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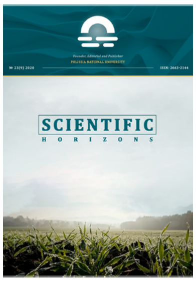

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Evaluation of barley plants growth and development at the beginning of tillering phenophase at different sowing dates

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Abstract. Global climate change, which has also occurred in the Western Forest-Steppe of Ukraine, has led to early sowing starting from the very beginning of the spring season. In this regard, to provide a scientific basis for spring barley cultivation technology, the issue of investigating the processes of plant growth and development before the onset of the tillering phenomenon, i.e., the second and third stages of organogenesis, is of particular relevance. The purpose of this study was to

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establish the regularities of dependence of spring barley plant growth and development on the influence of vegetation factors at different sowing dates in the Western Forest-Steppe of Ukraine. To summarise the findings, the following methods were employed: general scientific methods based on objectivity, evidence, reproduction, and mathematical and statistical methods for processing experimental data. The study found the dependence of the processes of growth and development of spring barley plants based on plant biomass, crude biomass, and dry matter content of the root system and aerial parts of plants, as well as leaf area according to the analysis at the beginning of the tillering phase, on the influence of sowing time. The study estimated the significance of the studied factor under the influence of supply conditions for the maximum realisation of spring barley productivity potential. As a result, a regularity was revealed, according to which a substantial decrease in the productivity potential of barley plants was established with a delay for each subsequent 10 days starting from the first sowing date on 10 March. The maximum data values were obtained at the first sowing date, where the plant biomass was 723.6 mg, the crude biomass of the root system was 67.5 mg, the dry matter of the root system was 18.0 mg, the crude biomass of the aerial part of the plant was 656.1 mg, the dry matter of the aerial part of the plant was 130.8 mg and the leaf surface area was 18.1 cm^2. As a result of the scientific substantiation, the practical value of the study lies in the favourability of early sowing dates to ensure maximum realisation of plant productivity potential due to vegetation factors

Keywords: plant biomass; crude biomass; dry matter; root system; aerial part of plants; leaf surface area; Student's t-test

INTRODUCTION

The issues of growth and development of spring barley plants at early sowing dates are insufficiently covered and understudied, which became the basis for conducting relevant research. In this regard, it is important to develop new approaches and improve the existing elements of crop cultivation technology that can ensure maximum fulfilment of the biological potential under the existing soil and climatic conditions as a result of changes in the soil and climate. Therefore, with climate change and improved agricultural technology, optimising barley sowing dates is becoming increasingly important.

Barley (*Hordeum vulgare* L.) is one of the most widely grown cereals and ranks fourth in the world in terms of production. Barley grain is widely used not only for food, technical and feed purposes, but also for brewing (Bratković *et al.*, 2024). Improving existing and developing new technologies for growing grain crops, including spring barley, has always been an important area of agricultural production. That is why one of the ways to increase barley grain yields is to create favourable conditions for the fulfilment of plant productivity potential. As a rule, the sustainable development of agricultural production of grain crops, including spring barley, largely depends on climatic conditions, which are determined by the ratio of heat, moisture, and light. They are one of the determining factors of plant life, which affect not only their growth and development, but also productivity in general (Shelkoplyas & Zhytkov, 2021; Balabukh *et al.*, 2021). Climate change, which has been observed over the past decades, is affecting the growth, development, and yield of crops.

M. Zulkiffal *et al.* (2021) noted that the main abiotic factors limiting global cereal production are drought and rising air temperatures. It is the presence of such conditions that leads to a 10-50% reduction in grain yields. This problem is also relevant for Ukraine. V. Balabukh (2023) believes that further changes in climate conditions are projected, associated with an increase in the number of extreme events such as heat, drought, and heavy rainfall. This will negatively affect the growth and development of crop plants. As a result of high air temperatures, the dates of onset of phenological phases and the duration of grain growth periods have shifted. Sowing dates should be shifted to reduce the impact of extreme conditions (Fatima *et al.*, 2020).

K. van der Wiel and R. Bintanja (2021), M. Appiah *et al.* (2023) describe that early sowing compared to late sowing increases the rate of photosynthesis, seed assimilates and germination activity. Late sowing substantially reduces barley grain yields. For the formation of yield and grain quality of spring barley, the tillering period is crucial – the emergence of the tube, when functional shoots and elements of ear productivity are laid down – important components of the future harvest. At low temperatures, the duration of the tillering period is extended, which leads to the development of more lateral shoots in plants. Since the dynamics of tillering is also influenced by the length of daylight hours, the conditions depending on the sowing date become a factor influencing the tillering processes and the number of shoots per unit area. High yields and good grain quality of barley will be achieved if the "inputs" are directed to plant development at the beginning of the growing season. There are a series of conditions for plant growth and development to achieve high yields and grain quality. At the beginning of the first stage of plant development, the main vegetative phase, phyllochrons, roots, and shoots are formed. The agronomic importance of this stage lies in the formation of sufficient biomass.

The ability to form leaves and productive shoots is a significant component of plant biomass accumulation during the vegetative growth phenophase. Leaf area is considered an indicator of plant growth and development and is closely related to leaf weight. These are the main factors that influence growth rate through leaf thickness and density (Panfilova *et al.*, 2019a). Leaf area is a significant parameter for assessing intrinsic plant processes, such as photosynthesis and transpiration. Photosynthesis is known to be the main source of dry matter and crop yields. Aboveground mass plays a significant role in plant life, as it mobilises carbohydrates and nitrogen-containing substances to form the productive part of the crop. During the process of photosynthesis, energy-rich substances and organic compounds of various chemical compositions are formed from simple substances (Panfilova *et al.*, 2019b). As a rule, the intensity of organic matter accumulation depends on the size of the leaf surface.

Considering the above, the purpose of this study was to establish the regularities of the influence of conditions at different sowing dates in the Western Forest-Steppe of Ukraine on the results of growth and development of spring barley plants at the beginning of the tillering phase to effectively fulfil the productivity potential of the crop.

MATERIALS AND METHODS

The field experiment was organised by laying out plots in 4 replications with a plot area of 20 m^2. Sowing dates: first – 10 March, second – 20 March, third – 30 March, fourth – 9 April, fifth – 19 April. The object of study is spring barley plants of the Sebastian variety. The seeding rate is 250 germinating seeds/m^2. The soil temperature was set according to the data from the Pessl Instruments iMetos IMT300USW weather station (Austria). The study was conducted during 2018-2020 at the Higher Education Institution "Podilskyi State University" in the Western Forest-Steppe of Ukraine.

Agrochemical characteristics of the soil of the experimental plots. The soil type is podzolised gleyey medium loamy chernozem, which is characterised by physical and agrochemical properties as favourable for growing crops. Humus content is 3.2%, provision of nutrients: alkaline hydrolyzed nitrogen – 100 mg per 1 kg of soil, mobile phosphorus P_2O_5 – 176 mg per 1 kg of soil, exchangeable potassium K_2O – 160 mg per 1 kg of soil. The reaction of the soil solution is close to neutral or neutral – the pH of the salt extract is 6.8-7.0 mg-eq/100 g of soil, the hydrolytic acidity is low – 0.56-0.62 mg-eq/100 g of soil, the amount of absorbed bases is 32-36 mg-eq/100 g of soil.

The content of humus was determined according to the Tyurin method, alkaline-hydrolysed nitrogen – by the Cornfield method, mobile phosphorus and exchangeable potassium – by the Chirikov method, the sum of absorbed bases by the Kappen-Hilkowitz method, the reaction of the soil solution pH salt – by the potentiometric method, and hydrolytic acidity – by the Kappen method. The experiment was organised under the condition of forming crops with a row spacing of 15 cm – a conventional row seeding method. Sowing depth was within 2-3 cm. The grain weight of barley seeds used for sowing was 48-52 mg. Leaf surface area was determined by the notching method, crude plant biomass – by weighing on the FEH-600L balance (Ukraine), and dry matter mass by the thermogravimetric method (Hrytsaenko *et al.*, 2003; Yeshchenko *et al.*, 2014). For the mathematical analysis of the obtained findings, the Student's t-test was used to determine the dependence of spring barley plant biomass, crude biomass and dry matter content of the root system and aerial parts of plants, as well as leaf area on sowing dates. Experimental studies of plants (both cultivated and wild), including the collection of plant material, were following the institutional, national, or international guidelines. The study adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The climate has been warming over the past two decades. In this regard, the issue of analysing early cereal crops in terms of growth and development at the beginning of the tillering phenomenon depending on different sowing dates is relevant. At the first sowing date of 10 March, the biomass of the barley plant at the beginning of tillering was 722.3 mg. In the second sowing term, the same indicator was characterised by a lower value of 593.5 mg, the difference of 128.8 mg was significant, Student's criterion t_f – 16.97 > $t_{0.05}$ – 2.01. At the third sowing date, the plant biomass index was 538.1 mg, which is 55.4 mg less than the data obtained at the second sowing date. The difference is significant at t_f – 6.70 > $t_{0.05}$ – 2.01. At the fourth sowing date, the plant biomass was significantly lower than at the third sowing date by 56.1 mg (t_f – 6.56 > $t_{0.05}$ – 2.01). At the fifth sowing date, the plant biomass was the lowest and amounted to 433.9 mg, the difference when compared to the data of the fourth sowing date of 48.1 mg was significant (t_f – 5.58 > $t_{0.05}$ – 2.01). The obtained findings of spring barley plant biomass, crude biomass, and dry matter content of the root system and aerial parts of plants, as well as leaf area at different sowing dates in 2018 are presented in Table 1.

***Table 1**. Characteristics of the growth and development of barley plants at the beginning of the tillering phenophase at different sowing dates (2018)*

Sowing period	Plant biomass, mg	Root system, mg		Aerial part, mg		Leaf area, cm^2
		raw biomass	dry matter	raw biomass	dry matter	
1	722.3 ± 4.9	67.3 ± 2.2	18.0 ± 0.50	655.0 ± 7.0	130.7 ± 3.7	17.9 ± 0.48
2	593.5 ± 5.8	44.5 ± 2.8	13.2 ± 0.61	549.0 ± 6.3	97.0 ± 2.3	15.6 ± 0.35
3	538.1 ± 5.9	31.5 ± 3.3	10.3 ± 0.70	506.6 ± 5.8	83.3 ± 1.9	14.2 ± 0.41
4	482.0 ± 6.2	19.7 ± 2.2	7.5 ± 0.52	462.3 ± 6.0	71.7 ± 2.6	12.9 ± 0.33
5	433.9 ± 6.0	12.2 ± 1.7	5.3 ± 0.49	421.7 ± 6.5	63.0 ± 1.8	11.0 ± 0.31

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

The weight of the crude biomass of the root system of barley plants at the first sowing date was 67.3 mg, while at the second – 44.5 mg. The difference in the comparison of the 22.8 mg data is significant, Student's criterion t_f is $6.40 > t_{0.05}$ – 2.01. When sowing in the third term, the same indicator of plants was even lower – 31.5 mg, the difference of 13.0 mg compared to the data of the second term is significant (t_f – $3.00 > t_{0.05}$ – 2.01). At the fourth sowing term, the crude biomass of the root system was 19.7 mg, which is 11.8 mg less than the same indicator of the third term plants (t_f – $2.98 > t_{0.05}$ – 2.01). The difference between the data of the fourth and fifth sowing periods of 7.5 mg was significant, which proves that the parameters of the indicator are much lower when sowing in the fifth period. The difference between the obtained data on the content of dry matter of the root system of spring barley plants in the comparison of the first and second sowing periods was 4.8 mg and was significant due to the reduced values in the second period (t_f – $6.15 > t_{0.05}$ – 2.01). When sowing in the third term, the weight of the root system dry matter was 10.3 mg, which is significantly less than the data of the second sowing term by 2.9 mg (t_f – $3.15 > t_{0.05}$ – 2.01). For sowing in the fourth term, the figure was 7.5 mg, which is significantly less than in the third term by 2.8 mg (t_f – $3.22 > t_{0.05}$ – 2.01). And at the fifth sowing term, the dry weight of the root system was 5.3 mg and was significantly less by 2.2 mg compared to the data for the fourth term, Student's criterion t_f – $3.10 > t_{0.05}$ – 2.0.

Analysis of the above-ground plant data in terms of crude biomass also proves that when the sowing date is shifted from 10 March to every 10 days thereafter, plant biomass significantly decreases. Specifically, the biomass in the second sowing term was 106.0 mg less than in the first term (t_f – $11.26 > t_{0.05}$ – 2.01). In the third sowing term, the biomass of the aboveground part of plants was even lower than that obtained in the second sowing term by 42.4 mg (t_f – $4.95 > t_{0.05}$ – 2.01). Under the conditions of the fourth sowing term, the biomass of the aboveground part of barley plants was 462.3 mg, which is 44.3 mg less than in the third sowing term, the difference is significant at t_f – $5.31 > t_{0.05}$ – 2.01. At the fifth sowing term, the lowest value of the biomass parameter was 421.7 mg, which was 40.6 mg less than the same indicator of the fourth sowing term (t_f – $4.59 > t_{0.05}$ – 2.01). The analysis of the data on the weight of the dry matter of the aboveground part of the barley plant also shows a pattern of its significant decrease when the sowing dates are shifted by every 10 days from the first date of 10 March. The respective values were found to be 130.7 ± 3.7 mg; 97.0 ± 2.3 mg; 83.3 ± 1.9 mg; 71.7 ± 2.6 mg; 63.0 ± 1.8 mg. The difference between the data of the first and second sowing periods of 33.7 mg is significant (t_f – $7.75 > t_{0.05}$ – 2.01). In the third sowing term, the dry matter weight was significantly lower than in the second term – by 13.7 mg (t_f – $4.60 > t_{0.05}$ – 2.01), and in the fourth sowing term it was even lower than in the third term – by 11.6 mg (t_f – $3.60 > t_{0.05}$ – 2.01). The lowest value for this analysis was found at the latest sowing date of 63.0 mg, where the difference was 8.7 mg and was also significant compared to the data obtained at the fourth sowing date (t_f – $2.75 > t_{0.05}$ – 2.01).

It was proved that the area of leaf surface of barley plants according to the state of development at the beginning of the tillering process at different sowing dates was also at different levels of significance. In the second sowing term, the index was significantly lower than in the first term by 2.3 cm^2 (t_f – $3.90 > t_{0.05}$ – 2.01). When spring barley was sown on 30 March, the leaf area was even significantly smaller by 1.4 cm^2 compared to the data obtained in the second term, with t_f – $2.64 > t_{0.05}$ – 2.01. At the fourth sowing date, 10 days after the third, the leaf area decreased by another 1.3 cm^2 (t_f – $2.5 > t_{0.05}$ – 2.01). Accordingly, under the condition of barley plants development at the fifth sowing date at the beginning of the tillering process, the leaf surface area was the smallest – 11.0 cm^2. Compared to the data of the fourth sowing term, the difference of 1.9 cm^2 is significant (t_f – $4.22 > t_{0.05}$ – 2.01).

The obtained findings of the growth and development of barley plants at the time of the tillering phenomenon at different sowing dates in 2019 are presented in Table 2. The established index of barley plant biomass at the first term sowing is 699.5 mg, which is 125.8 mg higher than the same index obtained at the second term sowing, the difference is significant at the level of error significance of 5.0% (t_f – 14.70 > $t_{0.05}$ – 2.01). In the third sowing term, plant biomass was 56.8 mg less than in the second sowing term, a significant difference (t_f – 7.11 > $t_{0.05}$ – 2.01). Under the condition of sowing the fourth term, the biomass of barley plants was 464.2 mg and, accordingly, was significantly less than the biomass of plants of the third term by 52.7 mg (t_f – 6.25 > $t_{0.05}$ – 2.01). And in the case of the fifth sowing period, the figure was the lowest at 415.4 mg. When compared to the data obtained during the fourth term, a significant difference was 48.8 mg, where t_f – 5.61 > $t_{0.05}$ – 2.01.

***Table 2**. Characteristics of the growth and development of barley plants at the beginning of the tillering phenophase at different sowing dates (2019)*

Sowing period	Plant biomass, mg	Root system, mg		Aerial part, mg		Leaf area, cm^2
		raw biomass	dry matter	raw biomass	dry matter	
1	699.5 ± 6.3	64.7 ± 2.7	16.6 ± 0.60	634.8 ± 6.8	127.7 ± 2.5	17.5 ± 0.62
2	573.7 ± 5.8	42.7 ± 1.9	11.6 ± 0.50	531.0 ± 5.7	94.5 ± 2.0	14.9 ± 0.39
3	516.9 ± 5.5	29.4 ± 2.3	9.3 ± 0.44	487.5 ± 6.3	81.5 ± 2.1	13.8 ± 0.38
4	464.2 ± 6.4	19.2 ± 1.7	7.0 ± 0.56	445.0 ± 6.7	69.6 ± 2.4	12.4 ± 0.45
5	415.4 ± 5.9	11.5 ± 2.0	5.0 ± 0.48	403.9 ± 5.0	61.4 ± 2.3	10.1 ± 0.45

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

Next, the indicators of barley growth and development were analysed according to the component part of the plant root system. In the first sowing term, the crude biomass of the root system of plants (64.7 mg) was significantly higher than in the second sowing term. The difference within 22.0 mg is significant at the error level of 5.0% (t_f – 6.67 > $t_{0.05}$ – 2.01). The biomass of the root system of barley plants of the third sowing period of 29.4 mg was also significantly lower than the corresponding indicators of the second sowing period (t_f – 4.46 > $t_{0.05}$ – 2.01). In an analogous pattern, the biomass of the root system of plants of the fourth sowing term is significantly lower compared to the biomass of the root system of the third term, the difference is 10.2 mg (t_f – 3.57 > $t_{0.05}$ – 2.01). The lowest biomass of the root system was found for plants in the fifth sowing term, where the index of 11.5 mg was lower compared to the data obtained in the fourth sowing term, the difference of 7.7 mg is significant (t_f – 2.94 > $t_{0.05}$ – 2.01). Assessment of barley plants development by indicators of root system dry matter at different sowing dates follows the pattern established according to the data of crude biomass. The highest value was obtained at the first sowing date – 16.6 mg and the lowest at the fifth date – 5.0 mg, the difference was 11.6 mg. For each subsequent sowing period, starting with the first, the figures have been consistently lower. The difference analysis for pairwise comparison of adjacent options is characterised by the following values. Indicators of the first and second sowing periods differed within 5.0 mg (t_f – 6.41 > $t_{0.05}$ – 2.01). Indicators of the second and third sowing terms by dry matter weight differed significantly by 2.3 mg (t_f – 3.48 > $t_{0.05}$ – 2.01). Likewise, the parameters of the data of the third and fourth sowing periods also differed by 2.3 mg at the established criterion t_f – 3.24 > $t_{0.05}$ – 2.01. The value of the indicator for the fifth sowing term compared to the data of the fourth term was significantly lower by 2.0 mg at the established criterion t_f – 2.74 > $t_{0.05}$ – 2.01.

The following analysis of the empirical data addresses the issue of plant growth and development according to the crude biomass of the aboveground part of barley plants at the beginning of the tillering process at different sowing dates. Comparison of the data from the first and second sowing dates showed a significant difference of 103.8 mg (t_f – 11.70 > $t_{0.05}$ – 2.01). When comparing the data of the second and third sowing periods, the difference was 43.5 mg with the best results of the second sowing period (t_f – 5.12 > $t_{0.05}$ – 2.01). The following analysis describes the comparison of the data from the third and fourth sowing dates, the difference at a significant level was 42.5 mg (t_f – 4.62 > $t_{0.05}$ – 2.01). And the difference between the data obtained in the fifth sowing term and the data of the fourth term of 41.1 mg was also significant (t_f – 4.92 > $t_{0.05}$ – 2.01). The analysis of the data on the dry matter content of the aboveground part of barley plants at different sowing dates corresponds to the pattern established in the data on crude biomass. The maximum values of dry matter in the plants of the first sowing term were established, where the index 127.7 mg was higher than the parameter established in the second sowing term by 33.2 mg, the difference was significant (t_f – 10.38 > $t_{0.05}$ – 2.01). At the third sowing date, dry matter in the amount of 81.5 mg was significantly lower than at the second sowing date by 13.0 mg (t_f – 4.48 > $t_{0.05}$ – 2.01). At the fourth sowing date, the dry matter content of the aboveground part of plants was significantly lower by 11.9 mg compared to the data obtained at the third sowing date, the difference was proved to be significant (t_f – 3.74 > $t_{0.05}$ – 2.01). And at the fifth sowing date, the dry matter content in the plants was the lowest at 61.4 mg. Compared to the data of the fourth sowing term, the indicator was significantly lower by 8.2 mg (t_f – 2.47 > $t_{0.05}$ – 2.01).

A detailed analysis of the data on the leaf area of spring barley plants shows that with each subsequent sowing date, 10 days after the first one on 10 March, the parameter significantly decreased. For instance, at the second sowing date, the leaf area of 14.9 cm was significantly lower than that of the first sowing date by 2.6 cm^2 at the level of significance of the error of 5.0% (t_f – 3.56 > $t_{0.05}$ – 2.01). When comparing the data of the second and third sowing terms by this indicator, the difference of 1.1 cm^2 was significant (t_f – 2.04 > $t_{0.05}$ – 2.01). At the fourth sowing date, at the time of the onset of the phenophase of three developed leaves, their surface area was 12.4 cm^2 and was significantly less than the data obtained at the third sowing date by 1.4 cm^2, t_f – 2.41 > $t_{0.05}$ – 2.01. And in the fifth sowing period, the value was the smallest – 10.1 cm^2. Compared to the data of the fourth sowing term, the difference of 2.3 cm^2 was significant (t_f – 3.65 > $t_{0.05}$ – 2.01).

The findings of studies of the growth and development of spring barley plants at different sowing dates at the onset of the tillering phenophase in 2020 are presented in Table 3. The index of plant biomass at the first sowing date was 749.0 mg, at the second sowing date it was significantly lower at 616.3 mg. The difference of 132.7 mg is significant, the t_f criterion is 14.71 > $t_{0.05}$ – 2.01. The biomass of barley plants at the third sowing term was significantly lower by 53.8 mg compared to the data obtained at the second sowing term, with t_f – 7.16 > $t_{0.05}$ – 2.01. The biomass of plants in the fourth sowing date was significantly lower than in the third sowing date. The difference was 60.3 mg (t_f – 7.56 > $t_{0.05}$ – 2.01). The lowest values of biomass of barley plants were obtained at the fifth sowing date of 455.3 mg. Accordingly, the difference of 46.9 mg compared to the data of the fourth term is significant (t_f – 5.35 > $t_{0.05}$ – 2.01).

***Table 3**. Characteristics of the state of growth and development of barley plants at the beginning of the tillering phenophase at different sowing dates (2020)*

Sowing period	Plant biomass, mg	Root system, mg		Aerial part, mg		Leaf area, cm^2
		raw biomass	dry matter	raw biomass	dry matter	
1	749.0 ± 7.0	70.5 ± 2.9	19.5 ± 0.70	678.5 ± 6.6	134.1 ± 3.1	18.9 ± 0.58
2	616.3 ± 5.7	46.5 ± 2.3	15.0 ± 0.61	569.8 ± 7.3	99.8 ± 2.7	16.1 ± 0.27
3	562.5 ± 4.9	33.9 ± 2.7	11.2 ± 0.59	528.6 ± 5.4	85.6 ± 2.9	15.0 ± 0.31
4	502.2 ± 6.3	20.5 ± 2.2	8.0 ± 0.40	481.7 ± 5.9	73.9 ± 2.0	13.5 ± 0.37
5	455.3 ± 6.1	13.3 ± 2.0	5.9 ± 0.47	442.0 ± 6.5	64.9 ± 2.4	11.4 ± 0.40

Source: *developed by the authors*

The crude biomass of the root system of plants at the first sowing date was characterised by the highest value of 70.5 mg. The difference in comparison with the same indicator at the second sowing date of 24.0 mg was significant (t_f – 6.49 > $t_{0.05}$ – 2.01). The index of crude biomass of the root system of barley plants of the third sowing period of 33.9 mg was 12.6 mg less than the data of the second sowing period, the difference was significant (t_f – 3.56 > $t_{0.05}$ – 2.01). When comparing the data from the third and fourth sowing dates, the difference was also significant at 13.4 mg (t_f – 3.85 > $t_{0.05}$ – 2.01). The lowest value of the crude biomass of the root system of barley plants was obtained at the fifth sowing date of 13.3 mg. The difference compared to the data of the fourth sowing period of 7.2 mg was significant (t_f – 2.42 > $t_{0.05}$ – 2.01). The analysis of the root system dry matter data depending on the sowing date showed a pattern where with each subsequent sowing date, 10 days after the first sowing on 10 March, there was a significant decrease in dry matter weight. The maximum value obtained in the first sowing period of 19.5 mg was 4.5 mg higher than in the second sowing period, where t_f – 4.89 > $t_{0.05}$ – 2.01. The value for the second sowing date of 15 mg was significantly higher than that of the third sowing date. The difference was 3.8 mg, Student's criterion t_f – 4.52 > $t_{0.05}$ – 2.01. The figure for the third sowing season is significantly higher than that for the fourth sowing season. The difference was 3.2 mg (t_f – 4.51 > $t_{0.05}$ – 2.01). And in the fifth sowing term, the value of 5.9 mg was significantly lower compared to the data of the fourth term. The difference of 2.1 mg was significant, Student's t_f – 3.44 > $t_{0.05}$ – 2.01.

The crude biomass of the aboveground part of plants decreased significantly from the first sowing date to each subsequent one. The value of 569.8 mg obtained in the second sowing period was significantly lower than in the first sowing period by 108.7 mg (t_f – 11.05 > $t_{0.05}$ – 2.01). The index of crude biomass of the aboveground part of plants in the third sowing term was 41.2 mg lower than that obtained in the second sowing term. The difference was significant (t_f – 4.54 > $t_{0.05}$ – 2.01). According to this pattern, the indicator of the fourth sowing term was significantly lower than the indicator of the third sowing term by 46.9 mg, t_f – 5.86 > $t_{0.05}$ – 2.01. The lowest value of the crude biomass of the aboveground part of barley plants was found when sowing in the fifth term, the difference to the data of the fourth sowing term of 39.7 mg was significant, Student's criterion t_f – 4.53 > $t_{0.05}$ – 2.01. The results of the analysis of the data on the dry matter content of the aboveground part of plants depending on the sowing dates show that with each subsequent term, starting from the first, the dry matter content of plants gradually decreased. Thus, in the second sowing term, the index of 99.8 mg was significantly lower than the same index obtained in the first sowing term by 34.3 mg (t_f – 8.35 > $t_{0.05}$ – 2.01). Accordingly, the third sowing season was significantly lower than the second sowing season. The difference was 14.2 mg at t_f – 3.59 > $t_{0.05}$ – 2.01. Comparison of the data of the fourth sowing period with the data of the third one was characterised by a significant difference of 11.7 mg (t_f – 3.32 > $t_{0.05}$ – 2.01). The comparison of the data of the fifth sowing term with the data of the fourth is determined by a significant difference at 9.0 mg, the Student's criterion t_f – 2.88 > $t_{0.05}$ – 2.01.

When characterising the leaf area data, a pattern of better results was also found at early sowing dates. The maximum value was obtained at the first sowing date of 18.9 cm^2. In the second sowing term, the data value was 2.8 cm^2 less, and a significant difference was found (t_f – 4.44 > $t_{0.05}$ – 2.01). The third sowing season was characterised by a lower value compared to the data obtained for the second sowing season. The difference of 1.1 cm^2 was significant, the Student's criterion t_f – 2.68 > $t_{0.05}$ – 2.01. At the fourth sowing date, the leaf surface area of the plants was 13.5 cm^2, which was 1.5 cm^2 less than the value of the third date, the difference was significant (t_f – 3.12 > $t_{0.05}$ – 2.01). The lowest value of the leaf area of barley plants was found for the fifth sowing date – 11.4 cm^2. The difference compared to the data of the fourth sowing term of 2.1 cm^2 was significant (t_f – 3.89 > $t_{0.05}$ – 2.01).

Thus, the dependence of growth and development of spring barley plants on sowing dates was established. According to the first, second, third, fourth, and fifth sowing dates, at the time of the tillering phenophase, the parameters of growth and development of spring barley plants significantly decreased. On average for three years, the respective values of the indicators were as follows: plant biomass – 723.6 mg; 594.5 mg; 539.2 mg; 482.8 mg; 434.9 mg; crude biomass of the root system – 67.5 mg; 44.6 mg; 31.6 mg; 19.8 mg; 12.3 mg; dry matter of the root system – 18.0 mg; 13.3 mg; 10.3 mg; 7.5 mg; 5.4 mg; crude biomass of the aerial part of plants – 656.1 mg; 549.9 mg; 507.6 mg; 463.0 mg; 422.5 mg; dry matter of the aerial part of plants – 130.8 mg; 97.1 mg; 83.5 mg; 71.7 mg; 63.1 mg; leaf surface area – 18.1 cm^2; 15.5 cm^2; 14.3 cm^2; 12.9 cm^2; 10.8 cm^2 (Table 4).

***Table 4**. Characteristics of the state of growth and development of barley plants at the beginning of the tillering phenophase at different sowing dates (average for 2018-2020)*

Sowing period	Plant biomass, mg	Root system, mg		Aerial part, mg		Leaf area, cm^2
		raw biomass	dry matter	raw biomass	dry matter	
1	723.6	67.5	18.0	656.1	130.8	18.1
2	594.5	44.6	13.3	549.9	97.1	15.5
3	539.2	31.6	10.3	507.6	83.5	14.3
4	482.8	19.8	7.5	463.0	71.7	12.9
5	434.9	12.3	5.4	422.5	63.1	10.8

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

Accordingly, the results of the accumulation of spring barley plants of crude biomass, dry matter, leaf surface formation as a result of the use of vegetation factors before the onset of the tillering phenomenon at different sowing dates are of particular interest, which is to understand the rational use of environmental resources from the very beginning of growth and development.

The general theoretical issues of plant growth and development include changes that occur in the body of all biological species without exception. All biological species are characterised by developmental stages, vegetation phases, and stages of organogenesis (Kalenska *et al.*, 2018; Celestina *et al.*, 2023). The changes that occur in plants during growth and development can be distinguished both visually and by various research methods. Functionally, growth and development are the result of the interaction between the genotype of a biological object and the external environment. The external environment as an influence factor should be considered in terms of several important components, the key of which is the energy factor. Accordingly, the outcome of the interaction depends on both the structure of the DNA and the integral or total effect of the constituent environmental conditions, which results in the formation of the phenotype (Shaaf *et al.*, 2018). This allows establishing and evaluating the results of the interaction of the components based on the parameters of biometric indicators, dry matter content, plant model, and other parameters. If the same biological object is evaluated in an experiment under different environmental conditions, according to their impact on growth and development, the result of changes is directed by environmental or vegetation factors. Such results will provide a basis for understanding the need for rational and efficient use of vegetation factors to achieve maximum results in the formation of highly productive agrophytocenoses. Growth is usually characterised by quantitative changes that increase plant size, volume, and mass of newly formed cells. Plants grow continuously until the end of the vegetation cycle. Growth processes are followed by qualitative changes as a result of increasing plant size in a natural sequence. This is plant development. Growth creates a resource for the differentiation of new specialised tissues that form new organs, which ensures structural and functional changes in the entire organism.

A considerable role is played by plant growth characteristics in different phases of their development to fulfil the productivity potential of grain crops. S. Harkness *et al*. (2020) note that upon early sowing, plants use as much precipitation as possible during the winter period, which reduces plant losses from drought in the summer. Sowing at a late date usually does not produce large yields. While early sowing and emergence of seedlings always lead to faster flowering and maturation, thereby helping to avoid the negative effects of heat and drought, which usually results in higher grain yields. High temperatures tend to accelerate plant growth and development (Kiriziy & Stasik, 2022). The vegetation period becomes shorter, which leads to less radiation absorption and less biomass formation, and as a result, it leads to lower grain yields (Yadav *et al.*, 2022). P. Pal *et al*. (2018) noted that to ensure maximum barley yields, sowing should be carried out at the appropriate time, which must be observed so that the crop plants germinate well and use soil moisture efficiently.

The lower leaves play an important role in the formation of the root system and the ear in the early stages of plant development in cereals. The number and size of leaves, the value of net photosynthetic productivity directly affect the accumulation of dry matter (Dubytsky *et al.*, 2023; Stasyk *et al.*, 2021). Leaves are the main part of plant phytomass (Hospodarenko *et al.*, 2020). The size and dynamics of leaf surface development depends on many factors. In recent years, the sowing date has become an essential factor in the formation of the leaf assimilation surface area, which determines the intensity of plant growth and development. Environmental conditions affect the balance of phytohormones, the direction of physiological processes, changes in linear dimensions, plant habitus, etc., in plant growth and development, specifically in spring barley.

In the technology of spring barley cultivation, the results of the implementation of growth and development processes during the period from sowing to the onset of the tillering phenomenon, or the second and third stages of organogenesis, are of particular interest. The second and third stages of organogenesis are the period of plant development during which the yield structure of the first and second elements is laid down. To produce stable, high-quality crops during the growing season, one needs favourable weather conditions, which unfortunately cannot be controlled. It is known that by changing the timing of sowing, one can influence the supply of heat and solar radiation to plants. That is why sowing at the optimum time will help plants pass through the stages of organogenesis on which the future productivity of the agrophytocenosis depends.

CONCLUSIONS

This study established the regularity of reduction of spring barley biological potential, which provides the starting resource of plants in terms of development at the beginning of the tillering phenophase, depending on the sowing time with a delay of 10 days starting from March 10. The results of the analysis of the total biomass of plants for the first sowing period were on average 723.6 mg, for the second – 594.5 mg, for the third – 539.2 mg, for the fourth – 482.8 mg, and for the fifth – only 434.9 mg, which indicates significant changes under the influence of vegetation factors. Analysis of the development of the root system, which contributes to the formation of the aerial part of spring barley plants and characterises the obtained results of the maximum parameters of crude biomass 67.5 mg and dry matter 18.0 mg at the first sowing term. With each subsequent sowing date after 10 days, the values of these indicators were significantly lower, and respectively amounted to: crude biomass – 44.6 mg, 31.6 mg, 19.8 mg, 12.3 mg, and dry matter – 13.3 mg, 10.3 mg, 7.5 mg, 5.4 mg. According to the obtained pattern, the aerial part of plants is best provided with development conditions similarly to sowing on 10 March, when the indicators of plant biomass and dry matter were the best and were characterised by data of 656.1 mg and 130.8 mg, respectively. With each subsequent shift of the sowing date by 10 days, the obtained indicators became significantly lower, and accordingly amounted to: crude biomass – 549.9 mg, 507.6 mg, 463.0 mg, 422.5 mg, and dry matter – 97.1 mg, 83.5 mg, 71.7 mg, 63.1 mg.

The results of the analysis of the leaf surface area of plants, on which the photosynthesis process depends, indicate the expediency of early sowing. The maximum value of 18.1 cm^2 was obtained at the end of plant growth and development at the beginning of the tillering phenomenon at the first sowing date of March 10. Sowing every 10 days resulted in a significant reduction in leaf area, where the indicators were 15.5 cm^2, 14.3 cm^2, 12.9 cm^2, and 10.8 cm^2, respectively. The described regularities of fulfilment of spring barley plants development potential at the beginning of tillering phenophase depending on sowing dates represent the results of efficient use of environmental resources, specifically, vegetation factors. Prospects for further investigation lie in assessing the intensity of the tillering process of spring barley plants depending on the sowing time. Dependence of plant model formation on the degree of synchronisation and homogeneity of tillering shoots development compared to the main shoot. It is also promising to investigate the fulfilment of the potential of spring barley ear productivity in terms of the number of grains according to the sowing time.

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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 на початку фенофази кущення за різних строків сівби

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Анотація. Глобальні зміни кліматичних умов, які також відбулися і в Західному Лісостепу України сприяють раннім строкам сівби розпочинаючи вже з самого початку весняної пори року. У зв'язку з цим для забезпечення наукового обгрунтування технології вирощування ячменю ярого питання вивчення процесів росту та розвитку рослин до настання фенофази кущення, тобто другого та третього етапів органогенезу набуває особливої актуальності. Мета досліджень полягала у встановлені закономірності залежності процесів росту та розвитку рослин ячменю ярого від впливу факторів вегетації за різних строків сівби в умовах Західного Лісостепу України. Для узагальнення результатів досліджень застосовані наступні методи: загальнонаукові, в основі яких є об'єктивність, доказовість, відтворення та математично-статистичні – для обробки експериментальних даних. Встановлено залежність процесів росту та розвитку рослин ячменю ярого на основі показників біомаси рослин, сирої біомаси та вмісту сухої речовини кореневої системи і надземної частини рослин, а також площі листкової поверхні за проведеним аналізом на початку фази кущення від впливу строків сівби. Оцінено значущість дослідженого фактору за впливом умов забезпечення для максимальної реалізації потенціалу продуктивності ячменю ярого. В результаті виявлено закономірність за якою встановлено істотне зниження потенціалу продуктивності рослин ячменю з відтермінуванням на кожних наступних 10 днів починаючи від першого строку сівби проведеного 10 березня. Максимальні значення даних отримано за першого строку сівби, де біомаса рослини становила 723,6 мг; сира біомаса кореневої системи – 67,5 мг; суха речовина кореневої системи – 18,0 мг; сира біомаса надземної частини рослини – 656,1 мг; суха речовина надземної частини рослини – 130,8 мг і площа листкової поверхні – 18,1 см^2. В результаті наукового обгрунтування практична цінність роботи полягає в сприятливості ранніх строків сівби для забезпечення максимальної реалізації потенціалу продуктивності рослин за рахунок факторів вегетації

Ключові слова: біомаса рослин; сира біомаса; суха речовина; коренева система; надземна частина рослин; площа листкової поверхні; критерій Стьюдента