may be due to the active use of its compounds by plants, as well as the influence of chemical processes that take place in the soil and contribute to the transition of this element into a form inaccessible to plants.

Conclusions and prospects. The use of local fertilization allows to optimize the nutrition of potato plants. During the period of active phosphorus consumption, the variants where fertilizers were applied locally had a higher content of phosphorus compounds than the variant where fertilizers were applied in a scattered manner. Even with the application of half the fertilizer rate ($P_{40}K_{90}$) locally on the background of N_{150}, a higher content of phosphorus and potassium in the soil during the growing season was observed than in the variant with the full fertilizer rate ($P_{80}K_{180}$) applied on the background of N_{150} by the scatter method.

It was found that fertilizer localization provided a longer period of phosphorus availability in high concentrations. Also, the formation of concentration zones in deeper soil layers was noted, which were less affected by the negative impact of weather conditions and provided potato plants with this element even when the upper soil layers were drying out.

To summarize, we can say that the local fertilization method is very promising. It provides a combination of several agrotechnical processes, namely cultivation and fertilization at the same time. This allows us to prepare the field for sowing faster, reduce soil compaction and cut the cost of agricultural activities. In turn, localization of fertilizers leads to an increase in nutrient consumption rates, ensures their better availability, especially during drought, and allows to reduce fertilizer doses by half without reducing crop productivity in such circumstances.

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Панчук Т. В., Бордюжа І. П., Бордюжа Н. П., Мізерна Н. А., Носуля А. М.

ВМІСТ РУХОМИХ ФОСФОРНИХ СПОЛУК ЗА РІЗНИХ СПОСОБІВ ТА НОРМ ВНЕСЕННЯ ДОБРИВ У ПЕРІОД ЇХ АКТИВНОГО СПОЖИВАННЯ РОСЛИНАМИ КАРТОПЛІ

Т. В. Панчук, І. П. Бордюжа, Н. П. Бордюжа, Н. А. Мізерна, А. М. Носуля

Анотація. *Внесення фосфоровмісних добрив обумовлює накопичення в ґрунті мінеральних і органічних сполук фосфору. Для встановлення оптимального рівня фосфатного живлення необхідно визначити ступінь доступності для рослин фосфору з ґрунту та із добрив (Шевченко, 2013). На його доступність впливають адсорбція, хемосорбція, біологічні перетворення, а також інші внутрішньоґрунтові процеси. Вони мають досить складну природу, тому закріплення фосфору в ґрунті, залежать від його типу і хімічних сполук у ньому. Встановлено, що переважна більшість ґрунтів по відношенню до фосфору з добрив має високу вбирну здатність. Насамперед фосфор фіксується у зоні внесення, залишаючись у розчинній та доступній для рослин формі (близько 25 % від внесеної кількості). Після розчинення внесених добрив між твердою фазою ґрунту та ґрунтовим розчином встановлюється динамічна рівновага. При засвоєнні фосфат-іонів, коренями рослин картоплі вона порушується, що сприяє переходу нових порцій фосфатів із ґрунту в ґрунтовий розчин. Водночас корені рослин картоплі в основному поглинають фосфор, який знаходиться на відстані не більше, як 2–2,5 мм.*

У статті висвітлено результати досліджень по впливу розкидного та локальних способів внесення добрив на тривалість локалізації, доступності та міграцію сполук фосфору в підгребеневій зоні за вирощування насіннєвої картоплі.

Наукові дослідження проводились в польовому досліді кафедри агрохімії та якості продукції рослинництва ім. О.І. Душечкіна Національного університету біоресурсів і природокористування України на території землекористування ТОВ «Біотех ЛТД» (Бориспільський район, Київська область) протягом 2019–2022 рр. Мінеральні добрива вносили згідно схеми досліду. РКД 8–24 застосовували у передпосівне удобрення у варіанті з розкидним способом за допомогою самохідного обприскувача Теспота Lazer 3000, а калій хлористий за допомогою агрегату John Deere 6195M та розкидача МВД 1000 з подальшим їх заробленням дискатором Vaderstad Carrier CR 400 на глибину 10 см. Локальне внесення проводили агрегатом у складі John Deere 8300 та культиватора Peliper RV 3000: фосфорні добрива (РКД 8–24) стрічкою (глибина 15 см), а калійні – смугою (ширина 10–12 см, глибина 18–20 см) (Bykin & Panchuk, 2021). Азотні добрива, як фон в усіх варіантах, вносили у передпосівний обробіток ґрунту у вигляді КАС – 25 + S_4 *з урахуванням азоту внесеного з РКД 8–24.*

Застосування локального внесення добрив дозволяє краще оптимізувати живлення рослин картоплі. Зокрема у період активного споживання фосфору у варіантах, де добрива вносились локальним способом відмічався вищий вміст сполук фосфору, а ніж у варіанті, де добрива вносились врозкид. Зокрема, навіть за внесення зменшеної норми добрив ($P_{40}K_{90}$*) локально на фоні* N_{150} *відмічався вищий вміст фосфору та калію у ґрунті протягом вегетаційного періоду, у* *порівнянні з варіантом, де застосовувалася повна норма добрив ($P_{80}K_{180}$) на фоні N_{150} розкидним способом.*

В умовах нашого досліду у фазу сходів за розкидного внесення добрив ($P_{80}K_{180}$) на фоні N_{150} вміст фосфору коливався від 129 до 392 мг/кг. У шарі 0–5 см він був найбільшим та змінювався від 352 до 392 мг/кг. Із збільшенням глибини вміст цього елементу знижувався, так у шарі 5–10 см його вміст досягав рівня від 335 до 379 мг/кг. На глибині 10–15 см він коливався від 160 до 311 мг/кг. За її подальшого збільшення до 15–20 см він був в межах 129–179 мг/кг. Високий вміст фосфору у верхніх шарах ґрунту в фазу сходів обумовлений розкидним внесенням добрив.

Встановлено, що локалізація добрив забезпечувала довший період доступності фосфору у високих концентраціях. Також відмічалось формування зон концентрації в глибших шарах ґрунту, які меншою мірою піддавались негативному впливу погодних умов та забезпечували рослини картоплі цим елементом навіть за пересихання верхніх шарів ґрунту.

Ключові слова: *фосфор, локальне внесення, розкидне внесення, локалізація, доступність*