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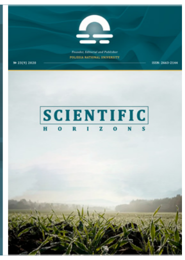

Evaluation of growth and development of barley plants of phenotype with three formed shoots at the end of the tillering phenophase at different sowing dates

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Abstract. The purpose of this study was to substantiate the optimal combination of agroecological resources of the Western Forest-Steppe of Ukraine and the biological potential of spring barley productivity in cultivation technology. The organised research was aimed at analysing the state of growth and development of spring barley plants on the example of the phenotype with three formed shoots at the end of the tillering phenophase, depending on the influence of environmental conditions at different sowing dates. To describe and summarise the experimental data, the study employed the method of establishing the significance of the difference in sample means by the t-criterion (difference analysis) was used. As a result of the study of barley growth and development, on the example of the analysis of the phenotype of plants with three formed shoots at the end of the tillering process, a pattern of gradual decrease in the realisation of the biological potential of shoots was obtained when the sowing dates were shifted by 10 days starting from the first sowing date – March 10. The maximum values of the growth and development of shoots of plants of this phenotype were obtained as a result of ensuring the sowing process on March 10 at the earliest. According to the order of the biological sequence of formation of the first, second, and third shoots, the indicators were for crude biomass – 4.2 g, 3.2 g, 2.2 g; dry matter content – 0.77 g, 0.58 g, 0.43 g, leaf surface area – 37.9 cm^2, 34.8 cm^2, and 30.9 cm^2. According to the analysis of the factual material obtained as a result of an organised experiment of growing plants in abiotic conditions at different sowing dates, the process of modifying the influence on the morphogenesis of barley shoots was established. The best results of intensification of spring barley tillering according to the parameters of the established data of shoot development on the example of the indicated plant phenotype were obtained under environmental conditions at early sowing dates. From a practical standpoint, the use of favourable environmental resources at early sowing dates in ensuring consistently high grain yields of spring barley crops continues to be an underutilised reserve in cultivation technology

Keywords: spring barley; abiotic conditions; biomass; leaf surface area; t-criterion; biological potential

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INTRODUCTION

Due to changes in agroclimatic resources in the Western Forest-Steppe of Ukraine, it has become relevant to investigate the growth and development of early spring cereals, including barley, at different sowing dates to improve cultivation technologies. Global barley grain production depends on yields under weather conditions and is characterised by data within 140-160 million tonnes per year. In the 2023-2024 season, it is estimated at around 144 million tonnes, which is down 5.6% year-on-year, according to experts. These results were influenced by lower yields and, accordingly, production volumes in several European countries and some regions of the African continent due to deteriorating weather conditions. Ukraine is a considerable influence on the global grain market, where the agricultural sector is essential for the global food balance. Ukraine produces approximately 7-10 million tonnes of barley annually, depending on weather conditions, growing technologies and global market conditions, and maintains its status as a leading barley producer in the world. Ukraine ranks 3rd in the global barley shipment ranking. Ukraine can produce up to 2.0 million tonnes of malting barley, of which the internal market can sell 0.9-1.0 million tonnes under favourable economic conditions.

The global climate change that has taken place in recent decades has markedly affected crop cultivation. Climate change in Ukraine is a part of global climate change, and it has its specific regional features, both as factors affecting barley grain production and the yield of all grain crops overall (van der Wiel & Bintanja, 2021; Appiah *et al.*, 2023). Barley is one of the oldest cultivated plants, with a history of cultivation spanning thousands of years (Lukinac & Jukić, 2022; Kaur *et al.,* 2024). It began to be cultivated 10-12 thousand years ago, along with other cereals, including wheat. Barley came to Europe in prehistoric times through the Balkans. It is known on Ukrainian lands according to the Tripoli culture of the 3-4 millennium BC. S. Tatsu *et al.* (2020) noted that barley is one of the leading crops used for the production of feed, beer, food, etc. Today, it continues to be one of the key crops in Ukraine's exports. D. Rico *et al.* (2020) argued that compliance with the requirements of cultivation technology will ensure stable and high barley yields.

Barley requirements for temperature conditions. Barley seeds begin to germinate at a temperature of 1-2°C. However, under such conditions, the germination process is very slow and is mostly directed towards the root system. At a temperature of 4°C, seed hatching takes 5 to 7 days, at 10°C – 3 days, and at 16-19°C – 1-2 days. Accordingly, the sowing-germination period depends on the soil temperature regime, as well as on the biological and physiological quality of the seeds. The hotter the temperature, the earlier the seedlings appear on the soil surface. However, the most favourable temperature at the beginning of barley development is 10-15°C, which is slightly lower than the optimal parameters of seed germination, which are 20-23°C. R. Shivhare *et al.* (2020) noted that hot temperature accelerates plant development by shortening the duration of the tillering phase, which leads to a decrease in barley ear productivity.

Barley requirements for moisture supply. Barley seeds germinate when water is absorbed in an amount equal to half of their weight (Springer & Mornhinweg, 2019). This is somewhat less than is required for wheat, rye, and oats, which reflects the xerophilicity of barley. With sufficient moisture supply, barley seeds swell in 24 hours, while with insufficient moisture supply, this process takes longer. The water requirement of barley plants is constantly increasing from germination to earing, with the maximum amount occurring between the beginning of the tube and the onset of earing. Moisture deficit during grain filling leads to a loss of optimal kernel weight parameters, which definitely reduces the yield level. The accumulation of starch in the grain decreases, the protein content increases, and the uniformity and size of the grain decreases.

Barley grain production in Ukraine can increase due to modernisation of agricultural technology, investments in modern machinery, use of precision farming systems, improvement of technological methods, and logistics approaches in the growing process to adapt to climate change, creation, and introduction of new varieties resistant to disease and drought, will help to increase and stabilise spring barley grain yields. The purpose of this study was to assess the state of growth and development of spring barley plants at the end of the tillering phenophase depending on the influence of environmental conditions at different sowing dates to ensure adaptation to climate change, the cultivation technology, and maximum use of the agro-ecological resource of the Western Forest-Steppe of Ukraine.

MATERIALS AND METHODS

The study included the phenotype of spring barley plants of the Sebastian variety with three formed shoots in terms of growth and development at the end of the tillering process. The influence factor is abiotic environmental conditions at five different sowing dates, 10 days after the first one on 10 March. The experimental studies were conducted in 2018-2020 at the Podilskyi State University, in the soil and climatic conditions of the Western Forest-Steppe of Ukraine. The key determining factors of soil fertility in the experimental plots included the provision of barley plants with the necessary nutrients for growth and development. The soil of the experimental plots was podzolised medium loamy, structured, with a humus content of 3.2%, pH parameters were close to neutral, hydrolytic acidity and the amount of absorbed bases per 100 g of soil were

0.56-0.62 mg-eq and 32-36 mg-eq, respectively. The presence of macro- and microelements per 1 kg of soil was as follows: alkaline-hydrolysed nitrogen – 100 mg, mobile phosphorus – 176 mg, exchangeable potassium – 160 mg.

Formal characteristics of the field experiment: row spacing of 15 cm, depth of seed placement during sowing 2-3 cm, seeding rate of 250 germinating seeds/m^2. The homogeneity of the used seeds by grain weight was within 48-52 mg. The area of the accounting plots was 20 m^2, the number of replications was 4 times. The following indicators were determined: crude plant biomass by weighing on the FEH-600L balance, dry matter mass by thermogravimetric method, leaf surface area by the method of notches (Hrytsaenko *et al.,* 2003). For the mathematical analysis of the obtained research results, the Student's t-test was applied to determine the dependence of spring barley shoots crude biomass, dry matter content, and leaf surface area on the influence of sowing dates (Yeshchenko *et al.,* 2014). The conducted study did not violate the basic standards and protocols following the Convention on Biological Diversity (1992) adopted at the Earth Summit in Rio de Janeiro, as well as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

In the presented study results, the analysis included indicators of crude biomass of shoots, dry matter content, and leaf surface area. Crude biomass is a physiological indicator that characterises the intensity of photosynthesis, transpiration, and the efficiency of solar energy use. The dry matter content (DMC) of plants is an indicator that characterises their productivity and efficiency of using environmental resources. In the analysis of the efficiency of crop cultivation technologies, DMC characterises the state of plant development and reflects the accumulation of organic substances, which are products of photosynthesis. A high DMC obtained at different stages of plant development during cultivation reflects intensive growth and development of the crop. Controlling the dry matter content provides a reasonable opportunity to adapt the agricultural technology to the conditions of the region where crop production is performed.

The key aspect of the analysis of leaf area was the assessment of photosynthetic activity. The leaf surface is the principal organ of photosynthesis. The larger the leaf area, the more solar energy the plant can absorb for the synthesis of organic matter. Monitoring the leaf area at different stages of the growing season provides objective information on plant growth rates and their condition, which is an essential element in modern research to ensure the development of spring barley cultivation technology. The analysis of spring barley shoot biomass data at the end of the tillering process, i.e., at the beginning of the fourth stage of organogenesis, revealed that with each 10-day delay in sowing date, starting from the first one on March 10, the shoot biomass steadily decreased (Table 1).

***Table 1**. Evaluation of spring barley growth and development at the end of tillering process at different sowing dates based on the analysis of the phenotype of plants with three formed shoots (2018)*

Indicator	Sowing period				
	first	second	third	fourth	fifth
First shoot					
Crude biomass, g	3.88 ± 0.11	3.45 ± 0.12	3.04 ± 0.10	2.65 ± 0.13	2.33 ± 0.06
Dry matter content, g	0.77 ± 0.017	0.61 ± 0.015	0.51 ± 0.012	0.41 ± 0.010	0.32 ± 0.016
Leaf surface area, cm^2	34.18 ± 0.81	31.82 ± 0.77	29.71 ± 0.67	27.31 ± 0.55	23.25 ± 0.65
Second shoot					
Crude biomass, g	2.89 ± 0.10	2.59 ± 0.09	2.36 ± 0.07	1.92 ± 0.08	1.70 ± 0.06
Dry matter content, g	0.58 ± 0.013	0.46 ± 0.014	0.38 ± 0.016	0.29 ± 0.007	0.24 ± 0.012
Leaf surface area, cm^2	32.84 ± 0.69	30.04 ± 0.70	27.76 ± 0.53	24.75 ± 0.77	21.55 ± 0.79
Third shoot					
Crude biomass, g	2.11 ± 0.08	1.85 ± 0.10	1.53 ± 0.09	1.23 ± 0.07	1.00 ± 0.08
Dry matter content, g	0.41 ± 0.018	0.32 ± 0.017	0.26 ± 0.011	0.19 ± 0.014	0.15 ± 0.013
Leaf surface area, cm^2	28.07 ± 0.32	26.07 ± 0.81	24.05 ± 0.50	22.08 ± 0.83	18.64 ± 0.86

***Source:** compiled by the authors of this study based on the research results*

Specifically, the difference in the biomass of plants of the first shoot when comparing the data obtained at the first and second sowing dates was 0.43 g, which is statistically significant (t_f - 2.65 > $t_{0.05}$ - 2.009). When comparing the data of shoot biomass at the second and third sowing dates, the difference of 0.41 g was also significant (t_f - 2.62 > $t_{0.05}$ - 2.009). The difference in the biomass of the first shoot of spring barley at the third and fourth sowing dates of 0.39 g was statistically significant (t_f - 2.37 > $t_{0.05}$ - 2.009). And when comparing the obtained data on the biomass of the first shoot at the fourth and fifth sowing dates, the difference of 0.32 g is statistically significant (t_f - 2.23 > $t_{0.05}$ - 2.009). Thus, with each delay of spring barley sowing by 10 days after the first one on March 10, the biomass of the first shoot at the end of the vegetative state of development significantly decreased. The obtained indicators of dry matter of the first shoot under analogous comparison options also indicate that with each subsequent sowing date, the established indicators were significantly lower. Comparison of the data obtained during the first and second sowing periods was characterised by a statistically significant difference in the dry matter content of the shoots, which was 0.16 g (t_f - 7.07 > $t_{0.05}$ - 2.009). When comparing the data obtained at the second and third sowing dates, the difference of 0.10 g was also significant (t_f - 5.20 > $t_{0.05}$ - 2.009). Additionally, the dry matter content of the shoot at the fourth sowing date was significantly lower by 0.10 g compared to the data at the third sowing date (t_f - 6.41 > $t_{0.05}$ - 2.009). When sowing in the fifth term, the indicator was 0.32 g, which was significantly less by 0.09 g compared to the data for the fourth sowing term, statistical criterion t_f - 4.78 > $t_{0.05}$ - 2.009.

The following is an analysis of the data on leaf area using an analogous comparison format. When comparing the area of the first shoot according to the data obtained during sowing on 10 March, the value was greater and amounted to 34.18 cm^2 and on 20 March, where the value was lower – 31.82 cm^2, the difference of 2.36 cm^2 was significant (t_f - 2.11 > $t_{0.05}$ - 2.009). When analysing the results obtained during the second and third sowing periods, it was found that the leaf surface area of the shoot in the third period was significantly less by 2.11 cm^2 (t_f - 2.06 > $t_{0.05}$ - 2.009). When analysing the data obtained at the third and fourth sowing dates, the leaf surface area of the shoot at the fourth date was significantly lower by 2.40 cm^2, as evidenced by statistical analysis (t_f - 2.77 > $t_{0.05}$ - 2.009). The smallest leaf surface area for the biological development of the first shoot was at the fifth sowing date – 23.25 cm^2. Comparison with the same indicator obtained at the fourth sowing date showed a significant difference in data at the level of 4.06 cm^2, where the value t_f was 4.77 > $t_{0.05}$ - 2.009.

The following is an assessment of the growth and development of the second shoot of spring barley plants depending on the sowing date at the end of the third stage of organogenesis. The biomass of the shoot at the first sowing date was 2.89 g, and at the second sowing date 10 days after the first – 2.59 g. The difference in the comparison was significant and amounted to 0.30 g (t_f - 2.23 > $t_{0.05}$ - 2.009). The biomass of the second shoot at the third sowing term of 2.36 g compared to the index obtained at the second sowing term was 0.23 g less, the difference was statistically significant (t_f - 2.02 > $t_{0.05}$ - 2.009). When barley was grown under the conditions of the fourth sowing term, the biomass of the shoot was even lower and amounted to 1.92 g. Compared to the results of the analysis at the third sowing date, the difference of 0.44 g was statistically significant (t_f - 4.15 > $t_{0.05}$ - 2.009). And under the conditions of the fifth sowing term, the biomass of the second shoot of 1.70 g was significantly lower than the biomass of the shoot when sown in the fourth term. The difference of 0.22 g was statistically significant (t_f - 2.20 > $t_{0.05}$ - 2.009).

The analysis of the data on the dry matter content of the second shoot of spring barley at the end of the vegetative state of plant development under conditions of five different sowing dates shows that when comparing the data obtained at the first and second sowing dates, the differences were 0.12 g, which were driven by substantially lower values obtained at the second sowing date (t_f - 6.28 > $t_{0.05}$ - 2.009). In the third sowing term, the value of 0.38 g provided a statistically significant difference of 0.08 g compared to the results obtained in the second sowing term (t_f - 3.77 > $t_{0.05}$ - 2.009). Comparison of the data obtained under the conditions of the fourth and third sowing terms characterised statistically significant differences in the parameters of indicators with a lower value when sowing in the fourth term, the difference was 0.09 g (t_f - 5.17 > $t_{0.05}$ - 2.009). Under the conditions of the fifth sowing term, the dry matter content was the lowest at 0.24 g, which is 0.05 g less than the value obtained during the fourth sowing term, but the difference was statistically significant (t_f - 3.62 > $t_{0.05}$ - 2.009).

According to the study results, it was found that with each 10-day delay in sowing dates, starting from the first one on 10 March, the leaf surface area of the second shoot by the degree of development at the end of the vegetative state of plants became smaller. Specifically, the indicators according to the first, second, third, fourth, and fifth sowing dates were 32.84 cm^2, 30.04 cm^2, 27.76 cm^2, 24.75 cm^2 and 21.55 cm^2. The difference of 2.80 cm^2 between the first and second indicators was significant (t_f - 2.85 > $t_{0.05}$ - 2.009). When comparing the second and third indices, the difference of 2.28 cm^2 was also statistically significant, i.e., the leaf surface area of the second shoot at the third sowing date became smaller (t_f - 2.59 > $t_{0.05}$ - 2.009). At the fourth sowing term, the index became even smaller, the differences compared to the data obtained under the conditions of the third sowing term of 3.01 cm^2 were statistically significant (t_f - 3.22 > $t_{0.05}$ - 2.009). And at the fifth sowing date, the established value of the leaf surface area of the shoot was 21.55 cm^2 was the smallest. The difference in comparison with the data obtained under the conditions of the fourth sowing date of 3.20 cm^2 was significant (t_f - 2.90 > $t_{0.05}$ - 2.009).

The development of the third shoot of spring barley plants, depending on the conditions of sowing time, was analogous to the established pattern, both in relation to the first and second shoots. At the first sowing date, the biomass of the shoot was 2.11 g, at the second – 1.85 g, which was 0.26 g less, the difference was statistically significant t_f - 2.03 > $t_{0.05}$ - 2.009.

Under the conditions of the third sowing term, the indicator of 1.53 g was significantly lower by 0.32 g compared to the data obtained during the second sowing term (t_f - 2.38 > $t_{0.05}$ - 2.009). The index of shoot biomass at sowing in the fourth term was 0.30 g less compared to the data for the third sowing term, the difference was significant (t_f - 2.63 > $t_{0.05}$ - 2.009). The conditions of spring barley cultivation at the fifth sowing term provided a shoot biomass of 1.00 g. The difference of 0.23 g compared to the data obtained at the fourth sowing term was statistically significant (t_f - 2.16 > $t_{0.05}$ - 2.009).

Based on the analysis of the data on the development of the third shoot of spring barley in terms of dry matter content, it was found that in the first sowing period the index was the highest at 0.41 g. Under the conditions of the second sowing term, it decreased by 0.09 g, where the value of the indicator was at the level of 0.32 g. The difference was significant based on statistical calculation (t_f - 3.64 > $t_{0.05}$ - 2.009). The conditions of the third sowing term led to a further decrease in the accumulation of dry matter content by the shoot. The established value at the level of 0.26 g was lower than the value of the indicator obtained under the conditions of the second sowing term. The difference of 0.06 g was significant (t_f - 2.97 > $t_{0.05}$ - 2.009). When barley was sown in the fourth term, the accumulation of dry matter by the shoot decreased by 0.07 g compared to the results obtained in the third term of sowing. The difference was statistically significant at the established criterion t_f - 3.93 > $t_{0.05}$ - 2.009. Under the conditions of the fifth sowing date, the dry matter content of the third shoot was the lowest and amounted to 0.15 g. Compared to the data obtained under the conditions of the fourth sowing term, the difference of 0.04 g was statistically significant (t_f - 2.09 > $t_{0.05}$ - 2.009).

When analysing the leaf surface area of the third shoot of spring barley plants under growing conditions at sowing on 10 March, an indicator of 28.07 cm^2 was obtained, and upon sowing on 20 March it significantly decreased by 2.0 cm^2 (t_f - 2.29 > $t_{0.05}$ - 2.009). The development of the shoot at the third sowing date was characterised by a value of 24.05 cm^2, which was significantly less than the value of 26.07 cm^2 obtained under the conditions of the second sowing date. The difference in the comparison data was 2.02 cm^2, which was statistically significant (t_f - 2.12 > $t_{0.05}$ - 2.009). The leaf surface area of the shoot under the conditions of the fourth sowing term at 22.08 cm^2 was 1.97 cm^2 smaller than the leaf surface area of the shoot when grown under the conditions of the third term. The differences in the indicators were statistically significant, the factual value of the Student's t-test was greater than the theoretical one (t_f - 2.03 > $t_{0.05}$ - 2.009). The environmental conditions of the fifth sowing term provided the smallest size of the leaf surface area of the shoot – 18.64 cm^2. The indicator was 3.44 cm^2 smaller than the data for barley cultivation under the conditions of the fourth sowing term, the difference was statistically significant (t_f - 2.87 > $t_{0.05}$ - 2.009).

The results of the study in 2019 are presented in Table 2. The biomass of the first shoot during sowing in the first term was 3.81 g and was 0.41 g greater than the results of the second sowing term, the difference was significant (t_f - 2.50 > $t_{0.05}$ - 2.009). Under the conditions of the second sowing term, the indicator was 3.40 g, which was 0.42 g greater than the value of the indicator obtained under the conditions of the third sowing term in terms of statistical significance (t_f - 2.65 > $t_{0.05}$ - 2.009). The development of spring barley during sowing in the third term provided a biomass of the first shoot of 2.98 g, which was naturally statistically higher compared to the value of the same indicator obtained in the fourth term (t_f - 3.28 > $t_{0.05}$ - 2.009). The parameter of the shoot index at the fourth sowing term of 2.54 g was greater than the index of 2.13 g obtained at the fifth sowing term, the differences in the data were statistically significant (t_f - 2.77 > $t_{0.05}$ - 2.009).

***Table 2**. Evaluation of spring barley growth and development at the end of tillering process at different sowing dates based on the analysis of the phenotype of plants with three formed shoots (2019)*

Indicator	Sowing period				
	first	second	third	fourth	fifth
First shoot					
Crude biomass, g	3.81 ± 0.10	3.40 ± 0.13	2.98 ± 0.09	2.54 ± 0.10	2.13 ± 0.11
Dry matter content, g	0.75 ± 0.016	0.59 ± 0.025	0.48 ± 0.019	0.39 ± 0.015	0.29 ± 0.018
Leaf surface area, cm^2	38.28 ± 0.64	35.51 ± 0.87	33.25 ± 0.70	28.67 ± 0.91	22.93 ± 0.75
Second shoot					
Crude biomass, g	2.79 ± 0.11	2.45 ± 0.12	2.13 ± 0.10	1.80 ± 0.09	1.51 ± 0.11
Dry matter content, g	0.57 ± 0.014	0.45 ± 0.021	0.35 ± 0.024	0.27 ± 0.019	0.20 ± 0.020
Leaf surface area, cm^2	34.11 ± 0.72	31.54 ± 0.81	28.78 ± 0.82	21.07 ± 0.79	16.85 ± 0.80
Third shoot					
Crude biomass, g	2.10 ± 0.08	1.79 ± 0.10	1.43 ± 0.11	1.13 ± 0.07	0.84 ± 0.12
Dry matter content, g	0.47 ± 0.025	0.34 ± 0.022	0.24 ± 0.025	0.16 ± 0.015	0.10 ± 0.016
Leaf surface area, cm^2	29.94 ± 0.67	27.07 ± 0.71	23.20 ± 0.83	18.03 ± 0.70	15.00 ± 0.73

***Source:** developed by the authors of this study based on the research results*

The following is a characteristic of the dry matter content of spring barley shoots at the end of the vegetative stage of plant development. The parameter of the first shoot at the second sowing date was 0.59 g less than the one obtained at the first sowing date, the difference of 0.16 g was statistically significant (t_f - 5.40 > $t_{0.05}$ - 2.009). The result obtained at the third sowing date was 0.48 g less than the second sowing date, the difference of 0.11 g was significant (t_f - 3.50 > $t_{0.05}$ - 2.009). The dry matter content of the shoot at the fourth sowing date was 0.39 g, which was 0.09 g less than the data at the third sowing date, the difference was statistically significant (t_f - 3.71 > $t_{0.05}$ - 2.009). The results of the data obtained at the fifth sowing date were the lowest in the study, the dry matter content was 0.29 g. Differences in comparison with the indicators obtained under the conditions of plant development at the fourth sowing date at the level of 0.10 g were statistically significant (t_f - 4.27 > $t_{0.05}$ - 2.009).

The characteristics of the development of the leaf surface area of shoots were highlighted by an analogous comparison scheme. The largest leaf area of the first shoot at 38.28 cm^2 was obtained at the first sowing date. Compared to the data for the second sowing date at 35.51 cm^2, the difference of 2.77 cm^2 was statistically significant (t_f - 2.56 > $t_{0.05}$ - 2.009). The analysis of the shoot data obtained under the conditions of the third sowing term, where the indicator was 33.25 cm^2, which characterised the pattern of a significant decrease in the leaf surface area of the shoot compared to the data for the second sowing term by 2.26 cm^2, the difference was significant (t_f - 2.02 > $t_{0.05}$ - 2.01). The leaf surface area of the shoot at the fourth sowing date at 28.67 cm^2 was significantly less than that obtained at the third sowing date. The difference was 4.58 cm^2, statistical criterion t_f - 3.98 > $t_{0.05}$ - 2.009. And the area of the leaf surface of the first shoot of spring barley at the fifth sowing date at 22.93 cm^2 was the smallest. The difference was found at the statistical level compared to the indicator obtained at the fourth sowing date – 5.74 cm^2 (t_f - 4.86 > $t_{0.05}$ - 2.009).

Statistical analysis of spring barley plants growth and development based on the biomass of the second shoot shows that the value of 2.79 g at the first sowing date was significantly greater compared to the data established when growing plants under the conditions of the second sowing date (t_f - 2.09 > $t_{0.05}$ - 2.009). Shoot biomass at the second sowing date of 2.45 g was 0.32 g greater than the index when growing barley at the third sowing date, the difference was statistically significant (t_f - 2.05 > $t_{0.05}$ - 2.009). The obtained shoot biomass at the third sowing date of 2.13 g was significantly greater than the established biomass results at the fourth sowing date (t_f - 2.46 > $t_{0.05}$ - 2.009). And, accordingly, the biomass of the second shoot of spring barley 1.80 g in the process of cultivation under the conditions of sowing in the fourth term at a statistically significant level of data discrepancy was 0.29 g greater than the indicator of 1.51 g obtained in the fifth sowing term (t_f - 2.04 > $t_{0.05}$ - 2.009).

When analysing the data on the dry matter content of the second shoot under the conditions of the second sowing term, the value of 0.45 g was lower compared to the results obtained under the conditions of growing the first sowing term of 0.57 g. The difference in data was statistically significant (t_f - 4.76 > $t_{0.05}$ - 2.009). The dry matter content obtained at the third sowing date of 0.35 g was significantly lower than the results of the index when growing spring barley at the second sowing date. The difference of 0.10 g was statistically significant (t_f - 3.14 > $t_{0.05}$ - 2.009). According to the same pattern, the value of the index obtained at the fourth sowing term of 0.27 g was characterised by a significantly lower value of the parameter compared to the data obtained at the third sowing term. The difference at the level of 0.08 g was statistically significant (t_f - 2.61 > $t_{0.05}$ - 2.009). In plant development under the conditions of the fifth sowing term, the dry matter content of the second shoot was 0.20 g. The established difference of 0.07 g was statistically significant when compared to the corresponding values obtained under the conditions of cultivation of the fourth sowing term (t_f - 2.54 > $t_{0.05}$ - 2.009).

The highest value of the leaf surface area of the second shoot was found at the first sowing date of 34.11 cm^2. Under the conditions of the second sowing date, the value was 31.54 cm^2. The difference of 2.57 cm^2 was significant (t_f - 2.37 > $t_{0.05}$ - 2.009). The shoot index at the second sowing date was significantly greater by 2.76 cm^2 than the result of leaf area established under the conditions of plant vegetation at the third sowing date (t_f - 2.39 > $t_{0.05}$ - 2.009). Analogously, the indicator of leaf surface area of the shoot at the third sowing date of 28.78 cm^2 was greater than the results obtained at the fourth sowing date by 7.71 cm^2. The differences in the data were statistically significant (t_f - 6.77 > $t_{0.05}$ - 2.009). The index of leaf surface area of the second shoot at the fourth sowing date of 21.07 cm^2 was greater than the index of 16.85 cm^2 of the fifth sowing date. Statistically, the difference of 4.22 cm^2 was significant at t_f - 3.75 > $t_{0.05}$ - 2.009.

Based on the analysis of the biomass data of the third shoot of spring barley plants, it was found that in the first sowing term, the results of the index were 2.10 g greater than those obtained when growing under the conditions of sowing in the second term. When compared, the difference of 0.31 g was statistically significant (t_f - 2.42 > $t_{0.05}$ - 2.009). The shoot biomass at the second sowing date of 1.79 g was significantly greater compared to the data obtained at the third sowing date, the difference was 0.36 g (t_f - 2.43 > $t_{0.05}$ - 2.009). Analogously, when comparing the biomass of the shoot at the third sowing date, an indicator of 1.43 g was obtained, which was greater than the biomass of the shoot at the fourth sowing date. The difference of 0.30 g was statistically significant (t_f - 2.30 > $t_{0.05}$ - 2.009). According to the same pattern, the index of shoot biomass when grown under the conditions of the fourth sowing term was 0.29 g greater than the index obtained at the fifth sowing term, the difference is statistically significant (t_f - 2.10 > $t_{0.05}$ - 2.009).

The analysis of the data on the development of the third shoot of spring barley plants in terms of dry matter content shows that the second sowing term yielded a value of 0.34 g, which is lower than the result obtained under the conditions of the first sowing term of 0.47 g, the difference of 0.13 g was statistically significant (t_f - 3.90 > $t_{0.05}$ - 2.009). The figure obtained at the third sowing date at 0.24 g in the statistical comparison was also 0.10 g smaller than the result of the second sowing date (t_f - 3.00 > $t_{0.05}$ - 2.009). As a result of the analysis of the data on the dry matter content of the third shoot under the conditions of plant development of the fourth sowing term, a value of 0.16 g was established, which at the statistical level was significantly less by 0.08 g compared to the data obtained in the third sowing term (t_f - 2.74 > $t_{0.05}$ - 2.009). Under the conditions of cultivation of the fifth sowing term, the value of the indicator was only 0.10 g, but when statistically compared with the data obtained under the conditions of the fourth sowing term, the difference of 0.06 g was significant (t_f - 2.73 > $t_{0.05}$ - 2.009).

Based on the analysis of the data of the third shoot of the leaf surface area, the highest parameter of the indicator was 29.94 cm^2 at the first sowing date. When grown at the second sowing date, the leaf surface area of the shoot was 27.07 cm^2. The difference of 2.87 cm^2 was significant, the statistical value of t_f was 2.94 > $t_{0.05}$ - 2.009. The parameter of the indicator at the third sowing date of 23.20 cm^2 was lower than the results obtained under the conditions of growing plants of the second sowing date. The difference in data at the statistical level of 3.87 cm^2 was significant (t_f - 3.54 > $t_{0.05}$ - 2.009). The established value of the leaf surface area of the shoot at the fourth sowing date at 18.03 cm^2 was smaller than the data established under the conditions of the third sowing date. The difference of 5.17 cm^2 was significant (t_f - 4.76 > $t_{0.05}$ - 2.009). The parameter of leaf surface area at the fifth sowing date at 15.00 cm^2 was significantly lower than the previous sowing date. The difference in data at 3.03 cm^2 was significant (t_f - 2.99 > $t_{0.05}$ - 2.009). The analysis of the biological development of spring barley on the example of the phenotype of plants with three developed shoots under different sowing dates at the end of the tillering process in 2020 is presented in Table 3.

***Table 3**. Evaluation of spring barley growth and development at the end of tillering process at different sowing dates based on the analysis of the phenotype of plants with three formed shoots (2020)*

Indicator	Sowing period				
	first	second	third	fourth	fifth
First shoot					
Crude biomass, g	4.81 ± 0.17	4.11 ± 0.15	3.56 ± 0.12	2.96 ± 0.16	2.48 ± 0.13
Dry matter content, g	0.80 ± 0.018	0.64 ± 0.034	0.55 ± 0.023	0.42 ± 0.027	0.36 ± 0.012
Leaf surface area, cm^2	41.13 ± 0.75	38.57 ± 0.78	35.69 ± 0.91	31.00 ± 0.81	25.30 ± 0.83
Second shoot					
Crude biomass, g	3.99 ± 0.13	3.32 ± 0.18	2.70 ± 0.11	2.15 ± 0.12	1.70 ± 0.14
Dry matter content, g	0.59 ± 0.031	0.49 ± 0.028	0.40 ± 0.033	0.30 ± 0.020	0.22 ± 0.019
Leaf surface area, cm^2	37.51 ± 0.86	34.55 ± 0.90	30.89 ± 0.83	25.83 ± 0.99	19.79 ± 1.00
Third shoot					
Crude biomass, g	2.50 ± 0.13	2.09 ± 0.11	1.69 ± 0.12	1.30 ± 0.13	0.96 ± 0.10
Dry matter content, g	0.42 ± 0.025	0.33 ± 0.029	0.25 ± 0.021	0.19 ± 0.016	0.14 ± 0.015
Leaf surface area, cm^2	34.84 ± 1.10	31.67 ± 0.77	27.12 ± 0.98	20.99 ± 1.00	15.25 ± 0.87

***Source:** compiled by the authors of this study based on the research findings*

It was found that the biomass of the first shoot of 4.11 g at the second sowing date was 0.70 g smaller than the biomass of the shoot of 4.81 g at the first sowing date, the difference was statistically significant (t_f - 3.09 > $t_{0.05}$ - 2.009). Under the conditions of the third sowing term, the shoot biomass index was 3.56 g. Compared to the biomass of the shoot at the second sowing date, the difference of 0.55 g was statistically significant (t_f - 2.86 > $t_{0.05}$ - 2.009). Under the conditions of the fourth sowing term, the value of the indicator was 2.96 g and, accordingly, 0.60 g smaller than the value of the same indicator obtained under the conditions of barley cultivation during sowing in the third term. The differences in the data were statistically significant (t_f - 3.00 > $t_{0.05}$ - 2.009). The index of biomass of the first shoot at the fifth sowing term of 2.48 g was 0.48 g smaller than the value obtained at the fourth sowing term, the difference was statistically significant (t_f - 2.33 > $t_{0.05}$ - 2.009).

The study found that the dry matter content of the first shoot at the first sowing date of 0.80 g was greater than the parameters of the indicator obtained at the second sowing date of 0.64 g, the difference at the level of 0.16 g was statistically significant (t_f - 4.16 > $t_{0.05}$ - 2.009).

The parameter of 0.55 g obtained under the conditions of sowing the third term was 0.09 g smaller than the second sowing term, the difference was statistically significant (t_f - 2.19 > $t_{0.05}$ - 2.009). The value of the shoot dry matter content at the fourth sowing term of 0.42 g was 0.13 g smaller than the parameter of the indicator obtained during sowing at the third term, which characterises the difference in data as statistically significant (t_f - 3.67 > $t_{0.05}$ - 2.009). The dry matter content of the first shoot at the fifth sowing date of 0.36 g was 0.06 g less than the dry matter content of the shoot of the fourth sowing date, the difference was significant (t_f - 2.03 > $t_{0.05}$ - 2.009).

The analysis of the development of the first shoot by the value of leaf surface area showed that the index for the second sowing date of 38.57 cm^2 was smaller by 2.56 cm^2 with a statistically significant difference in data compared to the results of the obtained plant vegetation conditions when sowing in the first term (t_f - 2.36 > $t_{0.05}$ - 2.009). The leaf surface of the shoot of 35.69 cm^2 at the third sowing date was 2.88 cm^2 smaller than the area parameter at the second sowing date, the difference was statistically significant (t_f - 2.40 > $t_{0.05}$ - 2.009). The indicator for the fourth sowing term of 31.00 cm^2 was smaller than the indicator obtained in the third sowing term by 4.69 cm^2, which characterised the difference in data as statistically significant (t_f - 3.85 > $t_{0.05}$ - 2.01). The data on the leaf surface area of the shoot at the fifth sowing date were characterised by a value of 25.30 cm^2. The difference with significantly lower parameters compared to the value obtained under the conditions of vegetation of plants of the fourth sowing term was 5.70 cm^2, which was statistically significant (t_f - 4.91 > $t_{0.05}$ - 2.009).

Based on the assessment of the development of the second shoot of spring barley plants by biomass parameters, it was found that the index for the second sowing term of 3.32 g was 0.67 g less than the result of 3.99 g obtained when growing under the conditions of sowing in the first term. The difference is statistically significant (t_f - 3.01 > $t_{0.05}$ - 2.009). The results obtained in the third sowing term showed that the biomass of the shoot was 2.70 g less than the value of the index obtained in the second sowing term, the difference of 0.62 g was statistically significant (t_f - 2.95 > $t_{0.05}$ - 2.009). The established index of shoot biomass under the conditions of the fourth sowing term of 2.15 g was 0.55 g less than the result obtained under the conditions of barley cultivation when sown in the third term. In this comparison, the difference was significant (t_f - 3.39 > $t_{0.05}$ - 2.009). And in the fifth term of sowing, the biomass of the second shoot of 1.70 g was 0.45 g less than the figure obtained during the fourth term, the difference was statistically significant (t_f - 2.44 > $t_{0.05}$ - 2.009).

The results of the dry matter content according to the state of biological development of the second shoot show that under the conditions of the second sowing term, the indicator of 0.49 g was less than the indicator of 0.59 g obtained during the organisation of sowing in the first term. The difference of 0.10 g was statistically significant (t_f - 2.39 > $t_{0.05}$ - 2.009). Under the conditions of plant development during sowing in the third term, the content of dry matter of the shoot was 0.40 g and was 0.09 g less than the value of the indicator obtained in the second term of barley sowing, the difference was statistically significant (t_f - 2.08 > $t_{0.05}$ - 2.009). The conditions of barley development of the fourth sowing term provided the content of shoot dry matter at the level of 0.30 g. The value of this indicator was lower at a statistically significant level of data discrepancy at the established difference of 0.10 g compared to the value obtained at the third sowing date (t_f - 2.59 > $t_{0.05}$ - 2.009). The dry matter content of the shoot at the fifth sowing date was 0.22 g. Compared to the value of the indicator obtained in the fourth term, the difference in the data discrepancy of 0.08 g was statistically significant (t_f - 2.90 > $t_{0.05}$ - 2.009).

The following is an analysis of the leaf surface area according to the biological stage of development of the second shoot of spring barley, depending on the influence of the conditions that developed at different sowing dates. When growing plants at the second sowing date, the area of 34.55 cm^2 was significantly smaller compared to the 37.51 cm^2 obtained at the first sowing date. The difference of 2.96 cm^2 was significant (t_f - 2.37 > $t_{0.05}$ - 2.009). Upon growing plants, when sowing was performed in the third term, the leaf surface area of the second shoot was 30.89 cm^2. Compared to the value of the same indicator obtained under the conditions of the second sowing term, the difference of 3.66 cm^2 was statistically significant (t_f - 2.99 > $t_{0.05}$ - 2.009). At the fourth sowing term, the obtained area of 25.83 cm^2 characterised the pattern of decrease in parameters compared to the results obtained at the third sowing term. The difference in data at the level of 5.06 cm^2 was statistically significant (t_f - 3.91 > $t_{0.05}$ - 2.009). The smallest leaf surface area of the second shoot was found at the fifth sowing date of 19.79 cm^2, which was 6.04 cm^2 smaller than the value obtained at the fourth sowing date, the difference was statistically significant (t_f - 4.29 > $t_{0.05}$ - 2.009).

Analysis of the data on the biomass of the third shoot according to the biological stage of development showd that the conditions at the second sowing date provided a parameter of 2.09 g. Compared to the results obtained during the cultivation of barley in the first sowing period, the indicator was 2.50 g, the difference of 0.41 g was statistically significant (t_f - 2.41 > $t_{0.05}$ - 2.009). The index of shoot biomass at the third sowing term of 1.69 g was naturally characterised by a decrease in the development potential compared to the results obtained under the conditions of development when sowing in the third term. The difference in the comparison data was 0.40 g and was statistically significant (t_f - 2.46 > $t_{0.05}$ - 2.009). Under the fourth sowing term, the shoot biomass of 1.30 g was estimated to be significantly lower than the results obtained when growing barley plants sown in the third term. The difference of 0.39 g was statistically significant (t_f - 2.21 > $t_{0.05}$ - 2.009). The following difference analysis showed that the biomass of the shoot at sowing in the fifth term was 0.96 g statistically less than the biomass of the shoot at the fourth sowing term, the difference of data at the level of 0.34 g was statistically significant (t_f - 2.07 > $t_{0.05}$ - 2.009).

Characteristics of the development of the third shoot of spring barley by estimating the dry matter content shows that the best result of 0.42 g was obtained under growing conditions when sowing in the first term. The value of the indicator at the second sowing date of 0.33 g was significantly less by 0.09 g (t_f - 2.35 > $t_{0.05}$ - 2.009). The dry matter content of the shoot under the conditions of development of plants of the third sowing date of 0.25 g compared to the dry matter content of the shoot at the second sowing date was lower, the difference of 0.08 g was statistically significant (t_f - 2.23 > $t_{0.05}$ - 2.009). At the fourth sowing date, the figure was even lower and amounted to 0.19 g. The difference of 0.06 g in comparison with the data of the dry matter content of the shoot of the third sowing term was significant (t_f - 2.27 > $t_{0.05}$ - 2.009). The influence of developmental conditions of the fifth sowing term provided the lowest accumulation of dry matter by the third shoot. A result of 0.14 g was obtained, where the difference of 0.05 g compared to the data of the same indicator at the fourth sowing date was statistically significant (t_f - 2.28 > $t_{0.05}$ - 2.009).

Based on the characteristics of the parameters of the leaf surface area of the third shoot at the second sowing date, a value of 31.67 cm^2 was established, which was lower than the result of 34.84 cm^2 obtained at the first sowing date. The difference of 3.17 cm^2 was statistically significant (t_f - 2.36 > $t_{0.05}$ - 2.009). Comparison of the index obtained at the third sowing term of 27.12 cm^2 with the same at the second sowing term characterises a decrease of the parameter by 4.55 cm^2. The statistical difference was significant at t_f - 3.65 > $t_{0.05}$ - 2.009. Under the condition of plant development at sowing in the fourth term, the leaf surface area of 20.99 cm^2 was 6.13 cm^2 smaller than that obtained when growing under the conditions of development at sowing in the third term. The difference in data was statistically significant (t_f - 4.37 > $t_{0.05}$ - 2.009). The smallest leaf surface area of the third shoot (15.25 cm^2) was obtained under the conditions of barley development when sown in the fifth term, which was smaller than the data obtained at the fourth sowing term. The difference of 5.74 cm^2 was significant (t_f - 4.33 > $t_{0.05}$ - 2.009).

As a result of the conducted study, the dependence of the processes of growth and development of spring barley on the state of plants at the end of the tillering phenophase on the conditions of vegetation factors of five sowing dates was established according to the structural analysis of the phenotype of plants with three formed shoots (Table 4).

***Table 4**. Evaluation of spring barley growth and development at the end of tillering process at different sowing dates based on the analysis of the phenotype of plants with three formed shoots (average for 2018-2020)*

Indicator	Sowing period				
	first	**second**	**third**	**fourth**	**fifth**
First shoot					
Crude biomass, g	4.17	3.65	3.19	2.72	2.31
Dry matter content, g	0.77	0.61	0.51	0.41	0.32
Leaf surface area, cm^2	37.9	35.3	32.9	29.0	23.8
Second shoot					
Crude biomass, g	3.22	2.79	2.40	1.96	1.64
Dry matter content, g	0.58	0.47	0.38	0.29	0.22
Leaf surface area, cm^2	34.8	32.0	29.1	23.9	19.4
Third shoot					
Crude biomass, g	2.24	1.91	1.55	1.22	0.93
Dry matter content, g	0.43	0.33	0.25	0.18	0.13
Leaf surface area, cm^2	30.9	28.3	24.8	20.4	16.3

***Source:** compiled by the authors of this study based on the research findings*

According to the first, second, third, fourth, and fifth sowing dates, morphobiological parameters on average for three years significantly decreased and were characterised by the following data: biomass of the first shoot – 4.17 g; 3.65 g; 3.19 g; 2.72 g; 2.31 g; the second – 3.22 g; 2.79 g; 2.40 g; 1.96 g; 1.64 g; the third – 2.24 g; 1.91 g; 1.55 g; 1.22 g; 0.93 g; dry matter content of the first shoot – 0.77 g; 0.61 g; 0.51 g; 0.41 g; 0.32 g; the second – 0.58 g; 0.47 g; 0.38 g; 0.29 g; 0.22 g; the third – 0.43 g; 0.33 g; 0.25 g; 0.18 g; 0.13 g; according to the leaf surface area of the first shoot – 37.9 cm^2; 35.3 cm^2; 32.9 cm^2; 29.0 cm^2; 23.8 cm^2; the second – 34.8 cm^2, 32.0 cm^2; 29.1 cm^2; 23.9 cm^2; 19.4 cm^2; the third – 30.9 cm^2; 28.3 cm^2; 24.8 cm^2; 20.4 cm^2; 16.3 cm^2 (Table 4).

The results of the morphobiological analysis of the phenotype of spring barley plants with three formed shoots at the end of the tillering phase in terms of individual data of shoot biomass, dry matter content, and leaf surface area at different sowing dates indicated the effectiveness of the implementation of abiotic resources of the environment when forming crops during the vegetative state of plant development. The significance of analysing the growth and development of spring barley plants from the beginning of the seed germination process to the end of the tillering phenophase is that this is the period of growth and development of vegetative organs. This is a separate part of the growing season, during which the potential for plant productivity and the structure of the agrophytocenosis overall are laid and formed. Next, the generative state of plant growth and development begins, the effectiveness of which largely depends on the vegetative state. Primarily, this applies to the functional element of the yield structure, namely productive shoots, the number of which, upon the onset of the generative state of development in barley plants, is determined and can no longer be controlled by both abiotic and technological factors. It is also significant that during the vegetative state of barley plant growth and development, the foundations of biological potential are laid by the number of spikelets in the ear. Therefore, considerable attention is paid to spring barley before the onset of the generative state of growth and development, since with its onset, the determination of this structural element of yield also occurs.

Abiotic environmental conditions during the period of barley vegetative development play a key role. R. Klymyshena and O. Horash (2024) argued that they are essential and are always influential on the processes of seed germination after sowing, on the accumulation of biological potential by barley plants before tillering, both from its beginning and its completion. Notably, at early sowing dates, the tillering process always occurs much earlier than at later dates. The conditions of abiotic factors of vegetation, specifically, such as the duration of daylight hours, which can be characterised by the process of energy flow of quanta, and temperature conditions (minimum, maximum, and optimal temperatures), which integrally interact and affect the duration of the tillering process regardless of sowing dates and determine their productivity. As a result of the influence of day length and air temperature, barley shoots enter a state of generative development, the fourth stage of organogenesis. Therefore, it is crucial to determine on which biological resource spring barley completes the tillering process, depending on the development conditions at different sowing dates, with reference to the most significant task of the technology process, which is to maximise the use of environmental resources.

The influence of abiotic factors of vegetation on the state of growth and development of spring barley at the end of the tillering process at different sowing dates can be established by analysing separately selected plant phenotypes. Accordingly, the results of barley development at the end of the tillering phenophase, depending on environmental conditions at different sowing dates, were presented on the example of analysing the phenotype of plants with three developed shoots according to individual indicators of each of them. The plant phenotype was the result of the interaction of genotype and environment. Plants with the same genotype exhibit phenotype traits according to the conditions of growth and development during the growing season. The phenotype itself includes morphological traits, physiological properties, resistance to environmental factors, and biometric parameters. Phenotype in crop production is a set of traits and properties of plants that are formed by the implementation of the genotype in the growing environment, which are also set by technology.

M. Zulkiffal *et al.* (2021) noted that the technological process of spring barley cultivation in the conditions of changes in abiotic factors requires a systematic solution. The primary types of abiotic factors include climatic factors, particularly temperature, distribution and instability of precipitation, reduction of surface water, intensity and duration of daylight hours, atmospheric pressure, and wind. The list also includes chemical and physical properties of the soil, including acidity, structure, density, soil porosity, water availability for plants and its ability to retain water, macro- and microelements, and the presence of toxic substances. S.I. Zandalinas *et al.* (2021) reported that hydrothermal conditions play a crucial role, characterising the interaction of water and thermal regimes in a particular area. They provide an opportunity for the development of vegetation. The key components of hydrothermal conditions include temperature regime – average, minimum, maximum temperatures, duration of the warm period; humidity – rainfall, soil moisture, groundwater level. The heat and moisture ratio is the balance between the amount of heat that ensures vegetation and the water required for plants. Abiotic factors form the conditions under which certain organisms can exist. According to V.O. Balabukh *et al.* (2021, 2023), the interaction of abiotic factors with biotic factors creates an ecosystem. In this aspect, the vector of spring barley breeding is also sufficiently focused on adaptation to changes in the parameters of abiotic factors that have occurred in recent decades. Environmental conditions are characterised by a rather significant impact on the existence and survival of biological organisms. A. Linchevskyi and I. Legkun (2020) addressed a new attitude towards culture and breeding in the context of climate change.

In the analysis of this area of the problem, there are relevant features that should be considered from the other perspective. In the southwestern Forest-Steppe of

Ukraine, from 2000 to 2010, there was a tendency for favourable conditions for spring barley sowing to occur earlier. In some years, the conventional sowing date of the first decade of April was shifted to the onset of favourable conditions after 20 March. Additionally, this decade saw an increase in the number of opportunities to sow spring barley in both the first and second decades of March. Spring conditions for spring barley cultivation over 2010-2020 were predominantly favourable for early sowing in the early part of March.

According to practical results, early sowing enables the efficient use of winter moisture reserves and fertilisers, which positively influences the tillering process and, ultimately, yields. If sowing is delayed, the field germination of seeds decreases, the root system of plants develops less well, and uniform tillering is not ensured. Based on these conditions, the relevance of the tasks of scientific research is the need to substantiate the optimal combination of the biological potential of spring barley productivity and agroecological resources in cultivation technology. In modern intensive systems of cereal crops cultivation, there is a requirement for increased attention to plants as a biological means of production. Particular significance is attached to the biological properties and characteristics of the crop in connection with the task of cultivation technology to maximise the potential of crop productivity. A series of scientific studies revealed that optimisation of plant growth and development in growing crops cannot be achieved without paying special attention to the biological object as the primary factor of technology.

The issue of spring barley cultivation under current changes in abiotic factors is receiving considerable attention both in Ukraine and around the world. Changes in the agroclimatic conditions of spring barley cultivation due to climate change are assessed. A. Polevoy *et al.* (2013a, b) showed that the A1B climate change scenario in Ukraine, the regional climate model MPI-M-REMO, and the global model ECHAM5-r3 were used to assess changes, as the most probable for the period up to 2050. The photosynthetic productivity and fluctuations in the average regional grain yield of spring barley in the districts of Odesa region, which belong to the Ukrainian part of the Danube Delta sub-basin, were also assessed using plant production models. Specifically, the analysis of spring barley development by phenological phases under climatic factors and the impact on spring barley yield in Europe was also given considerable attention by many scientists, particularly by M. Bicard *et al.* (2025).

Thus, the conducted study reflects the norm of spring barley response to environmental conditions, which characterises the properties of the crop based on the results of plant analysis, biologically fixed adaptation of ontogeny to changes in agroclimatic resources, resulting in the regulation of growth and development processes.

CONCLUSIONS

The conducted study established the dependence of the fulfilment of the biological potential of spring barley growth and development processes on the example of the analysis of the phenotype of plants with three formed shoots at the end of the tillering phenophase on the influence of vegetation factors at five equidistant 10-day sowing dates. It was proved that the key morphophysiological parameters of spring barley plants growth and development, specifically, crude biomass, dry matter content, leaf area of shoots, during the period of vegetative state of plants are limited by the resource of the environment, which gradually becomes smaller with the delay of sowing for every 10 days starting from the first one on March 10. As a result of the study, the maximum values of indicators were obtained for the first sowing date on 10 March. Accordingly, during the first, second, third, fourth, and fifth sowing periods, the obtained indicators decreased significantly. On average, according to the data of three years of research, they were characterised by the following parameters: biomass of the first shoot – 4.17 g; 3.65 g; 3.19 g; 2.72 g; 2.31 g; the second shoot – 3.22 g; 2.79 g; 2.40 g; 1.96 g; 1.64 g; the third shoot – 2.24 g; 1.91 g; 1.55 g; 1.22 g; 0.93 g; dry matter content of the first shoot – 0.77 g; 0.61 g; 0.51 g; 0.41 g; 0.32 g; the second shoot – 0.58 g; 0.47 g; 0.38 g; 0.29 g, 0.22 g; the third shoot – 0.43 g, 0.33 g, 0.25 g, 0.18 g, 0.13 g; leaf area of the first shoot – 37.9 cm^2, 35.3 cm^2, 32.9 cm^2, 29.0 cm^2, 23.8 cm^2; the second shoot – 34.8 cm^2, 32.0 cm^2, 29.1 cm^2, 23.9 cm^2, 19.4 cm^2; the third shoot – 30.9 cm^2, 28.3 cm^2, 24.8 cm^2, 20.4 cm^2, 16.3 cm^2. The obtained findings proved the expediency of ensuring early sowing in the organisation of the technological process of spring barley cultivation to favourably implement the productivity of the natural resource of plants during the vegetative state of the environment of the Western Forest-Steppe of Ukraine.

Prospects for further research include the assessment of fulfilling the productivity potential of spring barley plants during their generative state, depending on the influence of conditions at early sowing on the biometric parameters of shoots and elements of ear productivity to establish the degree of synchronisation and formation of homogeneity of the components of agrophytocenosis as characteristics of the perfection of the technological process of cultivation.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Оцінка стану росту та розвитку рослин ячменю фенотипу з трьома сформованими пагонами по завершенню фенофази кущення за різних строків сівби

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Анотація. Мета досліджень полягала в необхідності обґрунтування оптимального поєднання агроекологічних ресурсів умов середовища Західного Лісостепу України та біологічного потенціалу продуктивності ячменю ярого в процесі технології вирощування. Організовані дослідження спрямовані на аналіз стану росту та розвитку рослин ячменю ярого на прикладі фенотипу з трьома сформованими пагонами на завершенні фенофази кущіння залежно від впливу умов зовнішнього середовища за різних строків сівби. Для опису та узагальнення експериментальних даних застосовано метод встановлення істотності різниці вибіркових середніх за t – критерієм (різницевий аналіз). В результаті проведеного дослідження росту та розвитку ячменю на прикладі аналізу фенотипу рослин з трьома сформованими пагонами станом на завершенні процесу кущення отримано закономірність поступового зниження реалізації біологічного потенціалу пагонів при зміщенні строків сівби на 10 днів розпочинаючи від першого строку сівби – 10 березня. Максимальні значення показників росту та розвитку пагонів рослин означеного фенотипу отримані в результаті забезпечення процесу сівби, як найраніше, 10 березня. У відповідності до порядку біологічної черги формування першого, другого та третього пагонів показники становили для сирої біомаси – 4,2 г; 3,2; 2,2 г; вмісту сухої речовини – 0,77 г; 0,58; 0,43 г, площі листкової поверхні – 37,9 $см^2$; 34,8 та 30,9 $см^2$. Відповідно аналізу фактичного матеріалу отриманого в результаті організованого досліду вирощування рослин в абіотичних умовах за різних строків сівби встановлено процес модифікаційного впливу на морфогенез пагонів ячменю. Найкращі результати інтенсифікації кущення ячменю ярого за параметрами встановлених даних розвитку пагонів на прикладі означеного фенотипу рослин отримано в умовах середовища за ранніх строків сівби. З практичного погляду до теперішнього часу залишається недостатньо реалізованим резервом в технології вирощування використання сприятливих ресурсів середовища за ранніх строків сівби в забезпеченні стабільно високої урожайності зерна культури ячменю ярого

Ключові слова: ячмінь ярий; абіотичні умови; біомаса; площа листкової поверхні; t – критерій; біологічний потенціал