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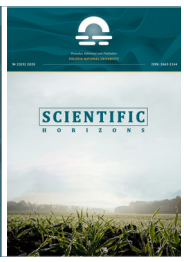

Assessment of the adaptability of winter rye hybrids for cultivation in the Forest-Steppe zone of Ukraine

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Abstract. The aim of the study was to substantiate the ecological and adaptive performance of modern winter rye hybrids for their use under different cultivation systems in the Forest-Steppe zone of Ukraine. The methodology combined field phenological and biometric observations, phytosanitary assessments, yield determination, and statistical analysis of variation parameters, ecological plasticity and stability based on the Eberhart-Russell model modified by Finlay-Wilkinson. The response of nine hybrids to contrasting abiotic factors was examined, and differences in the rate of spring vegetation recovery, formation of stem biomass and yield structure were identified. The level of winter hardiness and drought tolerance was analysed, demonstrating the ability of hybrids to maintain productivity under snow-deficient winters and uneven precipitation distribution. High ecological plasticity (bi = 0.93-1.02) and stability (S^2di = 0.09-0.14) of the leading genotypes were revealed, confirming their universality across diverse agroclimatic conditions. It was established that SU Futturi, KWS Vinetto, KWS Tayo and SU Arvid achieved yields of 8.4-9.6 t/ha, minimised leaf-area losses during hydrothermal stress and exhibited strong resistance to major diseases. It was generalised that the introduction of these hybrids enhanced the resource efficiency of production technologies, reduced agrochemical pressure and supported the formation of ecologically resilient agroecosystems. The practical value of the study lies in identifying hybrids suitable for both conventional and organic farming systems, with the results being applicable to agricultural producers, advisory services and breeding centres when optimising varietal policy and implementing environmentally oriented cultivation strategies

Keywords: ecological plasticity; yield stability; biometric traits; winter hardiness; hydrothermal stress; phytosanitary resistance

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INTRODUCTION

Contemporary challenges in agricultural production, driven by climatic variability, soil degradation and the growing demand for high-quality grain, have necessitated the adoption of crops capable of ensuring stable yields across a wide range of agro-ecological conditions. Winter rye, as a crop characterised by high adaptability and low resource requirements, occupies an important place in sustainable farming systems, while the use of its hybrid forms has gained strategic relevance for resource conservation and yield enhancement in regions exposed to elevated drought risk. The increasing interest in hybrid rye is associated with its ability to maintain productivity under conditions that are critical for other cereals, as well as with its potential to reduce agrochemical and energy pressures on the environment.

An analysis of recent studies indicates that winter rye as a crop, and its hybrid forms in particular, has attracted considerable attention among both Ukrainian and international researchers. The study by L. Biliavska and Y. Biliavskyi (2021) highlighted the important role of winter rye in Ukraine, although the issues of adaptability and efficiency of the newest hybrids remain insufficiently explored within specific soil-climatic zones. Research on the long-term soil and biological consequences of rye cultivation, conducted by V. Bogužas *et al.* (2022), demonstrated that the crop positively influenced soil structural quality, CO_2 emissions and the biodiversity of soil mesofauna, supporting the view of rye as a soil-protective species.

A significant contribution to the study of hybrid productivity and yield stability was made in the work of B. Hackauf *et al.* (2022), which showed that hybrid rye exhibits substantially lower yield variability and outperforms population cultivars under limited moisture availability. Similar conclusions were reached by S. Hadasch *et al.* (2020), who noted that yield stability in hybrids persisted even under adverse meteorological conditions. The issue of breeding progress was addressed in the study by F. Laidig *et al.* (2021), where it was emphasised that increases in rye productivity have been accompanied by improved disease resistance and reduced need for intensive technological operations. The environmental dimension constitutes an important component of current research. According to the analytical report External sustainability study confirms the excellent CO_2 balance of KWS hybrid rye (2023), hybrid rye demonstrates one of the lowest carbon footprints among cereals due to its reduced nitrogen fertiliser requirement and efficient biomass utilisation. These findings correspond with the conclusions of L. Riedesel *et al.* (2022), who stressed that new breeding lines of rye are characterised by reduced carbon emissions per unit of production and enhanced photosynthetic efficiency. In the Ukrainian scientific context, attention has been directed towards assessing varietal resources and their agro-ecological relevance. Thus, V. Sabluk *et al.* (2018) analysed the available domestic cultivars and identified promising directions for breeding activity, although the issue of hybridisation was addressed only superficially. The study by N. Symonenko *et al.* (2023) focused on technological aspects of winter rye cultivation; however, the authors did not examine the influence of hybrids on soil properties, energy efficiency or agro-ecological pressure. The issue of spatio-temporal variability in rye yield in Ukraine was investigated by A. Zymaroieva and Y. Nykytiuk (2023), who concluded that climatic instability increases the relevance of hybrid forms, yet calls for more detailed regional assessments. An important dimension is the interdisciplinary examination of rye within crop rotation systems. The research by M. Smith *et al.* (2023) demonstrated that greater crop diversity in rotations, including the incorporation of rye, enhances agroecosystem resilience and contributes to long-term increases in cereal yields. This finding aligns with broader trends towards ecologically oriented farming systems in which hybrid rye forms may play a pivotal role.

Thus, modern research emphasises the considerable potential of winter hybrid rye as a highly productive and ecologically efficient crop. At the same time, key questions remain insufficiently explored, including the adaptability of hybrids under diverse soil-climatic conditions of the Forest-Steppe of Ukraine, their influence on soil ecological status, the energy efficiency of cultivation technologies and opportunities for optimising agronomic practices from a resource-conservation perspective. The aim of the present study was to substantiate the adaptive characteristics of winter rye hybrids and determine their potential for introducing environmentally safe and resource-efficient cultivation technologies in the Forest-Steppe zone of Ukraine.

MATERIALS AND METHODS

A comprehensive study of productivity formation, growth and developmental characteristics, adaptive properties and competitive ability of modern winter rye hybrids was initiated in 2024 at the "Levor" Farming Enterprise, located in the Zhytomyr district of Zhytomyr region. The experimental sites were situated on typical chernozem soils. Nine winter rye (*Secale cereale* L.) hybrids of different breeding origins were selected for the experimental work, representing KWS Group (KWS Tayo, KWS Eterno, KWS Vinetto), Saaten-Union GmbH (SU Arvid, SU Baresi, SU Futturi) and DSV AG (Astranos, Stannos, Helltop). These hybrids were chosen for a comprehensive assessment of their adaptability, yield stability and ecological efficiency under the conditions of the Forest-Steppe zone of Ukraine (Fig. 1). All hybrids were listed in the State Register of Plant Varieties Suitable for Distribution in Ukraine (2024).

Figure 1. *Comprehensive assessment of adaptive traits and productivity formation in modern winter rye hybrids, 2025*
Source: *authors' photographs*

The experiment was established according to standard field-trial methodologies using the method of systematic replications. The trial design involved a comparison of modern winter rye hybrids under two cultivation systems: conventional production (with the application of mineral fertilisers and plant-protection products) and organic production (without chemical inputs, with the use of organic fertilisers and adherence to the principles of ecological farming). Both variants ensured comparable growing conditions and enabled the assessment of differences between technological systems. The size of each accounting plot was 25 m², and the experiment was conducted with four replications. The arrangement of treatments was sequential (Fig. 2).

Figure 2. *Experimental plots of winter rye hybrids, 2024-2025*
Source: *authors' photographs*

A comprehensive set of observations and measurements was carried out during the experiment. Phenological observations were performed to determine the duration of growth and developmental phases according to the BBCH scale. Biometric measurements were conducted on a sample of 20 plants in each replication, recording plant height, number of productive stems, ear length, grain weight per ear and leaf area index. Phytosanitary monitoring was performed at BBCH stages 37-75, assessing infection by powdery mildew, brown rust and snow mould using a nine-point scale in accordance with EPPO guidelines. Winter hardiness was evaluated by examining the stands after snowmelt and determining the proportion of surviving plants and the viability of tillering nodes. Drought tolerance was assessed based on the preservation of leaf area, productive tillering and changes in yield during periods of hydrothermal deficit. Agrochemical and soil analyses included measurements of soil acidity, nutrient content and agronomically valuable soil structure. Yield analysis involved harvesting the entire area of each accounting plot followed by recalculation to tonnes per hectare at standard grain moisture.

Assessment of the hybrids' adaptive properties was based on the analysis of yield variation parameters. The coefficient of variation (CV, %) was calculated as the ratio of standard deviation to the mean yield. Ecological plasticity (bi) and the stability coefficient (S^2di) were determined using the Eberhart-Russell model modified by Finlay-Wilkinson, enabling evaluation of the genotypes' response intensity to environmental changes and their capacity to maintain productivity across contrasting years. Statistical calculations were conducted using MS Excel and R 4.3.0. The weather conditions during 2024-2025 were analysed using data from the Zhytomyr meteorological station of the Ukrainian Hydrometeorological Centre. Mean monthly temperatures, precipitation amounts, the hydrothermal coefficient, the duration of snow-free periods and abnormal temperature events affecting plant growth and

development were taken into account. The obtained climatic data were used to interpret the hybrids' responses to weather fluctuations and to determine their ecological adaptability. Additional statistical information on temperature anomalies, precipitation levels and hydrothermal parameters was obtained from the official datasets of the State Statistics Service of Ukraine (n.d.).

To systematise the key indicators of adaptability, an integrated model was employed, comprising three blocks: the biological potential of the hybrids, agritechnological conditions and environmental factors. This approach enabled a comprehensive assessment of the interaction between genotype, cultivation technology and climatic influences, and made it possible to determine the ecological reliability of winter rye hybrids under the conditions of the Forest-Steppe zone. The authors adhered to 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

Adaptability represents one of the key characteristics of modern winter rye cultivars and hybrids, determining their capacity to maintain stable yield levels under variable environmental conditions. In the context of climate change and the increasing frequency of extreme weather events – such as droughts, sharp temperature fluctuations and excessive precipitation – indicators of ecological plasticity and stability acquire particular importance. The phenological analysis revealed differences in the duration of major growth and developmental phases among the hybrids. KWS Tayo, SU Arvid and Astranos were characterised by faster spring vegetation recovery and earlier transition to stem elongation, which promoted the formation of a more productive stem biomass. In contrast, KWS Eterno and Helltop exhibited a slightly prolonged initial vegetative period, enabling more efficient uptake of soil nutrients but delaying the formation of reproductive organs. These phenological distinctions shaped the hybrids' subsequent responses to weather conditions and influenced their level of ecological plasticity.

Winter rye hybrids demonstrated enhanced tolerance to abiotic stresses – primarily drought and low temperatures – owing to their well-developed root systems, more efficient use of water and nitrogen, and the ability to rapidly resume growth after winter dormancy. These traits improve the crop's adaptation to the conditions of the Forest-Steppe, where significant variability in climatic indicators occurs throughout the growing season. Recent research confirms that modern hybrids developed by leading breeding companies (KWS, Saaten-Union and others) exhibit higher yield stability compared with conventional cultivars, a pattern attributed to heterosis effects and improved resource-use efficiency (Table 1).

***Table 1**. Characteristics of winter rye hybrids*

Hybrid name	Breeding company	Year of registration in Ukraine	Yield potential, t/ha	Drought tolerance (1-9 points)	Lodging resistance (1-9 points)	Disease resistance (1-9 points)
KWS Tayo	KWS Group	2021	8.5-10.2	7-9	4-5	powdery mildew 8; brown rust 7-8; snow mould 8-9
KWS Eterno	KWS Group	2017	7.0-8.7	8-9	7-9	powdery mildew 9; snow mould 9
KWS Vinetto	KWS Group	2019	8.0-9.5	8	8	powdery mildew 8; snow mould 9
SU Arvid	Saaten-Union GmbH	2021	8.4-8.9	8-9	7	powdery mildew 8; brown rust 8; snow mould 9
SU Baresi	Saaten-Union GmbH	2023	8.7-9.0	7-9	7	powdery mildew 8; brown rust 8; snow mould 9
SU Futturi	Saaten-Union GmbH	2023	7.2-8.8	7-8	8-9	powdery mildew 9; brown rust 8; snow mould 9
Astranos	DSV AG	2022	7.0-8.5	7-9	6	powdery mildew 8-9; brown rust 5-9; snow mould 9
Stannos	DSV AG	2021	8.3-8.8	8	7-8	powdery mildew 9; brown rust 8; snow mould 9
Helltop	DSV AG	2012	8.5-9.1	7-8	8	powdery mildew 8-9

***Source:** compiled by the authors based on the State Register of Plant Varieties Suitable for Distribution in Ukraine (2024)*

The phytosanitary assessment demonstrated a consistently low level of infection by major spike and leaf diseases. The highest resistance to powdery mildew was recorded in SU Arvid, SU Futturi and KWS Vinetto, where infection intensity did not exceed 1-2 points. Symptoms of brown rust were observed

mainly in Astranos and Stannos, although they remained within biologically acceptable limits. Resistance to snow mould was high in all hybrids, confirming their suitability for conditions characterised by insufficient snow cover during the winter of 2024-2025. To obtain a comprehensive characterisation of ecological plasticity and stability of winter rye hybrids in the Forest-Steppe zone of Ukraine, an analysis of key adaptability indicators was undertaken based on field results and relevant literature sources. Determining yield level, variation parameters and ecological response coefficients made it possible to objectively assess the ability of genotypes to maintain productivity under diverse environmental conditions.

One of the important criteria is the coefficient of yield variation, which characterises the stability of crop productivity in years with contrasting weather conditions. The indicator of ecological plasticity (bi) reflects the intensity of a hybrid's response to changes in growing conditions: values of bi ≈ 1 indicate a universal genotype, bi > 1 indicate the ability to express a high yield potential under favourable conditions, whereas bi < 1 indicate enhanced tolerance to stress factors. The stability coefficient (S^2di) and drought tolerance level serve as additional criteria for determining the ecological reliability of the crop. The comparison of the two cultivation systems revealed substantial differences in the realisation of the hybrids' adaptive potential. Under conventional technology, a slightly higher yield level was achieved – on average by 0.3-0.6 t/ha – due to consistent nutrient supply and more effective disease control. At the same time, under organic production conditions, SU Futturi, KWS Vinetto and SU Arvid stood out by maintaining high stability and exhibiting minimal yield losses in the absence of mineral nutrition. This indicates that these genotypes are capable of effectively realising their inherent biological potential and adapting to environmentally constrained production systems.

The summarised data on productivity, variation characteristics and ecological response for the most common modern winter rye hybrids used in production or recommended for implementation in the Forest-Steppe zone of Ukraine are presented in Table 2. The obtained indicators make it possible to trace differences among genotypes in terms of adaptive potential, yield stability and their capacity to maintain consistent productivity under diverse agroclimatic conditions.

***Table 2**. Main adaptability indicators of winter rye hybrids*

Hybrid	Mean yield, t/ha	Yield variation coefficient, %	Plasticity (bi)	Stability (S^2di)	Drought tolerance, %
KWS Tayo	9.3	9.5	1.02	0.12	78
KWS Vinetto	8.7	8.0	0.97	0.09	82
SU Futturi	9.6	7.8	1.00	0.11	80
Astranos	8.4	11.2	0.93	0.14	75

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

The analysis of the data presented in Table 2 indicated that the examined winter rye hybrids were characterised by a high level of adaptability and yield stability under the conditions of the Forest-Steppe zone of Ukraine. The mean yield ranged from 9.3 t/ha (KWS Tayo) to 9.6 t/ha (SU Futturi), confirming the high genetic potential of modern hybrids and their ability to utilise environmental resources efficiently. According to the coefficient of yield variation (7.8-11.2%), all hybrids demonstrated relatively high productivity stability under different growing conditions. The lowest coefficients of variation were recorded for SU Futturi (7.8%) and KWS Vinetto (8.0%), which indicated their tolerance to fluctuations in hydrothermal conditions and their ability to maintain high yield levels even in years with stress-related weather events.

The ecological plasticity values (bi = 0.93-1.02) showed that most hybrids were universal in their response to environmental variation. Specifically, KWS Tayo (bi = 1.02) demonstrated slightly increased sensitivity to favourable growing conditions, whereas Astranos (bi = 0.93) exhibited greater tolerance to stress factors, maintaining relatively stable yields in less favourable years. Drought tolerance, determined from an integrated assessment of physiological and yield-related indicators, varied within the range of 75-82%, reflecting the strong ecological adaptation of the hybrids to the hydrothermal fluctuations characteristic of the Forest-Steppe. Particular attention should be given to KWS Vinetto and SU Futturi, which combined high yield, stability and enhanced drought tolerance, making them promising candidates for wider implementation under conditions of climate change. Winter survival assessment showed high winter hardiness across most hybrids, despite the deficit of snow cover during the winter of 2024-2025. The best survival rates after winter were observed in KWS Vinetto, SU Arvid and SU Futturi, where the proportion of surviving plants exceeded 90%. Astranos and Stannos displayed minor losses associated with sharp temperature fluctuations in January; however, these did not significantly affect final yield levels. The high degree of winter hardiness confirmed the genetic suitability of the hybrids for the Forest-Steppe environment.

Winter rye is known for its ability to adapt to diverse soil and climatic conditions, which underpins its

stable productivity even under extreme environmental factors. The adaptive mechanisms of the crop comprise a complex of morphological, physiological–biochemical and agro-ecological traits that ensure its competitive capacity among cereal species. Morphological traits – particularly a well-developed root system penetrating to depths of 1.5-2 m and high tillering capacity – enable more efficient utilisation of soil moisture and nutrients. Physiological mechanisms of adaptation include high photosynthetic activity at lower temperatures and the ability to use light energy efficiently, both of which contribute to increased tolerance to drought and temperature fluctuations.

Biometric observations revealed significant differences among the hybrids in plant height, the number of productive stems and spike parameters. The highest stem productivity was formed by KWS Tayo and SU Futturi, in which the number of productive stems exceeded the average level by 12-18%. The leaf area index at the stem-elongation stage was highest in KWS Eterno and KWS Vinetto, which ensured greater photosynthetic activity and more efficient light use during the early spring period. Astranos and Helltop were characterised by a more compact spike and a higher thousand-grain weight, which partially compensated for their lower density of productive stems. Biochemical mechanisms included the accumulation of soluble sugars in the tillering node, which played a key role in winter hardiness and in the energy supply required for regrowth in spring. Adaptive-ecological traits were reflected in high tolerance to soil acidity, strong competitiveness against weeds and the ability to form yields even on poor or low-fertility soils. The combination of these mechanisms formed the ecological resilience of winter rye hybrids and determined their suitability for cultivation in the Forest-Steppe zone of Ukraine.

The weather conditions of 2024-2025 had a pronounced influence on the realisation of adaptive traits. The deficit of snow cover during winter and periodic frosts enabled the identification of genotypes with high frost and winter tolerance, whereas spring over-moistening partially constrained the development of hybrids with lower root activity. In the summer months, short periods of intense heat and the absence of rainfall in the second half of the growing season revealed the adaptive advantages of KWS Vinetto, SU Futturi and KWS Tayo, which maintained high turgor and experienced minimal loss of productive leaf area. This enabled the formation of stable yield levels both under optimal and stress conditions. Winter rye also demonstrated higher competitiveness against weeds owing to its rapid early growth, vigorous root system and high stand density. These attributes made the crop a valuable component of ecologically sustainable crop rotations, particularly on soils with elevated acidity or low nutrient availability. Thus, winter rye, based on the entirety of its adaptive characteristics, emerged as the most environmentally resilient crop among those studied, suitable for cultivation under continental climate conditions and increased ecological variability.

The obtained results on the adaptability of modern winter rye hybrids were consistent with findings reported in recent international studies. The established yield stability and the ability of hybrids to sustain development under fluctuating temperature and moisture conditions supported the conclusion regarding the high ecological plasticity of the crop, as identified in the study by M. Pasqui and E. Di Giuseppe (2019). Their work indicated that the rising frequency of extreme weather events in Europe increased the demand for crops capable of adapting to heat and water stress. The winter hardiness and tolerance to hydrothermal fluctuations recorded in the field experiment reflected the patterns described by the authors. Yield stability under organic farming conditions also aligned with the results presented by Th. Miedaner *et al.* (2025), where hybrid rye demonstrated higher productivity stability than wheat under reduced agronomic inputs and moisture deficits. In the present experiment, a comparable response was characteristic of SU Futturi, KWS Vinetto and SU Arvid, which maintained high yield levels under resource-limited conditions, confirming the universal adaptive potential of the crop.

In the study by M.K. Kostrzewska and M. Jastrzębska (2025), it was demonstrated that rye hybrids were able to realise their yield potential even under continuous cultivation and minimal application of plant protection products. The high competitiveness against weeds and disease pathogens described in their research corresponded closely with the results of the present phytosanitary monitoring. The limited manifestation of powdery mildew, brown rust and snow mould confirmed the strong immunological potential of the hybrids, aligning with adaptability characteristics reported in the literature. The consistency of the results with contemporary views on evolutionary-genetic mechanisms of adaptation was further supported by the conclusions of W.Y. Yang and C.X. Ma (2024). Their study indicated that a deep root system, increased tillering capacity and the ability to rapidly resume vegetation were key traits underlying the ecological resilience of rye. The morphological and physiological features recorded in the experiment confirmed these adaptation mechanisms and explained the stability of productivity under Forest-Steppe conditions.

The results obtained under Ukrainian soil-climatic conditions were also consistent with the findings of O.V. Topchii *et al.* (2024), who reported that new winter rye cultivars were able to maintain high yield levels on soils with increased acidity and irregular precipitation patterns. In the present experiment, similar patterns manifested themselves in the stability of plant stand density and in the hybrids' response to soil acidity. The interpretation of the results also matched the

conclusions of A. Zymaroieva and Y. Nykytiuk (2023), who identified the leading role of agro-ecological factors – soil acidity, precipitation structure and hydrothermal regime – in determining rye yield. Within the conducted study, these factors likewise governed productivity variation, confirming their systemic influence. The conceptual propositions regarding the advantages of hybridisation, presented in the work of E.M.S. ter Steeg *et al.* (2022), were also in agreement with the findings. Their research emphasised that hybrid forms demonstrated greater yield stability under stress conditions, which was corroborated by the low coefficients of variation and high ecological plasticity observed in SU Futturi, KWS Tayo and KWS Vinetto. Overall, the concordance of the obtained results with modern studies confirmed that the adaptability of winter rye hybrids was determined by a combination of morphological, physiological and ecological mechanisms, together with genetically defined advantages of hybridisation, which collectively ensured yield stability under conditions of climatic variability.

CONCLUSIONS

The conducted study established that modern winter rye hybrids were characterised by a high level of ecological adaptability and the capacity to maintain stable productivity under the contrasting hydrothermal conditions of the Forest-Steppe zone of Ukraine. The analysis of phenological, biometric and phytosanitary indicators demonstrated that SU Futturi, KWS Vinetto, KWS Tayo and SU Arvid exhibited more efficient spring regrowth, high plant survival after winter and minimal loss of leaf area during periods of summer heat stress. The yield of the examined hybrids ranged from 8.4 to 9.6 t/ha, confirming the high genetic potential of the crop. The values of the coefficient of variation (7.8-11.2%) indicated yield stability even in years with significant weather fluctuations. The ecological plasticity index (bi = 0.93-1.02) reflected the universal response of most hybrids to environmental change, while stability parameters (S^2di = 0.09-0.14) outlined their capacity to sustain productivity under stress factors.

Drought-tolerance assessment showed that KWS Vinetto and SU Futturi displayed the highest levels of tolerance (up to 82%), giving them an advantage under moisture-deficit conditions. Phytosanitary observations indicated low infection levels of powdery mildew, brown rust and snow mould in most hybrids, demonstrating strong immunological potential and meeting the requirements of environmentally oriented production systems. Biometric traits – such as a well-developed root system, optimal density of productive stems and high grain weight per ear – formed a yield structure resilient to climatic and soil constraints. The integrated evaluation of hybrid performance confirmed that the examined material was suitable for cultivation in the Forest-Steppe zone, ensuring high efficiency of water and nutrient use, reduced agrochemical pressure and stable yield formation. The obtained data identified SU Futturi and KWS Vinetto as the most promising hybrids for implementation in both conventional and organic farming systems. The study confirmed that hybrid winter rye could play a key role in forming ecologically sustainable agroecosystems in the Forest-Steppe, contributing to a reduction in the carbon footprint of production and to improved resource efficiency of cultivation technologies. Future research should focus on refining technological elements of hybrid cultivation, assessing their carbon and water balances, and determining the long-term dynamics of adaptability under conditions of climatic variability.

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Оцінка адаптивності гібридів жита озимого для вирощування в умовах Лісостепу України

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Анотація. Метою дослідження було обґрунтувати екологічну та адаптивну результативність сучасних гібридів жита озимого для використання у різних технологічних системах вирощування Лісостепу України. Методологія роботи поєднувала польові фенологічні та біометричні спостереження, фітосанітарні оцінки, визначення продуктивності та статистичний аналіз параметрів варіації, пластичності й стабільності за моделлю Еберхарта-Рассела у модифікації Finlay-Wilkinson. Було досліджено реакцію дев'яти гібридів на контрастні абіотичні чинники, встановлено відмінності у темпах весняного відновлення вегетації, формуванні стеблової маси та структурі врожаю. Було проаналізовано рівень зимостійкості та посухотолерантності, що забезпечили здатність гібридів підтримувати продуктивність у роки з дефіцитом снігового покриву та нерівномірним розподілом опадів. Було виявлено високу екологічну пластичність (bi = 0,93-1,02) та стабільність (S^2di = 0,09-0,14) провідних генотипів, що підтверджує їхню універсальність за різних агрокліматичних умов. Було встановлено, що гібриди SU Futturi, KWS Vinetto, KWS Tayo та SU Arvid забезпечували врожайність 8,4-9,6 т/га, мінімізували втрати листкової поверхні у періоди гідротермічного стресу й характеризувалися високою стійкістю до основних хвороб. Було узагальнено, що впровадження цих гібридів сприяє підвищенню ресурсоефективності технологій, зменшенню агрохімічного навантаження та формуванню екологічно стійких агроекосистем. Практична цінність роботи полягає у визначенні гібридів, придатних для впровадження у традиційні та органічні системи землеробства, а результати можуть бути використані агровиробниками, консультантами та селекційними центрами під час оптимізації сортової політики та впровадження екологічно орієнтованих технологій

Ключові слова: екологічна пластичність; стабільність продуктивності; біометричні показники; зимостійкість; гідротермічний стрес; фітосанітарна стійкість