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INFLUENCE OF AGROCLIMATIC FACTORS AND ADAPTIVE TECHNOLOGIES ON THE PRODUCTIVITY OF BUCKWHEAT AND MILLET IN THE SOUTHERN STEPPE OF UKRAINE

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The study investigates the patterns of yield formation in buckwheat (Fagopyrum esculentum Moench) and millet (Panicum miliaceum L.) in the Southern Steppe of Ukraine under the influence of agroclimatic factors and adaptive cultivation technologies. Particular attention is given to the analysis of the interaction between temperature regimes and soil moisture during critical growth stages, including flowering and grain filling, and their impact on crop productivity and grain quality. It was established that buckwheat exhibits high sensitivity to temperature fluctuations and uneven precipitation distribution, resulting in reduced fruit set and grain weight. In contrast, millet demonstrates greater stress tolerance, more efficient water utilization, and the ability to maintain stable yields under drought conditions, making it a promising crop for adaptive farming systems in the Southern Steppe.

The study systematically examines the effects of agronomic practices on crop yield stability, including optimization of sowing dates, selection of stress-tolerant varieties, balanced mineral fertilization, soil management for moisture conservation, and monitoring of hydrothermal coefficients throughout the growing season. It was shown that the integrated application of these adaptive measures reduces the risk of yield losses during critical growth phases, maximizes the realization of potential productivity, and enhances the stability of cereal crop yields under variable climatic conditions.

Special attention was given to the evaluation of modern buckwheat varieties ("Dikul", "Devyatka", "Antaria") and millet varieties (Denwikske, "Kharkiv 31", "Bila Altanka") in terms of their ecological plasticity and adaptability within cropping systems. The results indicate that the combination of varietal selection and adaptive agronomic practices is a key factor in improving yield stability, optimizing resource use, and maintaining agroecosystem sustainability in the drought-prone Southern Steppe of Ukraine.

The findings of this research provide a scientific and methodological basis for the practical implementation of adaptive cultivation technologies, increasing crop resilience to abiotic stresses, enhancing resource efficiency, and supporting regional food security.

Key words: *buckwheat, millet, crop productivity, adaptive practices, stress tolerance, Southern Steppe, yield, cultivars.*

Аверчев О.В., Нікітенко М.П. Вплив агрокліматичних факторів та адаптивних технологій на продуктивність гречки та проса в умовах Південного Степу України

У статті досліджено закономірності формування продуктивності гречки (Fagopyrum esculentum Moench) та проса (Panicum miliaceum L.) у Південному Степу України під впливом агрокліматичних факторів та адаптивних технологічних заходів. Особлива увага приділена аналізу взаємодії температурного режиму та вологозабезпечення у критичні фази розвитку рослин, зокрема цвітіння та наливу зерна, та їхньому впливу на формування урожайності та якість продукції. Встановлено, що гречка характеризується високою чутливістю до температурних коливань і нерівномірного розподілу опадів, що проявляється у зниженні кількості зав'язі та маси зерна. Просо відзначається більшою стресостійкістю, здатністю ефективніше використовувати доступну вологу та підтримувати продуктивність у посушливі роки, що робить його перспективною культурою для адаптивних систем землеробства в умовах Південного Степу.

У роботі систематизовано вплив агротехнологічних заходів на стабільність продуктивності культур. Зокрема, досліджено ефективність оптимізації строків сівби, підбору сортів із підвищеною стресостійкістю, застосування збалансованого мінерального живлення, обробітку ґрунту для збереження вологи, а також моніторингу гідротермічного коефіцієнта впродовж вегетації. Показано, що комплексне використання цих адаптивних заходів дозволяє знизити ризики зменшення врожайності у критичні фази розвитку, забезпечити реалізацію потенційного продуктивного ресурсу рослин і підвищити стабільність урожайності круп'яних культур у змінних кліматичних умовах.

Особливу увагу приділено оцінці сучасних сортів гречки («Дикуль», «Дев'ятка», «Антарія») та проса (Денвікське, «Харківське 31», «Біла Альтанка») щодо їх здатності забезпечувати екологічну пластичність і адаптивність систем вирощування. Встановлено, що поєднання селекційного добору сортів із адаптивними технологічними заходами є ключовим чинником підвищення стабільності продуктивності, ефективного використання природних ресурсів та збереження агроекосистем у посушливих умовах Південного Степу України.

Результати дослідження можуть слугувати науково-методичною основою для практичного впровадження адаптивних технологій у виробництво круп'яних культур, підвищення їх стійкості до абіотичних стресів, оптимізації використання природних ресурсів та забезпечення продовольчої безпеки регіону.

Ключові слова: *гречка, просо, продуктивність культур, адаптивні заходи, стресостійкість, Південний Степ, врожайність, сорти.*

Problem Statement. In the context of ongoing climate change and the increasing incidence of extreme weather events, ensuring the stable productivity of agricultural crops has become a matter of strategic importance for food security. This issue is particularly critical for cereal crops, which represent a fundamental component of human nutrition and hold substantial potential within adaptive agricultural systems.

Crop yield formation is a complex, multifactorial process shaped by the interaction of abiotic factors (temperature, water availability, solar radiation), biotic factors, and anthropogenic influences. Even minor deviations of environmental conditions from optimal levels during critical growth stages can result in significant reductions in yield. Specifically, it has been demonstrated that elevated temperatures and water deficits

during the flowering and grain-filling phases can markedly limit the realization of a crop's productive potential.

In the Southern Steppe of Ukraine, this challenge is further complicated by the region's highly continental climate, uneven precipitation distribution, and frequent occurrences of both atmospheric and soil drought. Under these conditions, identifying the key determinants of cereal crop productivity and quantifying their relative contribution to yield formation is of particular importance.

Accordingly, there is a need for a comprehensive analysis of the effects of agroclimatic and agronomic factors on cereal crop productivity, aimed at substantiating adaptive cultivation strategies.

Review of Recent Studies and Publications. Recent scientific research indicates that the productivity of cereals and other small-grain crops is determined by a complex interplay of factors, among which meteorological conditions, agronomic practices, and the genetic characteristics of cultivars play a leading role.

A substantial body of literature has focused on assessing the impact of climatic factors on crop performance. It has been established that air temperature, duration of solar radiation, and moisture regime govern the intensity of photosynthetic processes, the development of generative organs, and grain filling. Specifically, for buckwheat, it has been shown that solar radiation and precipitation directly influence the number of grains per plant, whereas low temperatures and abrupt fluctuations in temperature regime reduce overall productivity [4].

For millet-type crops, the influence of meteorological factors varies depending on water availability. Under conditions of adequate soil moisture, photoperiod duration emerges as the determining factor, while under water stress, the amplitude of daily temperatures and thermal regime gain increased significance [1]. These findings underscore the necessity of a differentiated approach to evaluating yield determinants based on specific growing conditions.

In addition to climatic factors, agronomic elements play a crucial role. Studies demonstrate that the level of mineral nutrition, particularly nitrogen, and the irrigation regime significantly affect buckwheat productivity by enhancing photosynthetic activity and delaying plant senescence [5,6].

In the context of global climate change, it has been observed that rising temperatures generally tend to reduce the yields of most crops, including cereals, due to a shortened growing season and intensified water stress [2].

At the same time, certain crops, such as millet, exhibit relatively high tolerance to drought and elevated temperatures, which is considered an important adaptive advantage [3].

Overall, contemporary research highlights the multifactorial nature of cereal crop yield formation and confirms the critical role of climatic conditions in combination with agronomic practices. However, existing scientific data are often fragmented and do not fully account for regional specificity, indicating the need for further investigation in this area [10,11].

Unresolved Research Gaps. Despite a substantial body of research dedicated to the formation of cereal crop yields, several critical aspects remain insufficiently studied and require further scientific substantiation. In particular, the following issues warrant clarification:

- The characteristics of realizing the bioclimatic potential of the growing season for cereal crops under the conditions of the Southern Steppe of Ukraine;

- The influence not only of total precipitation but also of its intra-seasonal distribution on the productivity of buckwheat and millet;
- General patterns of interaction between temperature regime and water availability during critical periods of plant growth and development;
- The role of agronomic factors in mitigating the negative effects of climatic stress;
- The development of adaptive cultivation approaches for cereal crops in the context of contemporary climate change.

Existing scientific data are often fragmented and do not provide a comprehensive understanding of the interactions among the main determinants of productivity, highlighting the need for further research in this area.

The objective of this study is to identify the patterns of buckwheat and millet productivity in relation to agroclimatic factors in the Southern Steppe of Ukraine and to substantiate adaptive approaches for their cultivation.

Presentation of the Main Material. The productivity of cereal crops in the Southern Steppe of Ukraine is determined by the combined influence of agroclimatic and agronomic factors, among which thermal resources, water availability, their interaction during critical growth stages, and adaptive cultivation practices play a leading role.

The region's climate is characterized by abundant thermal resources, enabling the accumulation of high sums of active temperatures throughout the growing season. This creates favorable conditions for the growth and development of thermophilic crops, particularly millet and buckwheat. At the same time, the uneven distribution of temperature and frequent occurrences of extreme heat pose risks to the realization of the crops' productive potential, as illustrated in Figure 1.

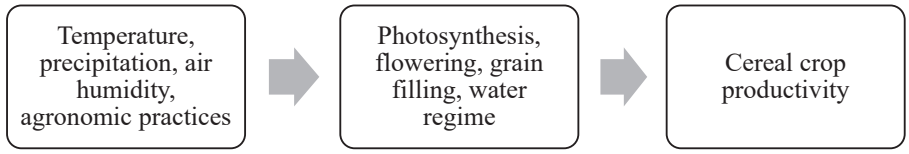

Fig. 1. Schematic representation of the influence of agroclimatic factors on cereal crop productivity.

The **temperature regime** is one of the key determinants of yield formation. For millet, as a thermophilic crop, elevated temperatures within optimal ranges promote the intensification of growth processes and the accumulation of yield. In contrast, the impact of temperature on buckwheat is more complex: temperatures above 28–30 °C, particularly during flowering, suppress pollination and reduce grain set. Consequently, temperature stress is particularly critical for buckwheat, explaining its lower yield stability compared to millet, as shown in Table 1.

Water availability is a limiting factor in most years for crop cultivation in the Southern Steppe. Research indicates that not only the total amount of precipitation but also its distribution throughout the growing season is of primary importance. The greatest sensitivity to moisture deficit occurs during flowering and grain-filling stages, when the majority of yield is formed. Insufficient moisture during this period leads to reduced photosynthetic intensity, accelerated plant senescence, and the development of poorly filled grains.

The analysis of the relationships between crop yield and meteorological indicators reveals the presence of strong correlations. Buckwheat exhibits high sensitivity to temperature (negative correlation) and to relative air humidity (positive correlation),

indicating its strong dependence on favorable moisture conditions. In contrast, for millet, thermal resources constitute the determining factor, while the crop shows lower sensitivity to fluctuations in water availability. This confirms the higher adaptive capacity of millet under drought-prone conditions, as illustrated in Figure 2.

Table 1

Influence of agroclimatic factors on the productivity of buckwheat and millet

Crop	Critical phase	Critical conditions	Δ Yield (%)	Correlation coefficient (r)
Temperature				
Buckwheat	Flowering, grain filling	>30 °C	–12…–18	–0.76
Millet	Tillering – stem elongation	20–28 °C	+5…+8	–0.52
Precipitation				
Buckwheat	Bud formation – flowering	150–200 mm	+10…+15	0.56
Millet	Emergence – tillering	100–150 mm	+4…+7	0.38
Precipitation distribution				
Buckwheat	Flowering, grain filling	Uneven	–10…–15	–
Millet	Flowering, grain filling	Uneven	–5…–10	–
Air humidity				
Buckwheat	Flowering	60–80 %	+7…+12	0.56
Millet	Vegetative growth	40–60 %	+3…+6	0.30
Hydrothermal coefficient (HTC)				
Buckwheat	Entire growing season	1.0–1.2	+12…+18	0.72
Millet	Early growth stages	0.8–1.0	+5…+9	0.48

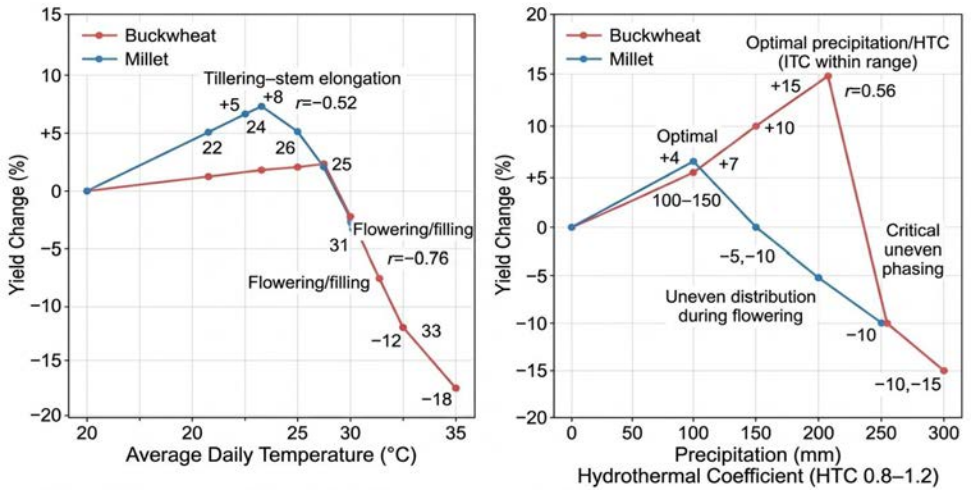

Fig. 2. Graphs illustrating the dependency of buckwheat and millet yield on temperature and precipitation

Comparative analysis of the ecological plasticity of the crops demonstrates that millet utilizes water more efficiently and is capable of maintaining productivity under high temperatures and limited precipitation. This is attributed to its physiological traits, including lower transpiration rates and the ability to complete grain formation over a shorter period. Conversely, buckwheat requires higher levels of moisture and is more sensitive to temperature stress, which constrains its productivity in dry years.

A key strategy to enhance yield stability involves the implementation of adaptive agronomic practices. In contemporary conditions, particular importance is given to optimizing sowing dates according to thermal and water regimes, selecting cultivars with increased tolerance to abiotic stressors, and rational use of mineral fertilization. Additionally, the improvement of soil management systems aimed at moisture conservation and enhancement of the soil's hydro-physical properties plays a significant role, as shown in Table 2.

Table 2

Elements of adaptive cultivation technology for buckwheat and millet under the conditions of the Southern Steppe of Ukraine

Element	Crop	Adaptive Feature	Effect on Productivity
Sowing dates	Buckwheat	Late April – early May	Avoidance of high temperatures and water deficit during critical flowering and grain-filling stages Ensures favorable conditions for early growth and development
	Millet	Mid–late May, after soil warming to 10–12 °C	
Cultivars	Buckwheat	"Dikul", "Devyatka", "Antaria"	Enhances yield stability under hot and drought-prone summer conditions Supports adaptive potential and consistent productivity under stress conditions
	Millet	"Denvikske", "Kharkiv 31", "Bila Altanka"	
Fertilization	Buckwheat	Basal phosphorus and potassium, balanced nitrogen, micronutrients (B, Zn, Fe)	Supports grain formation and photosynthesis during stress periods
	Millet		
Soil management	Buckwheat	Fine soil crumbling before sowing; minimal tillage under drought–	Conserves soil moisture, ensures uniform germination, and maintains productivity in critical phases–
	Millet		
Monitoring of hydrothermal coefficient (HTC) and weather risks	Buckwheat	Temperature forecasts and HTC analysis to adapt sowing and irrigation	Optimizes agronomic measures according to specific weather conditions, particularly important for buckwheat
	Millet		

In summary, the formation of cereal crop productivity results from the complex interaction of climatic and technological factors, with thermal and water availability during critical developmental stages playing a decisive role. The rational integration of these factors with adaptive agronomic practices enhances both the stability and overall yield of buckwheat and millet under the conditions of the Southern Steppe of Ukraine.

Conclusions. The productivity of buckwheat and millet in the Southern Steppe of Ukraine is determined by the interaction of agroclimatic factors, including temperature,

humidity, and precipitation distribution, as well as adaptive elements of cultivation technology. The flowering and grain-filling stages are the most critical periods for yield formation in both crops, during which water deficit and elevated temperatures reduce the number of grains and their weight. Buckwheat exhibits higher sensitivity to temperature stress and uneven moisture availability, whereas millet demonstrates greater stress tolerance and the ability to maintain productivity under drought conditions.

The effective implementation of adaptive measures–such as optimization of sowing dates, selection of stress-tolerant cultivars, balanced fertilization, soil management for moisture conservation, and monitoring of weather conditions–enhances yield stability and facilitates the realization of the crops' productive potential. The use of modern buckwheat and millet cultivars with increased resistance to abiotic stresses provides ecological plasticity and adaptability within the cropping system.

The proposed recommendations for adaptive cultivation technology of cereal crops can serve as a foundation for improving productivity and promoting efficient resource use under the arid conditions of the Southern Steppe of Ukraine.

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