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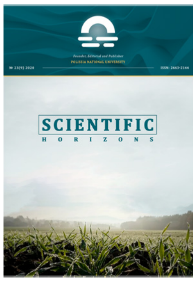

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Influence of Weather Conditions on the Duration of Interphysical Periods and Yield of Durum Winter Wheat

Margaryta Korkhova*, Vira Mykolaichuk

Mykolaiv National Agrarian University

54000, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine

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Abstract. Despite the high genetic potential of productivity of new varieties, the yield of durum winter wheat remains low. One of the reasons for this is non-compliance with the recommended cultivation technologies, which would take into account the genetic characteristics of different varieties, their adaptation to the climatic conditions of the region. Due to insufficient scientific studies of the impact of weather conditions on the productivity of durum winter wheat, taking into account the main strategy of agricultural adaptation to negative climate changes in the southern steppe of Ukraine, the research topic is relevant. The aim of the work was to determine the degree of influence of changes in weather and climatic conditions in the main interphase periods on the growth and development and yield of winter durum wheat grain, depending on the varietal composition. Field studies were conducted during 2014-2020 yrs in the experimental field of the MNAU training, research and practical center with four varieties of winter durum wheat. In the course of the study, generally accepted methods were used: system approach and systems analysis, monographic, analysis and synthesis, field research and statistical mathematical, etc. Its predecessor was black steam, the sowing period was October 1st. According to the results of research, it was determined that the formation of winter durum wheat grain yield was significantly influenced by the duration of interphase and vegetations and the amount of precipitation. The weather conditions of 2014, 2016 and 2019 were more favorable for the germination of winter durum wheat seeds, when the plants reached the sum of effective temperatures of 70.0-89.1°C, the duration of the interphase period "sowing-seedlings" was only 11-12 days. In favorable yields in 2016 and 2019 yrs the duration of the vegetation of plants was the longest – 296 and 288 days, respectively, with the amount of precipitation for the reporting period – 358.5-402.0 mm, and in unfavorable years in 2018 and 2020 yrs the vegetation was 272 and 276 days with the amount of precipitation 256.9 and 308.9 mm. The highest average yield of winter durum wheat grain by variety was formed in 2016 yr as 7.24 t/ha, which was by 8.3-43.5% higher than in other years studied

Keywords: durum wheat, varieties, interphase period, sum of effective temperatures, sum of precipitation, grain yield

*Corresponding author

INTRODUCTION

Modern agricultural production is threatened by climate change, which is characterised by rising temperatures, changes in precipitation patterns, and frequent extreme weather events (Arora, 2019; Ivanyuta *et al*., 2020). The consequences of global climate change are becoming more and more noticeable in Ukraine. Analysis of the frequency of extreme weather conditions, namely droughts, shows an alarming trend of their increase. Over the past 20 years, the average annual temperature has increased by another 0.8°C, and the average temperature in January and February – by 1-2°C. The duration of the growing season with a minimum threshold of 10°C over the past 30 years in Ukraine has increased by 16 days, which has already led to changes in the rhythm of seasonal phenomena – spring floods, the beginning of plant flowering in winter, snowfall in spring or autumn, etc. (Pisarenko *et al*., 2020).

According to the researchers, by 2070, wheat yields in the steppe zone may decrease to 5.5 cent./ha, so measures to develop effective adaptation should focus on preparing this region for the expected climate changes (Balabukh *et al*., 2017).

The Food and Agriculture Organization of the United Nations proposes a "Save and grow" agriculture intensification model to reduce the impact of climate change on wheat production, which consists in a sustainable increase in yields on existing agricultural land (Graziano da Silva, 2016).

Durum wheat is of interest to the global grain industry primarily as a raw material for pasta, baby food products, and baking (Pompa *et al*., 2021; Peressini *et al*., 2020). Compared to soft wheat, hard wheat has significant advantages – it is less affected by diseases and pests, does not crumble, is more resistant to lodging, is more resistant to air drought, and provides stable yields on a high agricultural background (Steiner *et al*., 2019; Korkhova, 2020). However, due to increased requirements for agroclimatic conditions, its acreage in the world ranges from 16 to 18 million hectares, which provides up to 8.0-10.0% of global wheat grain production (De Vita & Taranto, 2019).

In Ukraine, the acreage of durum wheat is about 500 thousand hectares, although, the soil and climatic conditions are favourable for growing and obtaining high yields, especially the winter crop (Franchesko, 2013). Modern varieties of durum winter wheat have a fairly high genetic potential for productivity and quality, as evidenced by the studies (Giunta *et al*., 2019; Stefanova-Dobreva & Muhova, 2020). However, the yield of this crop remains low due to abiotic and biotic stress factors, which negatively affect photosynthesis and, as a result, limit plant growth.

There is evidence that climate changes, namely rising air temperatures and changes in humidification during the growing season, negatively affect wheat yields in many regions of the world (Raza *et al*., 2019; Kucher, 2017; Sabella *et al*., 2020). Especially in recent years, there has been an increase in temperature in the autumn and winter period, the duration of the autumn vegetation of winter crops is gradually reduced. Often in winter, there is a long-term restoration of vegetation, and the final restoration of spring vegetation occurs two to three weeks earlier than long-term periods, which leads to a significant reduction in the winter dormancy period. An increase in air and soil temperature in winter contributes to better overwintering of winter durum wheat plants. In this regard, in the zone of the southern steppe of Ukraine, it is necessary to grow crops that can adapt to the climatic realities of today in the conditions of rainfall farming, which includes winter durum wheat (Balabukh's, 2018; Ostapenko & Kostyrya, 2020).

It is possible to balance the negative impact of weather and climatic conditions by strictly observing the recommended technologies for growing durum winter wheat, which would take into account the genetic characteristics of different varieties (Mereu, 2021; Kahiluoto *et al*., 2019). The relevance of the subject matter is conditioned by the fact that the choice of a variety adapted to the climatic conditions of the region is the main strategy for adapting agriculture to negative climate changes, especially in the south of Ukraine. Currently, Ukraine pays considerable attention to the investigation of the productivity of spring durum wheat, while the influence of weather conditions of the year on the yield of winter durum wheat varieties has not been sufficiently studied. The use of durum wheat varieties that are resistant to drought and unfavourable winter conditions can effectively increase grain productivity (Mengistu, 2019).

The purpose of the study was to determine the degree of influence of changes in weather and climatic conditions in the main interstage periods on the growth and yield of winter durum wheat grain, depending on the varietal composition.

LITERATURE REVIEW

Many researchers have proven that the yield of winter durum wheat depends on weather conditions [16]. V. Lubich & I. Polyanetska (2021) in the Right-bank forest-steppe of Ukraine, have determined that the yield of winter durum wheat varied from 3.74 to 5.46 t/ha for the Kontinent variety and from 4.63 to 7.99 t/ha for the Linkor variety, depending on the year of study.

N.E. Samofalova *et al*. (2019) prove that the temperature regime plays a crucial role in the yield of winter durum wheat, and its productivity depends not on the total amount of precipitation, but on their distribution, the presence of moisture in the soil, and temperature. However, these studies were conducted in different soil and climatic conditions, which differ from the southern steppe of Ukraine.

The seed germination phase is important in timely obtaining full-sized seedlings, forming the density of crops, and the future harvest of durum winter wheat (Poltoretsky, 2020). Predicting the emergence of seedlings and determining the duration of the "sowing-germination" interstage period is important in agricultural practice, because late shoots of winter wheat often lead to liquefaction of crops, weak tillering and plant development, which significantly reduces crop productivity. Long-term studies have determined that with timely receipt of full-sized shoots of winter wheat, plants develop well from autumn and create a secondary root system, which contributes to overwintering and increases plant resistance to drought (Zaiets, 2019; Zapisotska, 2021).

Based on the findings of A. Kovalenko *et al.* (2020), conducted in the southern steppe zone of Ukraine, under conditions of optimal soil moisture, the duration of the "sowing-germination" period when growing winter wheat on black fallow was 11 days, and in dry autumn, shoots appeared on 47th day.

The growth and development of winter durum wheat plants in the autumn period depend not only on the timely emergence of seedlings but also on the date of termination of the autumn vegetation. Too early or late termination of the autumn vegetation of plants is not favourable for sowing crops in the autumn-winter period (Mostipan, 2019).

M. Mostipan *et al.* (2021) claim that the highest yield of winter wheat (5.67 t/ha) for black fallow is formed in years with the cessation of autumn vegetation in the third decade of November.

Many studies have determined that the duration of the autumn vegetation of winter wheat plants should be from 40 to 60 days. During this period, plants should have time to gain the sum of effective temperatures from 300 to 350°C, which will ensure the accumulation of a sufficient amount of plastic substances in the tillering nodes and contribute to better overwintering of wheat plants and their resistance to adverse conditions of the spring-summer growing season (Gulyanov *et al.*, 2021).

The growth and development of winter wheat also depend on the time of resumption of the spring growing season (Miroshnychenko *et al.*, 2021). In recent years, due to the warming climate, the average date of vegetation resumption has somewhat shifted. In recent years, in Ukraine, in particular in Mykolaivska oblast, at the latest (April 6), the restoration of vegetation of winter grain crops was observed in 2003, which led to a significant shortage of crops (Ministry of Agrarian Policy and Food of Ukraine, 2022).

MATERIALS AND METHODS

Experimental studies were conducted over six agricultural years (2014/2015-2019/2020) in the experimental field of the MSAU Educational, Scientific, and Practical Centre, which belongs to the southern steppe zone of Ukraine. Agricultural technology in the experiment was generally accepted, namely: the predecessor – black fallow, the sowing period – October 1, the seeding rate – 5 million pcs/ha. The experiment included 4 variants (varieties), which were placed randomly in four repetitions. The area of the accounting plot – 25 m².

The soil of the experimental field is typical for southern chernozem residual-slightly alkalinised heavy loamy on loess soil with a humus content (0-30 cm) from 3.1 to 3.3 % and a neutral reaction of the soil solution (pH – 6.8-7.2). The arable soil layer contained an average of 15-25 mobile forms of nitrates (according to Grandval-Lajoux), mobile phosphorus – 41-46 (according to Machigin) and 389-425 mg/kg of exchange potassium (on a semi-lamp photometer).

The material for the research was durum wheat varieties Linkor, Kreiser, Bosfor, and Havan owned by the Plant Breeding and Genetics Institute – National Centre of Seed and Cultivar Investigation (PBGI – NCSCI), which are registered in the state register of plant varieties suitable for distribution in Ukraine in 2010-2011 (Ministry of Agrarian Policy and Food of Ukraine, 2022; Gadzalo *et al.*, 2021).

The analysis of agroclimatic conditions was carried out according to the Austrian-made PesslInstruments (iMETOS) weather station, which provides not only high-precision local meteorological data, but also a high-precision weather forecast for 6 days. The weather station is equipped with sensors that determine such indicators as: precipitation, air and soil temperature; humidity level of air, soil, and leaf; wind speed, etc.

Phenological observations were carried out in the main phases of plant growth and development according to the "Methodology of state variety control of agricultural crops" (Tkachuk *et al.*, 2017). The beginning of the phase was recorded when it occurred in 10% of plants and full – in 75% of plants. The interstage period was calculated as the time interval from the full previous phase to the beginning of the next phase; the duration of the growing season of the variety was calculated from the date of full germination to the date of waxy (economic) ripeness.

Winter durum wheat was harvested using a Sampo-500 combine. After threshing each site, the threshing machine of the combine was turned off, the collected grain was weighed separately and transferred to standard humidity (14%) and purity (100%).

The obtained results in the form of analytical digital material were subjected to statistical and mathematical processing performed by the method of variance and correlation analysis using Microsoft Excel and Agrostat software suites with the method of variation, correlation, and variance analysis.

The years of research differed significantly in weather conditions. Thus, the 2014/2015 and 2015/2016 agricultural years were medium-wet, with 337.5 and 358.5 mm of precipitation falling during the growing season, respectively, while in 2016/2017 – 159 mm; 2017/2018 – 256.9 mm, 2018/2019 – 402.0 mm, and 2019/2020 – 308.9 mm. Consequently, 2018/2019 was more favourable in terms of weather conditions, and 2016/2017 was less favourable. Such contrasting conditions allowed investigating the influence of weather conditions on the duration of interstage periods and the yield of durum winter wheat.

RESULTS AND DISCUSSION

The first stage of organogenesis of winter wheat is crucial for the development of crop density and plant yield. Timely full-sized shoots are the key to good growth and development of plants in the autumn period, and weak and sparse crops almost always form low productivity. Thus, the duration of the interstage period "sowing-germination" is very important, since plants that have time to form a powerful root system before the onset of dormancy, as a rule, have better resistance to overwintering and provide a high grain yield even with insufficient precipitation in the summer months.

It is known that the duration of germination of winter wheat seeds depends on the average daily air temperature. Therefore, the minimum temperature for germination of winter wheat seeds is +1-2°C, and the optimal temperature is 12-18°C. However, in addition to the air temperature, the humidity of the sown soil layer during the sowing of winter wheat is important, especially in the zone of risky agriculture, which includes Mykolaivska oblast. Winter wheat seeds can germinate quickly only if there is 10-15 mm of moisture in the sown soil layer. In recent years, especially in the steppe regions of Ukraine, soil drought is increasingly observed, which delays seed germination, so shoots can appear during thaws in winter, or even in spring, which does not allow plants to open up and leads to a significant decrease in grain yield.

Studies by V.F. Petrychenko *et al.* (2021) show that winter wheat plants should accumulate the sum of effective temperatures of 116-139°C from sowing to full germination. However, this issue requires additional investigation due to global warming and the emergence of varieties with a short period of vernalisation. In the years of research, the average air temperature for the "sowing-germination" period ranged from 7.2°C in 2016/2017 to 12.5°C in 2018/2019 (Table 1).

***Table 1**. Hydrothermal characteristics of the interstage period "sowing-germination" of durum winter wheat*

Indicators	Year						Average 2014-2020
	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020	
Duration of the interstage period, days	11	31	12	24	24	12	18.8
Average temperature (°C)	+10.8	+9.5	+7.2	+11.7	+12.5	+12.4	+10.8
Sum of effective temperatures, °C	70.0	158.0	86.6	176.0	176.0	89.1	113.4
Precipitation, mm	0.0	13.0	0.5	23.0	14.0	31.0	14.0
Soil moisture, %	15.0	12.0	11.7	18.2	12.5	20.0	14.9

More precipitation during the interstage period "sowing-germination" (31.0 mm) fell in the 2019/2020 agricultural year. In 2014/2015 and 2016/2017, moisture supply was worse – 0.0 and 0.5 mm for the reporting period.

The air temperature and humidity of the sown soil layer significantly affected the duration of the "sowing-germination" period, which ranged from 11 days (2014/2015) to 31 days (2015/2016). Plants have accumulated the sum of effective temperatures from 70.0 to 176.0°C. Thus, the most favourable weather conditions for the germination of winter durum wheat seeds were in 2014/2015, 2016/2017, and 2019/2020, when seedlings were obtained in the shortest period (11-12 days), while the plants managed to accumulate the sum of effective temperatures of 70.0, 86.6, and 89.1°C.

On average, for 2014/2015-2019/2020, the duration of the reporting period was 18.8 days, the average air temperature was +10.8°C, the sum of effective temperatures was 113.4°C with a humidity of the sown soil layer of 14.9%.

According to the obtained data, it is established that between the duration of the interfacial period "sowing-germination", the average daily air temperature and the sum of effective temperatures, there is a direct relationship with the average indicators of the correlation coefficient (<0.5), while between the duration of the interstage period from sowing to germination and precipitation, this relationship is with high indicators of the correlation coefficient (>0.5). That is, of the studied factors, the greatest influence on the duration of the interstage period "sowing-germination" of durum winter wheat is the amount of precipitation.

Further growth and development of plants depend on the date of termination of the autumn growing season. With the late termination of the autumn vegetation, plants outgrow, are affected by diseases and pests, and become less resistant to adverse wintering conditions. In years with an early cessation of autumn vegetation, plants can enter the winter unopened.

In 2016/2017, the termination of autumn vegetation occurred 1-2 weeks earlier than the long-term average – November 14. Close to the long-term average were 2014/2015 and 2019/2020, when the date of termination of the autumn growing season of winter wheat occurred within the long-term average period – November 21 and 24, respectively (Table 2).

***Table 2**. Dates of termination of autumn and resumption of spring vegetation of winter durum wheat, 2014-2020*

Years of research	Date of termination of the autumn vegetation	Date of resumption of spring vegetation
2014/2015	November 21	March 6
2015/2016	December 29	February 28
2016/2017	November 14	March 4
2017/2018	January 12, 2018	March 31
2018/2019	November 17	March 6
2019/2020	November 24	February 18

The autumn-winter period of 2017/2018 was abnormal in temperature, winter wheat plants temporarily stopped growing several times, and the average monthly air temperature in December was +5.2°C, which is 5.0-5.8°C higher than normal. The final cessation of vegetation of winter durum wheat plants occurred 3-4 weeks later than the long-term average – January 12. The autumn vegetation of winter wheat should last 40-60 days, while plants should gain the sum of effective temperatures of 300-350°C from sowing to a stable temperature transition through 5°C, which contributes to the accumulation of a sufficient amount of plastic substances by crops.

In the studied conditions, the autumn growing season of durum wheat lasted from 23 days (2016/2017) to 80 days (2015/2016), while the plants accumulated the sum of effective temperatures from 4.6 to 223.5°C. More precipitation (69.0 mm) for the reporting period was recorded in 2017/2018, less (5.9 mm) in 2019/2020 and completely absent (0.0 mm) in 2016/2017 (Table 3).

***Table 3**. Hydrothermal characteristics of the interstage period "germination-termination of autumn vegetation" of winter durum wheat, 2014-2020*

Indicators	Year						Average 2014-2020
	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020	
Duration of the interstage period, days	41	80	23	76	42	44	51
Average temperature (°C)	+6.9	+23.3	+2.3	+5.0	+9.4	+9.6	+9.4
Sum of effective temperatures, °C	133.0	159.0	4.6	101.0	200.0	223.5	136.9
Amount of precipitation for the interstage period, mm	47.0	49.0	0.0	69.0	17.0	5.9	31.3

Based on the observations, it was found that the best conditions for the growth and development of winter wheat plants in the autumn period were in 2014/2015 and 2018/2019, and the worst – in 2016/2017.

On average, for six years of research (2014/2015/2019/2020), the duration of the interstage period "germination-termination of autumn vegetation" of winter durum wheat was 51 days with an average daily air temperature of 9.4°C, the sum of effective temperatures – 136.9°C, and the sum of precipitation – 31.3 mm.

It is established that there is a high positive relationship (>0.5) between the duration of the interstage period of "germination-termination of autumn vegetation" of durum winter wheat and average daily temperatures and precipitation.

The duration of winter dormancy also affects the growth, development, and yield of durum wheat plants, which depends on the time of resumption of spring vegetation. Observations prove that the recovery time of spring vegetation significantly affects the growth and development, density, and grain yield of wheat plants. With the early resumption of vegetation on February 18, 2020 – plants grew more actively, but they bushed for a longer time and rooted more intensively, and in the years from late-March 31, 2018, there was a sharp transition from winter to summer.

Studies have determined that the duration of the winter dormancy period of plants on average for 2014/2015-2019/2020 was 97 days and ranged from 61 (2015/2016) to 110 days (2016/2017) (Fig. 1).

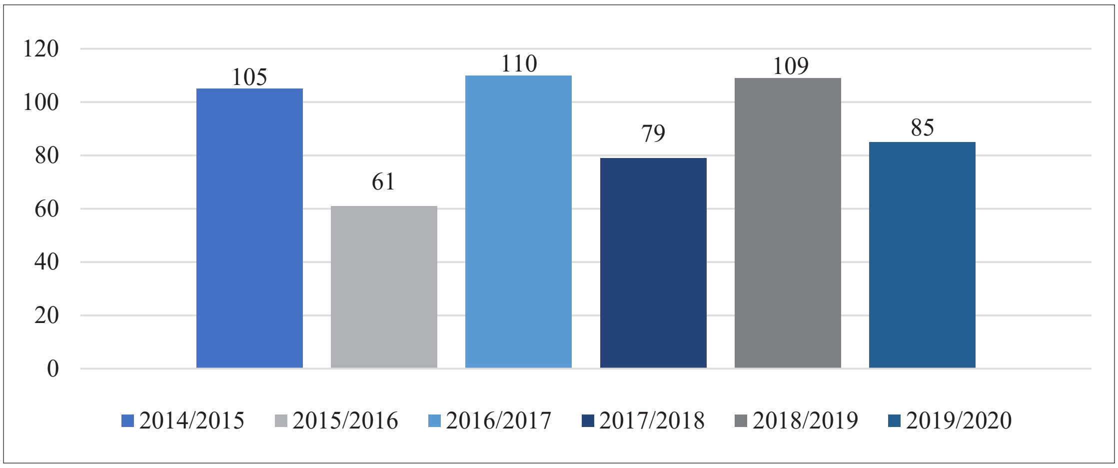

***Figure 1**. Duration of winter dormancy of durum winter wheat, days (2014/2015-2019/2020)*

During the interstage period of "termination of autumn-restoration of spring vegetation", the 2016/2017 agricultural year was drier over the years of research, when only 21.0 mm of precipitation fell in 110 days, while in 2014/2015 – 110.0 mm; 2015/2016 – 101.0 mm; 2017/2018 – 116.0 mm. The lowest average daily air temperature during this period (−2.1°C) was observed in 2018/2019, and the highest (+2.6°C) – in 2019/2020 (Fig. 2).

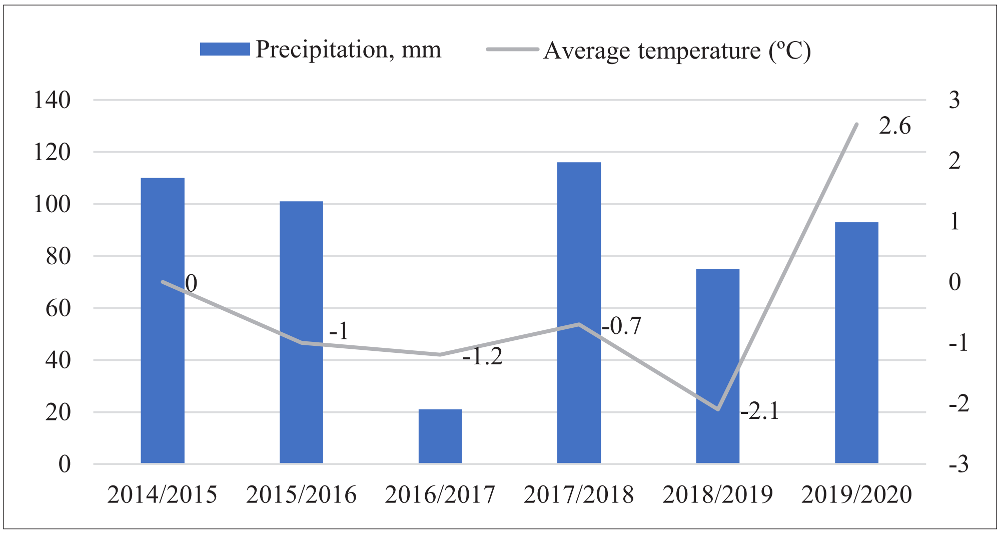

***Figure 2**. Average air temperature (°C) and precipitation amount (mm) for the interstage period "termination of autumn-restoration of spring vegetation" of winter durum wheat*

There is a low negative correlation between the duration of the dormant period of winter durum wheat plants and the average daily air temperature and precipitation (r=−0.27 and −0.20, respectively), that is, with an increase in the average daily temperature and precipitation, the duration of the dormant period decreases.

The period of "restoration of spring tillering-stem elongation" on average in Ukraine lasts 29-44 days. In the years of research, the average duration of the reporting period was 43 days with an average daily air temperature of +8.0°C, the sum of effective temperatures of 134.8°C, and the sum of precipitation of 41.6 mm (Table 4).

***Table 4**. Hydrothermal characteristics of the interstage period "restoration of spring vegetation-stem elongation" of winter durum wheat plants, 2014-2020*

Indicators	Years						Average
	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020	2014-2020
Duration of the interstage period, days	51	48	47	14	45	54	43
Average temperature (°C)	+7.1	+7.9	+7.9	+10.5	+7.5	+7.1	+8.0
Sum of effective temperatures, °C	125.5	148.2	135.9	130.5	125.2	143.6	134.8
Amount of precipitation, mm	117.0	33.5	21.0	0.0	52.0	21.0	40.8

The shortest duration (14 days) of the interstage period "restoration of spring vegetation-stem elongation" of winter durum wheat plants was recorded in 2017/2018, and the longest – 54 days in 2019/2020. In addition, in 2017/2018, there was no precipitation during this period, and the average daily temperature exceeded the long-term average, the sum of effective temperatures was within the long-term average. Thus, close to the optimal indicators for the reporting period was 2018/2019, the duration of vegetation was 45 days, with an average daily air temperature of +7.5°C with the sum of effective temperatures of 130.5°C and the sum of precipitation of 52.0 mm.

There is a high negative correlation (r=−0.98) between the duration of the interstage period "restoration of spring vegetation-stem elongation" and average daily temperatures, and the sum of effective temperatures and precipitation – a positive average (r=0.42 and r=0.49, respectively, the confidence level P=0.01). That is, the average daily temperature has the greatest influence on the duration of the study period of winter durum wheat.

It is known that the duration of the "stem elongation-earing" period is more affected by the air temperature. The higher the temperature, the shorter this period. With a reduced average daily air temperature, the interstage period "stem elongation-earing", on the contrary, is extended.

Analysing the interstage period "stem elongation-beginning of earing", it was found that its average duration in 2014/2015-2019/2020 is 34 days, with an average daily air temperature of +14.3°C, with the sum of effective temperatures of 303.9°C, and the sum of precipitation – 36.8 mm. This period was shorter (27 and 26 days) in 2014/2015 and 2018/2019, and longer (40 and 41 days) in 2019/2020 and 2016/2017, respectively (Table 5).

***Table 5**. Hydrothermal characteristics of the interstage period "stem elongation-beginning of earing" of winter durum wheat plants, 2014-2020*

Indicators	Years						Average 2014-2020
	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020	
Duration of the interstage period, days	27	37	41	33	26	40	34
Average temperature (°C)	+15.7	+14.1	+13.6	+16.7	+13.0	+12.8	+14.3
Sum of effective temperatures, °C	295.5	313.7	334.5	377.6	197.2	306.9	303.9
Amount of precipitation, mm	28.0	78.0	62.5	5.8	19.0	27	36.8

It was found that in 2018/2019 there was a relatively low average daily air temperature (+13.0°C), so plants in a shorter period gained the sum of effective temperatures of 197.2°C, despite the fact that the amount of precipitation for this period was less than the average for the years of research. 2016/2017 was characterised by relatively low average daily temperatures, but the sum of effective temperatures for 41 days was 334.5°C with precipitation significantly higher than the average values for the years of research.

In 2017/2018, the highest sum of effective temperatures (377.6°C) and the highest average daily air temperature (+16.7°C) were observed with the lowest precipitation (5.8 mm), while the interstage period was close to average in duration.

There is a high positive correlation between the duration of the interstage period "stem elongation-beginning of earing" of winter durum wheat plants and the sum of effective temperatures and precipitation (r=0.54 and r=0.57, respectively), and the average negative correlation between the duration of the interstage period and the average daily temperature (r=−0.32).

Analysing the duration of the interstage period "earing-milk ripeness of grain" of winter durum wheat plants, it was found that its average duration over the years of research was 21 days with the sum of effective temperatures accumulated by plants – 276.5°C. This period was shorter (16 days) in 2014/2015 with the sum of effective temperatures – 214.0°C. The longest interstage period of "earing-milk ripeness of grain" was established in 2019/2020 (25 days), which significantly differed from the long-term average indicators (Table 6).

***Table 6**. Hydrothermal characteristics of the interstage period "earing-milk ripeness of grain" of winter durum wheat plants, 2014-2020*

Indicators	Years						Average 2014-2020
	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020	
Duration of the interstage period, days	16	20	21	23	20	25	21
Average temperature (°C)	+20.4	+17.3	+17.3	+18.7	+20.0	+17.5	+18.5
Sum of effective temperatures, °C	214.0	253.5	307.7	291.5	294.4	298.0	276.5
Amount of precipitation, mm	20.0	49.0	21.0	30.0	49.0	53.0	37.0

The years of research also differed significantly in the average daily air temperature, which ranged from 17.3°C (2015/2016 and 2016/2017) to 20.4°C (2014/2015). A higher amount of precipitation (53 mm) for the reporting period "earing-milk ripeness of grain" was recorded in 2019/2020, which is 16 mm (30.2%) more than the average for the years of research, and the smallest 20.0 mm – in 2014/2015.

According to the results, it was found that between the duration of the interstage period "earing-milk ripeness" of winter durum wheat plants and the sum of effective temperatures, there is a high positive relationship (r=0.79), an average positive correlation for the duration of this interstage period with precipitation (r=0.48) and a high negative correlation with an average daily temperature (r=−0.62).

After analysing the duration of the interstage period "milk-wax ripeness of grain" of winter durum wheat plants for six years of research in the southern steppe zone of Ukraine, it was determined that the studied indicator ranged from 16 (2016/2017 and 2019/2020) to 23 days (2017/2018), which was affected by heterogeneous weather conditions in terms of temperature and precipitation. The average daily temperatures differed slightly from the average values of 22.7°C, and ranged from 21.2°C in 2016/2017 to 23.9°C in 2018/2019. The lowest values of the sum of effective temperatures (258.4°C) were accumulated by plants in 2016/2017, and the highest (419.0°C) in 2018/2019, which significantly distinguished them from the average values for all years of research (Table 7).

***Table 7**. Hydrothermal characteristics of the interstage period "milk-wax ripeness of grain" of winter durum wheat plants, 2014-2020*

Indicators	Years						Average 2014-2020
	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020	
Duration of the interstage period, days	22	19	17	23	22	16	20
Average temperature (°C)	+21.6	+23.3	+21.2	+22.7	+23.9	+23.4	22.7
Sum of effective temperatures, °C	364.5	317.0	258.4	388.0	418.0	287.3	338.9
Amount of precipitation, mm	15.5	35.0	3.3	13.1	176.0	78	53.5

The southern steppe of Ukraine is characterised by a heterogeneous distribution of precipitation during the growing season, especially during the grain-filling period. Over the years of observations, the lowest amount of precipitation was recorded in 2016/2017, which was only 3.3 mm, and the highest – in 2018/2019, which reached 176 mm.

Thus, in 2017 and 2019, the sum of effective temperatures and precipitation during the interstage period "milk-wax ripeness of grain" had significant deviations.

Analysis of the results obtained shows that an average positive correlation was established between the duration of the interstage period "milk ripeness-wax ripeness of grain" of winter durum wheat plants and the average daily temperature and precipitation (r=0.39 and r=0.31, respectively). A high positive relationship was established between the duration of the interstage period and the sum of the effective temperatures (r=0.88).

Calculating the duration of the growing season of winter durum wheat, it was determined that on average for 2014-2020, this figure was 278 days and ranged from 261 days in 2016/2017 to 296 days in 2015/2016. During the entire growing season, plants accumulated the sum of effective temperatures of 1,202.5-1,464.6°C (Table 8).

***Table 8**. Hydrothermal characteristics of the growing season of winter durum wheat plants, 2014-2020*

Indicators	Year						Average 2014-2020
	2014/2015	2015/2016	2016/2017	2017/2018	2018/2019	2019/2020	
Duration of the growing season, days	273	296	261	272	288	276	278
Sum of effective temperatures, °C	1,202.5	1,349.4	1,127.7	1,464.6	1,410.8	1,348.4	1,317.2
Precipitation, mm	337.5	358.5	159.0	256.9	402.0	308.9	303.8

More precipitation for the reporting period fell in 2018/2019-402.0 mm, which is 32.3 % more than the long-term average. The driest growing season for all the years studied was 2016/2017, during which only 159.0 mm fell, which is 52.3 % less than the long-term average data.

According to the findings and observations, it was determined that the highest grain yield of the studied varieties of winter durum wheat (6.63-7.91 t/ha) was obtained in 2015/2016, which is 17.3-30.7 % higher than the long-term average yield (Fig. 3).

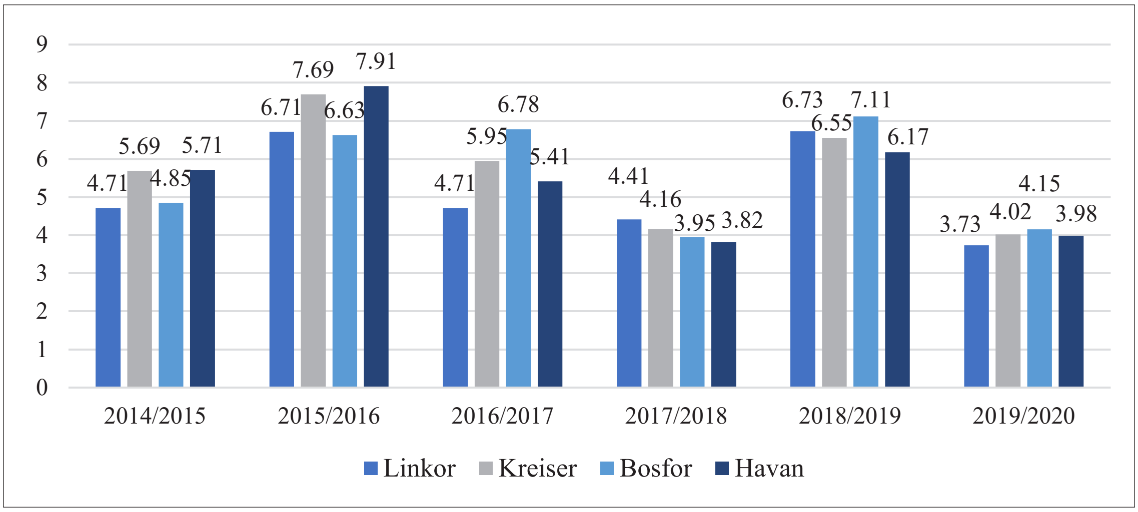

***Figure 3**. Winter durum wheat grain yield depending on the variety, 2014-2020*

***Note**: LSD_{05}=0.03 t/ha*

The yield of winter durum wheat in 2019/2020 was the smallest – 3.73-4.15 t/ha, which is 77.7-90.6 % less than in 2015/2016; 65.4-71.3 % less than in 2018/2019; 26.3-63 % more than in 2016/2017; 26.3-37.6 % more than in 2014/2015; 2.4-6.3 % more than in 2017/2018.

Among the studied varieties of durum winter wheat, the highest yield of grain (4.02-7.69 t/ha) was formed by the Kreiser variety, and the Linkor variety was less productive – 3.73-6.73 t/ha. In 2014/2015 and 2015/2016, a higher yield of winter durum wheat was obtained in the Havan variety – 5.71 and 7.91 t/ha, and a lower yield – 4.71 and 6.71 t/ha, respectively, in the Linkor variety. In 2016/2017 and 2019/2020, the Bosfor variety produced the highest grain yields – 6.78 and 4.15 t/ha, while in 2015/2016 and 2017/2018, the lowest – 6.63 and 3.95 t/ha, respectively. The Kreiser variety formed the highest yield indicators in 2014/2015 and 2015/2016-5.71 and 7.91 t/ha, while in 2017/2018 and 2018/2019, the lowest – 3.82 and 6.17 t/ha.

Similar results were obtained in the steppe zone during the state variety control. Thus, according to the economic and biological characteristics, the studied varieties of winter durum wheat belong to the medium-early ripeness group with a growing season duration of 270-273 days and an average grain yield of 4.71-6.00 t/ha (Gadzalo *et al.*, 2021; Ministry of Agrarian Policy and Food of Ukraine, 2022). In the years of research, when the duration of vegetation of plants of the studied crop was reduced to 272-276 days, the yield was obtained at the level of 3.73-5.71 t/ha. On the contrary, when the duration of the growing season increased to 288-296 days, the yield of durum wheat grain increased and reached the level of 6.17-7.91 t/ha, depending on the variety. Other researchers claim that the length of the growing season of winter durum wheat is almost independent of the weather conditions of the year (Lubich & Polyanetska, 2021).

CONCLUSIONS

Studies conducted in the conditions of the southern steppe of Ukraine with four varieties of durum winter wheat during 2014-2020 determined that weather conditions during the growing season of plants significantly affect the duration of interstage periods and crop development. The duration of the "sowing-germination" period is more influenced by the amount of precipitation. The duration of the interstage periods "germination-termination of vegetation", "stem elongation-beginning of earing" and "milk-wax ripeness" depended more on the sum of effective temperatures and precipitation. The average daily air temperature had a greater impact on the duration of the dormant period and "restoration of spring tillering-stem elongation".

The highest yield was obtained in 2015/2016 – 7.24 t/ha, the duration of the growing season was 296 days, and the amount of precipitation was 358.5 mm. This is 8.3% more than in 2018/2019; 21.1 % more than in 2016/2017; 27.6% more than in 2014/2015; 43.5 % more than in 2017/2018, and 45.2 % more than in 2019/2020. Thus, a pattern has been established that the longer the growing season of plants, the higher the yield of winter durum wheat grain.

Thus, it is determined that the yield of winter durum wheat grain is significantly influenced by the duration of interphase and growing seasons and the amount of precipitation. Thus, in the favourable years 2015/2016 and 2018/2019, the duration of the growing season of plants was the greatest – 296 and 288 days, respectively, with the amount of precipitation for the reporting period – 358.5 – 402.0 mm, and in unfavourable – 2017/2018 and 2019/2020, the growing season was 272 and 276 days with the amount of precipitation of 256.9 and 308.9 mm.

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Вплив погодних умов на тривалість міжфазних періодів та урожайність пшениці твердої озимої

Маргарита Михайлівна Корхова, Віра Георгієвна Миколайчук

Миколаївський національний аграрний університет
54000, вул. Георгія Гонгадзе, 9, м. Миколаїв, Україна

Анотація. Попри високий генетичний потенціал продуктивності нових сортів, урожайність пшениці твердої озимої залишається низькою. Однією із причин цьому є недотримання рекомендованих технологій вирощування, які б враховували генетичні особливості різних сортів, їх пристосування до кліматичних умов регіону. Через недостатні проведені наукові дослідження впливу погодних умов на продуктивність пшениці твердої озимої з врахуванням основної стратегії адаптації сільського господарства до негативних змін клімату на Півдні України, тема досліджень є актуальною. Метою роботи було визначити ступінь впливу змін погодно-кліматичних умов в основні міжфазні періоди на ріст і розвиток та урожайність зерна пшениці твердої озимої залежно від сортового складу. Упродовж шести років (2014/2015—2019/2020) на дослідному полі Навчально-науково-практичного центру Миколаївського національного аграрного університету (ННПЦ МНАУ) проводили польові дослідження з чотирма сортами пшениці твердої озимої. У ході дослідження були використані загальноприйняті методи: системний підхід і системний аналіз, монографічний, аналіз і синтез, польовий та статистичний. Попередник — чорний пар, строк сівби — 1 жовтня. За результатами досліджень визначено, що на формування врожайності зерна пшениці твердої озимої значний вплив мала тривалість міжфазних і вегетаційного періодів та сума опадів. Більш сприятливі для проростання насіння пшениці твердої озимої склалися погодні умови 2014, 2016 та 2019 рр., коли рослини набрали суму ефективних температур 70,0—89,1 °C, тривалість міжфазного періоду «сівба-сходи» при цьому становив лише 11—12 діб. У сприятливих за врожайністю 2016 р. та 2019 р. тривалість вегетаційного періоду рослин була найбільшою — 296 і 288 діб відповідно з сумою опадів за звітний період — 358,5—402,0 мм, а несприятливих 2018 р. та 2020 р. вегетаційний період становив 272 і 276 діб з сумою опадів 256,9 і 308,9 мм. Вищу середню по сортам врожайність зерна пшениці твердої озимої сформовано у 2016 р. — 7,24 т/га, що на 8,3—43,5 % — ніж у інші досліджувані роки

Ключові слова: пшениця тверда, сорти, міжфазний період, сума ефективних температур, сума опадів, урожайність зерна