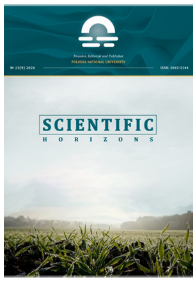
SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 28(3), 33-43



UDC 631.816.31: 631.42
DOI: 10.48077/scihor3.2025.33

Effectiveness of plant growth stimulants for winter wheat in the Left-Bank Forest-Steppe of Ukraine

Larysa Semenko
PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-4586-3681
Serhiy Veremeyenko
Doctor of Agricultural Sciences, Professor
National University of Water Management and Nature Management
33000, 11 Soborna Str., Rivne, Ukraine
https://orcid.org/0000-0003-4513-0733
Anatoly Bykin
Doctor of Agricultural Sciences, Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0001-7212-7340
Larysa Kucher*
PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0002-7211-693X
Tymur Panchuk
Doctor of Philosophy, Assistant Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0003-2629-1427

***Article's History*:**
Received: 25.09.2024
Revised: 03.02.2025
Accepted: 26.02.2025

Abstract. The study aimed to determine the effectiveness of plant growth stimulants on yield and grain quality indicators of winter wheat grown on dark grey podzolic soil developed from loess-like loam. The research assessed the impact of seed treatment with the BioZern fertiliser for stimulating the growth and development of cereal crops, the Medax Top growth regulator, the Turbo micronutrient fertiliser, and $MgSO_4$

***Suggested Citation*:**
Semenko, L., Veremeyenko, S., Bykin, A., Kucher, L., & Panchuk, T. (2025). Effectiveness of plant growth stimulants for winter wheat in the Left-Bank Forest-Steppe of Ukraine *Scientific Horizons*, 28(3), 33-43. doi: 10.48077/scihor3.2025.33.

*Corresponding author

in winter wheat cultivation under the conditions of Kyiv Region, at Biotech LTD. Seed treatment with BioZern in combination with Medax Top + Turbo + $MgSO_4$ resulted in a yield of 9.0 t/ha compared to 6.8 t/ha in the control. The application of plant growth stimulants (PGS) and micronutrients increased yield by 1.34-2.2 t/ha. The use of PGS in combination with $MgSO_4$ improved plant growth and development indicators, with an 8-10% increase in plant density, over a 20% rise in the number of productive stems per unit area, and a corresponding increase in the tillering coefficient. The application of PGS also significantly enhanced key indicators of wheat ear productivity. The number of spikelets, grains per spike, grain weight per spike, and total grain mass per spike increased in the studied crop. Growth ranged from 25% to 50% compared to the control. A key practical outcome of the study was the improvement of most indicators characterising product quality. In addition to an increase in the 1,000-grain weight, the test weight rose from 737 g/L in the control to 763-766 g/L in treatments with PGS. While vitreousness remained consistent across all treatments, PGS slightly reduced the grain protein content from 15.6% in the control to 14.0-14.2% in treated variants. The results confirm the high effectiveness of winter wheat seed treatment with the BioZern preparation, the application of the Medax Top growth regulator, the Turbo micronutrient fertiliser, and $MgSO_4$ under the conditions of Kyiv Region. These findings can be recommended for winter wheat cultivation

Keywords: plant growth regulators; grain quality; biometric growth indicators; yield; productivity

INTRODUCTION

Winter wheat is a crucial crop in Ukrainian agriculture, accounting for approximately 45% of the country's total sown area. Successful cultivation requires a series of precise agricultural practices that directly influence yield potential. However, in recent decades, growth-regulating substances or plant growth stimulants have become widely used in these operations. Manufacturers of these substances highlight their beneficial properties, which affect grain quality and yield indicators, resistance to adverse conditions, and the plant's ability to absorb organic and mineral nutrients. However, the effectiveness and practical implementation of combining different types of agrochemicals, including various forms of mineral fertilisers, growth regulators, and plant growth stimulants, remain insufficiently studied. Moreover, new types and formulations of agrochemicals are continually being developed and introduced to the market, cultivation conditions are evolving, and new varieties and hybrids are being introduced. This necessitates the development of recommendations for their effective use in production across different regions and conditions.

As highlighted by A. Panfilova *et al.* (2023), the implementation of modern agricultural technologies and high-yielding wheat varieties has the potential to significantly increase winter wheat production. However, the full potential of modern wheat varieties is not yet realised in production due to several limiting factors, including climatic conditions, soil properties, pests, and diseases. The future of the grain market heavily relies on the continued improvement of agricultural practices in winter wheat cultivation. In particular, more research is needed to understand the effects of new plant growth stimulants on crop development and yield in different varieties and hybrids. Achieving high yields is challenging, and adverse climatic conditions are a major cause of yield reduction. Addressing the impact of climate on winter wheat yield is a critical issue for researchers, as noted by S. Shylo *et al.* (2021).

V. Sarabi and E. Arjmand-Ghajur (2021) suggest that the use of plant growth stimulants allows for targeted regulation of key plant processes, enabling the full realisation of a variety's genetic potential. According to M. Korkhova *et al.* (2021), high-yielding winter wheat varieties have increased demands for soil fertility, moisture content, and weed control. When cultivating highyielding wheat varieties, proper fertilisation becomes crucial. Mineral fertilisers play a decisive role in achieving stable and high yields. The positive effects of mineral fertilisers applied to winter wheat are evident across various soil types and regions in Ukraine. This includes presowing (basic), at-sowing (row), and various top-dressing applications (surface, root, and foliar). A. Elkoussy *et al.* (2023) highlight that plant growth stimulants are an additional factor in increasing crop productivity, including winter wheat. They enhance the efficiency and return on investment of mineral fertilisers and pesticides. R. Kieloch and K. Marczewska-Kolasa (2022) note that plant growth regulators promote plant growth and development under both optimal and stressful conditions. They provide plants with resistance to abiotic stresses, mitigating the effects of herbicide stress and increasing plant tolerance. However, W. Miziniak and K. Matysiak (2023) indicate that the combined application of herbicides with mepiquat chloride only increases winter wheat grain yield in heavily weed-infested crops. The combined use of herbicides and growth stimulants requires careful timing, as herbicide application depends on the weed development stage, which may not coincide with the optimal timing for PGS application.

As D. Nsengiyumva *et al.* (2019) point out, the high effectiveness of plant growth regulators is due to their balanced composition of biologically active substances. These substances promote the rapid development of green mass and root systems. Researchers Z. Garban and G. Ilia (2024) and V. Kryzhanovskiy (2022) add that improved green mass and root activity lead to more efficient nutrient utilisation. This, in turn, enhances resistance to diseases, stresses, and adverse weather conditions. In addition to significantly increasing yield, plant growth stimulants, as highlighted by R. Babu *et al.* (2022), also shorten the maturation period, reduce nitrate, pesticide, and heavy metal content in plants, enhance the nutritional value of the harvested crop, and minimise losses during harvesting, transportation, and storage.

Therefore, this study aimed to determine the effectiveness of plant growth stimulants on the productivity and quality indicators of winter wheat grain in the Left-Bank Forest-Steppe region of Ukraine.

LITERATURE REVIEW

For the past few decades, Ukraine's agricultural sector has been a key driver of the country's economic development and a major source of foreign currency earnings (Kyfyak *et al.*, 2022). Winter wheat stands out as a crucial food and export crop. Winter wheat is one of the world's leading cereal crops, valued for its high nutritional and taste qualities, as well as its high productivity compared to other cereals (Tadesse *et al.,* 2020). Ukraine is a major agricultural exporter in Europe, with winter wheat playing a significant role (Kiforenko, 2023). While wheat is grown across various regions of Ukraine, the main cultivation areas are concentrated in the ForestSteppe zone, which provides the most favourable soil and climatic conditions for this crop (Lozinskiy & Samoilyk, 2023).

Many factors influence the yield and quality of winter wheat grain, and farmers use various methods to mitigate these factors. One common practice is the use of plant growth stimulants. The global market offers a wide range of these stimulants. However, there is a lack of information on their effectiveness in specific soil and climatic conditions. Winter wheat (*Triticum* L.) is the most valuable and high-yielding cereal crop. Its technological properties, including a high protein content (16%) and carbohydrate content (80%), make it suitable for use in the baking industry, pasta and confectionery production, and animal feed manufacturing (Kaplan Evlice, 2021; Ravshanov *et al.,* 2021).

Significant research has been conducted on the effects of plant growth stimulants applied either as foliar sprays or seed treatments on the development and productivity of agricultural crops. The application of growth regulators during seed preparation for sowing has been shown to increase seed germination energy and field emergence (Shalygina *et al.,* 2021; Tajdari *et al.,* 2024; Sethar *et al.,* 2024). Foliar application of products like the film-forming bioregulator Mars-ELBi, in conjunction with mineral fertilisers on typical chernozem soils, consistently increased winter wheat grain productivity when applied in spring after the resumption of spring growth (Yarchuk *et al.,* 2020). Under the influence of growth regulators, root system mass increased by up to 57% due to the formation of more secondary roots in cereals. This led to an increase in the number of spikelets per ear and the 1000-grain weight.

It is well-established that plant growth regulators facilitate plant growth and development under both optimal and stressful conditions. However, W. Miziniak and K. Matysiak (2023) found that the combined application of herbicides with mepiquat chloride only increased winter wheat grain yield in heavily weed-infested crops. The combined use of herbicides and PGRs requires careful timing, as herbicide application depends on the weed development stage, which may not coincide with the optimal timing for PGR application. I. Kosakivska *et al.* (2022) reported that treating winter wheat seeds with Fulvogumin and succinic acid increased germination energy to 9496%. Fulvogumin significantly increased root length. Pre-sowing application of Fulvogumin with succinic acid resulted in larger wheat seedlings (12.4 cm) and higher fresh weight (11.5 g/100 seeds). PGRs based on phytohormones are differentially distributed within plants.

Pre-sowing treatment of wheat seeds with exogenous phytohormones improves plant growth and development. According to O. Hordyna (2021), this treatment should be carried out simultaneously with seed dressing. It is recommended to reduce the dosage of seed dressing agents by 30% when used in a tank mixture with biostimulants. The author also found that biostimulants enhance metabolic processes in the plant and improve energy metabolism, contributing to higher field resistance of plants to abiotic and anthropogenic factors, including diseases. Treatment of winter wheat seeds of the Duma odeska variety with the natural growth biostimulant Azotofit-R, which actively fixes molecular and atmospheric nitrogen, improves seed germination and stimulates and improves root system development. Used alongside the biological fungicide Phytocide-R against fungi, it contributed to a yield of 6.09 t/ha. The use of growth regulators based on the metabolic products of micromycete fungi, a balanced complex of phytohormones of auxin and cytokinin nature, amino acids, carbohydrates, fatty acids, and micronutrients, increases germination energy and grain emergence. It also leads to a more branched root system and improved development of symbiotic microflora in the root growth zone (Tekaya *et al.,* 2022; Dymytrov *et al.,* 2023).

Anomalies observed in plants subjected to environmental stress include poor photosynthetic activity, the development of non-functional stomata, reduced wax deposition, poor root system development, and low resistance to pathogens (Pavlov *et al.,* 2021; Honchar *et al.,* 2023). The synthesis of natural antidepressants and anti-stress factors that confer resistance to drought, waterlogging, and other adverse environmental conditions in the soil and within the plant itself is promoted by the use of the biological inoculant PGPM. This can stimulate the improvement of plant vitality through various mechanisms, such as the production of plant growth hormones, nitrogen fixation, and the reduction of nitrate levels, among others. Furthermore, these PGPMs can act as biocontrol agents, helping plants develop resistance to pathogens at an early stage of development (Teraiya *et al.,* 2023). Biostimulants based on benzyladenine, kinetin, indole-3-butyric acid, and 1naphthaleneacetic acid are used to accelerate the breaking of seed dormancy in clonal production of forest crops (Dinçer, 2023).

MATERIALS AND METHODS

The field studies were conducted in the Kyiv Region, Ukraine, at the experimental field of "Biotekh LTD". The soil of the experimental plot is dark grey podzolic soil on loess-like loams. The agrochemical and physicochemical indicators are presented in Table 1. The climate of this area is temperate continental with a relatively mild winter. The duration of the growing season in this region ranges from 198 to 204 days, and the moisture coefficient is close to one.

Table 1*. Agrochemical and physicochemical indicators of dark grey podzolic soil on loess-like loams*

Indicator	Depth of sample collection, cm	
	0-20	20-40
pH_{KCl}	5.4	4.8
Humus content,%	2.8	2.6
Absorption capacity, mg-equiv/100g	27.9	24.1
Hydrolytic acidity, mg-equiv/100g	2.6	3.1
Base saturation degree, %	86.3	87.1
Available N, mg/kg	37.8	18.8
$P_2O_{5,}$ mg/kg	305	201
K_2O_2 mg/kg	342	282

Source: *developed by the authors*

Morphological and biometric observations were carried out using the state variety testing method (Tkachyk *et al.,* 2017). The BBCH scale, which is currently the most common among professionals in Ukraine, was used to describe the phenological development of plants. The number of plants (plants/m^2), the number of stems (stems/m^2), the tillering coefficient – at BBCH 29, the height of winter wheat plants at BBCH 29, BBCH 59, BBCH 92, the number of grains in a spike (grains), the mass of the spike (g), the mass of grains in the spike (g), and the grain yield per unit area (t/ha) were determined.

Quality indicators were analysed according to the standards set out in DSTU 37682019 (2019): protein content in the grain was determined using the Kjeldahl method; crude gluten content was measured using the washing method; and the falling number was determined using the Hagberg-Perten method. The falling number is a unit of measurement for the activity of the α amylase enzyme in wheat grain. This enzyme breaks down starch into monosaccharides, releasing carbon dioxide, which contributes to the porosity of bread during baking. The value of the falling number can easily indicate the quality of future bakery products:

- a very high falling number indicates low α-amylase activity, resulting in insufficient carbon dioxide for dough leavening, leading to dry, low-volume bread;
- a low falling number indicates excessive enzyme activity, resulting in sticky dough and overly soft bread;
- the optimal falling number for wheat is 250 seconds (Gilissen & Smulders, 2021).

The test weight was determined using a grain tester. The 1000-grain weight was calculated. Grain translucency was measured using a DC3-3 diaphanoscope. Vitreosity (%) is an indicator that determines the hardness of the grain endosperm. Higher vitreosity indicates better baking properties and, consequently, higher wheat quality and value. The total area of the experimental plot was 50 m^2, with a recorded area of 26 m^2 and four repetitions. Statistical analysis was performed using the ANOVA method. The fertiliser and PGR application scheme is shown in Table 2.

Table 2*. Experimental design*

Fertilisation variant	BBCH growth stage
1. Control (Background): N_{32} after previous crop harvest – UAN;N_{32} pre-sowing cultivation – UAN;LCF ($N_8P_{34)}$ – 150 kg/ha pre-sowing; KCl – 100 kg/ha pre-sowing	–
2. Background + Medax Top (1 L/ha) + Turbo (1 L/ha) + $MgSO_4$ (7 kg/ha)	BBCH 30-32 BBCH 37-39
3. Background + BioZern seed treatment 30 (2 L/t) + $MgSO_4$ (7 kg/ha)	BBC 37-39
4. Background + BioZern seed treatment 30 (2 L/t) + Medax Top (1 L/ha) + Turbo (1 L/ha) + $MgSO_4$ (7 kg/ha)	BBCH 30-32 BBCH 37-39

Source: *developed by the authors*

Medax Top (BASF) is a growth regulator that reduces plant lodging. It contains active ingredients: prohexadione calcium (50 g/L) + mepiquat chloride (300 g/L). The formulation is a concentrated suspension (CS). Turbo (TD Hermes) is a micronutrient fertiliser containing nitrogen (30%), potassium (3%), phosphorus (3%), magnesium (1.5%), sulphur (0.3%), and iron (0.2%), as well as humic substances, amino acids, and organic acids. $MgSO_4$ is a magnesium salt containing MgO (16%) and SO_3 (30%). BioZern is a fertiliser for stimulating the growth and development of cereal crops (wheat seed treatment): nitrogen (N) – 150 g/L, calcium (CaO) – 20 g/L, copper (Cu) – 10 g/L, manganese (Mn) – 20 g/L.

The experiment focused on the soft, awnless winter wheat (*Triticum aestivum* L.) variety Mulan, a German selection from Nordsaat Saatzucht GmbH. This variety is classified as a valuable, high-yielding, medium-ripening type, with a vegetation period of 275-280 days. It exhibits medium winter hardiness, increased resistance to drought, lodging, and diseases. The average plant height ranges from 80-90 cm. The seeding rate for winter wheat was 4.5 million seeds per hectare. The authors conducted the research following generally accepted methodological recommendations for crop cultivation. The experimental studies on winter wheat plants, including the collection of plant material, comply with the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The productivity and quality of crops are significantly influenced by the conditions of plant growth and development in the early stages of organogenesis when the potential of the future harvest is established. Analysis of the results of observations of the effect of PGRs in combination with the application of magnesium sulphate showed that their application improved plant development indicators. While the number of plants in the control variant was 510 plants/m^2, the use of PGRs with magnesium sulphate increased this indicator to 554-566 plants/m^2, the number of stems increased from 915 to 1,210 stems/m^2, and the tillering coefficient increased from 1.79 to 2.14 (Table 3).

***Table 3**. Effect of fertilisation during spring tillering (BBCH 29) on winter wheat growth indicators*

Variant number	Number of plants, plants/m^2	Number of stems, stems/m^2	Tillering coefficient
1	510	915	1.79
2	554	1,121	2.02
3	561	1,205	2.14
4	566	1,210	2.14

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

The highest indicators were observed in the variant with the combined application of Background + BioZern + Medax Top + Turbo + $MgSO_4$. This indicates an improvement in plant development when using PGRs on a high agricultural background. The largest winter wheat yield is obtained in the presence of a high stem density of productive shoots of plants per square meter of sown area and a high grain content in each ear (Zhuk & Stasik, 2024). The formation of the crop yield is significantly influenced by weather and climatic conditions, soil fertility, and the biological characteristics of the varieties being grown. Analysing the results, the tallest plants at the BBCH 29 stage (spring tillering) were observed in the treatment with Background + BioZern + Medax Top + Turbo + $MgSO_4$, measuring 29.1 cm (Fig. 1). This trend continued until the BBCH 92 stage (full maturity), with plants reaching 121 cm. The shortest plants were observed in the control group (N_{32} UAN + N_{32} + N_8P_{34} + KCl), ranging from 25.1 to 89.4 cm. In the treatment without BioZern, the difference compared to the control was 2.3 cm at the BBCH 29 stage, and this pattern persisted throughout the entire growing season.

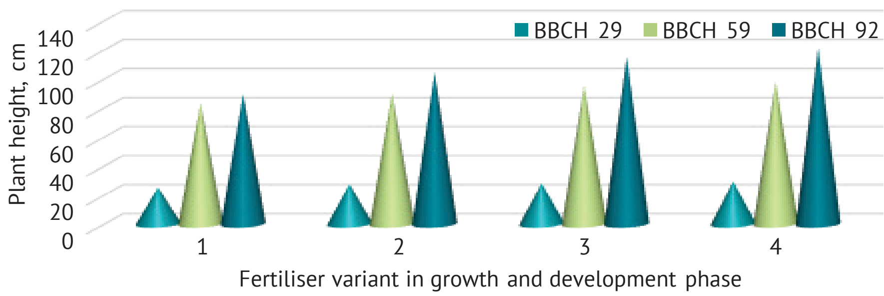


***Figure 1**. Winter wheat plant height depending on fertiliser rates, cm*

***Note:** LSD$_{0.05}$*
***Source:** developed by the authors*

Better initial plant development conditions resulted in higher ear productivity. For example, the number of spikelets in the control variant was 11, while in the second variant, it was 15.1, in the third variant 15.9, and the fourth variant 16.2 (Table 4).

The grain content per ear increased from 12 grains in the control to 15.6-17.1 grains with the use of PGRs. This led to an increase in ear weight and grain weight per ear. In the control group, the test weight was 737 g/L, which contributed to an increase in the 1000-grain weight to 42.8 g (Table 5). With a gradual increase in fertiliser doses and the use of growth-stimulating products, the test weight increased to 763 g/L, and the 1000-grain weight to 45.4 g. The best results were observed in the treatment with Background + BioZern + Medax Top + Turbo + $MgSO_4$ compared to the control. In this treatment, the test weight was 766 g/L, and the 1000-grain weight was 45.5 g.

***Table 4**. Influence of fertilisation on the spike productivity of winter wheat*

Variant number	Number of spikelets per ear	Number of grains per ear	Ear weight, g	Grain weight per ear, g
1	11.0	12.0	4.0	3.15
2	15.1	15.6	4.5	3.8
3	15.9	16.8	5.7	4.1
4	16.2	17.1	5.8	4.0
$LSD_{0.05}$	0.01	0.01	0.02	0.01

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

***Table 5**. Physical indicators of winter wheat grain quality*

Variant number	Test weight, g/L	1000-grain weight, g	Vitreosity,%	Mass fraction of protein content, %
1	737	42.8	50	15.6
2	763	45.4	50	14.2
3	765	46.3	50	14.0
4	766	45.5	50	14.1

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

The vitreosity index was not influenced by fertilisation and remained at 50% across all treatments. This corresponds to the first-class grain according to the quality indicators of soft wheat grain. According to the conducted studies, the falling number ranged from 302 to 305 seconds across all treatments, which is an optimal indicator for winter wheat (Table 6). According to DSTU 3768:2019 (2019), the falling number for soft wheat ranges from 180 to 220 seconds depending on the class (the higher the class, the higher the falling number). For the bread-baking process, flour with a falling number of 250 seconds is most suitable. If the falling number exceeds 350 seconds, it means that the flour needs to be supplemented with some type of amylolytic enzyme or malt.

Analysing the combined data on wheat quality indicators across the fertilisation treatments, the treatment with Background + BioZern 30 + Medax Top + Turbo + $MgSO_4$ was the best across all studied parameters. The worst treatment was the background fertilisation, where the grain quality was classified as second-class grain. In all other treatments, the grain was classified as firstclass grain. The analysis revealed a pattern: as the protein content increased, the mass fraction crude gluten content also increased. The highest gluten content was observed in the control sample (32.9). However, an increase in gluten and protein content can negatively impact the baking properties of flour. Therefore, the treatment with Background + BioZern + Medax Top + Turbo + $MgSO_4$ was considered the best, as it had a gluten content of 28.8.

***Table 6**. Physical indicators of winter wheat grain quality*

Variant number	Mass fraction of crude gluten	Gluten quality: units of the gluten strain meter instrument	Falling number, s
1	32.9	82 II	302
2	29.0	75 I	302
3	29.7	69 I	303
4	28.8	73 I	305

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

Considering that the 1000-grain weight increased by 2.0-2.5 grams in the experimental treatments compared to the control, this was undoubtedly the main factor contributing to the increased winter wheat grain yield with the use of PGRs. In the control treatment, the background fertilisation provided a grain yield of 6.8 t/ha. The additional application of Medax Top + Turbo + $MgSO_4$ increased the yield to 8.23 t/ha (a 1.43 t/ha increase). The application of BioZern + $MgSO_4$ yielded 6.68 t/ha (a 1.88 t/ha increase) compared to the control. The application of BioZern + Medax Top + Turbo + $MgSO_4$ resulted in the highest yield of 9.0 t/ha (a 2.2 t/ha increase or 32.3% more than the control) (Fig. 2). It should be noted that all treatments with PGRs resulted in significant yield increases.

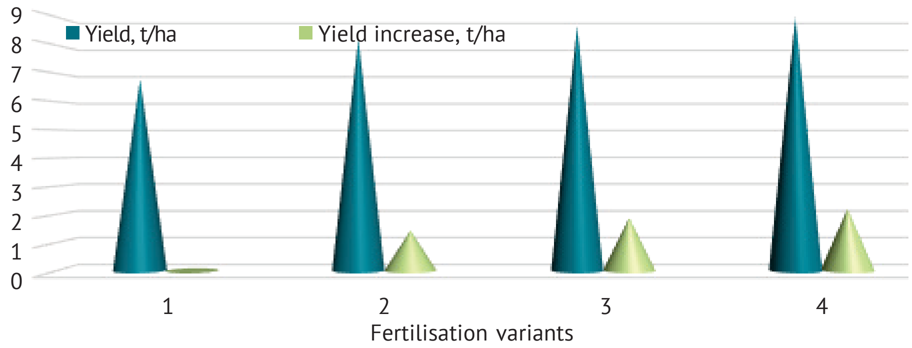


***Figure 2**. Winter wheat yield with the application of growth-stimulating products, 2020-2022*
***Note:** $LSD_{0.05}$ for yield – 0.36, for yield increase – 0.27*
***Source:** developed by the authors*

The substantial increase in winter wheat yield with the use of PGRs, at relatively low additional costs, indicates the economic and agricultural efficiency of using PGRs in winter wheat crops in the Forest-Steppe region of Ukraine. However, there are publications that express scepticism and negativity regarding PGRs in the formation of grain productivity, not only in winter wheat but also in other cereal crops. Some researchers believe that most regulators do accelerate and enhance certain biochemical reactions in plant organisms (Zaiets & Onufran, 2021). However, such changes are usually unstable and short-lived. Enhancing one or two, even very important, biochemical reactions lead to a disruption of homeostasis, i.e., the stability of the organism, but soon the plant begins to quickly restore it. Hence, the effect of using this type of stimulant often does not exceed 10%. The complexity of using growth stimulants in agricultural production lies in the fact that the effectiveness of many of them can be limited by the peculiarities of the regulatory processes of plant growth and development at different stages of their ontogenesis. This is because the action of stimulants in ultra-low concentrations (e.g., hormones or other active compounds) can be compensated by other mechanisms in plants or by external factors, such as environmental conditions and nutrient availability (Hamoda, 2024).

The Ukrainian agricultural market is under pressure to reduce fertiliser costs, leading to an intensive search for alternatives to expensive mineral fertilisers. Physiologically active substances and preparations are gaining particular attention (Kraus *et al.,* 2021). Furthermore, unstable weather conditions, characteristic of the Forest-Steppe zone of Ukraine, which are approaching those of the Steppe zone, hinder the proper return from mineral fertilisers. Therefore, it is advisable to use various preparations to reduce stress on plants and increase the efficiency of using nutrients from mineral fertilisers, especially those that simultaneously increase yield and grain quality (Amjad Bashir *et al.,* 2021).

Effective cultivation of high-quality winter wheat varieties requires a sufficient micronutrient supply, which acts as a stimulant for macronutrients, particularly nitrogen. Winter wheat's sensitivity to micronutrient deficiencies in the soil, mainly copper and manganese, is higher than in other crops (Radzikowska-Kujawska *et al.,* 2022). The availability of micronutrients is limited by soil characteristics and no-till fertilisation systems. Therefore, foliar application of micronutrients appears to be more effective than soil application and is becoming increasingly popular. When plants were foliar-fed with "ROSTOK" Macro (2 L/ha) + "ROSTOK" Copper (1 L/ha), the number of grains per ear increased by 3.3-5.3 grains, the grain weight per ear increased by 0.22-0.33 g, and the 1000-grain weight increased by 3.1-5.0 g. Winter wheat plants developed well throughout the growing season, resulting in a yield that exceeded the control by 0.36 t/ha. The use of this type of preparation with manganese increased the grain yield by 0.45 t/ha, which is also significantly less than that obtained with the BioZern + Medax Top + Turbo + $MgSO_4$ treatment. The authors indicate that foliar feeding also contributed to an increase in technological indicators (vitreosity, protein content, gluten quantity and quality) and an improvement in the quality class of winter wheat grain (Yamkovy *et al.,* 2021)

Research on the effect of pre-sowing treatment of winter wheat seeds on biometric indicators of seedlings notes a positive effect from the biopreparation Azotofit at a dose of 0.5 L/t, which is prepared based on nitrogen-fixing bacteria *Azotobacter chroococcum* (Korkhova *et al.,* 2022). The application of micronutrients in winter wheat fertilisation allows for improved grain quality, especially when used in conjunction with foliar nitrogen fertilisation. In this case, the protein content can increase by 0.7%, and its amino acid composition is significantly improved (Zhilyak *et al.,* 2024).

Various growth stimulants are widely used in crop production, contributing to plant resistance to diseases and adverse environmental factors, affecting seedling uniformity, increasing the flag leaf area, and enhancing nitrogen uptake by plants. Their use in combination with plant protection products allows for reduced production costs and increased yield by 0.3-0.72 t/ha. Spraying crops with Emistim C, Agrostimulin, and Triman at a dose of 0.005 L/ha, or Vermistim (9 L/ha) during the spring tillering phase, increases plant resistance to septoria by 2.3-7.1%, thus increasing grain yield (Nepran *et al.,* 2021). High effectiveness of fumar was established at the level of 9-36% – a preparation that contains the active substance dimethyl ether of aminofumaric acid, which acts to activate the biosynthesis of all the most important phytohormones for crop growth in various cereal crops (Garcia-Molina *et al.,* 2021). The inclusion of humic stimulants in tank mixtures with seed dressings ensured an increase in winter wheat yield relative to the control variant for the Vyshyvanka, Pryvablyva, Obriad, Trudivnytsia Myronivska varieties by 0.88-1.32 t/ha (Gangur *et al.,* 2020)

Therefore, comparing the results of this study with the articles of other authors confirms the effectiveness of using PGRs in the cultivation of winter wheat in the Forest-Steppe region of Ukraine. The use of PGRs together with micronutrients can increase crop yields, reduce costs, and improve grain quality, which is important for food security and economic development of the country.

CONCLUSIONS

The conducted research has shown that under the conditions of the Left-Bank Forest-Steppe of Ukraine, on a sufficiently high agricultural background, the use of plant growth regulators ensures better development of the studied crop, high grain quality indicators, and an increase in yield to 9.0 t/ha, which is 32.3% higher than the control. The best indicators for 1000-grain weight, test weight, protein content, and gluten content were obtained with the treatment: Background + BioZern + Medax Top + Turbo + $MgSO_4$. This fertilisation regime resulted in first-class quality grain with optimal baking properties. The results of the field studies indicate the feasibility and effectiveness of using PGRs in combination with other types of agrochemicals in winter wheat cultivation. The treatment Background + BioZern 30 + Medax Top + Turbo + $MgSO_4$ provided the best results across all studied indicators and ensured first-class grain. In contrast, the treatment with background fertilisation had the lowest quality indicators, and the resulting grain was classified as second-class.

The study found a direct correlation between protein and crude gluten content. As protein content increased, so did crude gluten content, reaching 32.9% in the control sample. According to the research, excessive protein and gluten content negatively affect the baking properties of flour. The treatment with Background + BioZern + Medax Top + Turbo + $MgSO_4$ was deemed optimal, with a crude gluten content of 28.8%. Plant growth regulators increased the 1000-grain weight by 2.0-2.5 g compared to the control, contributing to higher yields. The application of Medax Top + Turbo + $MgSO_4$ increased the yield to 8.23 t/ha, 1.43 t/ha more than the control. The highest yield of 9.0 t/ha, which was 2.2 t/ha (32.3%) higher than the control, was achieved with the BioZern + Medax Top + Turbo + $MgSO_4$ treatment.

All treatments using PGRs demonstrated statistically significant yield increases. These results align with studies highlighting the importance of balanced fertilisation and growth regulator application for improving the quality and yield of winter wheat. Specifically, foliar feeding with complex fertilisers contributes to an increase in the number of grains per ear, spikelets per ear, ear weight, and 1000-grain weight, positively impacting overall crop productivity. Optimising fertilisation systems and implementing appropriate agricultural practices are key to achieving highquality and high-yielding winter wheat. Given the prospect of introducing new forms of agrochemicals, such as plant growth stimulants, it is important to continue in-depth research on their effectiveness in various soil and climatic conditions.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Amjad Bashir, M., Rehim, A., Raza, Q.-U.-A., Muhammad Ali Raza, H., Zhai, L., Liu, H., & Wang, H. (2021). Biostimulants as plant growth stimulators in modernized agriculture and environmental sustainability. *Technology in Agriculture*. doi: 10.5772/intechopen.98295.

[2] Babu, R.S.H., Srilatha, V., & Joshi, V. (2022). Plant growth regulators. In *Plant growth regulators in tropical and sub-tropical fruit crops* (pp. 1-13). Florida: CRC Press. doi: 10.1201/9781003300342-1.

[3] Convention on Biological Diversity. (1992, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.
[4] Convention on International Trade in Endangered Species of Wild Fauna and Flora. (1979, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_129#Text.
[5] Dinçer, D. (2023). Determination of optimal plant growth regulators for breaking seed dormancy and micropropagation of Sorbus aucuparia L. *Baltic Forestry*, 29(1), article number id679. doi: 10.46490/bf679.
[6] DSTU 3768:2019. (2019). *Wheat. Technical specifications*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=82765.
[7] Dymytrov, S., Sabluk, V., & Humentyk, M. (2023). Formation of productivity of giant miscanthus (Miscanthus×giganteus) under symbiosis of its root system with fungi and bacteria. *Plant and Soil Science*, 14(2), 46-56. doi: 10.31548/plant2.2023.46.
[8] Elkoussy, A.H.A.E.-R.H., Ibrahim, M.E., Ali, A.A., Hussein, A.M.S., & Samak, A.A. (2023). Effect of surface irrigation systems and growth stimulants on water use efficiency and wheat yield and quality. *Menoufia Journal of Plant Production*, 8(10), 209-210. doi: 10.21608/mjppf.2023.327060.
[9] Gangur, V.V., Kocherga, A.A., Pypko, O.S., Yeshchenko, V.M., Kabak, Y.I., & Onoprienko, O.V. (2020). Effectiveness of stimulators for pre-sowing treatment of winter wheat seeds. *Bulletin of the Poltava State Agrarian Academy*, 3, 40-45. doi: 10.31210/visnyk2020.03.04.
[10] Garban, Z., & Ilia, G. (2024). Plant growth bioregulators. In *Biologically active substances usable in food, pharmaceutical and agrobiological fields* (pp. 193-223). Florida: CRC Press. doi: 10.1201/9781032702520-5.
[11] Garcia-Molina, A., Lehmann, M., Schneider, K., Klingl, A., & Leister, D. (2021). Inactivation of cytosolic FUMARASE2 enhances growth and photosynthesis under simultaneous copper and iron deprivation in Arabidopsis. *The Plant Journal,* 106(3), 766-784. doi: 10.1111/tpj.15199.
[12] Gilissen, L.J.W.J., & Smulders, M.J.M. (2021). Gluten quantity and quality in wheat and in wheat-derived products. In *Biotechnological strategies for the treatment of gluten intolerance* (pp. 97-129). Cambridge: Academic Press. doi: 10.1016/b978-0-12-821594-4.00008-6.
[13] Hamoda, A. (2024). Effect of nano-fertilizer and bio-growth regulator on yield attributes of wheat. *Journal of Plant Production*, 0(0), 101-109. doi: 10.21608/jpp.2024.266830.1305.
[14] Honchar, A., Tonkha, O., & Patyka, M. (2023). Peculiarities of *Bacillus Subtilis* strains influence on the development of *Triticum Aestivum* L. in inoculative cultures. *Plant and Soil Science*, 14(3), 35-46. doi: 10.31548/plant3.2023.35.
[15] Hordyna, O.Yu. (2021). Features of development of winter wheat plants in the autumn-winter vegetation period as affected by pre-sowing seed treatment. *Advanced Agritechnologies*, 9. doi: 10.47414/na.9.2021.257353.
[16] Kaplan Evlice, A. (2021). Nutritional and technological properties of wheat landraces. In *Wheat landraces* (pp. 93-119). Cham: Springer. doi: 10.1007/978-3-030-77388-5_6.
[17] Kieloch, R., & Marczewska-Kolasa, K. (2022). Possibility of joint application of herbicides with growth regulators in spring barley. *Progress in Plant Protection*, 61(4), 290-296. doi: 10.14199/ppp-2021-031.
[18] Kiforenko, O. (2023). Correlation between the Greatest Agricultural Products Exporters to the EU: Is Ukraine included? *Agris On-Line Papers in Economics and Informatics*, 15(3), 87-103. doi: 10.7160/aol.2023.150308.
[19] Korkhova, M.M., Nikonchuk, N.V., & Panfilova, A.V. (2021). Adaptive potential of new winter wheat varieties in the conditions of the Southern Steppe of Ukraine. *Taurian Scientific Herald*, 122, 48-55. doi: 10.32851/2226-0099.2021.122.7.
[20] Kosakivska, I.V., Voytenko, L.V., Vasyuk, V.A., & Shcherbatiuk, M.M. (2022). Effect of pre-sowing priming of seeds with exogenous abscisic acid on endogenous hormonal balance of spelt wheat under heat stress. *Zemdirbyste-Agriculture*, 109(1), 21-26. doi: 10.13080/z-a.2022.109.003.
[21] Kraus, K., Hnilickova, H., Pecka, J., Lhotska, M., Bezdickova, A., Martinek, P., Kucirkova, L., & Hnilicka, F. (2021). The effect of the application of stimulants on the photosynthetic apparatus and the yield of winter wheat. *Agronomy*, 12(1), article number 78. doi: 10.3390/agronomy12010078.
[22] Kryzhanovskiy, V.G. (2022). Peculiarities of grain quality formation of winter wheat varieties in the right bank Forest-steppe. *Scientific Reports of the National University of Life and Environmental Sciences of Ukraine,* 18(1). doi: 10.31548/dopovidi2022.01.008.
[23] Kyfyak, V., Verbivska, L., Alioshkina, L., Galunets, N., Kucher, L., & Skrypnyk, S. (2022). The influence of the social and economic situation on agribusiness. *Wseas Transactions on Environment and Development*, 18, 1021-1035. doi: 10.37394/232015.2022.18.98.
[24] Lozinskiy, M., & Samoilyk, M. (2023). Features of inheritance of grains number of the main ear of soft winter wheat during hybridization of forest-steppe, steppe and western European ecotypes. *Agrobiology*, 2(183), 78-87. doi: 10.33245/2310-9270-2023-183-2-78-87.

[25] Miziniak, W., & Matysiak, K. (2023). Interaction of herbicides with mepiquat chloride and prohexadione calcium in winter wheat. *Journal of Plant Protection Research*, 59(4). doi: 10.24425/jppr.2019.131270.
[26] Nepran, I.V., Romanova, T.A., & Romanov, O.V. (2021). The effectiveness of biologically active substances during chickpea cultivation. *Taurida Scientific Herald*, 122, 98-106. doi: 10.32851/2226-0099.2021.122.14.
[27] Nsengiyumva, D.S., Balabanov, P.A., & Kiseleva, I.S. (2019). Impact of fungal biologically active substances on plant growth. *AIP Conference Proceedings*, 2063(1), article number 040040. doi: 10.1063/1.5087372.
[28] Panfilova, A., Korkhova, M., & Markova, N. (2023). Influence of biologics on the productivity of winter wheat varieties under irrigation conditions. *Notulae Scientia Biologicae*, 15(2), article number 11352. doi: 10.55779/nsb15211352.
[29] Pavlov, O., Babenko, A., & Andrushchenko, A. (2021). Biological effectiveness of herbicides in winter wheat crops of autumn sowing. *Plant and Soil Science*, 12(4), 50-59. doi: 10.31548/agr2021.04.0050.
[30] Radzikowska-Kujawska, D., John, P., Piechota, T., Nowicki, M., & Kowalczewski, P.Ł. (2022). Response of winter wheat (*Triticum aestivum L.*) to selected biostimulants under drought conditions. *Agriculture,* 13(1), article number 121. doi: 10.3390/agriculture13010121.
[31] Ravshanov, H., Mamatov, F., Primov, O., Khazratkulova, S., & Baratov, D. (2021). Study on technological properties of winter wheat soils. *E3S Web of Conferences*, 304, article number 03010. doi: 10.1051/e3sconf/202130403010.
[32] Sarabi, V., & Arjmand-Ghajur, E. (2021). Exogenous plant growth regulators/plant growth promoting bacteria roles in mitigating water-deficit stress on chicory (*Cichorium pumilum* Jacq.) at a physiological level. *Agricultural Water Management*, 245, article number 106439. doi: 10.1016/j.agwat.2020.106439.
[33] Sethar, S.S., Panhwar, M.A., Sootahar, M.K., Qudoos, A., Khokhar, K.H., & Babar, H. (2024). Effect of seed priming on seed germination and seedling growth of wheat. *International Journal of Economic and Environmental Geology*, 15(3), 19-25. doi: 10.46660/ijeeg.v15i3.378.
[34] Shalygina, A.A., & Tedeeva, A.A. (2021). Influence of growth regulators on crop structure of winter wheat. *Agrarian Science*, 4, 64-67. doi: 10.32634/0869-8155-2021-348-4-64-67.
[35] Shylo, S., Tsentylo, L., & Babenko, A. (2021). Winter wheat yields depending on preceding crops in the Right-Bank Forest-Steppe of Ukraine. *Plant and Soil Science*, 12(3), 48-55. doi: 10.31548/agr2021.03.0048.
[36] Tadesse, Y., Chala, A., & Kassa, B. (2020). Yield loss due to septoria tritici blotch (*Septoria Tritici*) of bread wheat (*Triticum aestivum* L.) in the Central highlands of Ethiopia. *Journal of Biology, Agriculture and Healthcare*, 10(10). doi: 10.7176/jbah/10-10-01.
[37] Tajdari, H.R., Soleymani, A., Montajabi, N., Naderi Darbaghshahi, M.R., & Javanmard, H.R. (2024). The effect of foliar application of plant growth regulators on functional and qualitative characteristics of wheat (*Triticum aestivum* L.) under salinity and drought stress conditions. *Applied Water Science*, 14, article number 126. doi: 10.1007/s13201-024-02203-5.
[38] Tekaya, M., Dabbaghi, O., Guesmi, A., Attia, F., Chehab, H., Khezami, L., Algathami, F.K., Ben Hamadi, N., Hammami, M., Prinsen, E., & Mechri, B. (2022). Arbuscular mycorrhizas modulate carbohydrate, phenolic compounds and hormonal metabolism to enhance water deficit tolerance of olive trees (*Olea europaea*). *Agricultural Water Management,* 274, article number 107947. doi: 10.1016/j.agwat.2022.107947.
[39] Teraiya, S., Nirmal, D., & Joshi, P. (2023). Potential scope and prospects of plant growth-promoting microbes (PGPMs) in micropropagation technology. In *Plant-microbe interaction – recent advances in molecular and biochemical approaches* (pp. 249-277). Cambridge: Academic Press. doi: 10.1016/b978-0-323-91876-3.00017-8.
[40] Tkachyk, S.O., Leschuk, N.V., & Prysiazhniuk, O.I. (2017). *Methodology for the qualification examination of plant varieties for suitability for dissemination in Ukraine*. Vinnytsia: FOP D.Yu. Korzun.
[41] Yamkovy, V.Yu., Bunyak, O.I., & Yashchuk, N.O. (2021). Productivity and quality of winter wheat grain depending on foliar fertilization in the left-bank forest-steppe of Ukraine. *Agrarian Innovations,* 5, 101-107. doi: 10.32848/agrar.innov.2021.5.16.
[42] Yarchuk, I.I., Melnyk, T.V., & Morhun, O.V. (2020). Influence of multicomponent growth regulators on winter resistance forming and productivity of winter wheat. *The Scientific Journal Grain Crops*, 4(2), 263-271. doi: 10.31867/2523-4544/0134.
[43] Zaiets, S.O., & Onufran, L.I. (2021). Formation of soft winter wheat (*Triticum aestivum* L.) productivity depending on microfertilizers and growth regulator in the conditions of irrigation of south of Ukraine. In *New impulses for the development of natural sciences in Ukraine and eu countries* (pp. 84-105). Latvia: "Baltija Publishing". doi: 10.30525/978-9934-26-141-1-4.
[44] Zhilyak, I.D., Slobodianyk, H.Ya., & Zabolotnyi, O.I. (2024). Germination of winter wheat seeds depends on pre-sowing treatment with growth regulators. *Scientific Issue Ternopil Volodymyr Hnatiuk National Pedagogical University. Series: Biology*, 84(1), 66-73. doi: 10.25128/2078-2357.24.1.9.
[45] Zhuk, O.I., & Stasik, O.O. (2024). Growth of shoots, ear and yield structure of winter wheat under drought. *Faktori Eksperimental'noi Evolucii Organizmiv,* 35, 23-28. doi: 10.7124/feeo.v35.1653.

Ефективність застосування стимуляторів росту рослин по пшениці озимій в умовах Лівобережного лісостепу України

Лариса Семенко
Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-4586-3681
Сергій Веремеєнко
Доктор сільськогосподарських наук, професор
Національний університет водного господарства та природокористування
33000, вул. Соборна, 11, м. Рівне, Україна
https://orcid.org/0000-0003-4513-0733
Анатолій Бикін
Доктор сільськогосподарських наук, професор
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0001-7212-7340
Лариса Кучер
Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0002-7211-693X
Тимур Панчук
Доктор філософії, асистент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0000-0003-2629-1427

Анотація. Мета досліджень - визначення ефективності застосування стимуляторів росту рослин на урожайність та показники якості зерна пшениці озимої на темно-сірому опідзоленому на лесовидних суглинках ґрунті. У даній роботі на фоні стандартного удобрення досліджено вплив обробки насіння пшениці озимої добривом для стимуляції росту та розвитку зернових культур БіоЗерн, регулятору росту МедаксТоп, мікродобрива Turbo та $MgSO_4$ у посівах пшениці озимої в умовах Київській області, ТОВ «Біотех ЛТД». Обробка насіння БіоЗерн у поєднанні з препаратами МедаксТоп+Турбо+$MgSO_4$ забезпечило врожайність на рівні 9,0 т/га при 6,8 т/га на контролі. Підвищення врожайності за застосування стимуляторів росту рослин (СРР) та мікродобрив склало від 1,34 т/га до 2,2 т/га. Застосування СРР в поєднанні із $MgSO_4$ сприяло покращенню показників росту і розвитку рослин. Встановлено збільшення на 8-10 % кількості рослин у посівах, більш як на 20 % кількості продуктивних стебел на одиниці площі та коефіцієнту кущіння відповідно. Застосування СРР також суттєво покращило основні показники, які характеризують продуктивність колоса пшениці. Збільшилась кількість колосків, кількість зерен, вага зерен колосу досліджуваної культури та маса зерна в колосі. Ріст склав від 25 до 50 % відносно контролю. Важливим практичним результатом дослідження є покращення більшості показників, які характеризують якість продукції. Окрім збільшення величини маси 1000 зерен, зросла натура зерна з 737 г/л на контрольному варіанті до 763-766 г/л на варіантах внесення СРР. При однаковому значенні скловидності на усіх варіантах, СРР дещо знизили вміст білку в зерні з 15,6 % на контролі до 14,0-14,2 % на варіантах внесення СРР. Отримані результати доводять високу ефективність застосування обробки насіння пшениці озимої препаратом БіоЗерн, внесення регулятору росту МедаксТоп, мікродобрива Turbo та $MgSO_4$ у посівах культури в умовах Київській області і можуть бути рекомендовані при її вирощуванні

Ключові слова: регулятори росту рослин; якість зерна; біометричні показники росту; врожайність; продуктивність