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AGROCLIMATIC ASSESSMENT OF THE PROSPECTS FOR GROWING WINTER PEAS IN THE ODESA REGION

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Abstract

Peas are a key leguminous crop in Ukraine due to their valuable properties, which are beneficial for both agriculture and ecology. Pea grain is widely used in the food industry, serves as an important component of animal feed, and acts as a natural nitrogen fixer, improving soil fertility. These characteristics ensure its important role in enhancing the productivity of agricultural systems and supporting agroecological stability. Climate change, particularly warming and uneven rainfall distribution, presents challenges for growing traditional crops, including spring peas. As a result, the development of winter pea varieties becomes a promising solution. These varieties better utilize moisture during the late autumn and early spring periods, provide more stable yields, and protect the soil from erosion. This is especially important for regions at risk of soil degradation, such as the southern regions of Ukraine. The article presents the results of numerical calculations of the productivity of winter peas under the agrometeorological conditions that prevailed in 2023, compared to the agroclimatic conditions expected for 2031-2050. The obtained results confirm the potential of growing winter pea varieties as a strategy for adapting Ukrainian agriculture to climate change, as it increases yield, preserves soil, and ensures the stability of agroecosystems.

***Key words**: winter peas, productivity, yield, climate change, scenario, modelling, moisture availability of crops.*

INTRODUCTION

Pea (*Pisum sativum*) holds a leading position among leguminous crops in Ukraine due to its unique properties, which make it highly valuable for both agricultural production and agroecology. Compared to other legumes, peas exhibit high grain yield potential, excellent quality characteristics, and a short growing season. Pea grain serves as an essential component of human nutrition and a crucial element in livestock feed. Moreover, peas are an exceptionally effective precursor crop for many agricultural species, as they act as a natural nitrogen fixer. As a result, over 100 kg/ha of bound nitrogen remains in the soil after pea cultivation, reducing the need for mineral fertilizers, minimizing humus mineralization, and significantly enhancing soil fertility (Kyryllov & Zhyhaylo, 2024; Solomonov et al., 2022; Boincean et al., 2014; Vann et al., 2019).

Modern challenges, particularly climate change, have a significant impact on crop productivity. Global warming is accompanied by uneven precipitation distribution throughout the year, contributing to an increase in drought occurrences. These climatic changes negatively affect the yield of many crops, including spring peas, making the implementation of alternative cultivation approaches increasingly relevant (Vozhehova et al., 2023a, 2023b; Zhyhaylo et al., 2024a; Stepanenko et al., 2018).

In the past decade, there has been a growing trend toward the adoption of winter pea varieties, which offer several key advantages over spring peas (Zhyhaylo et al., 2024b; Kaminskyy et al., 2013; Sukhova, 2014). These varieties ensure more stable yields of both green biomass and grain due to their efficient utilization of moisture resources and moderate temperatures during the late autumn and early spring periods. Additionally, winter peas contribute to soil protection against wind and water erosion, which is particularly relevant for regions with a high risk of soil degradation. Investigating the agroclimatic conditions for winter pea cultivation may facilitate the expansion of its cultivation area in the southern regions of Ukraine, where climatic conditions are favorable for this crop.

MATERIALS AND METHODS

A study was conducted on the formation of productivity and yield of winter peas using the WINTERPEAS-24 mathematical model, which simulates the water-thermal regime and productivity of the crop. This model is a modified version of the fundamental mathematical model for crop yield formation proposed by A. M. Polovyi (Polovyi, 2007).
The natural-physical system "soil-plant-atmosphere" in the model is represented by three main components. The first component, the input, includes information about environmental characteristics and initial model parameters. The second component describes the internal structure of the system, which is characterized by equations governing radiation, heat, and water balance, mineral nutrition, and biomass accumulation in the plant cover. The third component, the output, represents the system's performance and provides quantitative indicators of the dynamics of dry biomass, leaf area, total biomass accumulation, and the economically valuable yield of winter pea grain.
The key conceptual principles of the model are as follows: plant growth and development are determined by genotype and environmental factors; biomass accumulation is simulated based on the distribution of photosynthesis products and absorbed mineral nutrients, considering the assimilate requirements of different plant organs for growth; and radiation, heat, and water regimes within the "soil-plant-atmosphere" system are modeled.
The model has a modular structure consisting of five blocks: input data, radiation and water-thermal regimes, photosynthesis, respiration, and growth and assimilate distribution (Figure 1).
The verification of the WINTERPEAS-24 model was performed by comparing the simulated productivity and yield indicators with actual field data from 2023.
To assess the prospects for winter pea cultivation in the coming decades, we used the Representative Concentration Pathway (RCP) climate change scenario - specifically, RCP8.5, which represents a high greenhouse gas emissions trajectory.
Numerical calculations of crop productivity and yield were conducted for two climate periods: 1986-2005, which serves as the baseline (Adamenko, 2011), and 2031-2050 under the RCP8.5 scenario.

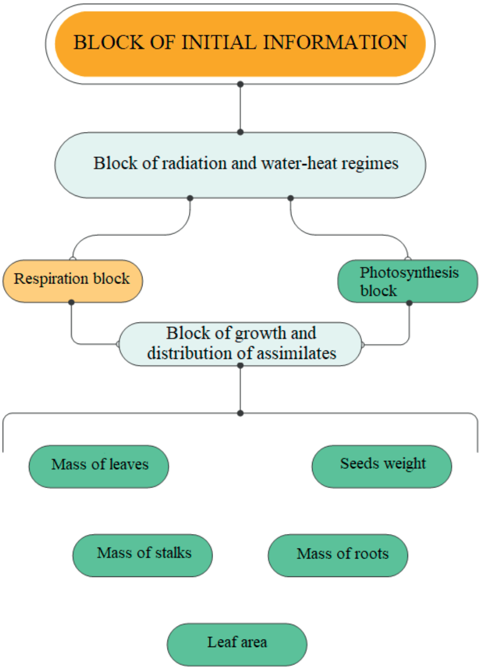
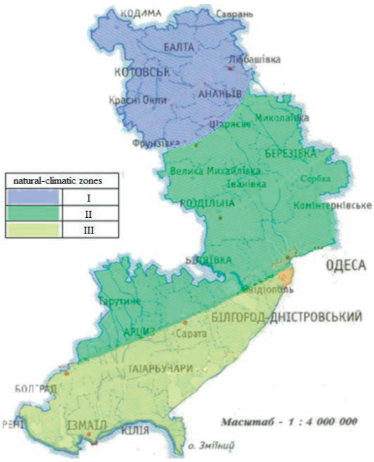


Figure 1. Block diagram of the WINTERPEAS-24 mathematical model for the water-thermal regime and productivity of winter peas

The calculations were carried out for two natural-climatic zones of the Odesa region: the Forest-Steppe and the Steppe zone, with further subdivisions into the Northern and Southern Steppe subzones (Figure 2).

RESULTS AND DISCUSSIONS

In 2023, the resumption of winter pea vegetation was observed in all natural-climatic zones of the Odesa region at the beginning of the first decade of March (Table 1). Pea maturation occurred in the Forest-Steppe and Northern Steppe in the middle of the first decade of June, while in the Southern Steppe, it was observed nine days earlier (May 29 vs. June 6).



The Forest-Steppe zone - I, the Northern Steppe subzone - II, the Southern Steppe - III.

Figure 2 - Natural-climatic zones (subzones) of the Odesa region

The duration of the spring-summer growing season in the Southern Steppe subzone was 90 days, which was 6-8 days shorter than in the Forest-Steppe zone and the Northern Steppe subzone.

Compared to the average long-term dates of the baseline period, the resumption of vegetation in 2023 began almost ten days earlier across the entire study area. However, the timing of pea maturation remained nearly unchanged from the long-term averages, resulting in an extended growing season by 7-12 days.

The average air temperature increases from north to south. In the Forest-Steppe zone, it matched the baseline value, whereas in the Steppe zone, temperatures were lower by 0.9°C and 1.0°C in the Northern and Southern Steppe subzones, respectively. Precipitation levels in all natural-climatic zones of the region exceeded the norm, reaching 168%, 174%, and 148%, respectively.

In 2023, soil moisture availability for crops in the Forest-Steppe zone was 91% of the baseline due to a moisture deficit of 153%, amounting to 0.73 relative units compared to the baseline value of 0.80 (Figure 3). In the Northern Steppe, moisture availability was higher at 0.75 relative units compared to 0.70 in the baseline period. In contrast, the Southern Steppe had the lowest moisture availability, at 0.59 relative units, which was only 89% of the norm. Thus, the best soil moisture conditions for pea crops were observed in the Northern Steppe subzone.

On average, in the region, the resumption of winter pea vegetation typically occurs at the end of the first or the beginning of the second decade of March (Table 1).

The seeds of this crop reach maturity in the first decade of June. The earliest maturation dates are observed in the Southern Steppe subzone, while in the Forest-Steppe zone, this process occurs the latest.

According to the RCP8.5 climate change scenario, vegetation resumption in the Forest-Steppe zone is expected to shift five days later compared to the baseline period. In contrast, in the Steppe zone, resumption is projected to occur 6-9 days earlier.

During the baseline climatic period, the average air temperature from vegetation resumption to maturation gradually increased from the northern to the southern part of the region. However, under the climate change scenario, this difference is expected to be nearly eliminated, with the average temperature in the north almost matching that of the south.

Table 1. Comparative assessment of the agrometeorological conditions of 2023 and the agroclimatic conditions of the multi-year periods of 1986-2005 and 2031-2050 during the spring-summer growing season of winter peas

Natural-climatic zones (subzones)	Period, years	Agrometeorological and agroclimatic characteristics							
		Date		duration of the vegetation period, days	average air temperature for period ($T_{cp.}$),°C	amount of precipitation for period (R), mm	total evaporation for the period (E), mm	evaporation for period, (E_0), mm	moisture deficit (D), mm
		resumption of vegetation	maturation						
Forest-Steppe zone	[1]1986-2005	13.03	09.06	89	10.9	117	181	226	45
	2023	02.03	06.06	96	10.8	197	186	255	69
	[2]2031-2050	18.03	13.06	88	11.0	161	174	188	14
Northern Steppe subzone	[1]1986-2005	11.03	04.06	86	11.8	101	157	226	69
	2023	01.03	06.06	98	10.9	176	144	192	48
	[2]2031-2050	05.03	08.06	100	10.5	133	158	203	45
Southern Steppe	[1]1986-2005	10.03	01.06	83	12.3	100	145	219	74
	2023	01.03	29.05	90	11.3	148	147	251	104
	[2]2031-2050	01.03	02.06	94	11.4	133	162	208	46

Note: 1 - Average multi-year data in the baseline climatic period; 2 - Climatic period under the scenario RCP8.5

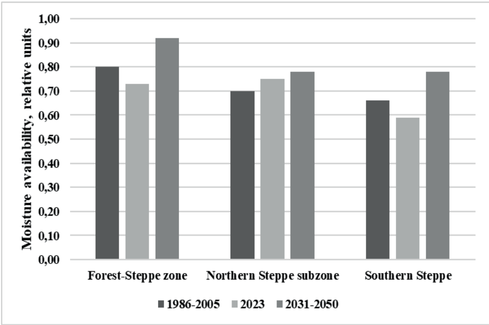


Figure 3. Soil Moisture Availability for Winter Pea Crops on Average During the Period from Vegetation Resumption to Maturation in Odesa Region

During the spring-summer growing season of the baseline period, precipitation levels decrease from north to south. However, under the RCP8.5 scenario, precipitation is expected to increase compared to the baseline across all zones and subzones, although the northern part of the region will continue to receive more rainfall than the south.

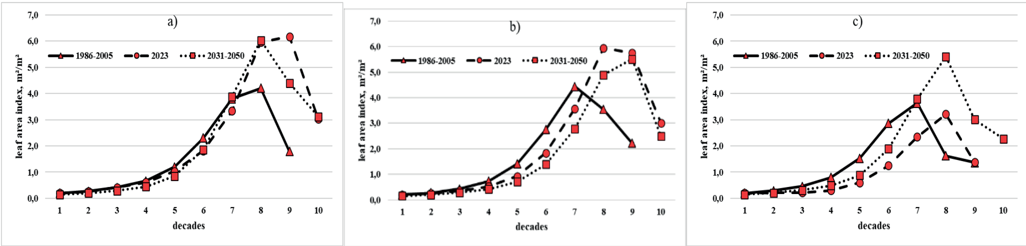
An analysis of soil moisture availability for winter pea crops showed that during the 1986-2005 period, this indicator in the Forest-Steppe zone (Figure 3) was 0.80 relative units, indicating favorable moisture conditions. In the Steppe region, particularly in both subzones, moisture availability was lower - 0.70 and 0.66 relative units, respectively - suggesting satisfactory conditions for plant growth. According to forecasts for the 2031-2050 period, moisture availability is expected to improve significantly compared to the baseline period. In the Forest-Steppe zone of Odesa region, it is projected to reach an excellent level of 0.92 relative units compared to 0.80, while in both Steppe subzones, moisture availability is expected to be good, reaching 0.78 relative units.

The agrometeorological conditions of 2023 contributed to high productivity of winter pea crops in the Forest-Steppe and Northern Steppe (Table 2). Modeling results showed that in the Forest-Steppe zone, the leaf area index reached 6.18 m²/m² by the ninth decade of vegetation, which is 1.5 times higher than the long-term average (Figure 4a). The photosynthetic potential of plants during this period was 151% of the baseline value. Additionally, a more intense accumulation of dry biomass was observed. The maximum increase in dry biomass reached 378 g/m², while the total biomass at maturity was 960 g/m², significantly exceeding the long-term average of 604 g/m².

Table 2. Comparative assessment of the productivity indicators of winter pea crops in 2023, the baseline climatic period, and under the scenario RCP8.5.

Characteristics		Natural-climatic zones (subzones)								
		Forest-Steppe zone			Steppe					
					Northern Steppe subzone			Southern Steppe		
		Period, years								
		1986-2005	2023	2031-2050	1986-2005	2023	2031-2050	1986-2005	2023	2031-2050
Maximum values	leaf area index, m²/m²	4.2	6.1	6.0	4.4	6.0	5.5	3.6	3.2	5.4
	biomass accumulation, g/m²	239	378	441	273	331	358	204	224	363
	total biomass, g/m²	604	960	1243	731	919	852	664	446	1070
Photosynthetic potential (PP), m²/m² for period		151	229	196	151	218	189	117	96	169

The agrometeorological conditions in the Northern Steppe this year also contributed to the high productivity of winter pea crops. The maximum leaf area index by the eighth decade of vegetation reached 6.0 m²/m² (Figure 4b), which is nearly 1.5 times higher than the long-term average. As a result, the photosynthetic potential for the growing season amounted to 144% of the long-term average. The total biomass at the time of pod maturation was 30% higher than the long-term average, reaching 919 g/m². In the Southern Steppe, agrometeorological conditions were less favorable compared to the long-term data. The maximum leaf area index by the eighth decade of vegetation reached 3.2 m²/m² (Figure 4c), which is lower than the average value of 3.6 m²/m². Due to a precipitation deficit in the early decades of vegetation, the photosynthetic potential of leaves decreased to 96 m²/m², amounting to 82% of the norm.



a) Forest-Steppe b) Northern Steppe c) Southern Steppe

Figure 4. Dynamics of winter pea leaf area from spring vegetation renewal - maturity. Odesa region

Maximum biomass accumulation by the eighth decade of the growing season exceeded the baseline (224 g/m² vs. 204 g/m²), but the total biomass at the end of the season was 50% lower than the long-term average, amounting to 446 g/m² compared to 664 g/m².

Under the implementation of the RCP8.5 climate scenario, agro-climatic conditions in the period 2031-2050 in both natural-climatic zones of the Odesa region are expected to positively influence the productivity of winter peas. The relative leaf area will increase: in the Forest-Steppe zone, it will reach 6.0 m²/m², in the Northern Steppe subzone - 5.5 m²/m², and in the Southern Steppe subzone - 5.4 m²/m². The photosynthetic potential, compared to the baseline, will increase by 130% in the Forest-Steppe zone, by 126% in the Northern Steppe subzone, and by 144% in the Southern Steppe subzone.

The maximum biomass accumulation during the budding stage is expected to exceed the baseline by 185%, 131%, and 178%, respectively. The total biomass estimates indicate an increase of 639 g/m² in the Forest-Steppe zone, and 121 g/m² and 406 g/m² in the Steppe subzones compared to the baseline period.

Grain yield of winter peas under baseline agro-climatic conditions is 3.4 t/ha in the Forest-Steppe and Northern Steppe zones, while in the Southern Steppe zone, it is 3.0 t/ha (Figure 5). Under the agro-meteorological conditions of 2023, pea yield in the Forest-Steppe and Northern Steppe subzones reached 176-177% of the baseline, while in the Southern Steppe, it matched the baseline level. Under the RCP8.5 scenario, with improved agro-climatic conditions, yield in the Forest-Steppe zone is projected to double, while in the Steppe zone, it is expected to increase 1.5 times.

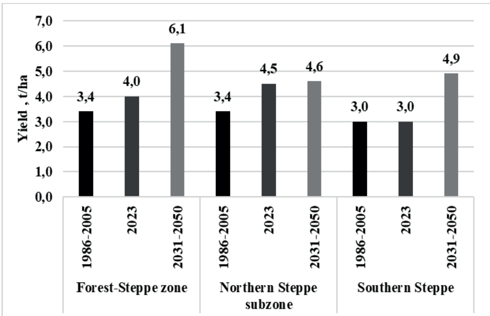


Figure 5. Winter pea yield in Odesa region

CONCLUSIONS

A series of numerical calculations were conducted using the WINTERPEAS-24 model. Agroclimatic indicators and productivity parameters of winter pea cultivation were assessed across the natural-climatic zones of the Odesa region, including the Forest-Steppe, Northern Steppe, and Southern Steppe.

It was established that, during the baseline climatic period (1986-2005), winter pea vegetation typically resumed in the region between the end of the first (March 10) and the beginning of the second decade of March (March 13), with pod maturation occurring in the first decade of June. The earliest maturation was observed in the southern steppe subzone

(June 1), while the latest occurred in the forest-steppe zone (June 9).

Compared to the climatic norms of the baseline period, the resumption of vegetation in 2023 occurred nearly a decade earlier (March 1-2) across the region, while pod maturation was observed three days earlier than the average historical date. The duration of the vegetation period from regrowth to maturation was extended by 7-8 days.

Under the RCP8.5 scenario for the period 2031-2050, vegetation regrowth in the forest-steppe zone is projected to begin one pentad later (March 18) than in the current climatic period, whereas in the steppe zone, it is expected to commence 6-9 days earlier (March 5 and March 1, respectively). Maturation in the Forest-Steppe and Northern Steppe zones is anticipated to occur four days earlier, while in the Southern Steppe, it will remain nearly unchanged.

The agroclimatic conditions of the baseline climatic period in the Forest-Steppe ensure favorable moisture availability for crops (0.80 relative units), while in both subzones of the Steppe, moisture availability is assessed as satisfactory (0.70 and 0.66 relative units, respectively). The temperature regime, on average, increases from north to south (10.9°C, 11.8°C, and 12.3°C, respectively).

In 2023, the temperature regime in the Forest-Steppe was nearly identical to the baseline, whereas in both Steppe subzones, the mean air temperature was 0.9°C and 1.0°C lower than the long-term average. Moisture conditions were most favorable for winter pea cultivation in the Northern Steppe (0.75 relative units), less favorable in the Forest-Steppe (0.73 relative units), and least favorable in the Southern Steppe, which experienced drought conditions (0.59 relative units).

According to projections, the temperature regime in the Forest-Steppe zone will remain nearly unchanged (11.0°C), while in the Northern and Southern Steppe zones, it will be lower (10.5°C and 11.4°C, respectively). Moisture availability is expected to improve (0.92, 0.78, and 0.78 relative units, respectively).

The optimal temperature regime and favorable to satisfactory moisture conditions during the actual climatic period have supported winter pea yields of 3.4 t/ha in the Forest-Steppe and Northern Steppe and 3.0 t/ha in the Southern Steppe.

Agrometeorological conditions in 2023 contributed to a high winter pea yield of 4.0 t/ha in the Forest-Steppe and 4.5 t/ha in the Northern Steppe of Odesa, while the yield in the Southern Steppe remained at the long-term average level of 3.0 t/ha.

Future agroclimatic conditions are projected to further enhance winter pea productivity, with yields reaching 6.1 t/ha in the Forest-Steppe and 4.6-4.9 t/ha in both Steppe subzones.

The findings of this study will contribute to improving the efficiency of winter pea cultivation and optimizing agronomic practices, which are crucial for the development of Ukraine’s agricultural sector under changing climatic conditions.

Winter pea cultivation should be considered as an adaptive strategy for mitigating the impacts of climate change on agricultural production.

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MISCELLANEOUS