

INCREASE IN WINTER BARLEY GRAIN PRODUCTION BY GROWING AT OPTIMAL SOWING DATES IN THE WESTERN FOREST-STEPPE OF UKRAINE

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Topicality. In Ukraine, the leading branch of agriculture is grain production. In the modern grain crop market, winter barley occupies one of the important places in the country's grain balance. A sustainable and uninterrupted production of high-quality grain products at low cost ensures the development of a reliable and powerful foundation for meeting the needs of the population. **Purpose.** To study and evaluate individual elements of cultivation technology, in particular to specify the sowing dates for different varieties of winter barley for the Western Forest-Steppe of Ukraine under field trial conditions, assuming the favourable effectiveness of the proposed methods, which provides for the achievement of guaranteed and stable high-quality grain yields. **Materials and methods.** The research was carried out in the fields of the Ternopil State Agricultural Research Station of the Institute of Agriculture in the Carpathian Region of NAAS of Ukraine in 2016–2024. In the experiments, the following winter barley varieties were sown: Burevii, Deviatyi val, Tutankhamon, Paladin Myronivskiyi, Valkiriia, MIP Status. Sowing was carried out in four dates: 15 and 25 September and 5 and 15 October. Field trials were set up and conducted in accordance with generally accepted research methodology (field, laboratory, comparative and analytical methods). **Results.** The main factors influenced on the formation of winter barley yield were systematised and identified. The optimal sowing dates in the context of climate change were determined experimentally. The dependence of the protein content in winter barley grain on the sowing date was established. The results of the research showed that sowing winter barley at the most optimal dates, namely 15–25 September, ensured higher yields (5.75 and 5.81 t/ha) compared to October (5.24 and 4.92 t/ha). It was found that the highest yield of all varieties was obtained in 2024, which was favourable in terms of weather conditions (6.43 t/ha), and the lowest in the dry year 2020 (3.73 t/ha). The protein content increased from the earliest to the latest sowing date: from 12.3 to 12.6 %. In years with different weather conditions, regardless of sowing dates, the highest quality indicators were recorded in 2019 (14.0 %), and the lowest in 2024 (10.4 %). **Conclusions.** The highest winter barley yield of 5.75; 5.81 t/ha was achieved by sowing at the optimal dates for the growing region (15 and 25 September), ensuring the profitability and return on investment of grain production in variable soil and climatic conditions and organisational and economic conditions of management.

Key words: weather conditions, variety, impact factor, sowing date, yield, protein content, economic efficiency.

Introduction. Winter barley (*Hordeum vulgare* L.) is one of the earliest ripening grain crops, characterised by high yield and valuable feed properties. This crop ripens 9–14 days earlier than winter wheat and 12–16 days earlier than spring barley, which reduces load during the harvest period and enables the successful cultivation of many post-harvest crops [1]. Winter barley is recommended for cultivation in 14 regions of Ukraine. However, most of its acreage is located in the southern part of the

country. The main reason for this is the low winter hardiness and frost resistance of barley varieties [2]. Numerous research suggests that thinning of crops of this type is most often caused by winterkilling. According to Academician A. A. Linchevskiyi, losses of winter barley yield from frost-killing are more significant than losses from diseases, pests and weeds combined [3].

Long-term research has established that the critical temperature at the depth of the tilling node for most winter barley varieties is

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-10 to -15 °C, which is 4–5 °C higher than the critical temperature for winter wheat. In recent years, according to data from the agrometeorological station located on the territory of the TSAES of Institute of Agriculture in the Carpathian region of NAAS, this indicator has not fallen below -7– -8 °C. Thus, climate change contributes to the successful overwintering of winter barley and the expansion of its sowing area. Compared to winter wheat, barley plants are characterised by slow hardening at above-zero and below-zero temperatures, which is explained by the physiological characteristics of this crop. As a result of intensive growth in autumn and relatively active life at temperatures close to 0 °C, winter barley plants accumulate few soluble carbohydrates and lose them quite quickly during overwintering. Therefore, the yield

of this crop largely depends on overwintering.

In the context of significant climate change, due to the value of winter barley, its acreage began to grow rapidly. A number of Western European countries have almost completely switched to autumn sowing. The main reason for the spread of winter barley acreage was its high yield. In Ukraine, the crop occupied 300,000 hectares in 2000. By 2021, winter barley acreage had increased significantly, reaching 1.3 million hectares, but after 2022, due to Russia's occupation of part of Ukraine's territory, acreage began to decline again, reaching 760,000 hectares in 2023 and 506,000 hectares in 2024 [4].

According to data from the Ministry of Agrarian Policy, Ukrainian farmers sowed 49.6 % less barley in 2024 than in the pre-war year of 2021 [5] (Fig.1).

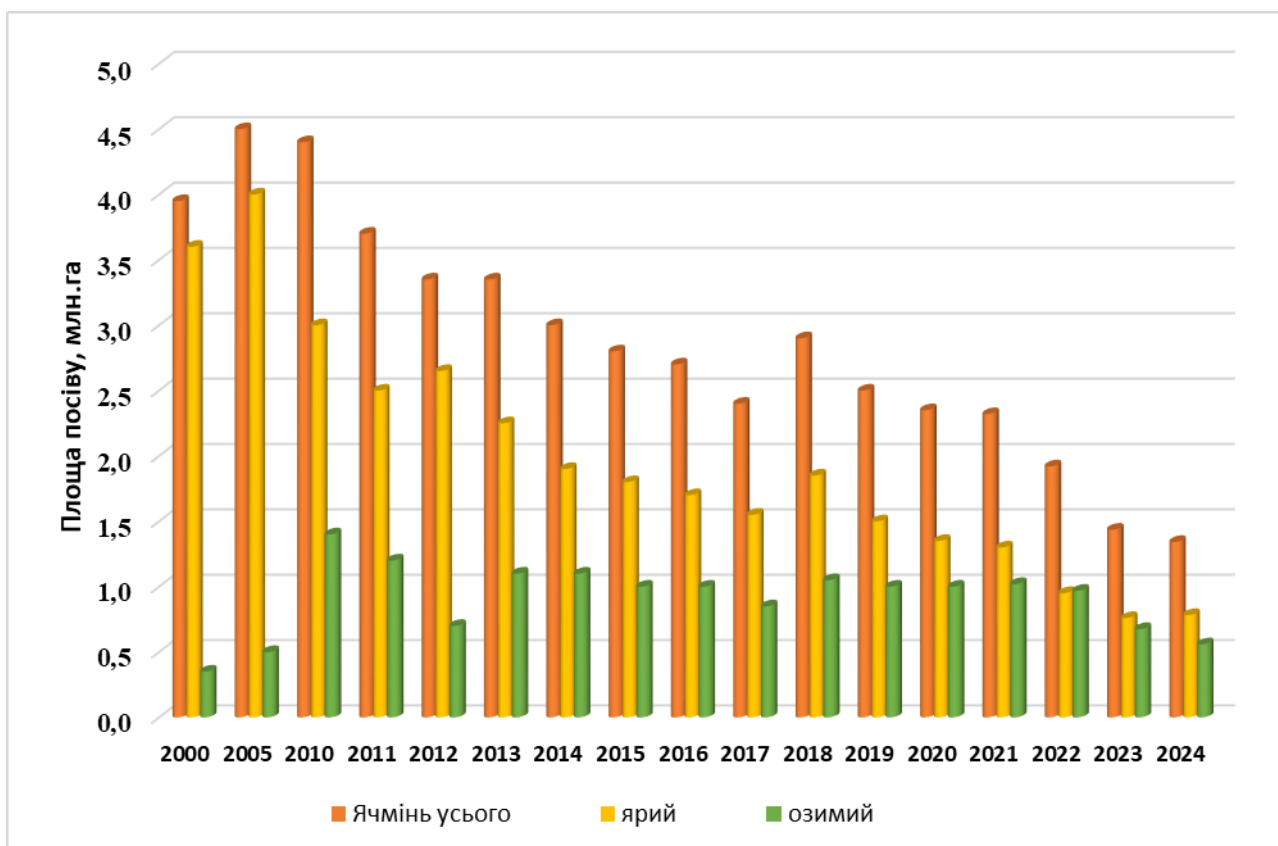


Fig. 1. Dynamics of barley sowing area in Ukraine, thousand hectares, 2000–2024.

Starting in 2022, under the influence of wartime challenges and their consequences, a significant reduction in acreage is expected, primarily due to restrictions on export logistics. However, the barley market is quite narrow, and Europe is not a target buyer for this crop. Our country usually exported barley to China, and without the grain corridor (maritime grain ship-

ments from Ukraine), selling barley through the former sales channels will be impossible under the current circumstances. Therefore, barley is focused on domestic consumption and, in limited quantities, on neighbouring countries.

According to the analysis of its yield, on average for this period, spring barley yield ranged from 1.91 to 3.53 t/ha, and winter barley

yield ranged from 2.05 to 4.37 t/ha, which indicates a positive trend in productivity growth.

Undoubtedly, crop productivity is primarily influenced by weather conditions and cultivation technology, as evidenced by the average winter barley yield in Ukraine in 2024, which

was 4.34 t/ha, while in agricultural enterprises it was 4.70 t/ha. Thanks to more favourable weather conditions, a particularly high yield of 6.0–6.5 t/ha was recorded in the western regions of Ukraine [6, 7] (Fig. 2).

We should not forget about weather con-

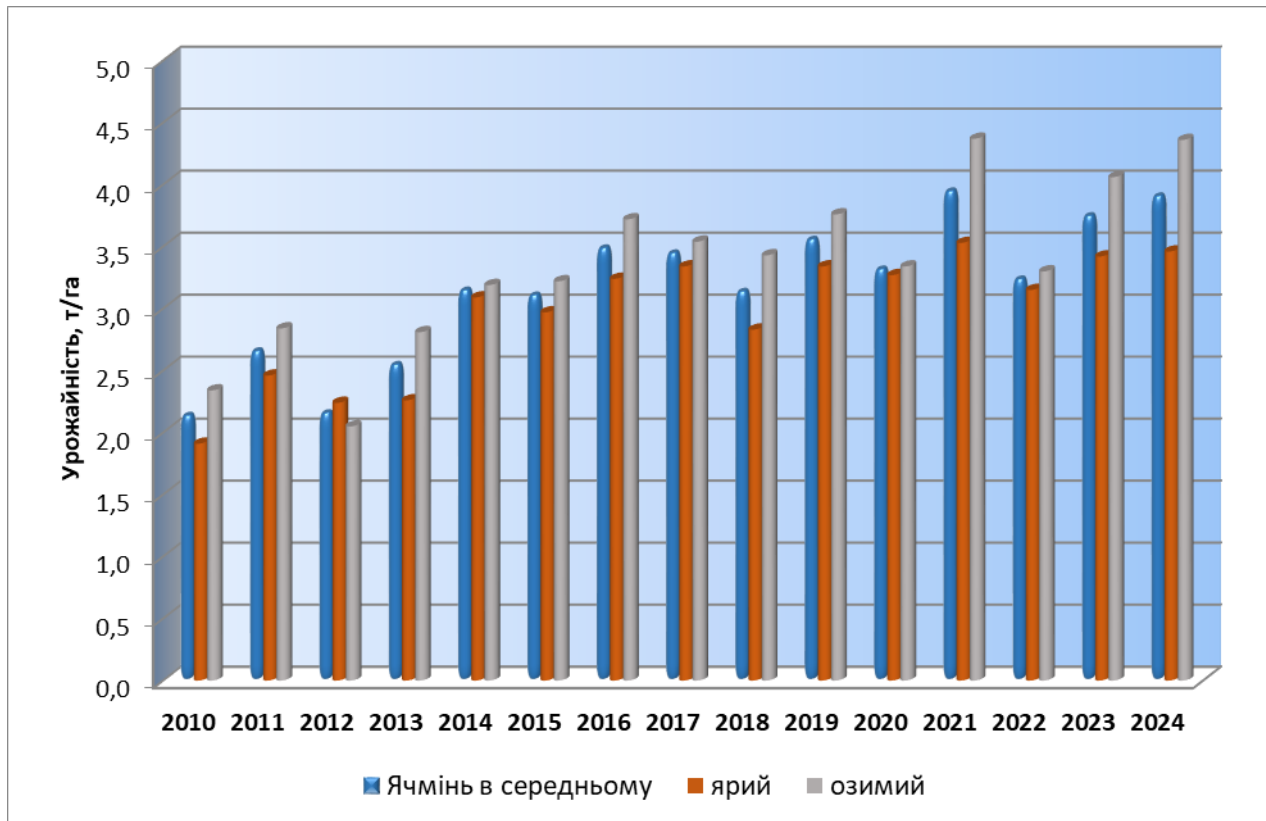


Fig. 2. Dynamics of barley yield in Ukraine, t/ha, 2010–2024.

ditions, which are often unfavourable, and therefore, in addition to the ability to form high productivity, barley plants must demonstrate high resistance to adverse factors [8]. This necessitates the targeted selection of agricultural techniques that would enhance, or at least not diminish, the natural adaptive properties of modern winter barley varieties. In any cultivation technology, great attention is paid to sowing dates, which directly affect not only the quantity and quality of the harvest, but also the formation of plant resistance to many unfavourable factors [9–11]. On the one hand, plants sown early are more susceptible to pathogens and pests, and their most productive main shoots are more often damaged, while on the other hand, crops sown late are mostly underdeveloped, poorly branched, more susceptible to mechanical damage during overwintering, and are more severely affected by dry winds in spring and summer [12]. Sowing at the optimal dates should ensure

that winter barley plants pass through the stages of organogenesis in the autumn period, on which the level of vital activity of the agrobiocenosis and its productivity subsequently depend.

Materials and Methods. The research was conducted during 2016–2024. Six winter barley varieties adapted to the Western Forest-Steppe zone of Ukraine were studied: Valkiriia, Burevii, Deviatyi Val (originator: Plant Breeding and Genetics Institute – National Centre of Seed and Cultivar Investigation); MIP Status, Paladin Myronivskiy, Tutankhamon (originator – the V. M. Remeslo Myronivka Institute of Wheat of NAAS), which were sown in four dates: 15 and 25 September and 5 and 15 October (Table 1).

The soil of the experimental plots was deep, low-humus chernozem with a medium loamy texture. The humus content was 3.55 %, and the pH was 5.6. Hydrolytic acidity was 2.21 mg-eq/100 g of dry soil; low soil availability of alkaline-hydrolysed nitrogen was 126.0 mg/kg

Table 1. Varietal composition of winter barley by year of research

Years under study	Variety
2016–2020	Tutankhamon
	Deviaty Val
2020–2023	Burevii
	Paladin Myronivskiy
2024	Valkiriia
	MIP Status

of soil (according to the Kornfield method); sulphur – 2.3 %, very low; elevated phosphorus content – 123.0 mg/100 g air-dry soil and elevated potassium content – 92.0 mg/100 g air-dry soil (according to the Chirikov method).

Repetition – three times. Sowing area of the plot was 28.05 m² (17 m × 1.65 m), registration area – 25.0 m² (15.15 m × 1.65 m). The order of placement of plots and repetitions were single-tier, sequential. A complete mineral fertiliser N₃₀P₃₀K₃₀ (nitroammophoska) was introduced into the soil for pre-sowing cultivation. Winter barley plants were fed with nitrogen fertiliser in the form of ammonium nitrate (N – 34.4 %): early spring feeding (N₃₀ kg a.i./ha) – on frozen-thawed soil, local feeding (N₃₀ kg a.i./ha) – at the end of the tillering stage. The seeds were treated with Avitsenna (0.5 l/t) + Commandor Extra (0.6 l/t) formulations. Sowing was carried out using an SN-16 seeder, with a seeding rate of 5 million germinated seeds per hectare.

The cultivation technology for winter barley was generally accepted for the Western Forest-Steppe zone of Ukraine. The predecessor was annual grasses. Investigations and related analyses of soil and plant material were carried out using recommended methodologies: easily hydrolysable nitrogen was analysed using the Tyurin-Kononova method, mobile forms of phosphorus and potassium – using the Chirikov method, humus content – using the Tyurin method, and pH – using the TsINAO method (GOST 26483–85); field germination, plant density in autumn, plant survivability during winter, and plant density before harvesting were determined on fixed plots with an area of 0.25 m² in four places diagonally across the plot, totalling 1 m²; sheaves were selected one to two days before harvesting from an area of 0.25 m² in four locations on the plot. Structural analysis of the harvest was carried out in accordance with the ‘Methodology for State Variety Testing

of Agricultural Crops’; the 1000-seed weight was determined in accordance with DSTU 4138-2002; the total nitrogen/protein content in the grain was determined using the Kjeldahl method; harvest calculation – by the method of threshing winter barley plots with a Sampo 500 combine harvester, followed by grain cleaning and recalculation to 100 % purity and 14 % moisture content; mathematical analysis of field trial results was performed using a program for analysis of variance and correlation-regression analysis in accordance with the methodology of V. O. Yeshchenko ‘Fundamentals of Scientific Research in Agronomy’ [13] and using the Statistica 5.0 software program; economic analysis was based on the application of generally accepted methods for evaluating technology in terms of yield, production cost per unit of output, profitability per hectare of sown area, and profitability level [14].

Study and evaluate individual elements of cultivation technology, in particular, clarify the sowing dates for different varieties of winter barley for the Western Forest-Steppe zone of Ukraine in field experiment conditions under favourable conditions for the proposed methods, which provides for guaranteed and stable yields of high-quality grain, were the main objectives of the work.

Results and Discussion. Significant attention is being paid to increasing the yield of winter barley in order to solve the problem of increasing and stabilising grain production in Ukraine, as this crop, together with spring barley, is strategically important and ranks second after winter wheat in terms of sowing area. It is common knowledge that climate warming requires adaptation of agricultural production and improvement of agrotechnical practices for crop cultivation. These conditions should be taken into account when determining such an important agrotechnical practice as the sowing date. This technique does not require any addi-

tional costs, and the correct date for the sowing campaign lays the foundation for successful overwintering and high crop productivity. Agrometeorological conditions during the observation period were characterised by only slight deviations from the long-term average in terms of precipitation, temperature regime, and their distribution during the growing season, with a

tendency towards growth. No particularly extreme conditions that would significantly affect the productivity of winter barley were observed.

According to the results of studies conducted between 2016 and 2024, it was found that the winter barley yield significantly depended on the sowing dates (Table 2).

The highest productivity was observed in

Table 2. Winter barley yield depending on sowing dates, t/ha

Year	Sowing date			
	15 September	25 September	5 October	15 October
2016	4.96	5.42	3.69	3.14
2017	5.47	5.54	5.19	4.66
2018	6.56	6.82	5.63	5.50
2019	6.02	5.91	5.76	5.55
2020	4.02	3.81	3.37	3.73
2021	6.10	6.40	6.14	5.60
2022	6.27	5.66	5.13	4.55
2023	6.10	6.05	5.52	5.29
2024	6.29	6.72	6.73	6.26
Average for years	5.75	5.81	5.24	4.92

variants with sowing dates in September, regardless of the year of research. The maximum yield – 5.75–5.81 t/ha, on average for all varieties, was recorded for sowing on 15 September and 25 September, slightly lower – for sowing on 5 October – 5.24 t/ha, and the lowest – 4.92 t/ha – for sowing on 15 October. According to the data, a delay in sowing beyond 25 September leads to a decrease in yield by 0.57–0.89 t/ha.

According to annual yield analysis, the highest results for all winter barley varieties were obtained in 2024 (6.50 t/ha) due to the formation of the main components of plant productivity and yield attributes. A warm winter, very early (1 February) resumption of vegetation, and a long period with average daily air temperatures between 5 and 10 °C, which lasted more than two months, contributed to the intensive tillering of late-sown plants of winter barley. These conditions have positively influenced such a structural indicator of yield as the productive stem density, which has hardly decreased in late-sown crops. Grain formation and filling also took place mainly under favourable agrometeorological conditions, which ultimately had a direct impact on the formation of winter barley grain yield.

The lowest yield (3.73 t/ha) was obtained in the dry year of 2020. Weather conditions were again a complicating factor: a long dry pe-

riod in autumn, which made it impossible to accumulate sufficient moisture in the soil, an abnormally snowless and warm winter, and a dry and warm spring.

According to research results, the yield potential of barley varieties (7–10.5 t/ha) is utilised on average by 30–50 %, decreasing in some years and periods to 24–26 %, which indicates the importance of further improving barley cultivation technology. Therefore, in the context of climate change, the adaptability of a variety to unfavourable conditions becomes one of its most important characteristics.

Today, the focus is not only on increasing the winter barley yield, but also on improving its grain quality – the complex of biological, physical, chemical and technological characteristics of the grain, which is influenced by the chosen cultivation technology. Among the factors that play a decisive role in the formation of barley grain quality are soil and climatic conditions, variety, and agrotechnical practices. The latter two factors are most human-controllable.

Based on the average indicators for nine years, the protein content in winter barley grain did not significantly depend on the sowing date, but tended to increase with a later sowing date: from 12.0 % for sowing on 25 September to 12.6 % for sowing on 15 October (Table 3).

In general, if the tendency of protein con-

Table 3. Protein content in winter barley grain depending on sowing dates, %

Year	Sowing date			
	15 September	25 September	5 October	15 October
2016	10.9	9.9	11.8	12.9
2017	13.4	12.3	12.2	12.3
2018	13.9	13.1	12.5	13.0
2019	14.2	14.1	14.0	13.7
2020	10.2	10.4	10.8	10.9
2021	12.1	11.5	12.0	12.3
2022	13.6	13.3	14.1	14.4
2023	12.5	12.7	12.9	13.0
2024	9.9	10.3	10.6	10.7
Average for years	12.3	12.0	12.3	12.6

Protein content change over nine years can be explained by varietal characteristics and the selection of new varieties that are more adaptable to local conditions, then individual decreases (for example, compare quality indicators in 2016, 2020, 2024) can only be explained by weather conditions and the response of plants to agroclimatic factors. Indeed, the winter barley varieties included in the study are declared by their originators as being intended for grain production, with a potential yield of 7–10.5 t/ha and a protein content of 12–14.5 %.

However, in some years, the decrease in protein content in winter barley grain has attracted the interest of brewers in this grain for use in brewing production. Very high protein content (over 13 %) in grain makes it unsuitable for brewing due to the deterioration of beer taste and reduction in yield. Good brewing barley must contain 9–10 % protein.

As is well known, grain yield and quality are strongly negatively correlated. In particular, the formation of the protein complex is significantly influenced by unregulated factors such as weather conditions during the grain filling and ripening period, precipitation, air

temperature and humidity, and solar radiation intensity.

The results of our research have shown a noticeable influence of weather conditions on the quality of winter barley varieties in different years under study. For example, the lowest protein content over nine years of research was observed in 2016 and 2024 (especially noticeable for crops sown in September) and in 2020, when the temperature regime was reduced during the grain formation and filling period, in combination with cloudy weather.

According to the correlation analysis between average yield and protein content in grain during the research period, depending on the sowing dates, it was found that the protein content increases when the yield of winter barley decreases. The correlation coefficient obtained ($r = -0.854$) confirms the inverse proportional relationship between winter barley yield per unit area and protein content in grain.

Based on the results of experimental data on winter barley cultivation, we conducted an economic analysis by comparing the results of crop production depending on the sowing dates (Table 4).

Table 4. Economic efficiency of winter barley cultivation depending on sowing dates, 2016–2023

Sowing date	Average yield, t/ha	Production costs, UAH/ha	Self-cost, UAH/t	Revenue from sales, UAH/ha	Conditional net profit, UAH/ha	Profitability, %
15 September	5.75	13,975	2,449	25,984	12,120	91.7
25 September	5.81	13,975	2,480	26,302	12,395	93.0
05 October	5.24	13,909	2,721	23,845	10,112	73.6
15 October	4.92	13,858	2,873	22,541	8,794	64.5

According to research results, the sowing dates for winter barley largely determined the

economic indicators of its cultivation. The lowest self-cost of 1 tonne of grain – at 2,449–2,480 UAH – was obtained when the barley was sown on 15 and 25 September, compared to 2,721 UAH when the barley was sown on 5 October and 2,873 UAH when the barley was sown on 15 October. Sowing in September also yielded the highest conditional net profit per hectare, which amounted to 12,120–12,395 UAH/ha, with a profitability level of 91.7–93.0 %. For sowing in October, the conditional net profit was significantly lower and ranged from 8,794 to 10,112 UAH/ha, with a profitability level of 65.4–73.6 %. According to these data, late (October) sowing dates were less economically advantageous because they were accompanied by a decrease in yield, which in turn affected the level of efficiency indicators.

Conclusions. The results of the studies showed that the highest yield – 5.75; 5.81 t/ha – was achieved by winter barley varieties sown at the optimal dates for the growing area – 15 and 25 September, respectively. When sowing is delayed beyond 25 September, the crop responds with a decrease in yield of 0.57 and 0.89 t/ha. It

was found that the maximum realisation (12.6 %) of the varietal indicators of protein content in the grain of the winter barley varieties studied is achieved by sowing on 15 October. The correlation coefficient ($r = -0.854$) confirmed the inverse proportional relationship between yield per unit area and protein content in grain.

After analysing the economic indicators of winter barley cultivation, on average for 2016–2024, we found that sowing on 25 September is the most economically effective decision. Sowing of winter barley in October leads to a significant decrease in net profit and profitability compared to September. In order to increase winter barley production in the Western Forest-Steppe zone, the most promising approach is to improve cultivation technologies, taking into account the variety composition, sowing dates, and agrotechnical practices. For the purpose of increasing the profitability and return on investment of grain production, the standardisation of production costs for their optimisation in variable soil and climatic and organisational and economic conditions of farming is of great importance.

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Актуальність. В Україні провідною галуззю сільського господарства є виробництво зерна. На сучасному ринку зернових культур ячмінь озимий займає одне з важливих місць в зерновому балансі країни. Створення надійної, потужної бази вирощування зерна для населення і кормів для тварин можливо лише на основі сталого, безперебійного надходження зернової продукції з високою якістю і низькою собівартістю. **Мета.** Вивчити та оцінити окремі елементи технології, зокрема уточнити строки сівби різних сортів ячменю озимого для зони Західного Лісостепу України в умовах польового експерименту за сприятливої ефективності запропонованих прийомів, що передбачає отримання гарантованих і сталих рівнів урожайності зерна високої якості. **Матеріали та методи.** Дослідження виконували у 2016–2024 рр. на полях Тернопільської державної сільськогосподарської дослідної станції ІСГ Карпатського регіону НААН. У дослідях висівали сорти ячменю озимого – Буревій, Дев’ятий вал, Тутанхамон, Паладін Миронівський, Валькірія, МПП Статус. Сівбу проводили в 4 строки: 15, 25 вересня та 5, 15 жовтня. Закладку і ведення польових дослідів здійснювали відповідно до загальноприйнятих методик дослідної справи. Методи: польовий, лабораторний, порівняльно-аналітичний. **Результати.** Систематизовано та виділено основні фактори впливу на формування врожаю ячменю озимого. Експериментально визначено оптимальні строки сівби в контексті зміни клімату. Встановлено залежність вмісту білка в зерні ячменю озимого від строку сівби. За результатами досліджень встановлено, що сівба ячменю озимого в найбільш оптимальні строки, а саме 15–25 вересня забезпечувала формування вищої врожайності (5,75 і 5,81 т/га), порівняно з жовтневими (5,24 і 4,92 т/га). Виявлено, що більшу врожайність усіх сортів було отримано в сприятливому, за погодними умовами, 2024 р. (6,43 т/га), найменшу – в посушливому 2020 р. (3,73 т/га). Вміст білка в зерні зростав від найбільш раннього до пізнього строку сівби: з 12,3 до 12,6%. У різні за погодними умовами, роки, незалежно від строків сівби, найвищі показники якості урожаю сформовано у 2019 р. (14,0%), найнижчі – у 2024 р. (10,4%). **Висновки.** Найвищу урожайність на рівні 5,75; 5,81 т/га формували сорти ячменю озимого за сівби в оптимальні, для зони вирощування, строки – 15 та 25 вересня, забезпечуючи прибутковість та окупність зерновиробництва у змінних ґрунтово-кліматичних та організаційно-економічних умовах господарювання.

Ключові слова: *погодні умови, сорт, фактор впливу, строк сівби, урожайність, вміст білка, економічна ефективність*