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Optimization of winter wheat sowing dates to climate change in the steppe zone of Ukraine

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ABSTRACT

In the dry steppe zone of Ukraine, the adaptation of winter wheat cultivation technology to climate change is an urgent issue. In particular, cultivars and sowing time are among the cheapest and most effective technology elements aimed at increasing the resistance of winter wheat plants to abiotic and biotic stresses. Therefore, the purpose of the study is to determine the effect of sowing time of different cultivars on the formation of winter wheat plant productivity. Based on the data of weather conditions in the pre-sowing, sowing and winter periods of the crop, a comparative analysis of temperature for 2013–2018 and 2019–2023 was carried out. Based on the results of field studies, the optimal sowing dates of modern winter wheat cultivars were determined, which resulted in higher yields. The research was conducted in the natural and climatic conditions of the southern steppe of Ukraine in the Mykolaiv Raion of Mykolaiv Oblast during the growing seasons 2018/2019–2022/2023. It was determined that plants had a longer duration of autumn vegetation (79–44 days) in 2021, while the shortest (44–10 days) – in 2022. It was determined that the shift of sowing dates of the studied cultivars by every 10 days (from September 20 to October 20), plant height decreased by 3.1–10.9% depending on the cultivar. On average, in 2019–2023, the highest yield of winter wheat grain was formed by the Duma Odeska cultivar (6.88 t/ha) when sown on October 10, and the lowest yield was formed by the Ozerna cultivar (5.56 t/ha) when sown on September 20. Thus, the best conditions for the formation of winter wheat grain yields were formed when sowing on October 10 (5.00–7.85 t/ha), and the worst – on September 20 (4.50–6.28 t/ha), depending on the variety and year of research. On average, by sowing date, the highest grain yields were formed by Duma Odeska in 2019 (7.22 t/ha), 2022 (6.12 t/ha) and 2023 (7.96 t/ha), and Ozerna in 2020 (5.20 t/ha) and 2021 (6.21 t/ha).

Keywords: winter wheat, cultivars, sowing dates, plant height, number of productive stems, grain weight per ear, grain yield.

INTRODUCTION

Climate change is one of the greatest threats to humanity, resulting in severe weather disasters, abrupt weather changes, flash floods, floods, strong winds, heavy rains, hail, droughts, and significant environmental and economic damage worldwide. Increased unpredictability of weather conditions threatens global food production (Mirón et al., 2023; Zidan et al., 2024).

Research data from scientists all over the world show that unless measures are taken to adapt agriculture to climate change, its global scale could decline by up to 30% by 2050 (Ritchie et al., 2024; Hristov et al., 2020).

Climate scientists have found that over the past two thousand years, there have been three periods of warming and three periods of cooling, the last of which ended in the first half of the nineteenth century (Hansen et al., 2025). Starting in the second half of the nineteenth century, air temperature stabilized, and at the end of it, warming began, reaching 0.7–0.8 °C by the end of the twentieth century. It is predicted that the air temperature near the planet's surface will increase by another 2–4.5 °C by the end of the 21st century (Scaffeta et al., 2024).

The consequences of global climate change are becoming increasingly noticeable in Ukraine as well (Boychenko et al., 2016). An analysis of the frequency of extreme weather events, namely droughts, shows an alarming trend of their increase. Over the past 20 years, the average annual temperature has increased by 0.8 °C, and the average temperature in January and February by 1–2 °C (Lindsey et al., 2024).

Climate change is particularly noticeable in the steppe zone. The World Meteorological Organization (WMO) regulatory documents state that the average annual air temperature in the Ukrainian steppe zone has increased by 0.2–0.3 °C since the beginning of the last century (Romanenko et al., 2022). The largest temperature increase is observed in winter (by 1.2–1.3 °C) and spring (by 0.8–0.9 °C). In summer, the air temperature decreased by 0.2–0.3 °C, while in autumn it remained at the same level as in the early twentieth century (Huseynov et al., 2024).

There are suggestions that global warming poses a threat to the southern region with desertification caused by declining water availability (Pal et al., 2023). Over the past 35 years, the dry steppe sub-zone has seen a steady trend of increasing average annual temperature from 9.3 (1973–1980) to 11.3 °C (2006–2010), i.e. by 2 °C. At the same time, changes in the average annual precipitation do not have a clear pattern over time, but there is a tendency to increase precipitation of stormy and unproductive nature (Pichura et al., 2021; 2025).

Climate change is affecting crop yields, particularly cereals, due to uneven precipitation across months and rising temperatures (Yuan et al., 2024). According to (Hrytsiuk et al., 2024), by 2070, wheat yields in the steppe zone could decline to 5.5 c/ha. In dry years, the southern regions of Ukraine (Odesa, Mykolaiv, and Kherson) suffer more from crop failure. Thus, in the dry year 2020, the average wheat yield in the South of Ukraine was 1.78–3.19 t/ha, which is 22.6–54.4% more than in the wet year 2021. That is, in dry years, wheat yields in the southern steppe zone of Ukraine can decrease by more than 2 times. Therefore, measures to develop effective adaptation should focus on preparing this region for expected climate change.

Sowing winter wheat at the optimum time is the cheapest, most environmentally friendly and energy-saving element of agricultural technology, which has become especially relevant with climate warming and the emergence of new varieties in production with a reduced vernalization period (Pochkolina et al., 2023).

The sowing dates of winter wheat significantly affect the time of emergence and seedling amicability, further growth and development of crops, and their productivity (Panfilova et al., 2019; Kanapickas et al., 2024). The duration of winter wheat seed germination is crucial in the formation of high-yielding crops, which is influenced by air temperature and soil moisture (Korkhova, 2022; Domaratskiy et al., 2022). The optimal time for sowing winter wheat occurs when the average daily air temperature is 14–16 °C, at which friendly winter wheat seedlings appear on the 7th-9th day, and at 15–18 °C – on the 5th-6th day. Average daily air temperatures above 25 °C are unfavorable for seed germination due to favorable conditions for disease development. At a temperature of 40 °C with a relative humidity of 30% and below, germinated seeds die due to intense moisture evaporation, and those that swell lose germination due to respiration, nutrient consumption, and mold damage (Petrychenko et al., 2021; Sharma et al., 2022).

According to the results of field experiments in Uzbekistan with three winter wheat cultivars sown in three terms, it was determined that on average in 2014–2016, a higher grain yield (6.62 t/ha) was formed when sown on October 1, which is 2.4% more than when sown on October 10 and 6.8% more than when sown on October 20 (Gandjaeva et al., 2019).

Studies conducted during 2021–2022 in the Odesa Oblast, which is part of the Ukrainian southern steppe zone, determined that for all studied winter wheat cultivars, the best sowing date was October 5, which resulted in a grain yield of 0.02–0.55 t/ha higher than sowing on September 25 and 0.02–0.89 t/ha higher than sowing on October 15 (Serhieiev et al., 2024). This raises the problem of researching sowing dates for each region of Ukraine and for each new crop.

MATERIAL AND METHODS

The field research was conducted over five years (2018–2023) at the Educational and Research Center of Mykolayiv National Agrarian University, located in the southern steppe zone of Ukraine.

The experimental design included:

- Factor A – soft winter wheat varieties of Ukrainian selection: Ozerna, Duma Odeska, and Mudrist Odeska.
- Factor B (sowing dates) – September 20, September 30, October 10 and October 20.

The area of the sowing plot was 50 m^2, and the accounting plot was 25 m^2. The experiment was designed by the method of randomization. The agricultural technique of the research included sowing winter wheat at a seeding rate of 4.5 million units/ha with a pea as a precursor.

The soil of the experimental field is typical southern black soil, residual slightly saline heavy loamy on loess, humus content (0–30 cm) – 3.1–3.3%, soil solution is neutral (pH 6.8–7.2). The topsoil contains 15–25 mobile forms of nitrate, 41–46 mobile phosphorus, and 389–425 mg/kg of exchangeable potassium.

All the winter wheat varieties under study are recommended for cultivation in the Ukrainian steppe zone. The ear has awns and belongs to the erithrospermum type, the plants are short in height and have high drought tolerance. However, there are some differences between the cultivars.

The Ozerna winter wheat cultivar is included in the State Register of Plant Varieties Suitable for Distribution in Ukraine for 2016. The cultivar is owned by the "Bor" farm. The crop belongs to the medium-early group in terms of the growing season, and to the valuable varieties in terms of grain quality.

The Duma Odeska cultivar was registered in Ukraine in 2018. The owner of the variety is the The Plant Breeding and Genetics Institute – National Center of Seed and Cultivar Investigation, a national center for seed science and cultivation. The crop is an early ripening cultivar in terms of the growing season and a valuable cultivar in terms of grain quality.

The Mudrist Odeska cultivar was registered in Ukraine in 2015. The owner of the variety is the The Plant Breeding and Genetics Institute – National Center of Seed and Cultivar Investigation, a national center for seed science and cultivation. The crop belongs to the medium-early group in terms of the growing season, and to the strong varieties in terms of grain quality.

Phenological observations, determination of plant height, and structural analysis of sheaf samples were carried out in accordance with the methodology of state variety testing of crops. The agroclimatic conditions were analyzed using data from the Austrian-made PesslInstruments weather station (iMETOS). The obtained experimental data were processed using multivariate analysis of variance (Ushkarenko et al., 2020). Modeling of yield formation was carried out using the licensed program "Statistica 10.0".

RESULTS AND DISCUSSION

One of the most important indicators of favorable conditions for plant development in the autumn is the temperature, which determines the characteristics of the subsequent growing season of winter crops and their level of productivity. For winter wheat, the average daily air temperature during the interphase "sowing-germination" period is considered optimal – 14±2 °C.

The analysis of temperature conditions during the pre-sowing and sowing periods of winter wheat in 2018–2022 showed that in the first decade of September the average air temperature was 19.7 °C, which is 0.6 °C higher than in the previous 5 years (2013–2017). The average daily air temperature in the second ten-day period of September decreased by 0.6 °C compared to the previous long-term figures. The average air temperature in the third ten-day period of September in 2018-2022 was 0.6 °C higher than in the previous five years (2013–2017) and amounted to 14.9 °C (Figure 1).

The average daily air temperature in the first ten-day period of October over the years of research was 12.7 °C, which is 2.0 °C higher than in the same period of 2013–2017. Analyzing the temperature conditions of the second and third ten-day periods of October, it can be stated that on average, in 2018–2022, they increased by 2.3 and 3.3 °C, respectively, compared to the period of the previous five years and amounted to 12.1 and 10.1 °C. Thus, it can be concluded that the average daily air temperature increased significantly on average in 2018–2022 in the second and third decades of October.

However, the air temperature regime should not be analyzed separately, rather in combination with other meteorological elements. In steppe zone, the moisture content of the sowing layer of soil during the period of wheat sowing is of great importance. It was found that on average for 2018–2022, there is a clear trend of increasing moisture reserves in the 0–10 cm soil layer: from the first to

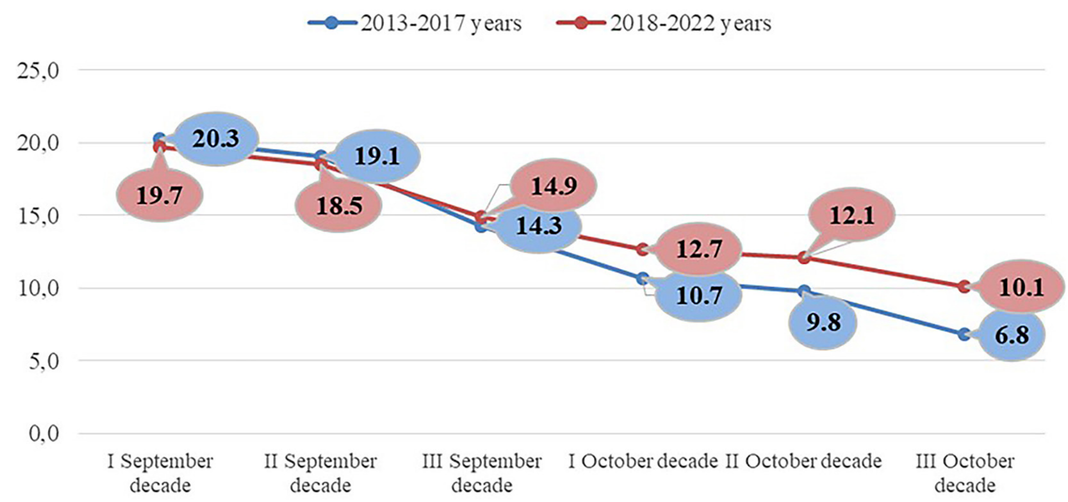

Figure 1. Average daily air temperature in autumn, average for 2018–2022, °C

the second decade (ten-day period) of September by 2.0 mm; from the second to the third decade of September – by 0.1 mm; from the third decade of September to the first decade of October – by 0.7 mm; from the first to the second decade of October – by 2.7 mm; from the second to the third decade of October – by 0.7 mm (Figure 2).

Thus, on average, in 2018–2022, moisture reserves in the 0–10 cm soil layer were sufficient (13.1 and 13.8 mm) for germination of winter wheat in the second and third decades of October, while insufficient moisture reserves were 7.6 mm in the first decade of September.

According to most authors, the autumn vegetation of soft winter wheat should last 40–60 days, when the plants reach a sum of effective temperatures of 300–350 °C from sowing to a stable transition through 5 °C (Korkhova and Mykolaichuk, 2022). On pure fallow land, vegetation should last 45–50 days, on occupied fallow land and non-fallow predecessors – 50–60 days, having reached the sum of active temperatures above 550–580 °C (Polishchuk et. al, 2024).

According to other authors (Atamanyuk et. al, 2023), for the formation of a stable winter wheat yield at the time of entering winter, it is necessary that the duration of the plant vegetation is 61–76 days, the plants accumulate the sum of effective temperatures of 250–300 °C, the amount of precipitation is 69–92 mm and the plant bushiness is 3.0–3.5 units. In such conditions, the crops have time to accumulate a sufficient amount of plastic substances for the wintering period, thanks to which they are better able to withstand the harsh conditions of both winter and spring-summer growing seasons.

During the years of research (2018–2022), the longest (79–44 days) duration of the autumn vegetation of winter wheat plants, depending on the sowing date, was recorded in 2021, which is explained by its late final termination on December 20 (Figure 3).

The shortest (44–10 days) duration of the autumn vegetation of winter soft wheat crops, depending on the sowing date, was observed in 2022, with the end of vegetation occurring very early – on November 15.

After analyzing the previous five years (2013–2017), it can be concluded that the autumn vegetation of winter wheat crops lasted somewhat longer, namely 80–49 days, depending on the sowing dates.

It was found that during the period from 2018/2019 to 2022/2023, the highest amount of effective temperatures (189.8–386.9 °C) in the interphase period "seedlings-termination of autumn vegetation" was obtained by plants sown on September 20, which is 33.0–139.3 °C higher than that on September 30; 104.6–234.1 °C higher than that on October 10 and 166.9–332.0 °C higher than that on October 20 (Table 1).

It was determined that, on average, over the years of research (2018–2022), the sum of effective temperatures for the reporting period was close to the optimal one recorded for sowing on September 20 – 260.0 °C, while the average for the previous five years was September 30 (304.4 °C) and October 10 (222.5 °C).

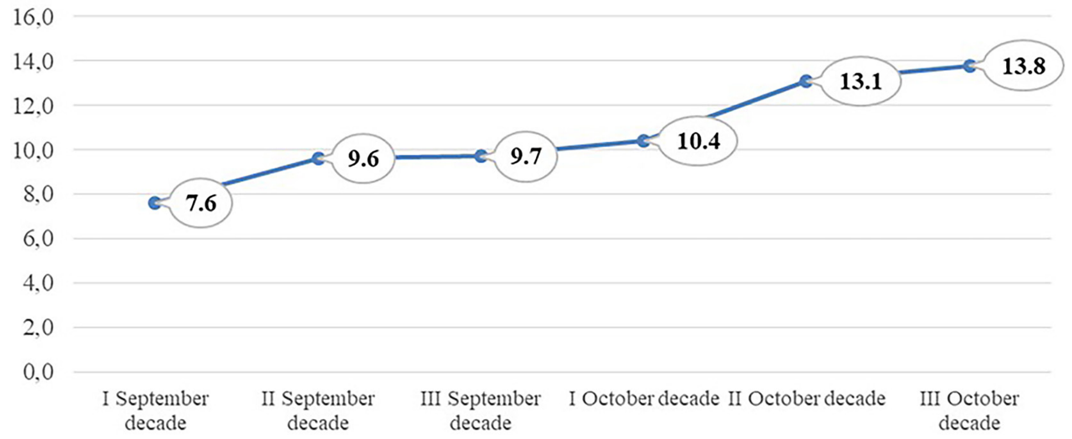

Figure 2. Average moisture content of the sowing soil layer per decade (ten-day period) at a depth of 0–10 cm in the autumn period, average for 2018–2022, mm

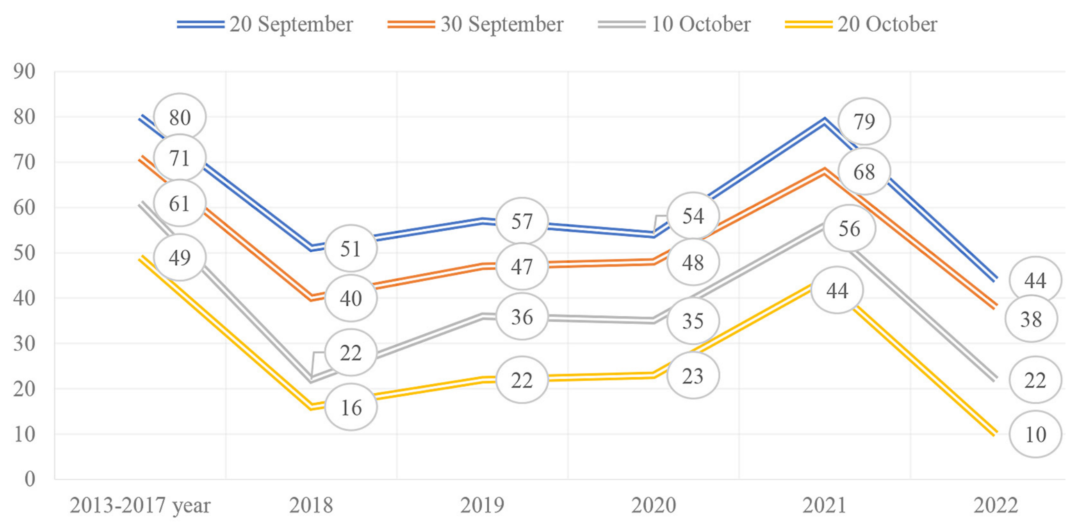

Figure 3. Autumn vegetation period of winter wheat plants depending on the sowing date in the years of research (2018–2022), in days

Over the past 10 years, the winter period has decreased to 2 months – January and February. It has been determined that over the period from 2014–2018 to 2019–2023, the average daily air temperature for the first decade of January increased by 4.3 °C (Figure 4).

For the period from 2019–2023, the lowest air temperature was observed in the second decade of January (-0.7 °C), while in the previous five years (2014–2018) the coldest was the third decade of January, with an average daily air temperature of minus 4.8 °C. It was determined that the air temperature for the third decade of February during the study period of 2019–2023 was 0.7 °C higher than in the previous period (2014–2018).

Ukrainian steppe region is characterized by frequent winter thaws and prolonged lack of low temperatures, which contributes to the resumption of vegetation in the winter months. The annual temporary renewal of vegetation during the winter contributes to the further development of winter crops and the transition to new phases of organogenesis.

In recent years, there has been a clear upward trend in positive temperatures in winter. Thus, if in the period from 2013/2014 to 2017/2018 the sum of effective temperatures for the period of short-term winter thaws was 0.4–14.4 °C, then from 2018/2019 to 2022/2023 it was 4.1–51.6 °C, which allows plants of late sowing to bush and earlier sowing to outgrow (Figure 5).

Over the years of our research, the warmest winter periods were 2020/2021 and 2022/2023, with the sum of effective temperatures during

Table 1. The sum of effective temperatures of winter wheat crops in the "sprouting – end of autumn vegetation" interphase depending on sowing dates, 2013–2022, °C

Years	Sowing dates			
	September 20	September 30	September 10	September 20
Average for 2013–2017	454.6	304.4	222.5	157.8
2018	255.2	194.5	62.3	44.7
2019	257.2	200.0	108.4	24.2
2020	386.9	247.6	152.8	54.9
2021	210.8	156.8	99.2	51.8
2022	189.8	162.4	85.2	22.9
Average for 2018–2022	260.0	192.3	101.6	39.7

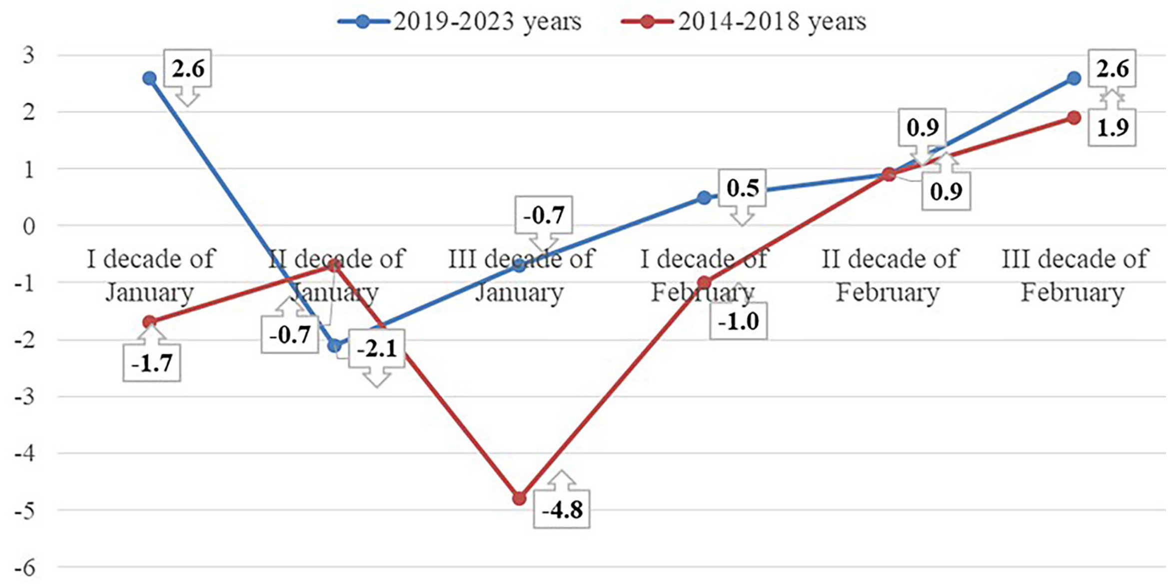

Figure 4. Average winter temperature per ten-day period, average for 2014–2023, °C

short-term winter thaws amounting to 51.6 °C and 46.7 °C, respectively.

The subsequent growth, development and yield formation of winter wheat depends on the time of spring vegetation recovery (SVR). Observations have shown that at different times of spring vegetation onset, winter wheat crops fall into different agroecological conditions, which significantly affects the growth, development, formation of crop density and yield (Hospodarenko et. al., 2020).

Studies have shown that in years with late spring, crops develop at higher air temperatures (8–10 °C) and higher solar energy intake, with a rapid increase in air temperature, which in turn impairs regeneration processes, inhibits growth, and causes the death of some shoots or even entire plants. In early spring, the vegetation of winter wheat before entering the tube takes place at low temperatures (4–7 °C), which slowly increase, which is favorable for plant regrowth, regeneration of damaged organs, and all growth processes (Ma et al., 2015).

According to long-term data, winter crops in Mykolaiv Oblast resume growing on March 20–23. However, in recent years, due to climate warming, the average date of renewal of spring vegetation has shifted slightly. Over the last 20 years (2003–2023), the vegetation of winter wheat crops in Mykolaiv Oblast started in 2008 at the earliest – on February 6. Late recovery of spring vegetation was recorded in 2003 – April 6. During the years of the research, the earliest renewal of spring vegetation was on February 18, 2020, and the latest – on March 29, 2022 (Table 2).

It was found that the interphase period "recovery of spring tillering – beginning of earing" of plants of the studied winter wheat varieties significantly

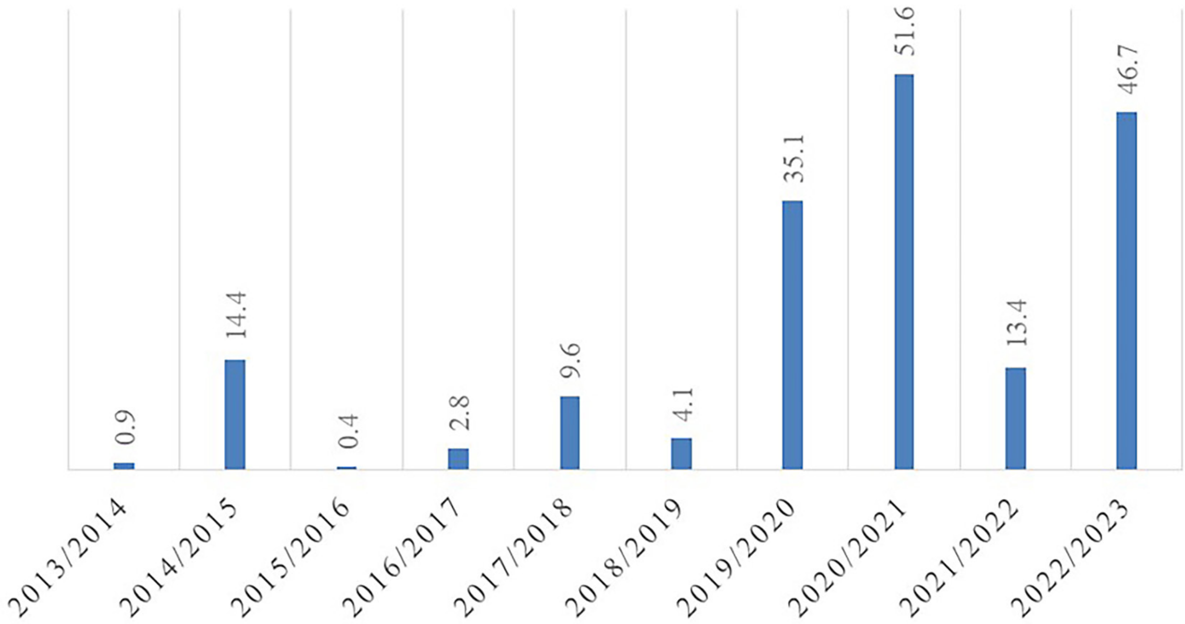

Figure 5. Total effective temperatures for the period of short-term winter thaws (2013/2014–2022/2023), °C

Table 2. Winter soft wheat renewal of spring vegetation in Mykolaiv region, 2018–2023

Years of research	End of autumn vegetation	Recovery of spring vegetation	Winter dormancy
2018/2019	November 17	March 6	104
2019/2020	November 24	February 18	83
2020/2021	November 19	March 28	112
2021/2022	November 20	March 29	88
2022/2023	November 30	March 8	84

depended on weather conditions and sowing dates. On average, over the years of research, it was determined that the shortest (64 days) interphase period "recovery of spring tillering – beginning of earing" was during sowing on September 20, when the plants accumulated the sum of effective temperatures of 316.8 °C (Table 3).

It was determined that the shift of winter wheat sowing dates by every 10 days, the interphase period was extended by 2–5 days, and the sum of effective temperatures increased by 15.3–50.8 °C.

It was determined that in 2019, the earing of winter wheat, on average, began the earliest by varieties when sown on September 20 – May 13, while when sown on September 30, October 10 and 20, the date of the earing phase was shifted 5–2 days later than when sown on September 20 (Table 4).

In 2020, the beginning of earing of winter wheat crops, on average, occurred from May 19 (September 20) to May 24 (October 20).

In the Ukrainian southern steppe, among the main structural elements of winter wheat crop productivity, the number of productive stems per area unit has a greater influence on the formation of grain yield, which depends on the formed density, weather conditions, varietal characteristics, pre-sowing seed treatment, etc (Panfilova, 2023; Korkhova, 2023). On average, during the period of field research in 2019-2023, a higher density of productive plant stems was formed by the variety Duma Odeska, which ranged from 556 pcs./m2 for sowing on October 20 to 797 pcs./m^2 for sowing on September 30 (Table 5).

It was determined that a larger number of productive stems per unit area (1 m^2) on average by sowing dates was formed by winter wheat crops of the studied varieties in 2019 – 736–747 pcs./m^2, which is 8–10 pcs./m^2 more than in 2021; 9–18 pcs./m^2 more than in 2023; 130–157 pcs./m^2 more than in 2022; 157–165 pcs./m^2 more than in 2020.

Table 3. Characteristics of the interphase period "recovery of spring tillering – beginning of earing" of winter wheat depending on sowing dates and temperature conditions, average for 2019–2023

Sowing dates	Interphase period, in days	Total effective temperature, °C	Total precipitation, mm
September 20	64	316.8	85.9
September 30	66	332.1	88.6
October 10	68	355.0	92.0
October 20	69	367.6	93.1
Average	67	342.9	89.9

Table 4. Dates of the phase "beginning of earing" in winter wheat crops depending on the sowing date (average for varieties), 2019–2023

Years	Sowing dates			
	September 20	September 30	October 10	October 20
2019	13.05	15.05	17.05	18.05
2020	20.05	21.05	22.05	23.05
2021	19.05	21.05	23.05	24.05
2022	16.05	17.05	19.05	20.05
2023	17.05	18.05	20.05	21.05

Table 5. The number of productive stems of winter wheat crops depending on the cultivar and sowing date, 2019–2023, pcs./m^2

Factor A (cultivars)	Factor B (sowing dates)	Years					Average
		2019	2020	2021	2022	2023	
Ozerna	September 20	756	542	751	619	709	675
	September 30	765	603	773	657	727	705
	October 10	732	579	701	605	741	672
	October 20	690	551	679	519	730	634
	Average	736	569	726	600	727	672
Duma Odeska	September 20	782	572	788	648	712	700
	September 30	778	607	780	665	797	725
	October 10	736	584	697	611	781	682
	October 20	693	556	686	542	770	649
	Average	747	580	738	617	765	689
Mudrist Odeska	September 20	776	580	793	623	704	695
	September 30	769	604	782	602	783	708
	October 10	722	571	680	569	766	662
	October 20	680	532	662	525	750	630
	Average	737	572	729	580	751	674
LSD_{05} (pcs./m²) by Factor A		8.8	20.5	19.1	20.6	11.7	
LSD_{05} (pcs./m²) by Factor B		12.8	12.2	18.6	15.5	16.1	

On average, over the years of research, a higher density of productive stems was formed by plants of the Duma Odeska cultivar – from 649 pcs/m² in the variant with sowing on October 20 to 725 pcs/m² when sown on September 30.

Thus, when sown on September 30, wheat plants were exposed to weather conditions that contributed to the formation of a greater number of productive stems. Further delaying the sowing of winter wheat by every 10 days contributed to a decrease in the number of productive stems by an average of 33–46 pcs./m² compared to sowing on October 10 and by 78–71 pcs./m² compared to sowing on October 20.

The weight of grain per ear significantly affects the formation of a high yield of winter wheat and depends on weather conditions, varietal characteristics, plant nutrition, etc. (Korkhova et. al., 2019). The studies conducted during 2019–2023 determined that the largest weight of grain per 1 ear on average for factor B (sowing time) was formed by plants of the Duma Odeska cultivar - 0.89–1.05 g. In Ozerna and Mudrist Odeska cultivars, this indicator was in the range of 0.90–1.00 g and 0.89–1.00 g, respectively, depending on the year of research (Table 6).

It was determined that with the shift of sowing dates from September 20 to October 20, the weight of grain per 1 ear in winter wheat crops of the studied cultivars in most years of research increased by 0.08–0.22 g/ear (Ozerna), by -0.06-0.17 g/ear (Duma Odeska), and by 0.07–0.20 g/ear.

The increased air temperature contributes to a decrease in the height of wheat crops, which is mainly due to a shorter duration of growth and development. At high temperatures, the phases of plant growth and development are accelerated, but the duration of their interphase periods is reduced, which mainly leads to a decrease in plant height (Hussain, 2021; Korkhova, 2022). The studies have shown that with the shift in sowing dates from September 20 to October 20, the height of plants of the studied varieties decreased by an average of 3.3–11.7 cm. The highest winter wheat crops, depending on the sowing dates, were formed in 2021 – 99.0–110.2 cm (Duma Odeska), 99.2–110.7 cm (Ozerna), 103.5–115.4 cm (Mudrist Odeska), and the lowest – in 2020 – 70.3–85.1 cm (Ozerna), 70.0–84.6 cm (Duma Odeska) and 77.6–90.9 cm (Mudrist Odeska) (Table 7).

The largest height of winter wheat crops (99.5 cm) was formed by the Mudrist Odeska, which is 5.0 and 5.5 cm more than in Ozerna and Duma Odeska cultivars, respectively.

The yield of winter wheat grain depends on many factors, the main ones being weather conditions, varietal characteristics, predecessors, sowing dates, nutritional conditions, etc. (Panfilova, 2025). According to the results of the studies conducted during 2019–2023, it was determined that the maximum grain yield (8.62 t/ha) was formed by Duma Odeska winter wheat crops in 2023 when sown on October 10 (Table 8). On average, over the years of research, it was determined that the highest yield of winter wheat grain by the studied cultivars (6.37–6.88 t/ha) was formed during sowing on October 10, which is 0.13–0.39 t/ha, or 1.9–6.1% more than during sowing on October

Table 6. Grain weight per ear depending on the cultivar and sowing date, 2019–2023, g

Factor A (cultivars)	Factor B (sowing dates)	Years					Average
		2019	2020	2021	2022	2023	
Ozerna	September 20	0.88	0.86	0.85	0.90	0.97	0.89
	September 30	0.92	0.94	0.86	0.92	0.90	0.91
	October 10	1.08	0.93	0.94	0.97	0.92	0.97
	October 20	1.10	0.94	0.94	0.92	0.93	0.97
	Average	1.00	0.92	0.90	0.93	0.93	0.94
Duma Odeska	September 20	0.91	0.87	0.85	0.93	0.95	0.90
	September 30	0.94	0.87	0.86	0.98	1.00	0.93
	October 10	1.08	0.90	0.92	1.05	1.11	1.01
	October 20	1.08	0.93	0.97	1.04	1.12	1.03
	Average	1.00	0.89	0.90	1.00	1.05	0.97
Mudrist Odeska	September 20	0.90	0.85	0.88	0.86	0.92	0.88
	September 30	0.94	0.88	0.90	0.90	0.96	0.92
	October 10	1.05	0.90	0.92	0.93	1.03	0.97
	October 20	1.10	0.92	0.97	0.93	1.06	1.00
	Average	1.00	0.89	0.92	0.91	0.99	0.94
LSD_{05} (g/ear) by Factor A		0.04	0.04	0.02	0.02	0.03	
LSD_{05} (g/ear) by Factor B		0.04	0.03	0.02	0.02	0.02	

Table 7. Height of winter wheat crops depending on the cultivar and sowing date, 2019–2023, cm

Factor A (cultivars)	Factor B (sowing dates)	Years					Average
		2019	2020	2021	2022	2023	
Ozerna	September 20	105.6	85.1	110.7	92.3	104.0	99.5
	September 30	100.2	82.3	107.4	89.6	101.7	96.2
	October 10	98.7	79.5	104.8	86.0	99.0	93.6
	October 20	95.1	70.3	99.2	84.5	94.3	88.7
	Average	99.9	79.3	105.5	88.1	99.8	94.5
Duma Odeska	September 20	104.1	84.6	110.2	92.0	103.7	98.9
	September 30	100.0	82.0	106.6	89.2	101.2	95.8
	October 10	97.3	79.1	104.2	85.7	98.6	93.0
	October 20	94.8	70.0	99.0	84.1	94.0	88.4
	Average	99.1	78.9	105.0	87.8	99.4	94.0
Mudrist Odeska	September 20	112.5	90.9	115.4	97.8	109.7	105.3
	September 30	106.7	88.3	111.2	93.4	105.4	101.0
	October 10	103.9	85.4	108.7	90.5	102.6	98.2
	October 20	100.1	77.6	103.5	87.9	99.0	93.6
	Average	105.8	85.6	109.7	92.4	104.2	99.5
LSD_{05} (cm) by Factor A		3.8	4.6	4.2	4.9	6.4	
LSD_{05} (cm) by Factor B		2.9	3.4	3.9	3.6	3.6	

Table 8. Winter wheat grain yield depending on the cultivar and sowing date, 2019–2023, t/ha

Factor A (cultivars)	Factor B (sowing dates)	Years					Average
		2019	2020	2021	2022	2023	
Ozerna	September 20	6.28	4.50	5.74	5.43	5.87	5.56
	September 30	7.02	5.67	6.12	5.91	6.40	6.22
	October 10	7.85	5.53	6.58	5.78	6.78	6.43
	October 20	7.50	5.09	6.37	4.62	6.61	6.04
	Average	7.16	5.20	6.21	5.44	6.42	6.09
Duma Odeska	September 20	6.12	4.78	5.51	6.01	6.71	5.83
	September 30	7.24	5.01	6.19	6.50	7.92	6.57
	October 10	7.75	5.25	6.37	6.41	8.62	6.88
	October 20	7.77	5.14	6.65	5.57	8.60	6.75
	Average	7.22	5.05	6.18	6.12	7.96	6.51
Mudrist Odeska	September 20	6.01	4.70	5.62	5.37	6.17	5.57
	September 30	7.14	5.25	6.00	5.42	7.43	6.25
	October 10	7.55	5.00	6.25	5.29	7.76	6.37
	October 20	7.40	4.71	6.40	4.70	7.90	6.22
	Average	7.03	4.92	6.07	5.20	7.32	6.10
LSD_{05} (t/ha) by Factor A		0.25	0.22	0.18	0.12	0.08	0.04
LSD_{05} (t/ha) by Factor A		0.15	0.17	0.11	0.12	0.12	0.04

20; by 0.21–0.31 t/ha, or 3.4–4.7% more than during the sowing on September 30 and by 0.87–1.05 t/ha, or 15.6–18.0% more than during the sowing on September 20 (Figure 6).

According to the results of the analysis of variance, it was found that the studied factors significantly influenced the formation of winter wheat grain yield. On average, in 2019–2023, factor B (sowing dates) had a greater share of influence on the yield – 73.0%, while factor A (cultivars) had only 22.9%. The correlation between factors A and B was 3.6% (Figure 7).

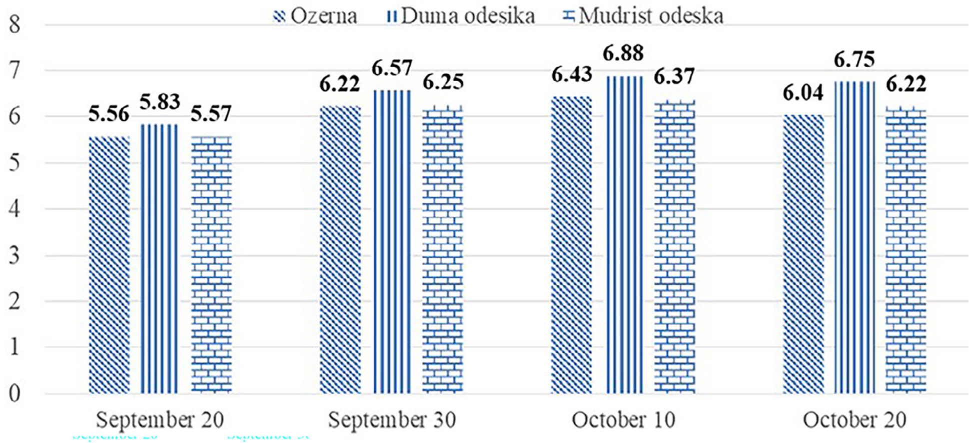

Figure 6. Winter wheat grain yield depending on the cultivar and sowing date, average for 2019–2023, t/ha

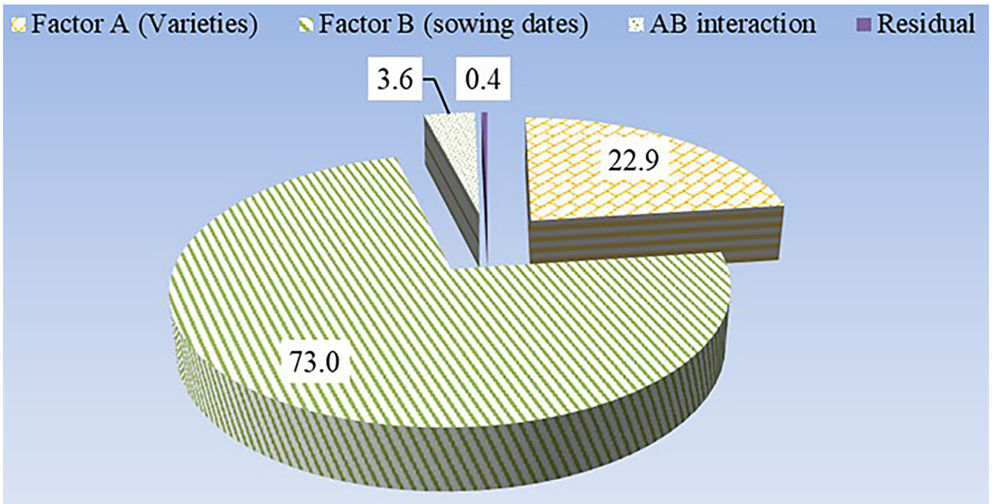

Figure 7. Share of influence of factors on the formation of winter wheat grain yield, average for 2019–2023, %

CONCLUSIONS

The growth, development and formation of productivity of modern durum wheat varieties depending on the sowing time in non-irrigated conditions of southern Ukraine were studied. It was determined that the average daily air temperature for the I-III decade of October 2018–2022 increased by 2.0–3.3 °C compared to the period of 2013–2017, which allows to extend the sowing period of winter wheat. It has been proved that the duration of the autumn vegetation of winter wheat crops in 2018–2022 was on average 23–27 days shorter depending on the sowing dates compared to the previous period (2013–2017). It was determined that the air temperature in the winter months (January–February) of 2019-2023 increased by 0.7–4.3 °C compared to the previous period (2014–2018). It was found that the period of short-term winter thaws was extended, during which wheat plants gained 3.2–42.0 °C more effective temperatures than in the previous period (2014–2018). It was determined that the phase "beginning of earing" occurred earlier in 2019 (May 13–18) and later in 2021 (May 19–24), depending on the sowing date. A higher density of productive plant stems and grain weight per 1 ear on average in 2019–2023 was formed by the variety Duma Odeska (689 pcs./m² and 0.97 pcs./m²), which is 15–17 pcs./m² and 0.3 g/ear more than in other studied varieties. It was determined that factor B (sowing time) has a greater influence on the formation of winter wheat grain yield than factor A (cultivars). On average, over the five years of research (2019–2023), a higher grain yield was formed by plants of the studied winter wheat varieties when sown on October 10 (6.37–6.88 t/ha), which is 0.12–0.31 t/ha more than when sown on September 30; 0.74–0.87 t/ha more than when sown on September 20 and 0.13–0.39 t/ha more than when sown on October 20. Thus, the optimal time for sowing winter wheat varieties Duma Odeska and Mudrist Odeska is from October 10 to 20, and for Ozerna – from September 30 to October 10.

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REFERENCES

1. Atamanyuk, I., Havrysh, V., Nitsenko, V., Diachenko, O., Tepliuk, M., Chebakova, T., Trofimova, H. (2023). Forecasting of winter wheat yield: A mathematical model and field experiments. *Agriculture. 13*(1), 41. https://doi.org/10.3390/agriculture13010041
2. Boychenko, S., Voloshchuk, V., Movchan, Y., Serdjuchenko, N., Tkachenko, V., Tyshchenko, S. Savchenko, S. (2016). *Features of Climate Change on Ukraine: Scenarios, Consequences for Nature and Agroecosystems.* Proceedings of the National aviation university, 4, 96–113.
3. Domaratskiy, Ye., Bazaliy, V., Dobrovolskiy, A., Pichura, V. Kozlova O. (2022). Influence of eco-safe growth-regulating substances on the phytosanitary state of agrocenoses of wheat varieties of various types of development in non-irrigated conditions of the steppe zone. *Journal of Ecological Engineering 23*(8), 299–308.
4. Gandjaeva, L. (2019). Effect of sowing date on yield of winter wheat cultivars Grom, Asr and Kuma in Khorezm region. *Bulgarian journal of agricultural sciencearrow_drop_down, 25*, 3. 474–479.
5. Hansen, J.E., Kharecha, P., Sato, M., Tselioudis, J., Kelly, J., Bauer, S.E., Ruedy, R., Jeong, E., Jin, Q., Rignot, E., Velicogna, I., Schoeberl, M.R., Schuckmann, K., Amponsem, J., Cao, J., Keskinen, A., Li, G. & Pokela, A. (2025). Global Warming Has Accelerated: Are the United Nations and the Public Well-Informed? *Environment: Science and Policy for Sustainable Development, 67*(1). https://doi.org/10.1080/00139157.2025.2434494
6. Huseynov, J., Tagiyev, A. (2024). *The changes of the air temperature characteristics in the azerbaijan territory during global climate changes period.* Visnyk of Taras Shevchenko National University of Kyiv Geology 3(3 (106)): 76–82. https://doi.org/10.17721/1728-2713.106.10
7. Hussain, J., Khaliq, T., Habib ur Rahman, M., Ullah, A., Ahmed, I., Srivastava, A.K., Gaiser, T., Ahmad, A. (2021). Effect of temperature on sowing dates of wheat under arid and semi-arid climatic regions and impact quantification of climate change through mechanistic modeling with evidence from field. *Atmosphere, 12*(7), 927; https://doi.org/10.3390/atmos12070927.
8. Hrytsiuk, P., Babych, T., Hladka, O. and Nehrey, M. (2023). Modeling of wheat yield in the steppe region of Ukraine using machine learning techniques. *Information Control Systems & Technologies.*
9. Kanapickas, A., Vagusevičienė, I., Sujetovienė, G. (2024) The effects of different sowing dates on the autumn development and yield of winter wheat in Central Lithuania. *Atmosphere. 5*(6), 738; https://doi.org/10.3390/atmos15060738
10. Korkhova, M., Drobitko, A., Panfilova, A., Smirnova, I. (2022). The role of winter wheat pl ant height in the formation of grain yield depending on varietal characteristics and weather conditions. *Scientific Horizons, 25*(11), 41–50.
11. Korkhova, M., Panfilova, A., Chernova, A. Rozhok, O. (2019). the effect of pre-sowing seed treatment with biopreparations on productivity of cultivars of *Triticum spelta* L. *AgroLife Scientific Journal*, *8*(1), 120–127.
12. Korkhova, M., Smirnova, I., Drobitko, A. (2022). Influence of irrigation and weather conditions on the duration of interphase periods of winter wheat varieties. *Ukrainian Black Sea Region Agrarian Science*, *26*(3), 55–65.
13. Korkhova, M., Smirnova, I., Panfilova, A., Bilichenko, O. (2023). Productivity of winter wheat depending on varietal characteristics and pre-sowing treatment of seeds with biological products. *Scientific Horizons*, *26*(5), 65–75.
14. Korkhova, M., Mykolaichuk, V., A. (2022). influence of weather conditions on the duration of interphysical periods and yield of durum winter wheat. *Scientific Horizons*, *25*(2), 36–46. https://doi.org/10.48077/scihor.25(2).2022.36-46
15. Lindsey,R.,Dahlman,L.(2024).ClimateChange:Global Temperature. Understanding Climate.https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature
16. Liu Z., Cammarano D., Liu X, Tian Y., Zhu Y., Cao Y., Cao Q. (2025). Winter wheat yield responses

to growing degree days: Long-term trends and adaptability in major producing areas of China. *Ecological Indicators. 170*, 113058. https://doi.org/10.1016/j.ecolind.2024.113058

17. Ma, L., Qiao, J., Kong, X., Zou, Y. (2015). Effect of Low Temperature and Wheat Winter-Hardiness on Survival of *Puccinia striiformis* f. sp. tritici under controlled conditions. *PLOS One, 10*(6): e0130691. https://doi.org/10.1371/journal.pone.0130691
18. Mirón, I.J., Linares, C., Diaz, J. (2023). The influence of climate change on food production and food safety. *Environmental Research, 216*(3), 114674. https://doi.org/10.1016/j.envres.2022.114674
19. Pal, S.C., Chatterjee U., Chakrabortty R., Roy P., Chowdhuri I., Saha, A., Towfiqul Islam, A.R. Md., Alam, E., Islam Md K. (2023). Anthropogenic drivers induced desertification under changing climate: Issues, policy interventions, and the way forward. *Progress in Disaster Science, 20*, 100303. https://doi.org/10.1016/j.pdisas.2023.100303
20. Panfilova, A., Korkhova, M., Markova, N. (2019). Optimization of elements of the technology of Triticum aestivum L. cultivation Kolchuga variety in the conditions Southern Steppe of Ukraine. *AgroLife Scientific Journal*, *8*(2), 112–121.
21. Panfilova, A., Korkhova, M., Markova, N. (2023). Influence of biologics on the productivity of winter wheat varieties under irrigation conditions. *Notulae Scientia Biologicae*, *15*(2), 11352.
22. Panfilova, A., Korkhova, M., Domaratskiy, Y., Kozlova, O. (2025). Development of winter wheat productivity under the influence of biopreparations and different moisture conditions in the steppe zone. *Ecological Engineering and Environmental Technology*, *26*(3), 245–254.
23. Petrychenko, V. F., Lykhochvor, V. V., Korniichuk, O. V., Olifir Y. M. (2021). *Ukrainian Journal of Ecology, 11*(3), 161–166, https://doi.org/10.15421/2021_158
24. Pochkolina, S., Kohut, I., Serhieiev, L., Melnyk, O. (2023). Grain yield of promising and new winter wheat varieties depending on different sowing dates in the Southern Ukraine. *Grain Crops, 7*(2), 285–290. https://doi.org/10.31867/2523 4544/0289
25. Polishchuk, V., Konovalov, D., Brovdi, A. (2024). Influence of weather conditions on winter wheat (*Triticum aestivum* L.) overwintering. *Agronomy Research, 22*(3), 1266–1274. https://doi.org/10.15159/ar.24.061
26. Pichura, V., Potravka, L., Dudiak, N., Vdovenko, N. (2021) Space-time modeling of climate change and bioclimatic potential of steppe soils. *Indian Journal of Ecology, 48*(3), 671–680.
27. Pichura, V., Potravka, L., Domaratskiy, Y., Dudiak, N., Yaremko, Y. (2025). Spatio-temporal research on the effect of pre-crops on winter wheat growth and productivity to the BBCH scale in soil-climatic conditions of the steppe zone of Ukraine. *Bulg. J. Agric. Sci., 31*(1), 115–132
28. Romanenko, V., Kovalevskyi, S. (2022). Analysis of climate changes in the forest fund lands of Boyarka Forest Research Station. *Ukrainian Journal of Forest and Wood Science, 13*(3), 69–75. https://doi.org/10.31548/forest.13(3).2022.69-75
29. Hospodarenko, H. M., Cherno, O. D., Ryabovol, Y. S., Liubych, V. V. (2020). Growth and development of winter wheat in the spring-summer period of vegetation depending on conditions of mineral nutrition in the right–bank of lisosteppe of Ukraine. *Bulletin of Uman National University of Horticulture, 2*, 3–8. https://doi.org/10.31395/2310-0478-2020-2-3-8
30. Hristov, J., Toreti., A., Pérez Domínguez, I., Dentener, F., Fellmann, T., Elleby, C., Ceglar, A., Fumagalli, D., Niemeyer, S., Cerrani, L., Panarello, L., Bratu, M. (2020). *Analysis of climate change impacts on EU agriculture by 2050*, EUR 30078 EN, Publications Office of the European Union, Luxembourg, 2020, https://doi.org/10.2760/121115, JRC119632
31. Sharma, S., Singh, V., Tanwar, H., Singh Mor, V., Chander Punia, R., Singh Dalal, M., Khan M., Sangwan S., Bhuker A., Shekhar Dagar C., Yashveer S., Singh J. (2022). Impact of high temperature on germination, seedling growth and enzymatic activity of wheat. *Agriculture. 12*(9), 1500. https://doi.org/10.3390/agriculture12091500
32. Scafetta, N. (2024). Impacts and risks of “realistic” global warming projections for the 21st century. *Geoscience Frontiers. 15*(2). 101774. https://doi.org/10.1016/j.gsf.2023.101774
33. Serhieiev, L., Kohut, I., Melnyk, O., Zhuk, M., Pochkolina, S. (2024). Yield and quality of winter wheat depending on sowing dates in the Southern Steppe of Ukraine. *Scientific Horizons, 27*(10), 55–69. https://doi.org/10.48077/scihor10.2024.55
34. Ushkarenko, V.O. and Vozhegova, R.A. (2020). *Methodology of the field experiment*. Oldie+: Odesa. Ukraine, 448.
35. Yuan, X., Li S., Chen, J., Yu, H., Yang, T., Wang, C., Huang, S., Chen, H., Ao, X. (2024). Impacts of global climate change on agricultural production: A comprehensive review. *Agronomy 14*(7), 1360; https://doi.org/10.3390/agronomy14071360
36. Zidan, F., Febriyanti, D. E. (2024). Optimizing agricultural yields with artificial intelligence-based climate adaptation strategies. *IAIC Transactions on Sustainable Digital Innovation (ITSDI). 5*(2). 136–147.