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# EFFICIENCY OF LOCAL APPLICATION OF PHOSPHORUS-POTASSIUM FERTILIZERS IN POTATO CULTIVATION

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**Problem Statement.** Obtaining consistently high yields of agricultural crops, and potatoes in particular, is one of the most important tasks of the modern agricultural sector of the economy. Today, Ukraine occupies leading positions in global potato production, confidently entering the top three largest producer countries in the world. In recent years, the highest volumes of production of this crop are demonstrated by China with an indicator of 93 million tons and India, which produces 51 million tons.

Ukraine, having a gross harvest at the level of 23 million tons, closes this global top three. In total, these three states provide approximately 45% of all global potato production. In addition, countries such as the USA, Bangladesh, Germany, Poland, the Netherlands, and Canada significantly increase production volumes, together producing approximately 24% of the global volume [1].

At the same time, Ukraine stands out not only by the scale of cultivation but also by an extremely high level of domestic consumption. Our state ranks second in the world in terms of potato consumption per capita. The average statistical indicator of consumption in Ukraine is 139 kg per year per 1 person. To understand the scale, it is worth noting that the global average potato consumption is only about 33 kg/person/year. Such data make it possible to fully realize the strategic importance of potatoes for Ukrainians and their key role in ensuring national food security [1].

According to UCAB statistical data, in recent years, the area under potatoes in Ukraine has increased by 2.72%, or by 35 thousand hectares, reaching the mark of 1325 thousand hectares. However, despite the expansion of sown areas, average yield indicators remain very low. An analysis of recent years shows that in 2022 the yield was at the level of 16.5 t/ha, in 2023 it was 17.3 t/ha, in 2024 this indicator decreased to 14.5 t/ha, an insignificant increase in yield occurred in 2025 – 18.3 t/ha. Thus, the average yield for the last three years fixed at the level of 16.7 t/ha. This indicator is extremely low compared to the leading countries of the world, where intensive cultivation technologies are introduced. For example, in the USA this indicator reaches 50 t/ha, in Canada – 43 t/ha, in Holland – 43 t/ha, in France – 43 t/ha, and in Germany – 45 t/ha [2].

It should be emphasized that low yields in Ukraine are not a fatal inevitability. In certain advanced farms in Ukraine, thanks to the introduction of the latest scientific developments and intensive nutrition technologies into production, the yield consistently reaches 35-45 t/ha. This convincingly proves that the overall potential of economic productivity of potatoes in the country currently remains underutilized [2].

The main problem hindering the achievement of high results is the imperfection of nutrition systems. Obtaining high potato yields undoubtedly requires the use of significant rates of nutrients. Under the traditional, most widespread in domestic practice method of application, fertilizer granules are broadcast over the field surface using centrifugal units and are only later mixed with the soil during mechanical tillage. This method has a number of fundamental drawbacks. One of them is the critical unevenness of fertilizer distribution, which is especially acute in fields with problematic soil texture. Such unevenness causes field variegation, desynchronization of emergence, as well as uneven growth and development of potato plants [3].

An even more serious problem is that intensive mixing of fertilizer granules with a large volume of soil highly activates

the processes of their dissolution, chemical absorption, and strong binding of nutrients by the soil absorbing complex. As a result, a massive transition of vital elements into a form unavailable to plants occurs. Considering this, solving the problem of low yield and low quality of seed material requires urgent optimization of the method of fertilizer application, in particular, the transition to the local application of phosphorus and potassium fertilizers, which allows creating zones of high concentration of available elements directly in the zone of plant root system location [4].

**Analysis of Recent Research and Publications.** Long-term fundamental research conducted by scientists in many countries of the world convincingly proves the exceptional importance of proper use of mineral fertilizers to ensure a significant increase in crop yields. Potato plants are characterized by increased demands for the availability of nutrients. These substances must be present in the soil not only in sufficient quantities but also necessarily in an available, easily assimilable form. This specificity is largely determined by the biological and morphological features of the potato, and, above all, its poorly developed root system, which forms a relatively small volume and is located mainly in the upper, arable soil layer [5].

An analysis of scientific sources confirms that the overall effectiveness of mineral fertilizers directly and inextricably depends on the methods and quality of their application. With the traditional broadcast method, fertilizers are randomly distributed over the soil surface. It has been established that with this technology, about 50% of fertilizer granules are accumulated in the 0–15 cm soil layer, and a significant part of them eventually becomes poorly available to plants. The primary reason for this is that the potato root system, during prolonged vegetation, constantly searching for moisture and nutrients, develops and inevitably locates deeper than this horizon [6].

Moreover, climatic conditions in Ukraine are undergoing noticeable changes, and soil drought is becoming quite a frequent meteorological phenomenon. It provokes rapid drying of the topsoil (exactly where the lion's share of broadcasted fertilizers is located). The lack of moisture stops the transition of elements into the soil solution, which catastrophically increases the proportion of unavailable nutrients for the root system, especially under conditions of improper soil texture [7].

Researchers also emphasize the technological flaws of the broadcast method. In production conditions, it is extremely difficult to maintain ideally required intervals between equipment passes without the use of special navigation equipment, so the quality of fertilizer application sharply decreases. The uneven spatial distribution of nutrients in the soil leads to uneven emergence of plants, their further development, and maturation, which ultimately results in a significant shortfall in yield and deterioration of its fractional quality. A separate negative factor is that during fertilizer broadcasting, repeated soil compaction by the running systems of machinery occurs, which subsequently causes a negative impact on potato growth. It is proved that up to 50% of the entire field area is subjected to such compaction [7].

An important technological technique analyzed in the scientific literature is the speed of fertilizer incorporation into the soil. Standards indicate that the time interval between fertilizer broadcasting and their incorporation should not exceed 6 hours. A delay in mixing fertilizers with the soil inevitably causes high nutrient losses and leads to environmental pollution. However, even timely incorporation has hidden threats: under intensive mixing of fertilizers with a large volume of soil, processes of chemical binding of nutrients and their rapid transition into hard-to-reach forms for plants are activated [8]. Foreign scientific studies confirm that potato has a relatively low overall need for phosphorus (from 25 to 45 kg/ha), but at the same time is characterized by a critically high need specifically for the available forms of this element due to the low efficiency of its assimilation. This is due to the fact that potato forms a shallow root system (most roots are located in the top 30 cm of soil) and a very low root length density, which is about a quarter of the wheat figures. Accordingly, the critical levels of phosphorus in the soil for potatoes are almost twice as high as for most other crops, and the efficiency of its use can be significantly improved precisely thanks to band (local) application [8].

In addition, foreign scientists emphasize that the movement of phosphorus to the root surface occurs primarily by diffusion. Therefore, localized subsurface band application of fertilizers not only guarantees the placement of nutrients directly in the root zone of plants but also minimizes chemical fixation (binding) reactions, allowing more phosphorus and potassium to remain available for uptake. As for potassium, its demand is also extremely high, especially during tuber initiation and bulking, and potatoes require 6–9 times more available potassium in the soil to reach 90% of their yield potential compared to crops like wheat or sugar beets. That is why advanced foreign publications recognize the band application of phosphorus and potassium as the most beneficial in terms of nutrient use efficiency due to the immediate proximity of the applied band to the main root mass [9].

Considering the above, advanced scientific studies indicate that an increase in the availability of nutrients and a significant reduction in costs are possible exclusively through the spatial optimization of fertilization. The most promising way to improve potato nutrition, reduce nutrient losses, eliminate the negative impact on the environment, and obtain high, stable yields is the local band application of mineral fertilizers directly into the zone of plant root system location [10].

Local application radically changes the architecture of nutrition. With this method, the total mass of the root system may change slightly, however, the development of small absorbing roots in the fertilizer application zone is repeatedly enhanced. It has been established that the root system intentionally concentrates in locally nutrient-enriched zones. This leads to a sharp increase in the coefficients of nutrient utilization by the plant compared to the broadcast method. Due to limited contact with the soil, a high content of nutrients in an available state under local application is maintained for a much longer time, providing significant yield increases. Of course, the final effectiveness

of this method is affected by a number of associated factors: the physicochemical properties of the fertilizers themselves, the initial soil fertility, its texture, the level of plant moisture supply, and the genetic characteristics of varieties [11].

In addition to the direct trophic effect, local fertilizer placement positively affects the overall ability of plants to withstand stressful abiotic conditions. It significantly improves the processes of storage substances synthesis in tubers and reduces the unproductive use of nutrients by weeds. A very important indicator of efficiency is that plant water consumption per unit of produced output under local application is reduced by 10–15%. According to generalized data from many studies, the average increase in potato yield from the transition to local fertilizer placement is about 3–4 t/ha [12].

Detailing the role of individual elements, it should be noted that local phosphorus application plays a critical role in metabolism. It provides accelerated growth and development of roots and shoots, guarantees an uninterrupted supply of energy (through the synthesis of high-energy compounds) for passing such vital processes as the absorption of ions from the soil solution and their transportation through tissues. Due to local placement, phosphorus compounds remain more available throughout the vegetation period, which directly causes the formation of an optimal number of tubers on each bush [13].

In turn, local application of potassium fertilizers repeatedly increases the intensity of potassium supply to plant tissues. Optimal potassium nutrition is the key to the active synthesis of carbohydrates in leaves and their rapid transport to storage organs. Potassium acts as the main regulator of water metabolism, significantly improves the absorption of moisture and associated nutrients by the roots, strengthens the general resistance of plants to diseases, and significantly improves the quality parameters of the formed tubers [14,15].

**The Aim of the Article.** The aim of the conducted studies was to comprehensively investigate the effectiveness of using phosphorus and potassium under different methods (broadcast and local) and different rates of mineral fertilizer application, as well as to reliably establish their direct impact on the level of overall productivity and the yield of the seed potato fraction.

**Materials and Methods of Research.** To achieve the set goal and solve scientific and practical tasks, a large-scale field experiment was laid out. The research was conducted at the base of the Department of Agrochemistry and Quality of Plant Products named after O. I. Dushechkin of the National University of Life and Environmental Sciences (NUBiP) of Ukraine. The direct site for the field stage was the production areas of Biotech LTD LLC, geographically located in the Boryspil district of the Kyiv region according to the developed and scientifically grounded experimental design (Table 1). A highly productive early-maturing potato variety Tyras was selected as the object of research [16].

To ensure high accuracy of the field experiment, the area of one sown plot was 500 $m^2$, of which the accounting plot (from which the crop was directly harvested for analysis) was 350 $m^2$. The experiment was repeated 3 times, which fully meets the requirements for setting up field experiments. The placement of variants within the experimental array was systematic.

The agrochemical characteristics of the field were of critical importance for interpreting the results. The soil of the experimental plot is classified as dark gray podzolized coarse-silty light loamy, formed on loess rock. Analysis of soil samples showed that it was characterized by a slightly acidic reaction of the soil solution (pH was 5.56). The soil had a high degree of supply of mobile compounds of macronutrients: the phosphorus content was 254 mg/kg, and exchangeable potassium – 216 mg/kg. In addition, an increased content of exchangeable magnesium was recorded at the level of 2.29 meq/100 g and an average calcium content – 7.58 meq/100 g. Instead, the content of mobile sulfur was low (3.15 mg/kg), as well as the content of mineral forms of nitrogen (15.3 mg/kg). Such initial soil parameters necessitated careful balancing of the mineral nutrition system. In the nutrition system, according to the experimental design, a number of high-quality industrially produced fertilizers were used. Nitrogen was applied in the form of urea-ammonium nitrate UAN-25, which contains 25% total nitrogen (N) and 2.40% sulfur (S). Phosphorus was applied in the form of liquid fertilizers brand APP 8:24, the composition of which includes 8% nitrogen and 24% water-soluble phosphorus oxide ($P_2O_5$). The source of potassium was traditional potassium chloride with an active ingredient content ($K_2O$) of 60%. Mesonutrients were compensated by the application of magnesium sulfate, containing 16% magnesium oxide (MgO), and calcium nitrate, which contains 15.5% nitrogen and 19% calcium (Ca). Before planting, the seed material was treated on the inspection table with growth stimulants: Gros Korenerist (1.5 l/t) and the preparation Ecoline Phosphite (K) (1 l/t). The common background for all plots was the surface application of nitrogen fertilizers (UAN-25) at the rate of N150 followed by mandatory incorporation into the soil. The application methods were differentiated using various agricultural units. On the control plots (broadcast method), APP was applied

Table 1

**Scheme of the field experiment studying the effectiveness of different fertilizer application methods**

| Variant | P and K application method | Application rate, kg a.i./ha | Ratio to the base rate |
|---|---|---|---|
| 1 | Broadcast (control) | $P_{80}K_{180}$* | Full (100%) |
| 2 | Local | $P_{80}K_{180}$* | Full (100%) |
| 3 | Local | $P_{60}K_{135}$* | Reduced (75%) |
| 4 | Local | $P_{40}K_{90}$* | Reduced (50%) |

*Note: *A common background of nitrogen nutrition $N_{150}$ was applied in all experiment variants.*

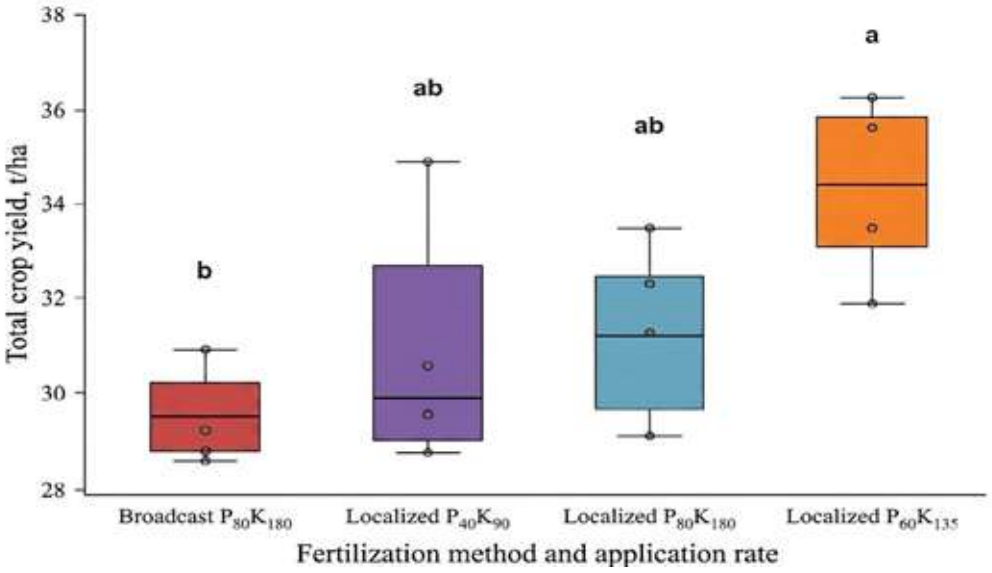


**Fig. 1. Yield of seed potatoes under different methods and rates of fertilizer application**

with a TECNOMA Laser sprayer. Potassium chloride was broadcast using a John Deere 6195M + MVD 1000 unit. After that, the field was treated with a Vaderstad Carrier CR 400 disc harrow to a depth of 10–15 cm to incorporate the fertilizers. Precise local application of phosphorus and potassium was carried out by a John Deere 8300 tractor aggregated with a Peliper complex. The system provided different-depth placement: phosphorus was applied using an injector to a depth of 15 cm, and potassium to 18–20 cm. Fertilizers were formed in the soil in narrow bands 10–12 cm wide, creating zones with a high concentration of nutrients.

The crop was harvested mechanically from the accounting plots during the technical ripeness period using standard methods. Statistical analysis was performed using one-way analysis of variance (ANOVA). Differences among treatment means were evaluated using Tukey's Honestly Significant Difference (HSD) test at α = 0.05, which is appropriate for multiple pairwise comparisons following ANOVA. All statistical calculations and data visualizations were performed using the R programming language within the RStudio integrated development environment. Experimental research on plants, including the collection of plant material, complied with institutional, national, or international guidelines. The authors adhered to the standards of the Convention on Biological Diversity (1992).

**Research Results.** The study allowed objectively evaluating how the spatial placement of fertilizers affects the productivity of potato plants. In the control, where the full rate ($P_{80}K_{180}$) was traditionally applied broadcast, the yield was 29.3 t/ha. Although this indicator is better than the average for Ukraine, at the same time the result demonstrates the limitation of broadcast application, in which phosphorus and potassium fertilizers remain in the upper soil layer and have a direct impact of moisture shortage, resulting in reduced availability of nutrients. Changing the method of fertilizer application demonstrated a positive dynamic. Local application of the same full rate $P_{80}K_{180}$ against the background of $N_{150}$ caused an increase in productivity. In this variant, the yield increased to 31.5 t/ha, which is 2.20 t/ha higher than the control variant. This proves that the placement of nutrients in the zone of root system development (at a depth of 15–20 cm) contributes to the reduction of their chemical fixation by the soil, its drying out, and makes nutrition more stable.

At the same time, the best result was obtained by optimizing the fertilizer rate, namely by reducing it by 25% ($P_{60}K_{135}$) and local placement, which gave the highest yield level in the experiment – 34.2 t/ha. This is 4.90 t/ha higher than the variant with broadcast application (control) and 2.70 t/ha more than the variant with local application of the full rate of fertilizers. This result is explained by the physiological reaction of the root system to the osmotic pressure of the soil solution. Local application of excessively high doses ($P_{80}K_{180}$) in a narrow band creates a high concentration of salts, which can cause short-term stress and inhibit the growth of young absorbing roots in the initial stages of potato development. The reduced rate ($P_{60}K_{135}$) became optimal: it provided the plant with a sufficient amount of nutrients without salt stress, stimulating root system growth and intensive tuber formation. Even a further, more radical reduction of the fertilizer rate by 50% from the control ($P_{40}K_{90}$) with local application proved to be more effective than the broadcast method. At this fertilizer rate, the yield level reached 30.9 t/ha. This indicator is 1.60 t/ha higher than the control, but at the same time is 0.6 t/ha less than the variant with the application of the full rate of phosphorus and potassium fertilizers by the local method (P80K180). Although this indicator is lower than the absolute maximum ($P_{60}K_{135}$) – it proves that the spatial proximity of fertilizers to the roots is much more important than their gross quantity. Analysis of variance and pairwise comparison of mean values by Tukey's test (HSD, α = 0.05) demonstrated a statistically significant impact of fertilizer application methods and rates on overall yield. The highest efficiency was provided by the variant with local fertilizer application at the rate of $P_{60}K_{135}$,

which significantly exceeded the indicators of traditional broadcast application of the full rate $P_{80}K_{180}$ (index "b"). The variants of local fertilization with extreme rates $P_{40}K_{90}$ and $P_{80}K_{180}$ formed intermediate yield levels, which had no statistically significant difference from both the maximum and minimum values in the experiment. When evaluating cultivation efficiency, attention should also be paid not only to the gross harvest but also to the marketable structure of the crop, which is especially important for seed production. Tubers must meet standards (DSTU) in size and uniformity. High quality of seed potatoes guarantees the proper operation of planting machines and optimizes costs for the per-hectare seed rate. The fractional composition of the harvested crop is given in Table 2. According to the obtained data, with the traditional broadcast application of $N_{150}P_{80}K_{180}$, the yield of standard seed tubers (ranging in size from 28 to 55 mm) was 23.3 t/ha. This corresponds to 79.5% of the total gross harvest. At the same time, the volume of non-standard (very small and excessively large tubers) reached 6.01 t/ha. Such a high share of rejects is a consequence of an uneven supply of nutrients to plants during the growing season. Moisture deficit in the top layer causes the cessation of growth of a part of the laid stolons (a small fraction is formed), while individual tubers on bushes that found themselves in slightly better microconditions overgrow.

Localization of the same full rate ($P_{80}K_{180}$) significantly changed the situation, increasing the yield of the target fraction. The standard yield increased by 5.0 t/ha, reaching 28.3 t/ha (89.8% of the total harvest). The mass of non-standard tubers decreased to 3.25 t/ha. Due to the concentration of nutrition, all plants were able to evenly lay down and develop tubers. The highest yield of the standard part of the crop, as well as the largest total mass, was recorded with the local application of the rate reduced by 25% ($P_{60}K_{135}$).

This variant provided the highest yield of the seed fraction – 31.0 t/ha, or 90.6% of the total volume. The amount of non-standard was 3.17 t/ha. Balanced local nutrition provided ideal conditions for stable and uniform tuber formation. Further reduction of the rate to $P_{40}K_{90}$ (by 50% of the full rate) with local application led to a deterioration of the crop structure. The yield of standard fractions decreased to 26.1 t/ha (4.9 t/ha less than the previous variant). The specific weight of the standard dropped to 84.5%, and the mass of non-standard tubers increased to 4.81 t/ha, mostly due to the appearance of a large number of overgrown tubers (>55 mm), whose mass was 3.69 t/ha.

A nutrient deficit in the final stages of vegetation causes competition between tubers, which determines the loss of their marketable uniformity. Thus, the analysis of the crop structure confirms that the introduction of local fertilizer application technology with the rate of $P_{60}K_{135}$ (against the background of surface application of $N_{150}$) is the most economically and agronomically justified step. This allows not only to increase the total harvest of seed potatoes but also ensures the formation of the maximum yield of high-quality planting material.

**Findings.** Conducted field studies convincingly prove the high effectiveness of spatial optimization of mineral nutrition systems. It has been established that the local band application of phosphorus-potassium fertilizers into the zone of active development of the potato root system (variety Tyras) not only stabilizes nutrition under moisture deficit conditions but also guarantees a higher yield level compared to the traditional broadcast method. Depending on the fertilizer rate, the yield increase under local application ranged from 1.6 t/ha to 4.9 t/ha compared to the control.

1. The highest agronomic and economic efficiency was demonstrated by local fertilizer application with an

Table 2

**Structure of the seed potato crop under different methods of fertilizer application, 2022–2025 (x ± SD, n = 8)**

| Fertilizer application method | Application rate, kg/ha a.i. | Fraction of tubers <28 mm (non-standard), t/ha | Fraction of tubers 28–35 mm, t/ha | Fraction of tubers 35–45 mm, t/ha | Fraction of tubers 45–55 mm, t/ha | Fraction of tubers >55 mm (non-standard), t/ha | Total standard fraction (28–55 mm), t/ha | Total non-standard fraction (<28,>55 mm), t/ha | Total yield, t/ha |
|---|---|---|---|---|---|---|---|---|---|
| Broadcast | $P_{80}K_{180}$* | 1,61 ± 0,09$^{a}$ | 3,52 ± 0,30$^{a}$ | 10,70 ± 0,10$^{c}$ | 9,10 ± 1,36$^{b}$ | 4,40 ± 0,43$^{a}$ | 23,3 ± 0,88$^{c}$ | 6,01 ± 0,33$^{a}$ | 34,24± 2,02$^{a}$ |
| Local | $P_{80}K_{180}$* | 1,14 ± 0,07$^{b}$ | 2,87 ± 0,24$^{b}$ | 13,50 ± 0,95$^{ab}$ | 11,90 ± 1,06$^{ab}$ | 2,11 ± 0,19$^{c}$ | 28,3 ± 2,13$^{ab}$ | 3,25 ± 0,09$^{c}$ | 31,52± 1,89$^{ab}$ |
| Local | $P_{60}K_{135}$* | 1,03 ± 0,09$^{b}$ | 3,27 ± 0,19$^{ab}$ | 14,20 ± 0,81$^{a}$ | 13,60 ± 1,38$^{a}$ | 2,14 ± 0,24$^{c}$ | 31,0 ± 1,36$^{a}$ | 3,17 ± 0,11$^{c}$ | 30,88± 2,75$^{ab}$ |
| Local | $P_{40}K_{90}$* | 1,12 ± 0,05$^{b}$ | 2,97 ± 0,29$^{ab}$ | 12,20 ± 1,35$^{bc}$ | 10,90 ± 1,67$^{ab}$ | 3,69 ± 0,36$^{b}$ | 26,1 ± 1,58$^{bc}$ | 4,81 ± 0,26$^{b}$ | 29,33± 1,07$^{ab}$ |

**Note:** **against the background of $N_{150}$ application*

**Note:** *the letters indicate values significantly different within one column according to the result of the Tukey test ($p < 0.05$)*

**Source:** *developed by the authors*

optimized, reduced by 25% rate ($P_{60}K_{135}$ against the background of $N_{150}$). This approach provided the maximum overall yield in the experiment, which amounted to 34.2 t/ha. In addition to the quantitative increase, this variant provided the best marketable structure of the crop: the yield of the target high-quality seed fraction (standard tubers 28–55 mm in size) reached 31.0 t/ha, which is 90.6% of the total gross harvest, with a minimum mass of non-standard rejects (3.17 t/ha).

2. Considering modern economic challenges and climate changes, wide production implementation of local fertilizer application systems in potato cultivation technologies is economically justified and has significant prospects.

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**Бикін А.В., Кучер Л.І., Панчук Т.В., Мороз С.Ю., Пошкребнов В.В., Ретьман М.С. Ефективність локального внесення фосфорно-калійних добрив за вирощування картоплі**

**Мета.** Метою проведених досліджень було комплексно дослідити ефективність використання фосфору та калію за різних способів (розкидного та локального) і різних норм внесення мінеральних добрив, а також достовірно встановити їхній безпосередній вплив на рівень загальної продуктивності та вихід фракції насіннєвої картоплі.

**Методи.** Для виконання поставлених завдань було реалізовано масштабний польовий експеримент на виробничих площах ТОВ «Біотех ЛТД» (Бориспільський район, Київська область) на темно-сірому опідзоленому ґрунті. Дослідження проводили на за використання ранньостиглого сорту «Тирас». Схема досліду базувалася на порівнянні традиційного (розкидне внесення) та локального (в зону розвитку основної маси кореневої системи) способів внесення добрив. Базовий фон живлення для всіх без винятку ділянок складав азот у нормі 150 кг/га д.р. Контрольний варіант передбачав суцільне внесення повної норми добрив ($P_{80}K_{180}$). Дослідні варіанти включали локальне внесення повної норми, а також норм, зменшених на 25% ($P_{60}K_{135}$) та 50% ($P_{40}K_{90}$). Технологічна операція здійснювалася спеціалізованими агрегатами на глибину 15–20 см. Облік урожаю проводили механізованим способом з подальшим детальним фракційним аналізом (виділення стандартних насіннєвих екземплярів 28–55 мм та нестандартних). Статистичну вірогідність отриманих масивів даних оцінювали за допомогою однофакторного дисперсійного аналізу (ANOVA) із застосуванням критерію Тьюкі (HSD) при α = 0,05.

**Результати.** Експериментальні дані об'єктивно доводять, що просторова локалізація поживних речовин має визначальний вплив на продуктивність рослин картоплі. На контрольному варіанті із розкидним внесенням повної норми добрив врожайність досягала 29,3 т/га, водночас маса стандартної насіннєвої фракції склала 23,3 т/га (79,5% від валу), а обсяг нестандарту досяг 6,01 т/га. Перехід на локальний спосіб внесення аналогічної норми добрив забезпечив зростання загального збору до 31,5 т/га, а виходу цільової фракції – до 28,3 т/га. Найвищу врожайність продемонстрував варіант із локальним внесенням зменшеної норми на 25% ($P_{60}K_{135}$). За таких умов зафіксовано абсолютний максимум маси врожаю на рівні 34,2 т/га. Цей підхід забезпечив найкращу товарну структуру: маса високоякісного насіннєвого матеріалу досягла 31,0 т/га (90,6% від загального валового збору), тоді як обсяг нестандартних екземплярів мінімізувався до 3,17 т/га. Подальше зниження норми на 50% за локального внесення (врожай 30,9 т/га) також виявилося результативнішим за традиційний підхід, підтверджуючи фізіологічну перевагу просторової наближеності елементів до кореневої системи над їх загальною фізичною масою.

**Висновки.** Проведені польові дослідження переконливо доводять високу ефективність просторової оптимізації систем мінерального живлення. Доведено, що локальне внесення добрив безпосередньо у зону активного розвитку кореневої системи стабілізує засвоєння сполук за умов дефіциту вологи та мінімізує їх перехід у недоступні форми. За такого способу найбільш економічно та агрономічно доцільним є застосування зменшеної на 25% норми добрив. Такий підхід гарантує не лише отримання максимального валового збору, але й формування бездоганної структури врожаю з найвищим відсотком якісного насіннєвого матеріалу. Широке впровадження подібних інноваційних рішень у виробництво є стратегічно важливим інструментом розкриття генетичного потенціалу рослин.

**Ключові слова:** продуктивність агроценозу, насіннєва фракція, стрічковий спосіб, оптимізація живлення, макроелементи, сорт Тирас, рівень урожайності, абіотичний стрес.

**Bykin A.V., Kucher L.I., Panchuk T.V., Moroz S.Yu., Poshkrebnov V.V., Retman M.S. Efficiency of local application of phosphorus-potassium fertilizers in potato cultivation**

**Purpose.** The purpose of the conducted research was to comprehensively study the effectiveness of using macronutrients under different technologies of their spatial

distribution (broadcast and band) and different rates of mineral agrochemicals application. The main task was to reliably establish their direct impact on the level of overall productivity and the yield of the target seed fraction of tubers. In addition, the study aimed to determine the optimal spatial architecture of nutrition, which would minimize the negative impact of abiotic stresses (in particular, moisture deficit in the upper soil layers) and significantly reduce the chemical binding of nutrients by the soil absorbing complex. This is fundamentally important for optimizing modern agricultural production and ensuring yield stability.

**Methods.** To achieve the set objectives, a large-scale field experiment was implemented on the production areas of Biotech LTD LLC (Boryspil district of Kyiv region) on dark gray podzolized soil. The research was conducted on plantings of the early-maturing variety "Tyras". The experimental design was based on comparing the traditional (continuous broadcasting) and innovative band (in the zone of the main root system mass) placement of nutrients. The basic nutritional background for all plots without exception was nitrogen at a rate of 150 kg/ha of active ingredient. The control variant involved the continuous distribution of the full rate of macronutrients ($P_{80}K_{180}$). The experimental variants included band placement of the full rate, as well as rates reduced by 25% ($P_{60}K_{135}$) and 50% ($P_{40}K_{90}$). The technological operation was carried out by specialized units with injectors to a depth of 15–20 cm. Harvesting was carried out mechanistically with subsequent detailed fractional analysis (separation of standard seed specimens of 28–55 mm and non-standard ones). The statistical reliability of the obtained data arrays was evaluated using one-way analysis of variance (ANOVA) applying the Tukey test (HSD) at $\alpha = 0.05$.

**Results.** Experimental data objectively prove that the spatial localization of nutrients has a decisive influence on the productivity of the plant organism. In the control variant with the continuous distribution of the full rate, the gross harvest was 29.3 t/ha, while the mass of the standard seed fraction was 23.3 t/ha (79.5% of the gross), and the volume of non-standard tubers reached 6.01 t/ha. The transition to the band placement of a similar full rate provided an increase in the gross harvest to 31.5 t/ha, and the yield of the target fraction to 28.3 t/ha. The highest agronomic performance was demonstrated by the variant with spatial optimization and a 25% reduction in the rate ($P_{60}K_{135}$). Under these conditions, an absolute maximum gross mass was recorded at the level of 34.2 t/ha. This approach provided the best marketable structure: the mass of high-quality seed material reached 31.0 t/ha (90.6% of the total gross harvest), while the volume of non-standard specimens was minimized to 3.17 t/ha. A radical 50% reduction in the rate with band application (gross harvest 30.9 t/ha) also proved to be more effective than the traditional approach, confirming the physiological advantage of the spatial proximity of elements to the root system over their total physical mass.

**Findings.** The conducted studies convincingly demonstrated the high efficiency of spatial optimization of mineral nutrition systems. It is proved that the band placement of agrochemicals directly into the zone of active root system development stabilizes the assimilation of compounds under moisture deficit conditions and minimizes their transition into inaccessible forms. The most economically and agronomically justified is the use of band technology with an optimized macronutrient rate reduced by 25%. Such an approach guarantees not only obtaining the maximum gross harvest but also the formation of a flawless crop structure with the highest percentage of high-quality seed material. The wide implementation of such innovative solutions in production is a strategically important tool for unlocking the genetic potential of plants.

**Key words:** agrocenosis productivity, seed fraction, band method, nutrition optimization, macronutrients, Tyras variety, yield level, abiotic stress.

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