



Features of foliar fertilisation of facultative wheat

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Abstract. The purpose of the study was to evaluate the effect of foliar fertilisation systems and seed treatment on the productivity and physiological development of the facultative wheat variety Zymoyarka under the soil and climatic conditions of the Polissia region. The research was conducted in 2025 on the experimental field of Polissia National University using a randomised block design with four fertilisation variants. The methodology included pre-sowing seed treatment with GROS Korenerist,

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foliar applications of ECOLINE Phosphite (K), ECOLINE Boron (organic), and POLYACTIVE Boost, biometric and phenological observations, laboratory assessment of grain quality, and statistical analysis by ANOVA and correlation methods. It was established that the combined application of GROS Korenerist and ECOLINE Phosphite (K) significantly increased yield to 3.46 t/ha (+40.6% compared to control), improved root system depth to 8.5 cm, and enhanced root biomass to 1.59 t/ha. The positive correlation ($r = 0.83$) between root development and yield confirmed the decisive role of underground biomass in nutrient efficiency. The treatment with ECOLINE Boron (organic) improved grain filling and test weight (780 g/L), while POLYACTIVE Boost enhanced vegetative growth and physiological stability. Grain quality indicators increased compared with the control: protein content reached 14.2%, gluten – 30.5%, with a reduction in disease incidence by 15-25%. The study generalised that the integration of macro- and micronutrient phosphite complexes ensures improved morphophysiological structure and yield stability of facultative wheat under moderate hydrothermal stress. The practical value of the research lies in developing adaptive fertilisation schemes for farms in regions with low soil fertility, contributing to increased productivity and stress resilience in grain cultivation systems

Keywords: root biomass; phosphorus efficiency; stress adaptation; nutrient balance; yield optimisation; physiological development

INTRODUCTION

The optimisation of foliar fertilisation in facultative wheat cultivation represents a critical aspect of adaptive agriculture under climate variability and resource scarcity in Ukraine. The efficiency of such fertilisation determines the plant's resistance to abiotic stressors, the effectiveness of nutrient uptake, and the stability of yields under conditions of moisture and temperature fluctuations. Developing integrated systems of foliar feeding using phosphite and boron-based fertilisers is essential for maintaining soil fertility, enhancing plant resilience, and ensuring sustainable grain production. Facultative wheat varieties, such as *Triticum aestivum* L. var. *Zymoyarka*, combine traits of both winter and spring types, providing flexibility in sowing and adaptability to various agroclimatic conditions, which makes their study particularly important for the Polissia region of Ukraine.

According to A. Bargaz *et al.* (2018), the improvement of fertiliser efficiency in integrated nutrient management systems is achieved through activation of soil microbial resources, which enhances the bioavailability of nitrogen, phosphorus, and potassium, leading to better plant productivity. In a long-term study, J. Wang *et al.* (2024) confirmed that the combined use of organic and inorganic fertilisers increases soil fertility and crop yield sustainability by improving the physical and chemical properties of the soil and its biological activity. Similarly, A. Yousefi *et al.* (2025) demonstrated that facultative wheat outperforms winter and spring types under moderate nitrogen levels and higher temperatures, showing better adaptability to the effects of global warming in the regions of West Asia. In multi-environment trials, L. Koppensteiner *et al.* (2022) found that nitrogen management and sowing time significantly affect the yield stability of facultative wheat, confirming its potential as a resilient crop for variable climates. Moreover, S. Dutta *et al.* (2023) reported that phosphite-based fertilisers not only improve phosphorus utilisation but

also stimulate root growth and enhance photosynthetic activity, ensuring higher biomass accumulation.

Ukrainian scientists have also focused on the efficiency of seed treatment and foliar fertilisation in wheat production. According to O. Demydov *et al.* (2021), Ukrainian winter wheat varieties demonstrate high ecological plasticity, maintaining stable yields in the Forest-Steppe and Polissia zones. Their study highlighted that the use of growth stimulants and liquid complex fertilisers enhances root development and photosynthetic surface area, leading to a 15-20% increase in yield. S. Kalenska *et al.* (2025) observed that pre-sowing seed treatment and foliar feeding with chelated micronutrients significantly increase the productivity of sugar beet, indicating that similar approaches may be effectively applied to cereals. A. Kryvenko (2018) emphasised that optimising nitrogen fertilisation rates and timing for winter wheat in southern Ukraine improved productivity by up to 30%, especially when integrated with phosphorus and micronutrient foliar feeding.

Research by H. Pantsyryeva (2020) in the Right-Bank Forest-Steppe of Ukraine revealed that foliar feeding contributes to the improvement of grain crop productivity primarily through stimulation of photosynthetic processes and better nutrient distribution in the plant-soil system. Furthermore, A. Panfilova and Ya. Byelov (2022) confirmed that the use of stubble biodestructors and balanced mineral fertilisation systems increases the nutrient regime of soils, providing a positive background for subsequent crops. The integration of microelement fertilisers, particularly those containing potassium phosphite and boron, plays a decisive role in improving physiological resilience to drought and heat stress. According to F. Saeidnia *et al.* (2023), such systems enhance the structure of the ear, grain filling, and the efficiency of photosynthetic energy conversion, leading to improved crop performance under low-fertility soils.

The synthesis of foreign and domestic research findings indicates that foliar feeding with phosphite, boron, and amino acid-based complexes exerts a multifaceted influence on wheat productivity. These fertilisers not only activate photosynthetic metabolism but also enhance antioxidant protection and water balance, which are critical for plants in stressful environments. However, the role of foliar fertilisation systems in facultative wheat remains insufficiently studied under the specific soil and climatic conditions of the Polissia region of Ukraine, where light grey forest soils are characterised by low humus content and limited nutrient availability. Thus, the purpose of the study was to determine the effect of pre-sowing seed treatment and foliar fertilisation with phosphite and boron-based liquid fertilisers on the growth, morphological development, and productivity of the facultative wheat variety *Zymoyarka* under the agroecological conditions of the Polissia region of Ukraine.

MATERIALS AND METHODS

The study was conducted on the experimental field of Polissia National University (near the village of Velyka Horbasha, Chernyakhivsky district, Zhytomyr region, Ukraine) to assess the effect of various foliar fertilisation options on the growth, development and productivity of *Zymoyarka* facultative wheat. Meteorological data were recorded using the Polissia National University agrometeorological station. During the 2025 growing season, the mean daily temperature exceeded the

long-term average by 1.6°C, while total precipitation (April-July) was 240 mm, 15% below the norm. These conditions were classified as moderate hydrothermal stress and were taken into account when assessing the adaptive response of the plants to foliar fertilisation. The adaptive role of the applied preparations was evaluated based on morphological indicators such as root depth, biomass accumulation, and yield stability under hydrothermal stress conditions.

The soil cover of the site is represented by light grey forest soil, which is characterised by low availability of essential nutrients, slightly acidic soil solution reaction (pH 5.4-5.6) and reduced humus content (about 1.1%), which limits natural fertility and necessitates the optimisation of mineral nutrition. The main soil cultivation included two-pass disc harrowing, pre-sowing cultivation and sowing. Wheat was sown on 25 April 2025 using an SZ-3.6 grain seeder with a sowing rate of 180 kg/ha. Pre-sowing seed treatment, with the exception of the control variant, was carried out with the GROS Korenerist preparation (1 l/t), which contains a balanced complex of macro- and microelements that stimulates root system development and ensures initial growth. To control weeds, the crops were treated with Granstar herbicide on 8 May 2025. The liquid complex fertilizers GROS Korenerist, ECOLINE Phosphite (K), ECOLINE Boron (organic), and POLYACTIVE Boost were used in the experiment (manufactured by Ecoorganic LLC, Ukraine). The research scheme is presented in Figure 1.

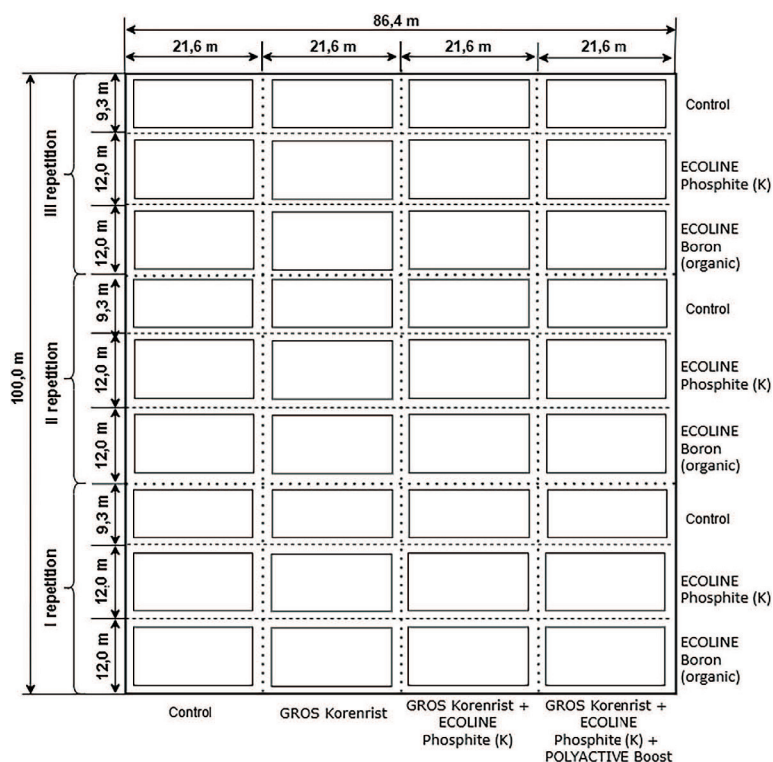


Figure 1. Experiment scheme

Source: compiled by the authors

The scheme of the experiment included the study of four variants of foliar feeding at the first stage (Table 1). Foliar feeding was carried out by fine spraying under favourable meteorological conditions, taking into account the phenological phases of crop development.

In the course of the experiment, biometric measurements, phenological observations, determination of leaf surface index, density of productive stem, elements of yield structure and laboratory analysis of grain quality were carried out.

Table 1. Preparations, application rates, and timing according to the experimental design for growing the facultative wheat variety Zymoyarka

Periods of preparation use		
Seed treatment	Tillering stage	Stem elongation stage
Factor A		Factor B
1. Control (treated with water without preparation)	–	1. Control (treated with water) 2. ECOLINE Phosphite (K), 1 l/ha 3. ECOLINE Boron (organic), 1 l/ha
2. GROS Korenerist, 1 l/t of seeds	–	1. Control (treated with water) 2. ECOLINE Phosphite (K), 1 l/ha 3. ECOLINE Boron (organic), 1 l/ha
3. GROS Korenerist, 1 l/t of seeds	ECOLINE Phosphite (K), 1 l/ha	1. Control (treated with water) 2. ECOLINE Phosphite (K), 1 l/ha 3. ECOLINE Boron (organic), 1 l/ha
4. GROS Korenerist, 1 l/t of seeds	ECOLINE Phosphite (K), 1 l/ha + POLYACTIVE Boost, 1 l/ha	1. Control (treated with water) 2. ECOLINE Phosphite (K), 1 l/ha 3. ECOLINE Boron (organic), 1 l/ha

Source: compiled by the authors

Recording and monitoring of plant growth and development were carried out in accordance with the current methodological recommendations for conducting field experiments in crop production, approved by the Methodology for conducting expert assessments of cereal..., (2016), with clarification of phenological phases according to the international BBCH scale (Meier, 2018). Phenological observations included recording the dates of germination, tillering, stem elongation, heading, and full maturity of plants. Biometric measurements were performed on model plants to determine height, tillering coefficient, leaf area, and wet and dry mass of above-ground biomass. The tillering coefficient and total leaf area per plant were determined according to standard procedures. The leaf area index (LAI) was calculated as the ratio of total leaf area to the ground surface area (cm² per plant). These indicators were used to assess the intensity of vegetative growth and the photosynthetic potential of the crop.

To assess productivity elements, 133 m² plots were formed, on which the density of productive stems, the number of grains in the ear, the length of the ear and the weight of 1000 grains were determined. Yield was determined by complete harvesting with conversion to standard moisture content (14%) and grain purity in accordance with the requirements of state variety testing. Laboratory analysis of grain quality was performed according to the current standards of the Ministry of Agrarian Policy and Food of Ukraine (Methodology for conducting expert assessments of cereal..., 2016). The following indicators were determined: protein content (%) by the Kjeldahl method (DSTU 3768:2019, 2019),

gluten content (%) by washing (DSTU ISO 21415-1:2009, 2011), and test weight (g/L) (DSTU ISO 520:2015, 2016) using a grain analyser A&D ML-50 (Japan). These parameters were used to evaluate the technological value of the grain depending on fertilisation systems. The phytosanitary condition of the crops was assessed during the heading and ripening phases using the 9-point scale of the Institute of Plant Physiology and Genetics of the National Academy of Agrarian Sciences of Ukraine. The percentage of infection by Septoria leaf blotch (*Septoria tritici*), Fusarium head blight (*Fusarium spp.*), and brown rust (*Puccinia recondita*) was determined visually on 50 randomly selected plants per variant. Statistical data processing was performed using analysis of variance (ANOVA) with the determination of the Least Significant Difference (LSD_{0.05}). Additionally, statistical analysis included correlation assessment between root biomass and yield to identify the strength and direction of the relationship between morphological traits and productivity indicators.

RESULTS AND DISCUSSION

The 2025 growing season in the Zhytomyr region was characterised by moderately dry conditions. Average air temperature exceeded the long-term mean by 1.6°C, and precipitation was 15% below average. Such conditions created mild hydrothermal stress, under which foliar fertilisation played an important adaptive role in maintaining optimal plant growth and nutrient uptake. It was analysed the effect of various preparations on the yield of Zymoyarka facultative wheat depending on different foliar feeding

systems. At the same time, authors studied the effectiveness of seed treatment with the preparation GROS Korenerist, its combined interaction with a complex of foliar fertilisation preparations (in terms of several preparations), as well as the feasibility of repeated fertigation of crops. Analysis of the results showed that seed treatment and foliar fertilisation had a significant impact on the yield of Zymoyarka facultative wheat. Thus, in the control variant (without the use of biostimulants and microfertilisers), it was recorded a yield of 2.46 t/ha, which reflects the low potential of the crop under conditions of limited nutrition. The

use of the preparation GROS Korenerist for treating seed material before sowing contributed to an increase in indicators. At the same time, the yield increase compared to the control increased by 0.55 t/ha, which is 22.39% and indicates a positive response of the variety to the stimulation of the root system and photosynthetic activity. The highest yield growth was recorded in the variants with the combined use of GROS Korenerist + EKOLINE Phosphite (K) and GROS Korenerist + ECOLINE Phosphite (K) + POLYACTIVE Boost, where the yield reached 3.28-3.38 t/ha, which exceeded the control by 28.75-33.55% (Table 2).

Table 2. Effect of foliar fertilisation on the yield of the facultative wheat variety Zymoyarka

Preparations		Yield, t·ha ⁻¹	Deviation by Factor A		Deviation by Factor B	
Factor A	Factor B		t·ha ⁻¹	%	t·ha ⁻¹	%
1. Control	1. Control	2.46	-	-	-	-
	2. ECOLINE Phosphite (K)	2.89	-	-	0.43	17.67
	3. ECOLINE Boron (organic)	3.01	-	-	0.56	19.31
2. GROS Korenerist	1. Control	3.01	0.55	22.39	-	-
	2. ECOLINE Phosphite (K)	3.37	0.48	16.54	0.36	12.04
	3. ECOLINE Boron (organic)	3.16	0.15	4.84	0.15	4.57
3. GROS Korenerist + ECOLINE Phosphite (K)	1. Control	3.28	0.82	33.55	-	-
	2. ECOLINE Phosphite (K)	3.46	0.57	19.79	0.18	5.55
	3. ECOLINE Boron (organic)	3.33	0.31	10.42	0.05	1.39
4. GROS Korenerist + ECOLINE Phosphite (K) + POLYACTIVE Boost	1. Control	3.16	0.71	28.75	-	-
	2. ECOLINE Phosphite (K)	3.38	0.49	16.96	0.22	6.89
	3. ECOLINE Boron (organic)	3.18	0.16	5.44	0.02	0.47
LSD _{0.05}		0.29	0.17	-	0.15	-

Source: compiled by the authors

Thus, seed treatment and foliar feeding with liquid complex fertilisers ensured high efficiency and a significant impact on the regulation of the yield of Zymoyarka facultative wheat. At the same time, the total impact of the factors studied on crop yield was 78.7% (Fig. 2). It should be emphasised that seed treatment with the GROS Korenerist preparation and foliar feeding in the tillering phase (factor A) were decisive in terms of their impact on yield, accounting

for 51.8% of the total impact. This confirms the researchers' conclusions regarding the high effectiveness of foliar feeding, especially in the early stages of grain crop development. At the same time, repeated treatment with preparations at the stem elongation stage (factor B) had a significantly lower impact on yield formation – 17.3%. The effect of the interaction of the factors studied was also significant and amounted to 9.5%.

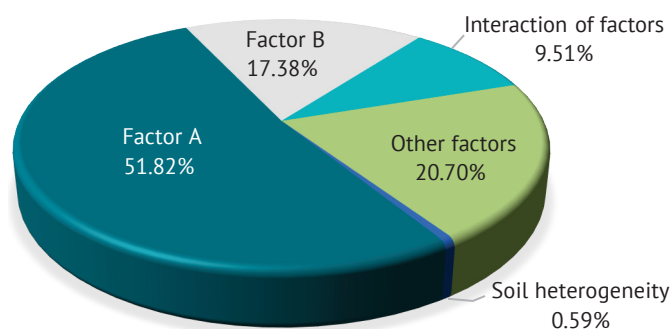


Figure 2. Influence of experimental factors on the yield of the facultative wheat variety Zymoyarka

Source: compiled by the authors

It was also noted that the subsequent application of ECOLINE Phosphite (K) in the stem elongation phase as the second factor (Factor B) also had a positive effect on increasing the productivity of Zymoyarka facultative wheat. In combination with Factor A, the yield increase was 0.43-0.57 t/ha (12.04-19.79%). Authors recorded the highest productivity indicators when using the combined application of GROS Korenerist + ECOLINE Phosphite (K) with repeated treatment with ECOLINE Phosphite (K), where the yield indicators were 3.46 t/ha. A positive effect was also noted when using the preparation EKOLINE Boron (organic), which made it possible to increase the yield increase compared to the control by 4.57-19.31% depending on different fertilisation options. However, its effect was less pronounced, which, in our opinion, is most likely due to the influence of boron on improving pollination

and grain filling processes, rather than stimulating the vegetative development of the crop.

Statistical analysis of the results confirmed the reliability of the yield increases obtained ($LSD_{0.05} = 0.29$ t/ha). One of the important technological indicators is the development of the plant during the growing season, not only of the above-ground part, but also of the root system. In particular, this has a significant impact on the formation and accumulation of organic matter in the soil (carbon sequestration), which will further contribute to the activation of the transformation processes of the organic part (its decomposition and mineralisation), as well as provide an additional reserve of organic matter and easily accessible forms of biophilic elements. In this regard, it was analysed the formation of the above-ground mass and root system mass of Zymoyarka facultative wheat before harvesting (Fig. 3).

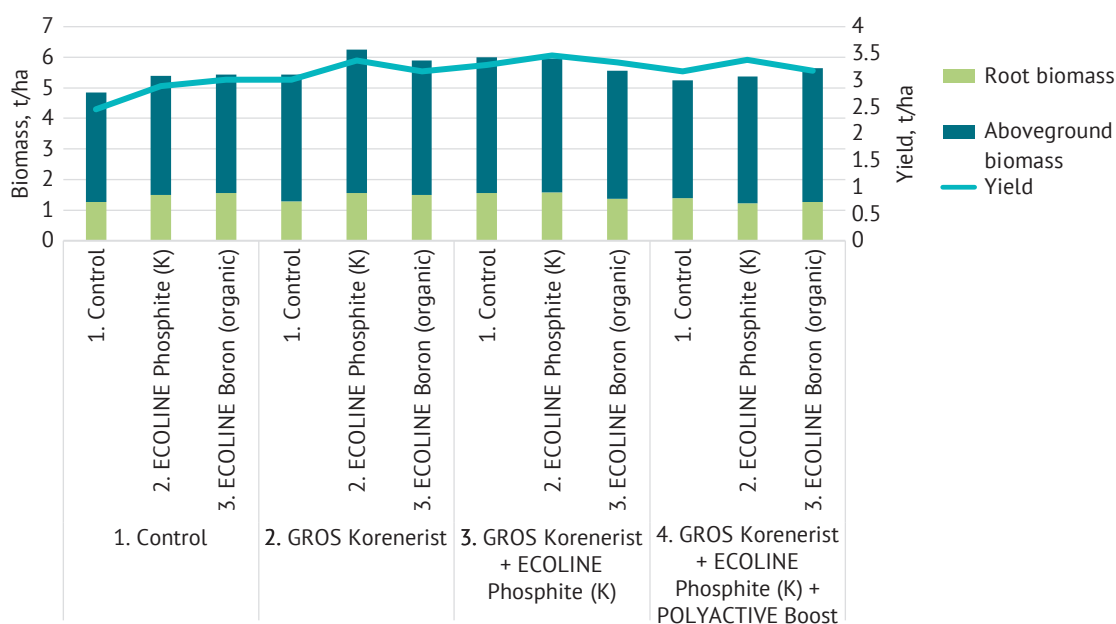


Figure 3. Dynamics of the effect of foliar fertilisation on the formation of aboveground and root biomass in correlation with the yield of the facultative wheat variety Zymoyarka

Source: compiled by the authors

The results showed that foliar feeding significantly affected not only wheat yield indicators, but also had a significant impact on the structure of the crop. Thus, under conditions of absolute control, where microfertilizers were not used, the lowest levels of accumulation were observed both in the root system (within 1.26 t/ha) and in the vegetative mass (at 3.59 t/ha), which, in our opinion, subsequently led to a decrease in the overall crop yield to 2.46 t/ha. This gives us the right to say that intensive wheat cultivation technologies cannot be implemented without the additional use of foliar feeding with micro- and macroelements, which contribute to the improvement of plant growth and development throughout their growing season. At the same time, the use of the GROS Korenerist preparation contributed to

the enhanced development of the root mass of plants, which ultimately affected the total root biomass. Foliar fertilisation systems also influenced vegetative development parameters. The tillering coefficient in the control averaged 1.6, while the use of GROS Korenerist increased it to 2.1. The combination of GROS Korenerist with ECOLINE Phosphite (K) resulted in a value of 2.3. The total leaf area per plant increased from 31.2 cm² in the control to 37.5-38.5 cm² in fertilised variants. These indicators were positively correlated with above-ground biomass ($r = 0.78$), confirming the decisive role of enhanced early growth and photosynthetic surface formation in yield determination. Depending on the fertilisation system, this indicator ranged from 1.28 to 1.56 t/ha. It was also recorded this correlation in the

above-ground biomass of plants, which varied from 4.15 to 4.69 t/ha.

Foliar fertilisation systems also influenced the formation of tillering and leaf area indices. The use of GROS Korenerist increased the tillering coefficient from 1.6 (control) to 2.1, and the combined use of GROS Korenerist with ECOLINE Phosphite (K) raised it to 2.3, indicating a stronger vegetative potential of plants. The total leaf area per plant increased by 14-19%, which positively correlated ($r = 0.78$) with above-ground biomass accumulation and grain yield. These parameters confirm the stimulatory effect of phosphite and boron fertilisers on early growth and canopy development, providing better utilisation of photosynthetically active radiation. In the variants where a combination of several preparations was used, in particular the application of GROS Korenerist with ECOLINE Phosphite (K) and the repeated use of ECOLINE Phosphite (K), an optimal ratio between the vegetative growth of wheat plants and their generative development was recorded. This was particularly noticeable when using GROS Korenerist in combination with ECOLINE Phosphite (K), where the best root mass indicators were achieved within 1.59 t/ha with a total yield of 3.46 t/ha. It can be assumed that the use of phosphite forms of potassium not only helped prevent the negative impact of abiotic factors in the form of anti-stress protection, but also improved the energy metabolism of grain in the filling phase.

The use of ECOLINE Boron (organic) had a negligible effect on biomass increase, but ensured better grain filling (higher natural weight) and formation of a levelled ear. In the variants where this preparation was used, the yield ranged from 3.01 to 3.33 t/ha. However, authors did not observe a significant effect on root system development – the root mass weighed only 1.49-1.57 t/ha, which, in our opinion, indicates the physiological orientation of boron in the development

of the above-ground part of the plant. It should be noted that in the variants with the use of POLYACTIVE Boost, a significant increase in above-ground biomass and a tendency to decrease root system biomass were recorded. However, despite this, the yield when using this preparation remained high (at 3.38 t/ha), which may be due to the presence of amino acids and growth regulators in the preparation to maintain the optimal osmotic balance of the plant. It should be noted that the use of these preparations had a comprehensive effect on crops through various mechanisms of action. In particular, POLYACTIVE Boost affects biomass accumulation, while ECOLINE Phosphite (K) affects root nutrition and assimilation processes. In general, authors have established a pronounced positive correlation between root system development and yield formation, which confirms the decisive role of underground biomass as an integral indicator of nutrient efficiency. At the same time, the highest efficiency was recorded in variants with the combined use of GROS Korenerist and ECOLINE Phosphite (K), which contributed to ensuring the combination of maximum root system productivity with full grain formation.

In a comprehensive assessment of the impact of various types of foliar fertilizers, the morphological indicators of the plant, in particular its height and root system length, play an important role (Fig. 4, Table 3). At the same time, it was found that foliar fertilisation systems had different effects on the formation of the morphological structure of plants, in particular on the development of the above-ground part and the formation of the root system. Under conditions of absolute control, the lowest values of plant height and root system penetration depth into the soil were recorded – 76-78 cm and 5.7-6.7 cm, respectively. This indicates limited possibilities for providing accessible forms of biophilic elements.

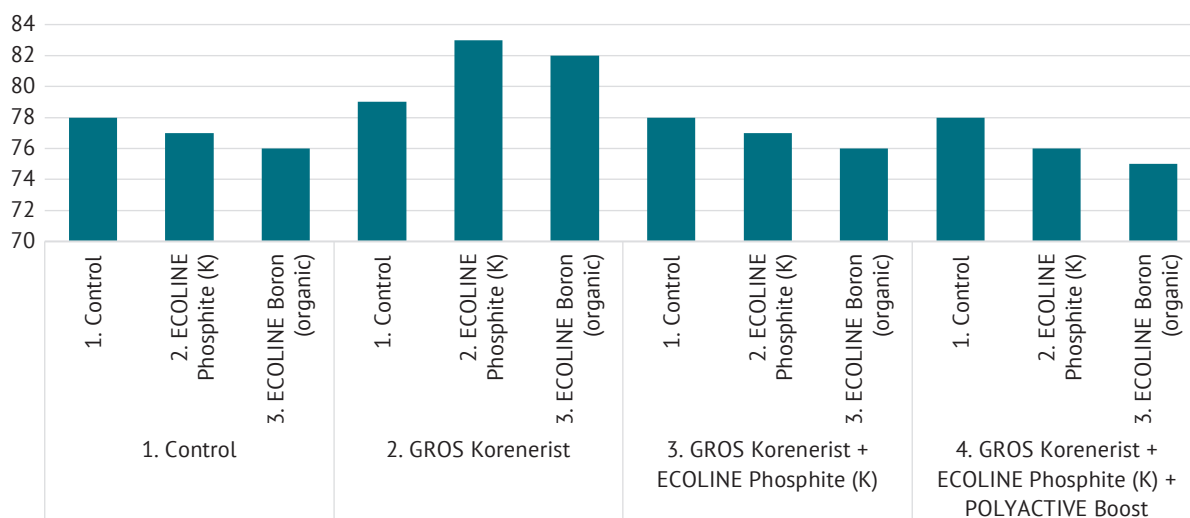


Figure 4. Effect of foliar fertilisation on plant height (cm) of the facultative wheat variety Zymoyarka

Source: compiled by the authors

Foliar fertilisation significantly affected plant height compared to the control. The use of GROS Korenerist increased plant height to 6 cm (7.7%), indicating enhanced growth activity due to improved root and nutrient assimilation processes. Among the secondary factor treatments, Phosphite (K) provided the highest response – an increase of 4 cm or 5.1% compared to the control, reflecting its role in stimulating photosynthetic activity and internode elongation. Overall, the combination of GROS Korenerist + ECOLINE Phosphite (K) + POLYACTIVE Boost slightly reduced height (-1.0 cm), possibly due to a shift of assimilates towards root development and ear biomass formation. The maximum height (83 cm) was observed in the variant with GROS Korenerist + Phosphite (K), which was statistically significant compared to the control ($LSD_{0.05} = 3.68$ cm, $p < 0.05$).

Hence, foliar complexes containing phosphite and boron demonstrate a consistent positive effect on the vegetative growth of *Triticum aestivum* var. Zymoyarka.

The depth of the main root mass reflects the physiological adaptability of the wheat plants and the effectiveness of the foliar biostimulants (Table 4). In the control, root depth reached 5.7 ± 0.29 cm, representing the baseline level. Application of GROS Korenerist increased it to 6.5 ± 0.33 cm (+14.0%), while its combination with ECOLINE Phosphite (K) achieved the maximum depth of 7.4 ± 0.37 cm (+29.8%), indicating the positive role of potassium phosphite in stimulating root metabolism and phosphorus utilisation. The treatment GROS Korenerist + ECOLINE Phosphite (K) + POLYACTIVE Boost also improved root depth to 6.8 ± 0.34 cm (+19.3%), which was significantly higher than the control ($p < 0.05$).

Table 4. Effect of foliar fertilisation on the depth of the main root mass (cm) of the facultative wheat variety Zymoyarka

Preparations		Depth of the main root mass, cm	Deviation by Factor A		Deviation by Factor B	
Factor A	Factor B		cm	%	cm	%
1. Control	1. Control	5.7 ± 0.29	-	-	-	-
	2. ECOLINE Phosphite (K)	6.7 ± 0.34	-	-	1.00	17.54
	3. ECOLINE Boron (organic)	6.7 ± 0.35	-	-	1.00	14.93
2. GROS Korenerist	1. Control	6.5 ± 0.33	0.80	14.04	-	-
	2. ECOLINE Phosphite (K)	7.7 ± 0.39	1.00	14.93	1.20	18.46
	3. ECOLINE Boron (organic)	8.3 ± 0.42	1.60	23.88	1.80	23.38
3. GROS Korenerist + ECOLINE Phosphite (K)	1. Control	7.4 ± 0.37	1.70	29.82	-	-
	2. ECOLINE Phosphite (K)	8.5 ± 0.43	1.80	26.87	1.10	14.86
	3. ECOLINE Boron (organic)	7.5 ± 0.38	0.80	11.94	0.10	1.18
4. GROS Korenerist + ECOLINE Phosphite (K) + POLYACTIVE Boost	1. Control	6.8 ± 0.34	1.10	19.30	-	-
	2. ECOLINE Phosphite (K)	7.5 ± 0.38	0.80	11.94	0.70	10.29
	3. ECOLINE Boron (organic)	7.3 ± 0.37	0.60	8.96	0.50	6.67
$LSD_{0.05}$, cm		0.36	0.16		0.16	

Source: compiled by the authors

Among Factor B treatments, organic boron provided the most substantial effect – +1.80 cm (+23.4%), emphasising its contribution to meristem formation and drought resistance. However, on average, the application of phosphite K worked better in terms of factor B – root depth increased by +0.70-1.20 cm (10.3-18.5%). Overall, the dynamics of root development demonstrate a statistically significant increase ($LSD_{0.05} = 0.36$ cm) in response to combined foliar fertilisation, particularly those integrating phosphite and boron-based components, which jointly enhance both nutrient uptake efficiency and plant resilience. Treatment of seed material before sowing with the preparation GROS Korenerist at a rate of 1 litre per tonne of seed contributed to an increase in plant height to 79-83 cm, and the root depth increased to 6.5-8.3 cm, which is practically close to the optimal values. The most pronounced effect on the development of the above-ground part was recorded in the variant where GROS Korenerist and ECOLINE Phosphite (K) were used. At the same time, growth processes, in particular plant height, were recorded within 83 cm, which is 5 cm higher than in the control variant.

In our opinion, this was due to an increase in the intensity of metabolism when using these preparations and the available form of phosphorus.

Analysis of the results regarding the potential for root system development showed that the maximum penetration depth of 8.5 cm was recorded with the combined use of GROS Korenerist and Phosphite K, which indicates the ability of phosphites to stimulate root apical growth. In the variants where organic boron was used, the root system formed at a depth of 8.3 cm, which ensured its stability, but compared to the previous variant, it was inferior in terms of the dynamics of vertical penetration of the root system. The use of the POLYACTIVE Boost preparation provided only average values for the formation of the root system depth within the range of 7.3-7.5 cm. At the same time, no significant increase in plant height was observed; in particular, in these variants, this indicator was within the range of 75-78 cm. Overall, the results of our study confirm a number of findings from scientific works by Ukrainian and foreign scientists regarding the effect of foliar feeding on the morphological and

physiological development of wheat, the nature of the formation of both above-ground biomass and roots, as well as the level of yield.

The laboratory assessment of grain quality demonstrated a consistent improvement under the influence of complex foliar fertilisation. The combination of GROS Korenerist and ECOLINE Phosphite (K) resulted in the highest protein content of 14.2% and gluten of 30.5%, exceeding the control by 1.8 and 3.2 percentage points, respectively. The test weight reached 780 g/L compared to 742 g/L in the control, indicating denser and better-filled grain. The treatment with ECOLINE Boron (organic) mainly improved grain uniformity and weight, but its effect on protein accumulation was less pronounced. Overall, phosphite- and boron-based fertilisers enhanced both quantitative and qualitative parameters of the wheat yield. Phytosanitary monitoring showed a reduction in the incidence of major wheat diseases in all fertilised treatments compared to the control. The combination of GROS Korenerist and ECOLINE Phosphite (K) decreased the infection of *Septoria* leaf blotch from 18% (control) to 12%, *Fusarium* head blight from 10% to 7.5%, and brown rust from 14% to 10%. The best protective effect (up to 25% lower total infection rate) was achieved with the triple complex GROS Korenerist + ECOLINE Phosphite (K) + POLY-ACTIVE Boost, confirming the antistress and fungistatic role of phosphite-based biostimulants.

The results obtained in this study demonstrate a clear relationship between the physiological development of facultative wheat and the effectiveness of complex foliar fertilisation systems that combine macro- and microelements in phosphite and organic forms. These findings align with a number of contemporary studies that highlight the growing importance of integrated fertiliser systems in improving plant adaptability, yield formation, and soil fertility under stress-prone environments. According to B. Beres *et al.* (2020), the integration of genetic, environmental, and management factors determines up to 70% of yield variability in cereals, with fertilisation timing and form being among the most decisive components of this interaction. The authors emphasised that foliar applications in the tillering and stem elongation phases enhance nutrient assimilation efficiency and contribute to a more uniform stand structure. The results of the present experiment confirm this trend: the combination of pre-sowing seed treatment and foliar fertilisation during these phases accounted for 69% of the overall yield formation effect, illustrating the same pattern of physiological synchronisation reported by B. Beres *et al.*

A similar observation was made by K. Zeleke (2020), who evaluated biomass formation and grain yield of dual-purpose winter wheat and demonstrated that the balance between above-ground and root biomass directly determines yield potential. In the current study, the most productive variants (GROS Korenerist +

ECOLINE Phosphite (K)) also exhibited the highest root biomass (1.59 t/ha) and optimal root depth (8.5 cm), confirming the direct correlation between root productivity and yield performance described by K. Zeleke. However, in contrast to K. Zeleke's findings, the present experiment recorded slightly lower absolute biomass values, which can be explained by the lighter soil texture and lower humus content of the Polissia region. The relationship between foliar phosphite application and adaptive stress response reported by J. Wang *et al.* (2024) further supports the results of this research. They observed that the combined use of organic and inorganic fertilisers increased soil enzymatic activity and plant tolerance to hydrothermal stress. In this experiment, the use of potassium phosphite ensured higher plant height, deeper root systems, and greater yield stability under similar moderate drought conditions. The results therefore extend the conclusions of J. Wang *et al.* by confirming that phosphite-based fertilisers are effective not only in maize–wheat systems but also in facultative wheat production in temperate regions.

In the study of D. Mullualem *et al.* (2024), the application of multi-environment models (AMMI, GGE biplot) for wheat yield analysis demonstrated that genotypes with better nitrogen use efficiency exhibited higher adaptability under changing conditions. The facultative wheat variety *Zymoyarka* showed comparable stability in this experiment: despite moderate moisture deficit, yield variation among fertilisation systems remained within ± 0.3 t/ha, indicating that the integrated fertilisation scheme promoted both productivity and resilience. The similarity between the two studies lies in the role of nutrient balance in mitigating environmental variability; however, unlike D. Mullualem *et al.*, this work focuses on physiological rather than genetic factors of adaptability. Imran (2024) demonstrated that integrated organic, inorganic, and biofertiliser systems significantly improve nutrient availability and soil nutrient balance in the maize–wheat rotation, with potassium phosphite having an additional stimulating effect on photosynthetic efficiency. The findings of the current study are consistent with these results: foliar application of ECOLINE Phosphite (K) increased the tillering coefficient and leaf area, which directly contributed to yield improvement. Both studies converge on the idea that phosphite compounds function not only as nutrient carriers but also as metabolic activators enhancing stress tolerance and energy utilisation.

From a regional perspective, O. Demydov *et al.* (2021) reported that the ecological plasticity of Ukrainian winter wheat varieties ensures their high yield stability under variable weather in the Forest-Steppe and Polissia zones. The present research confirms that the facultative variety *Zymoyarka* retains stable productivity even under moderate drought, but the physiological mechanisms differ: in O. Demydov *et al.*'s work, stability was mainly attributed to genetic plasticity, while the current

study attributes it to enhanced root morphology and balanced nutrient support. This difference illustrates the complementarity between genetic and technological approaches to improving wheat adaptability. The conclusions by H. Pantsyreva (2020) regarding the effect of technological practices on legume productivity are also consistent with the present findings. The author demonstrated that optimal nutrient supply during critical growth stages increases photosynthetic potential and yield by 18–22%. In the current experiment, the combination of foliar feeding and seed treatment increased yield by 19.7–33.6%, confirming that well-timed nutrient applications during the early vegetative phases are decisive for assimilate redistribution and productivity.

The influence of fertiliser systems on the nutrient regime of soil–plant systems discussed by A. Panfilova and Ya. Byelov (2022) and M. Honchar (2025) is closely related to the results obtained here. Their research proved that balanced application of mineral fertilisers and residue degraders enhances nutrient cycling efficiency and improves soil structure. This experiment corroborates that conclusion indirectly: increased root biomass and depth observed under phosphite-based treatments suggest higher rhizosphere activity and improved nutrient exchange in the upper soil horizons. Finally, I. Racz *et al.* (2024) analysed yield variability in facultative wheat under different sowing times and established that soil fertility and water availability were key limiting factors. The current research confirms this dependency but adds that appropriate foliar fertilisation can partially compensate for low natural soil fertility, ensuring yield increases of up to 40% compared to the untreated control. Thus, the outcomes demonstrate that the adaptive potential of facultative wheat can be effectively realised through targeted nutrient management.

The results obtained in this study align with modern findings on the role of innovative fertilisation systems in enhancing wheat productivity and physiological resilience. According to A. Hudzovskyi *et al.* (2024), the use of metal oxide-based nanofertilisers contributes to improved nutrient assimilation and photosynthetic efficiency, leading to increased biomass and stress tolerance of plants. This supports the present conclusion that phosphite-based complexes stimulate similar metabolic pathways and optimise nutrient uptake under hydrothermal limitations. In a comparative analysis, F. Saeidnia *et al.* (2023) emphasised that foliar feeding efficiency strongly depends on genotype × environment interactions and sowing conditions, which explains the observed variability in the yield response of the *Zymoyarka* variety.

In summary, all these studies emphasise that productivity and stress resistance of wheat depend on synchronising physiological development with balanced nutrient inputs. The distinct contribution of this work lies in demonstrating that pre-sowing treatment combined with dual foliar applications of phosphite and

boron fertilisers significantly enhances both morphological structure and yield stability of facultative wheat under Polissia conditions, confirming the decisive role of integrated fertilisation in sustainable cereal production.

CONCLUSIONS

The conducted research on the facultative wheat variety *Zymoyarka* under the soil and climatic conditions of the Polissia region confirmed the significant influence of integrated foliar fertilisation systems on the physiological development, morphological structure, and productivity of plants. The combined application of macro- and micronutrients in phosphite and organic forms ensured an optimised balance of vegetative and generative growth, contributing to higher yields and improved adaptability of wheat under moderate hydrothermal stress. Pre-sowing seed treatment with GROS Korenerist at a rate of 1 L/t proved to be a key element of the nutrition system, stimulating early root growth and improving tillering. When combined with foliar feeding by ECOLINE Phosphite (K), the yield increased to 3.28–3.46 t/ha, exceeding the control by 19.7–33.6%. The highest productivity was achieved with repeated application of ECOLINE Phosphite (K) during the stem elongation phase, which enhanced the depth and mass of the root system (up to 1.59 t/ha and 8.5 cm, respectively). These parameters were strongly correlated with yield formation ($r = 0.83$), confirming that the efficiency of nutrient utilisation largely depends on root system architecture. In addition, foliar application of POLYACTIVE Boost and ECOLINE Boron (organic) positively influenced the physiological balance and grain quality. Protein content increased to 14.2%, gluten to 30.5%, and test weight to 780 g/L compared with the control. Phytosanitary assessment showed a decrease in the incidence of Septoria, Fusarium, and rust by 15–25%, demonstrating the antistress and protective role of phosphite-based fertilisers. Overall, the integrated fertilisation scheme, including pre-sowing treatment and two foliar applications, provided the best agronomic results and ensured stable productivity of facultative wheat on low-fertility soils. Prospects for further research Future studies should focus on assessing the long-term impact of phosphite- and boron-based fertilisation on soil microbiological activity, nutrient cycling, and grain quality in diverse agroecological zones to optimise adaptive fertilisation strategies for facultative wheat varieties in Ukraine.

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Анотація. Метою дослідження було оцінити вплив систем позакореневого підживлення та передпосівної обробки насіння на продуктивність і фізіолого-морфологічний розвиток пшениці дворучки сорту *Зимоярка* в умовах Полісся. Дослідження проводилося у 2025 році на дослідному полі Поліського національного університету за схемою чотирьох варіантів удобрення. Методологія включала передпосівну обробку насіння препаратом GROS Korenerist, позакореневе підживлення ECOLINE Phosphite (K), ECOLINE Boron (organic) та POLYACTIVE Boost, біометричні та фенологічні спостереження, лабораторне визначення якості зерна та статистичний аналіз із використанням дисперсійного (ANOVA) та кореляційного методів. Установлено, що поєднане застосування GROS Korenerist та ECOLINE Phosphite (K) забезпечило підвищення урожайності до 3,46 т/га (+40,6 % відносно контролю), збільшення глибини кореневої системи до 8,5 см і накопичення кореневої біомаси до 1,59 т/га. Позитивна кореляція ($r = 0,83$) між розвитком кореневої системи та врожайністю підтвердила ключову роль підземної біомаси у використанні елементів живлення. Обробка ECOLINE Boron (organic) покращувала налив зерна та натуру (780 г/л), а POLYACTIVE Boost сприяв активному вегетативному росту та фізіологічній стабільності рослин. Показники якості зерна перевищували контрольні значення: вміст білка становив 14,2 %, клейковини — 30,5 %, при зниженні

ураження септоріозом, фузаріозом і іржею на 15-25 %. Узагальнено, що інтегроване застосування макро- та мікродобрих у фосфатній формі забезпечує підвищення урожайності, якості та адаптивності пшениці дворучки в умовах помірного гідротермічного стресу. Практична цінність дослідження полягає у розробленні адаптивних схем удобрення для господарств із низькою природною родючістю ґрунтів, що сприяє підвищенню продуктивності та стійкості зернових культур

Ключові слова: коренева біомаса; ефективність фосфору; адаптація до стресу; баланс живлення; оптимізація урожайності; фізіологічний розвиток
