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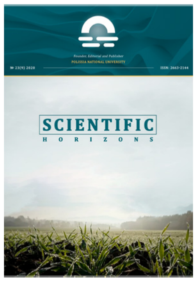

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The effect of the application of liquid complex fertilizers and mixtures based on them on the productivity of corn in the conditions of the Western Polissia

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Abstract. The issues of optimising the phosphorous nutrition of corn are becoming increasingly relevant due to trends in the increasing cost of mineral fertilisers and meteorological risks in the post-sowing period. The purpose of the study is to determine the economic efficiency of liquid complex fertilisers applied during corn sowing as the main source of phosphorus and as an additional element in the nutrition system. A field experiment was performed, which included options for applying LCF, separate application of granular mineral fertiliser, joint use of LCF and granular fertiliser, and tank mixtures of LCF with zinc and a bacterial product based on *Pseudomonas fluorenses* to implement the set tasks. It was identified that the use of LCF in sowing contributes to a better supply of young plants with phosphorus, and, as a result, to the development of a more productive cob. Therewith, the use of LCF exclusively as a food source in doses up to 50-60 L/ha does not allow for realising the inherent potential and leads to a lack of grains from the cob compared with the option with full nutrition. The highest yield was obtained in the version using granular fertiliser and 60 litres of liquid complex fertiliser mixed with a bacterial preparation, while the yield increase relative to the version without granular fertiliser was 32% (2.8 t/ha). Separate application

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of liquid complex fertiliser under no circumstances provided a result comparable to the application of granular fertiliser, but the addition of 25 L/ha of LCF to the main application of granular fertiliser allowed obtaining a yield increase of 1.3 t/ha. The results obtained prove the high efficiency of the liquid form of starter fertiliser when applied on light granulometric soils and should be considered when planning resource-saving technology for growing corn in an area with a high degree of meteorological risks

Keywords: grain quality indicators; local application; resource-saving technologies; efficiency of phosphorous fertilisers; bacterial preparations

INTRODUCTION

Rational management of crop production in modern conditions involves not only meeting the conditions of environmental safety and soil conservation but also considering dynamically changing economic conditions. An important component of ensuring the economic efficiency of corn cultivation is the construction of a proper nutrition system, which should be based on the calculation of the removal of nutrients by the planned crop, the distribution of the total need for mineral elements for individual stages of vegetation, and consider the specific features of soil, climatic conditions, and the level of technological equipment of the manufacturer.

The need for applied studies in the area of optimising mineral nutrition is due, in particular, to increasing climate changes, which are more contrasting in the Western Polesia zone than the national average (Veremeenko *et al.*, 2021), which is a prerequisite for rethinking agronomic risks and forming a holistic strategy for production adaptation (Baliuk *et al.,* 2018, Volkogon *et al.*, 2019; Trofymenko *et al.,* 2019).

According to previous studies (Kalenska *et al.,* 2018), reduced doses of mineral fertilisers do not ensure the formation of the maximum yield, and the use of high ones leads to a decrease in their profitability. Therewith, in years with unfavourable meteorological conditions, it is even possible to reduce the yield and worsen its biological quality due to an increase in the total salt concentration in the soil solution (Kohan *et al.,* 2019).

It is the phosphate regimen of the soil and the planning of the most efficient phosphorus nutrition that is the subject under study by leading researchers around the world (Nosko, 2017; Kratz *et al.,* 2019; Brod *et al.*, 2022). J. Zhu states that phosphorus is one of the macronutrients that limit crop productivity the most and phosphorus deficiency is common in agricultural soils around the world (Zhu & Min, 2018). Despite the long-term use of phosphorous fertilisers to increase yields, the availability of phosphorus is often low due to the high affinity of phosphate for the solid phase of the soil, which not only reduces the effectiveness of fertilisers but also leads to a number of environmental problems (Tian *et al.,* 2017; Koch *et al.,* 2018; Hospodarenko *et al.,* 2022).

Sod-podzolic soils, having a typically acidic reaction of the soil solution and sandy-loamy granulometric composition, are simultaneously exposed to the risks of washing (Li *et al.,* 2022; Raguet *et al.,* 2023) and blocking phosphorus in an unfavourable pH environment (Barrow, 2017). Therewith, the studies by researchers from North Carolina (Gatiboni *et al.,* 2020) show that the use of starter phosphorous fertilisers on poor soils has a good economic effect. Substantially higher (in comparison with conventional mineral forms) is the efficiency of organic forms of phosphorous fertilisers (Gronberg *et al.,* 2017; Li *et al.,* 2020; Jin *et al.,* 2023), however, the volume of such raw materials in the modern realities of the economic complex of Ukraine is extremely insufficient.

Plants absorb the maximum amount of phosphorus during grain formation, but the critical period of phosphorus nutrition for grain crops begins two weeks after sowing in the 3-4-leaf phase. Lack of phosphorus during this period affects the development of the root system, worsens the formation of reproductive organs (Liu *et al.,* 2022).

The efficiency and practical feasibility of using liquid forms of mineral (in particular, phosphorous) fertilisers are justified by numerous studies (Harahap *et al.,* 2019; Drazic *et al.,* 2020).

According to M. Battisti *et al.* (2022), the use of starting phosphorous fertiliser contributes to a faster passage of phenological phases of development, substantially increasing the yield of corn and the quality of its grain.

The efficiency of applying phosphorous fertilisers for corn, as a rule, is lower than nitrogen fertilisers and substantially depends on the level of mobile phosphates in the soil. Therewith, the synergistic effect of the level of nitrogen supply on the absorption of phosphorus by corn plants (Battisti *et al.,* 2022). Similar results were obtained in studies by DJ. Quinn *et al.* (2020), according to which, the full formation of the productive corn crop is impossible either under the condition of a separate high phosphorous background or nitrogen, but only in the case of joint provision of availability levels of both.

The studies by Q. Zeng *et al.* (2022) prove that under the conditions of systematic application of phosphorous fertilisers, the activity of soil phosphorus-mobilising biota is suppressed, which increases the risk of accumulation of hard-to-reach phosphates even in poor soils. This creates prerequisites for the effective use of bacterial strains for the targeted mobilisation of blocked forms of phosphorus in the soil.

B.-G. Yu *et al.* (2022) concluded that the use of even a small amount of phosphorous fertilisers (25 kg of P_2O_5) can substantially increase the yield and quality of corn grain, while a further increase in phosphorus nutrition does not lead to positive changes. The author noted that the use of phosphorous fertilisers increases zinc deficiency, especially in soils with its low supply. Based on this, on the sod-podzolic soils of Polesia, there is a high probability of a positive reaction of corn to its application, in particular, as part of liquid complex fertilisers during sowing.

Therewith, the comparative effectiveness of a unit of the active substance of phosphorus when it is applied in various forms (granular, liquid), in particular, on light soils with a granulometric composition, which are characterised by a low content of available nutrients, remains unexplored.

The purpose of the study consisted in the assessment of the effectiveness of the application of liquid complex fertiliser as the main source of phosphorous nutrition and an additional component in the corn nutrition system during sowing. The tasks included conducting a comparative analysis of the economic efficiency of various doses of liquid Complex Fertiliser of the 5-20-5 composition in comparison with a separate application of granular complex fertiliser and determining the combined efficiency of applying granular and liquid forms of fertilisers.

MATERIALS AND METHODS

The study programme was conducted on the territory of the Rivne region (Western Polesia of Ukraine) within the production branch of the Department of Agrochemistry, Soil Science, and Agriculture of the National University of Water and Environment Engineering during 2020-2022. Plot location: 50.998433, 26.563218. Before laying the experimental site, three soil sections and a number of digs were created to establish the general genetic characteristics of the soil and its local differences. According to the results of the examination, it was established that the existing type of soil is sod-podzolic sandy-loamy, zonal for the Western Polesia of Ukraine. The humus content is 1.0-1.1%, the thickness of the humus-eluvial horizon is up to 20 cm. The reaction of the soil solution at the time of laying is neutral, previously liming was conducted with the full norm of limestone ameliorant (2018). The initial supply of phosphorus and potassium is low. All field observations at the site were conducted in accordance with the current standards and methods of phenological and soil observations, determination of phosphorus and potassium by the method of Kirsanov (DSTU 4405:2005, 2005).

Sunflower predecessor crop, tillage – deep loosening to a depth of 30 cm after harvesting the predecessor, working unit – Case Quadtrac 500 + Case Ecolo Tiger 730c. In the spring, the soil was re-treated with a disk unit to a depth of 6-8 cm. For sowing, the experiment used a hybrid of intensive corn type LG 30273, FAO 270. Seeding rate – 78,000 seeds/ha, wide-row sowing method, row spacing – 70 cm, Vaderstad Tempo 8 seed drill, sowing depth – 4 cm. The sowing period is when stable temperatures above 12 degrees occur at a depth of 10 cm, which corresponded to May 1-5.

As nitrogen nutrition, anhydrous ammonia was applied at a dose of 140 kg/ha of physical weight, the application period was two weeks before the planned sowing, and the application depth was 18-20 cm. Phosphorus-potassium nutrition was provided by applying granular complex fertiliser to the row. NPK Polifoska 8, produced by GrypaAzoty, with an 8-24-24 composition, was used as fertiliser. As a liquid fertiliser, the product Diaphan-Action, produced by Quantum, was used. Detailed fertiliser characteristics are shown in Table 1.

Table 1. *Characteristics of fertilisers used in the experiment*

Material	Diafan 5-20-5	Polifoska 8-24-24
Form	liquid	granulated
Total nitrogen, %	5 (64 g/L)	8
Ammonium nitrogen, %	5 (64 g/L)	8
Total phosphorus, %	20 (254 g/L)	24
Phosphorus is soluble in water, %	20 (254 g/L)	21
Total potassium, %	5 (64 g/L)	24
Potassium is water-soluble, %	5 (64 g/L)	24
Available sulfur, %	-	9
Density, g/cm^3	1.28	-

Source: *compiled by the authors*

Other sources of phosphorus and potassium were not used at the sites. The experiment includes the zinc-containing preparation Zintrac. The preparation was used in a tank mixture with liquid fertiliser, the estimated application dose is 1 L/ha. The purpose of using the preparation is to provide a sufficient amount of available zinc in the period up to BBCH 13, to avoid potential crop losses from zinc deficiency, which is characteristic of light granulometric soils. A bacterial preparation based on a strain of live bacteria *Pseudomonas fluorenses (*Rhizophos) was also included in the experiment, applied to test the possibility of increasing the availability of phosphorus in conditions of its deficiency due to microbiological activities. The preparation was used in a tank mixture with liquid fertiliser, the application dose is 0.2 L/ha.

Schemes for laying experimental plots are shown in Table 2. The repetition rate of vegetation records and crop structure is fivefold, and the yield is threefold. Harvesting was conducted by direct combining with threefold yield calculation for each site. Sampling to assess the quality indicators of the crop was conducted from a batch of grain after complete threshing of the accounting area. Selection of cobs for structure assessment – before threshing in fivefold repetition from each site.

***Table 2.** Experiment scheme*

No.	Option
1	Diafan Action 30 L/ha
2	Diafan Action 40 L/ha
3	Diafan Action 50 L/ha
4	Diafan action 60 L/ha
5	Diafan action 70 L/ha
6	Diafan Action 80 L/ha
7	Diafan action 90 L/ha
8	Polifoska 8 150 kg/ha
9	Polifoska 8 150 kg/ha + Diaphan Action 25 L/ha
10	Polifoska 8 150 kg/ha + Diafan Action 25 L/ha + Zn
11	Diafan action 60 L/ha + Zn
12	Diafan action 60 L/ha + Rhizofos
13	Polifoska 8 150 kg/ha + Diaphan Action 60 L/ha + Rhizofos

***Source**: compiled by the authors*

Statistical processing of data obtained from the results of field and laboratory observations was conducted using generally accepted methods using Microsoft Excel, Statgraphics Centurion, and Statistica software tools.

RESULTS AND DISCUSSION

Corn hybrid LG 30273 of the French selection by Limagrain under favourable growing conditions forms a sixteen-row cob with 40-42 full-fledged grains in each row, which corresponds to a total of 640-650 grains per cob. Therewith, the beginning should be evenly pollinated, without constrictions and shifts of rows. Therewith, in conditions of insufficient nutrition, or the manifestation of additional stresses during the development of generative organs, hybrid 30273 is able to reduce the row amount in cobs to fourteen or even twelve rows. If the impact of unfavourable conditions occurs at a later date, the plant is able to partially reduce grains, reducing their number within rows to 3032 or less, which proportionally leads to a decrease in the factual yield. In some variants of the experiment, the predicted variability of the cob structure was observed (Fig. 1).

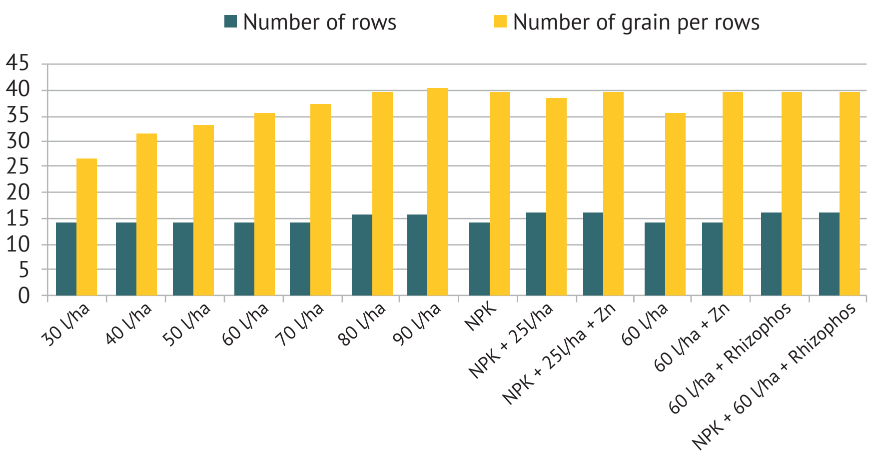

***Figure 1.** Structure of a corn cob depending on fertiliser*

***Source:** compiled by the authors*

Thus, the use of reduced norms of phosphorus nutrition contributed to the formation of an ear of fourteen rows of grains instead of sixteen. Analysing the options using only Diafan 5-20-5 fertiliser in doses from 30 to 90 litres, the number of grains in the row increased from 26 to 40 in proportion to the increase in the fertiliser dose. Therewith, only variants using doses of 80 and 90 litres had a cob with sixteen rows. Thus, the number of grains from one cob gradually increased from 364 to 640, that is, by 76% compared to the option using a minimum dose of fertiliser.

A separate application of complex granular fertiliser 8:24:24 with a dose of 150 kg/ha ensured the formation of a cob with fourteen rows and 39 grains in a row, which may be a consequence of the slower solubility of granular fertiliser compared to the liquid form, and, accordingly, the existing phosphorus deficiency in the root zone during the development of rows. Therewith, the additional application of a minimum amount of liquid complex fertiliser (LCF) allowed forming a cob with sixteen rows and 38-39 grains in a row. Analysing the effectiveness of introducing additional components into the mixture to the LCF, an increase in the number of grains in a row from 35 to 39 is notable when adding a zinc-containing preparation to 60 L/ha of the LCF without using granular fertiliser. An increase in the row of the cob from fourteen to sixteen rows when introducing a bacterial preparation of phosphorus-mobilising action (Rhizofos) into the mixture, while the options with the introduction of only 60 litres of LCF and 60 litres of LCF together with the full norm of granular fertiliser did not differ from each other in terms of the structure of the cob (Fig. 1).

The use of liquid forms of complex fertilisers contributes to a better supply of young plants with phosphorus, and, as a result, to the development of a more productive cob. Therewith, the use of only LCD in doses of 50-60 L/ha in the nutrition system does not allow the further realisation of the inherent potential and leads to a lack of grains from the cob relative to the option with full nutrition using granular forms of fertilisers. A more clarifying indicator, in this case, should be considered the mass of grains obtained on average from one cob (Fig. 2).

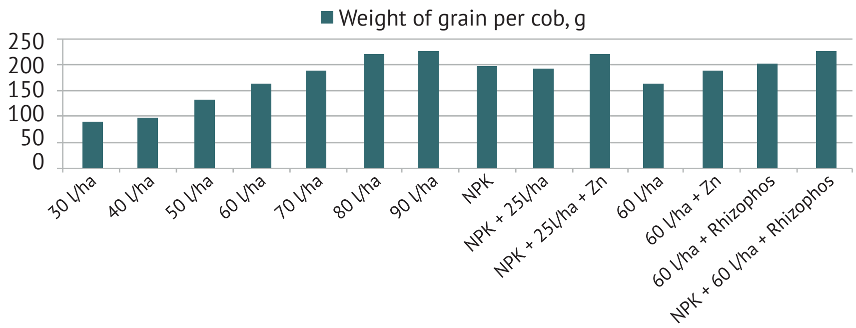

***Figure 2.** Average weight of grain per cob, depending on fertiliser*
***Source:** compiled by the authors*

The weight of grains from one cob varied within the variants of the experiment from 88.5 to 227.3 g. In the plot of separate application of LCF, the values of the indicator increased in proportion to the increase in the dose of application of LCF from 88.5 to 227.3 g, while increasing the dose from 30 to 40 litres per hectare had a slight positive effect, then a further increase in the dose from 40 to 80 litres contributed to an increase in the mass of grains in the cob by 36.4; 29.0; 26.6; 31.2 g for every subsequent 10 litres of fertiliser, which is certainly a substantial trend. For comparison, a separate application of exclusively granular fertiliser provided the formation of 197 g of grain from one cob, which, approximately, corresponds to the option using 70 litres of LCF. From the standpoint of nutrition, 18 kg of active phosphorus in a completely water-soluble form was added in the LCF variant, while 36 kg of P_2O_5 was added together with granular fertiliser, of which 31.5 kg was water-soluble. It is substantial that the addition of 25 litres of Diafan against the background of the introduction of granular fertiliser did not give any positive effect, but the introduction of an additional zinc-containing product into the tank mixture contributed to an increase in the grain mass in the cob to 219 g (+14.7% relative to a similar option without zinc).

Analysing the effect of additional components in combination with LCF, the positive effect of zinc, the introduction of which provided an increase in the mass of cob grains from 161.8 to 185.7 g when using only 60 litres of Diaphan can also be noted. The use of phosphorus-mobilising bacterial preparation increased the indicator from 161.8 to 201.4 g, or by 24.5%, while the implementation of the same tank mixture against the background of additional application of 150 kg of NPK 8:24:24 provided the formation of 227.2 g of grain on average per cob, which is 12.8% more compared to the option without granular NPK or 15.3% more compared to the option of applying only granular fertiliser.

In general, the weight of grain from one cob closely correlates with the structure of the cob described above, the highest, statistically identical values are obtained in variants using 90 L/ha of LCF, the introduction of 150 kg/ha of granular complex fertiliser with the addition of 25 L of LCF and the introduction of granular fertiliser with the addition of 60 L of LCF mixed with a phosphorus-mobilising preparation. Important indicators that characterise the realisation of potential yield are also the thousand grain weight and the grain unit, which are shown in Figure 3.

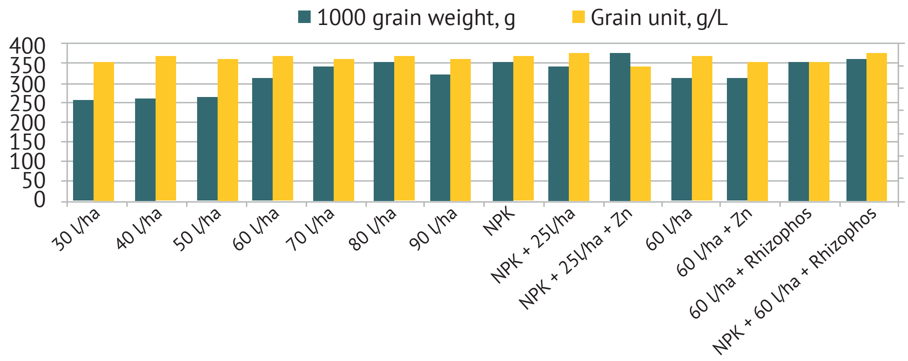

Figure 3. *Quality indicators of corn grain depending on fertiliser*
Source: *compiled by the authors*

The LG 30273 hybrid is characterised by a high thousand grain weight (more than 320 g) under normal conditions. The conditions of the growing season, in particular, during the period of grain filling, have a substantial impact on the indicator. Thus, insufficient moisture supply in the period after flowering, a sharp decrease in air temperature or its extensive amplitude during the ripening period can cause insufficient accumulation of substances in grains, and the formation of empty grains, which leads to a decrease in yield even with a sufficient number of grains per unit of sowing area.

According to the experimental variants, the thousand grain weight ranged from 259 to 379 g. An increase in the dose of LCF application from 30 to 80 litres contributed to a proportional increase in the thousand grain weight from 259 to 354 g. The option of a separate application of granular fertiliser had a result of 349 g, the addition of 25 litres per hectare of liquid fertiliser did not statistically change the value of the thousand grain weight, as in the case of the mass of grain from the cob, while the additional application of zinc contributed to an increase in the thousand grain weight to 379 g (+9.5% compared with the option without zinc). Therewith, the additional introduction of zinc against the background of only 60 litres of LCF did not affect the thousand grain weight index. The use of the phosphorus-mobilising preparation against the background of 60 litres of LCF allowed obtaining an increase in the thousand grain weight by 43 g, or 13.9% (from 309 to 352 g), and a similar option against the background of granular fertiliser provided the thousand grain weight value – 361 g, which is only 2.5% more than in the option without the introduction of granular fertiliser.

Regarding the grain unit indicator, it is impossible to note such evident trends, however, the maximum values of the indicator (648, 654, 642 g/L) were recorded in variants using granular fertiliser. The increase in the indicator of nature in the variant using granular fertiliser + LCF + Rhizophos relative to the similar variant without the use of granular fertiliser from 614 to 648 g/L (+5.5%) is substantial. Reduced grain unit when adding a zinc-containing product is notable. Thus, the addition of zinc to the NPK + variant of 25 L LCF to the tank mixture caused a decrease in the grain unit from 654 to 612 g/L, and the additional introduction of zinc to 60 L LCF caused a decrease in the indicator from 635 to 613 g/L.

There was no direct correlation between the thousand grain weight and the nature of the grain. A normal unit at a low thousand grain weight describes the case of the formation of a small but well-filled grain, and low grain unit at a high thousand grain weight is an indicator of the development of a large grain that was not fully filled. An integral indicator that characterises the efficiency of the nutrition system is the obtained yield (Fig. 4).

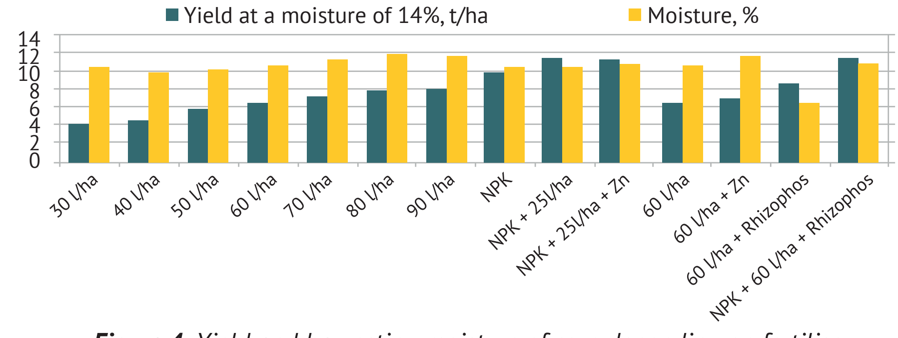

Figure 4. *Yield and harvesting moisture of corn depending on fertiliser*
Source: *compiled by the authors*

Under the condition of the same seeding structures (seeding rate, row spacing width, and row direction), the main factors of yield formation will be the analysed above number of rows of grains, the number of grains in a row, and the thousand grain weight, but the influence of additional factors that are not considered when assessing the indicators of the crop structure is also likely – the percentage of plants without a cob, the formation of individual additional cobs on the plant.

Analysing the indicators of factual yield, a substantial advantage of options with the introduction of granular complex fertiliser is noted. All cases of fertiliser application at 8:24:24 showed a result of more than 10 t/ha, while the additional application of 25 litres of LCF contributed to an increase in yield from 10.02 to 11.31 t/ha (+12.9%), and the additional introduction of zinc did not affect the result in any way. The highest yield (11.51 tonnes) was obtained using granular fertiliser and 60 litres of liquid complex fertiliser mixed with a phosphorus-mobilising preparation, while the yield increase relative to the option without granular fertiliser was 32% (2.8 t/ha).

Separate application of liquid complex fertiliser under no circumstances provided a result comparable to the application of granular fertiliser. Thus, an increase in the dose of LCF application from 30 to 90 litres per hectare increased the yield from 4.12 to 8.14 t/ha, while an additional application of every 10 litres of LCF (2.6 kg P_2O_5 in an accessible form) formed an average of an additional 670 kg of the yield. However, even the introduction of high doses of LCF (90 L, which corresponded to 115 kg) did not bring the factual yield (8.14) closer to the level of at least net application of 150 kg of granular complex fertiliser (corresponding yield of 10.02 t/ha).

The results of using the preparation Rizofos are interesting. Its additional application to 60 litres of LCF contributed to an increase in yield from 6.53 to 8.72 t/ha (+33.5% of the indicator), and the option of joint application of LCF + Rhizophos against the background of granular fertiliser provided absolutely the best yield result. Thus, the use of the Rizofos preparation in conditions of general phosphorus deficiency has had an unambiguously positive effect on providing crops with available phosphorus, and, indirectly, on its productivity.

Comparison of NPK+25 L of LCF and NPK+60 L of LCF+Rhizophos variants shows no substantial difference in yields (11.37 and 11.51 t/ha), that is, an increase in the dose of LCF more than twice and additional introduction of the phosphorus-mobilising preparation into the tank mixture did not have a statistically positive effect on yield. This phenomenon may be associated with the release of phosphorus from the zone of the limiting factor, respectively, further increased availability of it did not lead to an increase in productivity. This can be confirmed in the results of monitoring the residual amounts of phosphorus and potassium in soil samples taken after harvesting (Fig. 5).

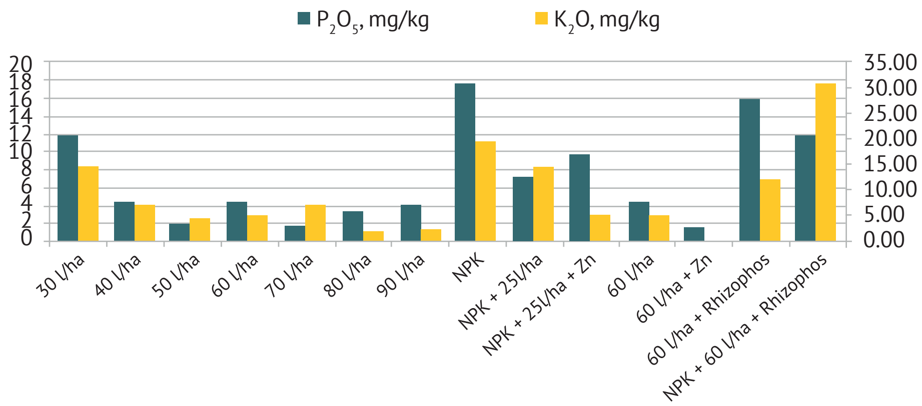

Figure 5. *Residual phosphorus and potassium content in the soil after corn harvesting*

Source: *compiled by the authors*

Analysing the residual amounts of phosphorus in the soil, its overall low content in most variants of the experiment is noted. As part of the variants with application doses from 40 to 90 litres, the residues in the soil were low and very low, statistically indistinguishable (range of changes from 1.6 to 4.5 mg/kg of the soil). The high residual content of P_2O_5 in the variant with the minimum dose of LCF (11.7 mg/kg) indicates incomplete removal of phosphorus or its untimely availability in conditions of severe deficiency (the yield was also the lowest – 4.12 t/ha). In turn, statistically substantially higher phosphorus residues were observed in all variants where granular fertiliser was applied, so the option of separate application of Polifoska 150 was characterised by a residual amount of 17.5 mg/kg of P_2O_5. An increase in the residual phosphorus content in the version where the preparation Rizofos was introduced is notable – 15.7 mg/kg against 4.5 mg/kg in the same version without the preparation.

An increase in corn yield was observed when using liquid complex fertiliser, which correlates with the results of M. Blandino *et al.* (2022) for 2014-2017 in

Northwest Italy. Blandino recorded an increase in yields from 7% to 15%, while the increase in this study was 12.9%. D. Quinn *et al.* (2020) in their meta-analysis show that the practical response to initial fertiliser is present in a wide window of conditions, and increases with the decrease in the overall supply of nutrients to the soil of the site, which explains the high efficiency of the application of such an agricultural practice. However, according to M. Blandino *et al.* (2022), in Italy, there was a simultaneous decrease in the harvesting moisture content of grain by 2.2% relative to the control, while the results of this study show the opposite trend. The discrepancy may be due to the variability of climatic conditions and the genetic characteristics of the corn hybrids used. M. Battisti *et al.* (2022) in their paper also prove the advantage of using a starter NP fertiliser in comparison with a granular analogue. In the conditions of Ukraine, the prospects for the introduction of liquid fertilisers are justified by Gamayunova *et. al.* (2020), noting that in conditions of unstable moisture, which in modern agroclimatic conditions is characteristic of the entire territory of the country, the efficiency of the liquid form is higher, compared to solid granular analogues. Thus, in the case of sod-podzolic soils that lose moisture very quickly, the use of liquid complex fertilisers is a way to reduce agronomic risks and make more efficient use of the active substance of the fertiliser.

The effectiveness of additional use of the bacterial preparation and the associated increase in the amount of available phosphorus coincides with the data obtained by Q. Zeng *et al.* (2022) since the site that was used for the experiment during previous periods of use was in intensive crop production using full standards of phosphorous fertilisers. Phares *et al.* (2022) prove a substantial positive effect of a bacterial product based on the Bacillus strain when growing corn for grain, in particular, demonstrating that when the bacterium is introduced into the fertiliser system, the efficiency of assimilation of nutrients from solid granular fertilisers and, ultimately, the yield of the crop increase. Sofyan *et al.* (2023) obtained results according to which the use of bacterial preparations can increase the yield of corn by mobilising NPK from the soil while reducing the norms of fertilisers used is advisable. Since the accumulation of bound phosphates occurs even in soils of light granulometric composition and under conditions of podzolic soil formation (Tian *et al.,* 2017; Hospodarenko *et al.,* 2022), the method of improving nutrition by mobilising soil reserves by microbial cultures is extremely promising, in particular, in the Polesia zone of Ukraine.

Similarly, Yu *et al.* (2022) show the high efficiency of zinc application in corn cultivation, in particular, with intensive use of phosphorous fertilisers, which correspond to the results obtained. Zhang *et al.* (2020) also noted a positive effect of the soil use of zinc-containing preparations on the development and productivity of corn, arguing that the resulting increase in yield is achieved by increasing the concentration of chlorophyll in the leaves and more efficient use of soil moisture. Similar results are also presented in the paper of Azam *et al.* (2022).

Thus, the convergence of the obtained agronomic reactions for the use of starting liquid fertilisers, bacterial preparation, and zinc with the results of world practices can be stated. Therewith, in the specific soil and climatic conditions of Polesia of Ukraine, which were analysed, the trends of better cob grain number, higher thousand grain weight and, as a result, corn yield were more contrasting, which is due to the properties of sod-podzolic soil (low content of nutrients, low capacity of cationic exchange, and buffering), which make it a convenient object for tracking the reaction of plants to fertiliser

CONCLUSIONS

The use of the liquid form of starting phosphorous fertiliser has a number of technological advantages (optimal uniformity of application, fast availability, reduced risks of phytotoxic effects on the crop) and shows a higher economic efficiency of the unit of the active substance relative to the granular form. The rapid action of the liquid form of fertiliser contributes to the better development of young plants and the development of cobs with a large number of grains. Thus, the use of liquid fertiliser P_2O_5 at a rate equivalent to 20 kg/ha of active substance contributed to the formation of a better cob grain number compared to the application of granular fertiliser P_2O_5 at a rate of 36 kg/ha. Therewith, the use of only a liquid form of fertiliser, even in high doses (90-100 kg/ha), is not enough to ensure full nutrition of corn during the entire growing season, so the option with the introduction of only a granular form of fertiliser had a yield advantage.

Additional application of the minimum dose of liquid fertiliser (25 L/ha) against the background of the main nutrition with granular fertiliser ensures optimal development of the crop throughout the growing season and allows obtaining an additional 1.3 t/ha (12.9%) of the yield.

The use of zinc as an additional component of the tank mixture contributes to the formation of more grains in a row and a higher mass of grain from one cob. An important component of the phosphorous nutrition strategy may also be using bacterial preparations based on strains of phosphorus-mobilising bacteria, in particular, *Pseudomonas fluorenses*, which increases the overall supply of plants with available phosphorus and gives a substantial increase in yield in conditions of phosphorus deficiency.

Further refinement and disclosure requires the issue of the effectiveness of the use of bacterial preparations to improve the phosphorus nutrition of field crops in the conditions of Western Polesia. The research on the effectiveness of liquid complex fertilisers of the composition 5-20-5 in the cultivation of sunflower is promising as well. This crop in the conditions of the specified soil-climatic zone is new, technological approaches to its cultivation on light soils are not sufficiently justified, and substantial variability of the root system can favourably affect the effectiveness of applying starter fertilisers.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Вплив застосування рідких комплексних добрив та сумішей на їх основі на продуктивність кукурудзи в умовах Західного Полісся

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Анотація. Питання оптимізації фосфорного живлення кукурудзи стають все більш актуальними з огляду на тенденції підвищення вартості мінеральних добрив та зростаючі метеорологічні ризики в період після посіву. Метою представлених матеріалів є дослідження господарської ефективності рідких комплексних добрив, що внесені при посіві кукурудзи, в якості основного джерела фосфору та як додаткового елемента в складі системи живлення. Для реалізації поставлених задач був виконаний польовий дослід, схема якого включала варіанти окремого внесення РКД, окремого внесення гранульованого мінерального добрива, сумісного застосування РКД та гранульованого добрива, а також бакових сумішей РКД із цинком та бактеріальним продуктом на основі *Pseudomonas fluorenses*. Встановлено, що застосування РКД при посіві сприяє кращому забезпеченню молодих рослин фосфором, та, як результат, – закладці більш продуктивного качана. При цьому використання в якості джерела живлення виключно РКД у дозах до 50-60 л/га, не дає змоги реалізувати закладений потенціал та призводить до недоотримання зерен із качана відносно варіанту з повноцінним живленням. Найвищу врожайність було отримано у варіанті із застосуванням гранульованого добрива та 60 л рідкого комплексного добрива в суміші з бактеріальним препаратом, при цьому приріст врожайності відносно варіанту без гранульованого добрива становив 32 % (2,8 т/га). Окреме застосування рідкого комплексного добрива за жодних умов не забезпечило результату співставного із внесенням гранульованого добрива, однак додавання 25 л/га РКД до основного внесення гранульованого добрива дозволило отримати приріст врожаю в 1,3 т/га. Отримані результати доводять високу ефективність рідкої форми стартового добрива при його внесенні на легких за гранулометричним складом ґрунтах та мають бути враховані при плануванні ресурсоощадної технології вирощування кукурудзи в зоні із високим ступенем метеорологічних ризиків

Ключові слова: якісні показники зерна; локальне внесення; ресурсозберігаючі технології; ефективність фосфорних добрив; бактеріальні препарати