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The impact of climate change on the forage base in the Republic of Moldova

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Abstract. The study aimed to determine the optimal conditions for using biological products to improve the agroecological efficiency of grain crops, by analysing their impact on plant physiological processes, productivity and soil resources. The study presented the results of the study of the influence of biological products on the yield, product quality, dynamics of plant development phases and soil microflora composition when growing barley of the Helios variety and buckwheat of the Antaria variety in the South of Ukraine. The experiment was conducted using nitrogen-fixing, mycorrhizal and phosphate-mobilising biological products, both individually and in combination, with the establishment of control and experimental plots. The analysis included an assessment of yields, protein content in grain, changes in plant development stages and the activity of soil microorganisms. The results of the study demonstrated that the use of biological products provided a significant increase in yields: barley showed an increase of 20-25%, and buckwheat – by 18-22% compared to the control plots. The protein content of the grain also increased, reaching 12% for barley and 14% for buckwheat. The duration of plant development phases was

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reduced, which contributed to more efficient use of soil resources and optimisation of growth processes. Changes in the composition of soil microflora were particularly noticeable: the number of nitrogen-fixing bacteria increased by 40% and phosphate-mobilising – by 50%, which improved the availability of nutrients for plants. The highest results were achieved when using combinations of biological products that demonstrated a synergistic effect, increasing crop productivity and improving product quality. The results confirmed the effectiveness of biological products in creating sustainable agroecosystems, ensuring environmental safety, reducing the need for chemical fertilisers and increasing the economic profitability of agricultural production. The use of biological products is a promising area for optimising modern agricultural technologies in regions with unfavourable soil and climatic conditions

Keywords: agrotechnology; yield; agroecosystems; environmental sustainability; organic nutrition

INTRODUCTION

In the context of an escalating global climate crisis, the forage base of agriculture is facing increasing challenges, particularly in countries with vulnerable ecological and agricultural systems such as the Republic of Moldova. Climate-related impacts – including loss of livelihoods, food and water insecurity, and adverse effects on human capital – combined with poverty and inequality, pose serious threats to agricultural sustainability. Where climate stressors intersect with other economic and environmental pressures, compound risks emerge, intensifying vulnerability, exacerbate grievances, and deepen existing fragility (IPCC..., 2023). The risk of internal displacement, migration, and rural instability due to environmental degradation has also been increasingly documented (Koubi *et al.*, 2021).

Weather instability, rising average temperatures, more frequent droughts, and irregular precipitation patterns are negatively affecting the cultivation of forage crops by reducing both their yield and nutritional quality. Studies such as that by R. Prăvălie *et al.* (2020) have highlighted that forage production systems in Eastern Europe are particularly sensitive to seasonal droughts, which lower biomass yields and disrupt nutrient cycling. Likewise, research by A. Iglesias & L. Garrote (2019) emphasised that precipitation variability has become the primary driver of forage yield reductions across Southern and Eastern Europe, including Moldova, with extreme weather events now occurring more frequently. This directly impacts the productivity of the livestock sector, as feed is a critical factor in maintaining animal health and performance. S. Ruban *et al.* (2024) have shown that nutrient imbalances in forage under climate-induced stress led to suboptimal animal productivity, especially among ruminants. Additionally, C.M. Godde *et al.* (2021) reported that forage crops exposed to elevated CO_2 and temperature scenarios tend to develop altered fibre composition, reducing digestibility and thus limiting feed efficiency.

The lack of a stable forage base increases dependence on imported feed resources and raises production costs, thereby reducing the economic viability of farms and amplifying food security risks. In support of this, M. MacLeod *et al.* (2023) identified forage instability as a key economic risk factor in livestock supply chains in marginal regions. Under these conditions, it becomes crucial to develop adaptive strategies aimed at preserving and restoring forage productivity, introducing stress-resistant crop varieties, and improving agronomic practices in line with new climatic realities. Studying the impact of climate factors on the forage sector is an essential scientific priority that can support sustainable agricultural development and ensure food security in the region. The objective of the study is to examine how climate variability – particularly changes in temperature and precipitation patterns – affects forage crop cultivation and the resulting implications for livestock production in the Republic of Moldova.

MATERIALS AND METHODS

From 2020 to 2023, a four-year study was conducted in three representative agricultural zones of the Republic of Moldova: Briceni (north), Chișinău (centre), and Cahul (south). These areas were purposefully selected due to their distinct microclimatic and pedological conditions, enabling a comparative analysis of climate impacts on forage production and livestock productivity. The study employed a multidisciplinary methodology that integrated climatological, agronomic, and zootechnical data with literature-based synthesis. Climatic data – including average monthly and annual air temperatures, precipitation levels, and drought occurrence, were obtained from the State Hydrometeorological Service of Moldova (n.d). Data from three meteorological stations corresponding to the selected regions were used to ensure spatial representativeness. The collected data were analysed in relation to the vegetative stages of key forage crops – such as alfalfa, maize for silage, and perennial grasses – with emphasis on deviations from climatic norms and their impact on biomass accumulation.

Agronomic data on forage yield (t/ha) were extracted from field trial reports and official agricultural statistics published by the National Bureau of Statistics of the Republic of Moldova (n.d.) (NBS). Changes in feed quality indicators were used to estimate implications for ruminant nutrition and productivity. Data on livestock production were also sourced from NBS reports and included annual production volumes of milk (litres/cow/year), meat (kg/live weight per animal), and wool (kg/sheep/year). These indicators were analysed in conjunction with forage availability to assess indirect effects of climate anomalies on animal productivity. Where appropriate, analysis was conducted using Microsoft Excel and SPSS (v.26), to quantify the relationships between climate parameters and production outcomes. In addition, Moldovan and international peer-reviewed literature published in the last five years was reviewed to contextualise experimental findings and reinforce methodological validity. The integration of quantitative field data with scientific literature ensured a robust interpretation of climate impacts on the forage-livestock system of Moldova, thereby strengthening the relevance of the proposed adaptation strategies.

RESULTS AND DISCUSSION

The Republic of Moldova is located in the central part of Europe, in the north-eastern Balkans, and covers an area of 33,843.5 km^2. It lies within a moderately continental climatic zone, which is somewhat modified by its proximity to the Black Sea and the influence of warm, humid air masses from the Mediterranean region. According to Law of Republic of Moldova No.438 on "Regional development in the Republic of Moldova" (2006), it was customary to distinguish three main geographical zones – North, Centre, and South (Fig. 1).

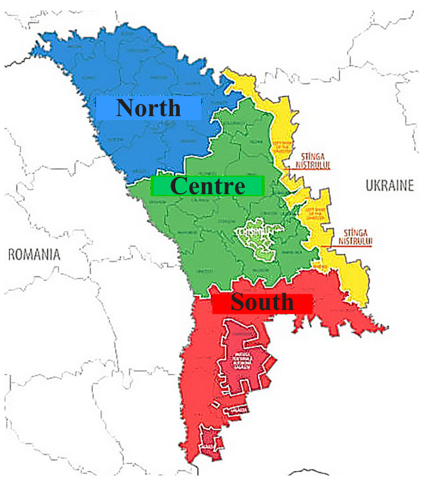

Figure 1. *Geographical areas*
Source: *Law of Republic of Moldova No.438 on "Regional development in the Republic of Moldova" (2006)*

These regions increasingly face unstable meteorological conditions, with drought and rising temperatures becoming the norm in recent decades. Both low and high temperatures negatively impact the plant growth and development, resulting in yields below the actual productive potential of the given crop. The data in Figure 2 show that at temperatures up to +18°C, plants grow very slowly, while temperatures around +22°C enhance plant development. However, the ideal temperatures for most plants range between +22°C and +28°C. Temperatures of +28°C to +30°C reduce reproductive capacity, and at temperatures above +30°C, induced male sterility is observed (Fig. 2).

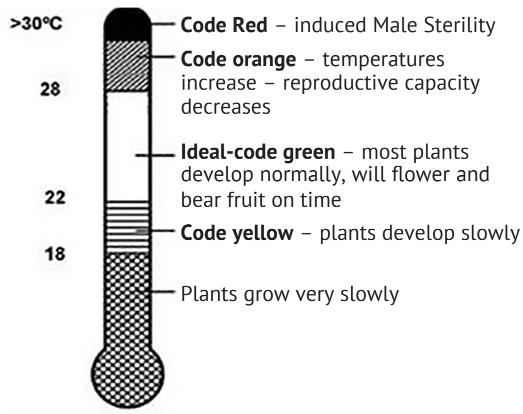

Figure 2. *Influence of temperatures of the Republic of Moldova*
Source: *Climate change knowledge portal (n.d.)*

Agriculture is the sector of the Moldovan economy most susceptible to climate change because of its strong dependence on weather conditions. One of the primary causes of erratic harvests and a natural risk to Moldovan agriculture is climate volatility. Climate conditions have a significant impact on agricultural production. In many parts of Europe, agricultural yields and livestock output are already being impacted by changes in the average temperature and precipitation, as well as weather and climatic extremes. According to research dating back to 1850, the temperature of the Earth and oceans has risen by an average of 0.06°C per decade, with the warming rate tripling since 1982 to approximately 0.20°C per decade (NOA, 2023; Yuan *et al.*, 2024). As L. Kumar *et al.* (2022) reported, climate change is an ongoing process, with spatially varying impacts. Agri-food production could be significantly impacted by projected climate change, either directly through altered temperature and precipitation patterns or indirectly through the effects of invasive plants, pests, and diseases, as well as by coastal flooding, soil salinisation, and invasive plant infestations.

Projections indicate that the agro-ecological zones (AEZs) of the Republic of Moldova will experience a moderate decrease in winter precipitation, ranging from -2.1% in the northern AEZ to -3.8% in the southern AEZ (Fig. 3). In contrast, a slight increase in spring precipitation is expected: from 3.5 to 5.7% in the northern AEZ and from 1.0 to 4.8% in the central AEZ, compared to the reference period of 1995-2014.

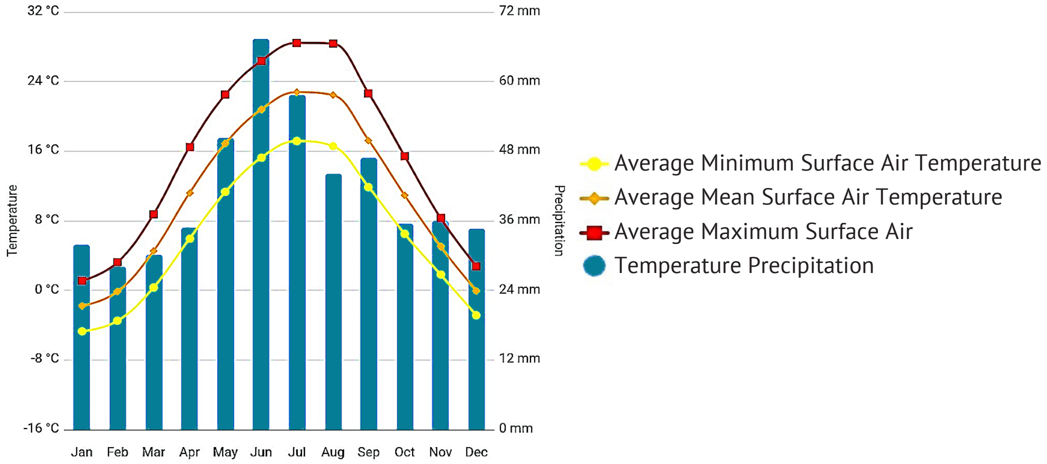

Figure 3. *Climate Projections for Agro-Ecological Zones of the Republic of Moldova*
Source: *Climate change knowledge portal (n.d.)*

By the end of the 21st century, winters in the Republic of Moldova are projected to become wetter. The largest increase in winter precipitation, according to the SSP5 – 8.5 scenario, is expected to reach 13.3% in the northern region, while the southern region will experience the lowest increase, at 2.4%, by the year 2100. Throughout much of the year, a significant precipitation deficit was recorded across the territory of the Republic of Moldova. Agro-meteorological conditions during most of the 2021 growing season were generally unfavourable for the development of major-agricultural crop yields due to high temperatures and a lack of rainfall. This trend has been observed consistently across all three geographical zones – North, Centre, and South (Table 1).

According to the geographical region of the country, the amount of precipitation (Table 2) was distributed as follows: North: 402-614 mm (60-85% of the norm), Centre: 430-666 mm (60-90% of the norm), South: 352-490 mm (55-75% of the norm).

Table 1. *Average air temperature by year depending on the geographical zone, °C*

Geographical zone	Years				On average over 4 years
	2020	2021	2022	2023	
North	10.7	8.9	10.1	11.0	10.2
Centre	12.7	10.6	11.7	12.7	11.9
South	13.1	11.4	12.5	13.3	12.6
Average per country	12.17 ± 0.74	10.30 ± 0.74	11.43 ± 0.71	12.33 ± 0.69	11.6 ±0.73

Source: *National Bureau of Statistics of the Republic of Moldova (n.d.)*

Table 2. *The Amount of precipitation per year, mm*

Geographical zone	Years			
	2020	2021	2022	2023
North	614	605	402	458
Centre	562	666	444	430
South	460	490	352	389
Average per country	545.33 ± 45,23	587.33 ± 51.59	399.33 ± 26.59	425.67 ± 20.04

Source: *National Bureau of Statistics of the Republic of Moldova (n.d.)*

This distribution demonstrates the variability in precipitation across Moldova's regions, with the southern part receiving the least amount, which is a critical factor in the context of drought and agricultural productivity. At the same time, agricultural lands have low resilience to the increasing incidence of extreme weather conditions. The country faces several environmental issues, such as landslides, soil erosion, deforestation, the spread of pests and diseases, and the invasion of plants and animals into agricultural lands, among others. The growth of forage crops under high temperatures, drought, or floods can induce stress responses in green plants, potentially affecting not only their yield but also their composition and, consequently, their nutritional value for ruminants. For example, studies have shown that forage quality declines with rising temperatures. Therefore, to ensure future livestock productivity, the forage crop sector must consider environmental effects on both crop yields and quality parameters (Hart *et al.*, 2022). More efficient use of resources means more products and other ecosystem services are produced per unit of resource input when livestock systems are intensified sustainably (Dubeux *et al.*, 2024).

Climate change may lead to the deterioration of certain ecosystems in some parts of the country, with many species exhibiting reduced reproductive capacity and increased susceptibility to other factors. To mitigate the effects of drought in agriculture, irrigation is employed (irrigated land – 3,110 km^2), drought-resistant plant species are cultivated, and various agronomic systems are implemented to reduce water loss from the soil. Drought years with high temperatures recur approximately every 2-3 years in Moldova. According to statistical data regarding the sown area for root crops intended for feed, the most unproductive year was 2022, with an average area of 5.67 hectares across the three geographical zones. The situation improved in 2023, reaching an average sown area of 9.33 hectares, largely due to increased precipitation levels in 2023, which averaged 425.67 mm compared to 399.33 mm in 2022 nationwide. Table 3 indicates that the Southern region had the smallest sown area for corn, ranging from 520 to 1,499 hectares over the past four years, compared to the Northern region, which had sown areas of 1466 to 2,599 hectares, and the Central region, which ranged from 1,999 to 4,191 hectares (National Bureau of Statistics…, n.d.).

Table 3. *The area sown with agricultural crops in agricultural enterprises and farmer households by years*

Geographical zone	Root crops for fodder				Corn for silage, green mass and haylage			
	Years							
	2020	2021	2022	2023	2020	2021	2022	2023
North	2	2	7	12	2,599	1,466	2,153	1,570
Centre	19	33	10	11	4,191	1,999	2,412	2,705
South	152	80	-	5	1,499	520	1,122	575
Average per country	57.67 ± 47.4	38.33 ± 22.6	5.67 ± 2.9	9.33 ± 2.1	2,763.00 ± 781.4	1,328.33 ± 432.9	1,895.66 ± 393.9	1,616.66 ± 615.3

Source: *National Bureau of Statistics of the Republic of Moldova (n.d.)*

On average, the area of land sown with corn for silage, green mass, and hay has decreased compared to 2020, with reductions of 51.9, 31.4, and 41.5% in the years 2021, 2022, and 2023, respectively. Due to high temperatures in the Southern geographical zone, with an average of +12.6° cover the four reference years, the yield of root crops for feed was severely compromised, resulting in a productivity of only 66.3 quintals in 2021. This occurred despite higher precipitation (490 mm) and lower average temperature (11.4°C) in the Southern zone compared to other years. A similar trend was observed in this zone for corn yields for silage, green mass, and hay, which averaged 366.1 quintals per hectare. The least productive years for yields per hectare were 2020 and 2022, indicating a nationwide average productivity of root crops of 43.33 and 23.90 quintals per hectare, and 107.07 and 109.80 quintals per hectare for corn for silage, green mass, and hay. This decline was attributed to higher average temperatures (+12.17°C in 2020 and +11.43°C in 2022) and lower precipitation levels (545.33 mm and 399.33 mm, respectively) (Table 4).

Table 4. *Average harvest of agricultural crops in agricultural enterprises and farmer households by year, q/ha*

Geographical zone	Root crops for fodder				Corn for silage, green mass and haylage			
	Years							
	2020	2021	2022	2023	2020	2021	2022	2023
North	60.0	292.5	30.0	25.5	103.9	281.0	109.2	220.7
Centre	70.0	21.7	41.7	114.2	100.6	278.8	117.5	171.7
South	-	66.3	-	-	116.7	366.1	102.7	172.3
Average per country	43.33 ± 21.8	126.89 ± 83.8	23.90 ± 12.4	46.56 ±39.6	107.07 ± 4.9	308.63 ± 28.7	109.80 ± 4.2	188.23 ±16.2

Source: *National Bureau of Statistics of the Republic of Moldova (n.d.)*

Regarding the sown area for feed crops, the Central region prioritised with an area of 4,342 to 5,743 hectares, which is 22.0 and 92.3% more than the North and South regions in 2020; 19.3 and 59.6% more in 2021; 5.4 and 45.5% more in 2022; and 41.7 and 91.7% more compared to the North and South regions in subsequent years. Annual grasses are primarily cultivated in the North, with areas ranging from 241 to 421 hectares, which is 71.6 and 88.2% more compared to the Central and South regions in 2020; 46.9% more in 2021; 29.1 and 54.9% more in 2022; and 39.8 and 117.0% more in 2023 (Table 5).

Table 5. *The area sown on agricultural crops at agricultural enterprises and farmer households, ha*

Geographical zone	Forage crops				Annual herbs				Perennial herbs			
	Years											
	2020	2021	2022	2023	2020	2021	2022	2023	2020	2021	2022	2023
North	4,706	3,644	4,129	3,376	350	241	319	421	1,701	1,755	1,599	1,441
Centre	5,743	4,342	4,351	4,785	204	258	247	301	1,317	1,957	1,464	1,454
South	2,986	2,721	2,990	2,496	186	164	206	194	1,147	1,464	1,638	1,702
Average per country	4,478.33 ± 803.98	3,569.00 ± 469.44	3,823.33 ± 421.57	3,552.33 ± 666.63	246.66 ± 51.93	221.00 ± 28.91	257.33 ± 33.03	305.33 ± 65.56	1,388.33 ± 169.85	1,725.33 ± 143.09	1,567.00 ± 52.71	1,532.33 ± 84.91

Source: *National Bureau of Statistics of the Republic of Moldova (n.d.)*

However, the area sown with perennial grasses in the North has been declining over the monitored years, with a decrease of 15.3% in 2023 compared to the previous year. In 2020, the Southern region experienced a notable increase in the areas cultivated with perennial grasses, showing a rise of 48.4% in 2023 compared to 2020. The analysis of the presented data demonstrates a clear trend of declining forage crop cultivation across the Republic of Moldova, decreasing from an average of 4,478.33 hectares in 2020 to 3,552.33 hectares in 2023. The area under perennial grasses declined from 1,725.33 hectares to 1,532.33 hectares, whereas the area planted with annual grasses increased from 221 hectares to 305.33 hectares. The livestock sector will be impacted by the changing climate, but more indirectly. Lower humidity and higher temperatures will directly increase physiological stress and most likely have an impact on animal growth. Weather-related effects on fodder plants and grazing areas will be the indirect effect. Given their higher heat tolerance and capacity to survive on more drought-tolerant feed, it is probable that the population of goats and donkeys in the southern portion of the country will rise while that of cattle will decline. However, the northern part of the country can provide better development conditions for the animal's subsector (Agriculture and horticulture, n.d.).

The increased temperature conditions, low precipitation, and declining areas cultivated with forage plants have also led to a reduction in livestock numbers, including cattle and pigs. Both regionally and nationally, the number of beef cattle has noticeably decreased. In the North, the count dropped from 59,785 head in 2020 to 48,613 head in 2023; in the Central region, from 41.208 to 36.285 head; and in the South, from 16.367 to 12.013 head. A similar trend is observed in the number of dairy cows, with reductions of 16.7% in the North, 22.9% in the Central region, and 24.9% in the South in 2023 compared to 2020. The number of pigs has also decreased across all geographical regions of the Republic of Moldova over the past four years, with a notable decline in the North, where the livestock count dropped by 18.85% in 2023 compared to 2020. In the South, the pig population decreased by 12.18% up to 2022 but showed a slight increase of 2.9% in 2023 compared to 2020 (Table 6).

Table 6. *Livestock dynamics in farm of all categories, heads*

Specification	Years	Geographical zone			Average per country
		North	Centre	South	
Cattle for meat	2020	59,785	41,208	16,367	39,120.00±12,577.10
	2021	53,487	36,059	13,671	34,405.66±11,523.57
	2022	50,705	34,992	12,671	32,789.66±11,034.83
	2023	48,613	36,285	12,013	32,303.66±10,751.40
Dairy cows	2020	42,817	23,180	11,842	95,279.66±68,535.97
	2021	38,586	19,778	9,937	22,767.00±8,404.20
	2022	36,803	19,399	9,022	21,741.33±8,104.74
	2023	35,671	17,869	8,892	20,810.66±7,869.11

Table 6, Continued

Specification	Years	Geographical zone			Average per country
		North	Centre	South	
Pigs	2020	82,079	261,365	41,459	128,301.00±67,557.42
	2021	75,177	212,986	39,238	109,132.00±52,952.98
	2022	69,617	233,030	39,169	112,605.33±61,027.97
	2023	66,599	219,521	42,651	109,590±55,398.37
Sheep and goats	2020	158,260	164,029	223,332	181,873.66±20,795.96
	2021	147,865	146,599	203,005	165,823.00±18,594.59
	2022	136,407	139,250	194,018	156,558.33±18,747.80
	2023	141,018	139,385	185,854	155,419.00±15,224.80

Source: *National Bureau of Statistics of the Republic of Moldova (n.d.)*

On average, the number of sheep and goats has significantly decreased, showing declines of 8.8, 13.9, and 14.5% in 2021, 2022, and 2023, respectively, compared to 2020. Regionally, the largest decrease in the sheep and goat population occurred in the South, with a reduction of 16.8% in 2023; the Central region experienced a drop of 15.1% in 2022; and the North saw a decline of 13.8% in 2022, all compared to the reference year of 2020. After analysing the production of live weight meat, the Central region has the highest level of this indicator, ranging from 815,921 to 759,584 quintals, with a decrease of 6.9% in 2023 compared to 2020. In contrast, the Northern region recorded an increase of 14.9% in live weight production, while the Southern region saw a significant increase of 43.3% in 2023 compared to 2020 (Fig. 4). The production of cow's milk in the Republic of Moldova has increased significantly, from an average of 60,967.67 quintals in 2020 to 113,889 quintals in 2023, marking an overall increase of 86.8% (Fig. 5).

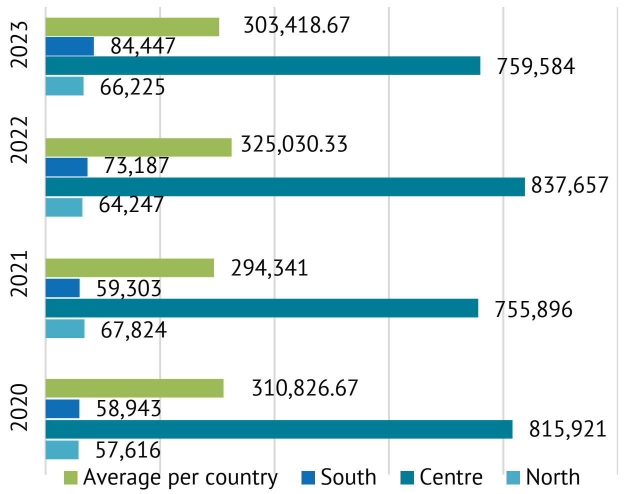

Figure 4. *Live meat production*
Source: *National Bureau of Statistics of the Republic of Moldova (n.d.)*

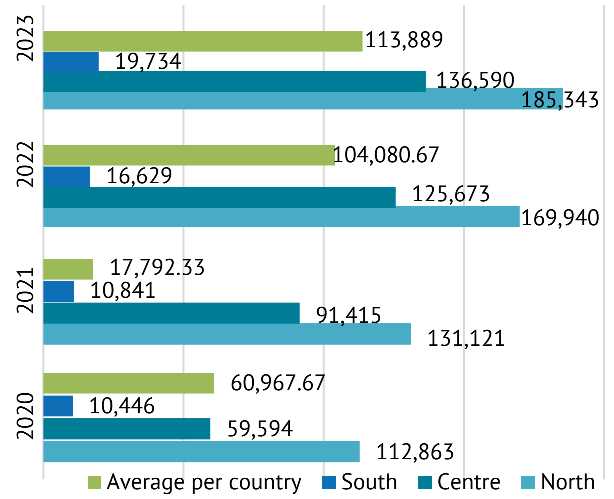

Figure 5. *Cow milk production*
Source: *National Bureau of Statistics of the Republic of Moldova (n.d.)*

The Northern region leads in this ranking, with cow's milk productivity rising from 112,863 quintals in 2020 to 185,343 quintals in 2023, representing a 64.2% increase compared to the reference year 2020. Notably, there has also been a significant increase in milk production in the Central region, with a rise of 129.2%, and in the Southern region, with an 88.9% increase in 2023 compared to 2020. The wool production in physical mass varies annually across the Republic of Moldova, with an average of 56.33 quintals in 2022 and a decline to 45.67 quintals in 2023. The Southern region is considered the leading area for wool production, with a yield ranging from 127 to 103 quintals, marking an 18.9% decrease in 2023 compared to 2020. In contrast, both the Northern and Central regions experienced increases in wool productivity up to 2022, followed by a sharp decline in 2023, showing decreases of 14.3% and 47.3%, respectively, compared to 2020 (Table 7).

Table 7. *Wool production (in physical mass) at agricultural enterprises and farmer households, q*

Geographical zone	Years			
	2020	2021	2022	2023
North	7	7	26	6
Centre	19	23	32	28
South	127	118	111	103
Average per country	51.00±38.16	49.33±39.64	56.33±27.39	45.67±29.36

Source: *National Bureau of Statistics of the Republic of Moldova (n.d.)*

Animal production based on grain crops may be less sensitive to climate change compared to ruminants that rely on conserved forage (hay and silage) and grazing (Orosz & Balogh, 2023; Tothi *et al.*, 2024). For cereal plants, which produce concentrated feed for animals, low temperatures reduce yields per unit area, or plants may fail to mature. High temperatures during the grain-filling stage led to deformed grains, reducing both yield and nutritional quality. Temperature and precipitation changes, as well as extreme weather and climatic conditions, already impact crop productivity and livestock production in Europe. In some regions of southern Europe, this may lead to the abandonment of agricultural lands affected by climate stress. Weather and climatic conditions also affect water resources needed for irrigation, animal watering practices, agricultural product processing, and transportation and storage conditions.

C. Ringler *et al.* (2022), reports that access to sufficient, clean fresh water is essential for all life. This is particularly concerning as climate change will increasingly affect all aspects of food systems. Long-term consequences of climate change, mostly caused by human activity, pose a major threat to ecosystems, communities, and biodiversity. Research shows that there is frequently a nonlinear and region-specific link between precipitation and agricultural yields. (Mahadevan *et al.*, 2024). According to L.E. Sollenberger & M.M. Kohmann (2024) incorporating forage legumes into pastures is a recommended strategy for mitigating climate change, though the desired benefits from legumes depend on their resilience when exposed to climate change factors. To address the challenges posed by climate change and its multidimensional interactions, comprehensive strategies must be adopted. Smart agricultural management practices, water-efficient irrigation systems, encouraging climate-resilient crop varieties, enhancing soil conservation and enhancement strategies, putting into practice creative and sustainable fertiliser production plans, and workable water reuse and recycling solutions are a few examples (Wang *et al.*, 2018; Ahmad *et al.*, 2024).

R. Murabildayeva, *et al.* (2024) comes to the conclusion that the following suggested agricultural adaptation strategies and actions can be prioritised at the local and regional levels: management of crop varieties and land use change and innovative breeding techniques; management of water and soil, including agronomic practices; and training and knowledge transfer for farmers through research and development, including the creation of early warning systems. Given the threat of climate change and the anticipated effects on forage production in the future, it is also advised to continue research and extension on best practices to enhance livestock production using high-quality and high-yielding conserved forages that are adapted to the agroecological conditions of the particular regions (Tulu *et al.*, 2023). According to A. Maher *et al.* (2025), grasslands worldwide also face management issues brought on by both new and existing stressors, such as increased fire frequency and intensity, woody species expansion, annual grass invasion, recurrent grazing during the growing season, and climate change.

Although livestock systems based on grain crops show relatively greater resilience to climate variability, the forage- and pasture-dependent ruminant sector remains particularly vulnerable to the multifaceted impacts of climate change. The ongoing shifts in temperature, precipitation patterns, and water availability are already altering the agricultural landscape across Europe, including Moldova, with tangible consequences for crop productivity, forage quality, and animal performance. As climate extremes become more frequent, there is an urgent need to prioritise adaptive responses at both policy and farm levels. This includes the promotion of integrated crop-livestock systems, the development and dissemination of climate-resilient forage species, and the implementation of water- and soil-saving innovations. Only through coordinated action – encompassing research, technological innovation, farmer education, and region-specific strategies – can we ensure the long-term sustainability of livestock production and safeguard food security in the face of an increasingly unstable climate.

CONCLUSIONS

The conducted research confirms that climate change has a significant and growing impact on the forage base in the Republic of Moldova. Increasing temperatures, prolonged droughts, and irregular precipitation patterns have created unfavourable conditions for the cultivation and productivity of forage crops. The analysis of long-term data revealed a steady decline in both the total sown areas and the average yields of key forage species. These negative trends have led to a reduction in the volume and nutritional value of feed resources available for animal husbandry. As a consequence of the diminishing forage base, livestock production in Moldova has experienced a gradual downturn. Reduced availability of quality feed has limited the growth potential of ruminant and monogastric species alike, resulting in declining livestock populations. This, in turn, has led to a decrease in the output of animal-origin products such as milk, meat, and eggs. The reduction in these essential food commodities not only undermines the economic sustainability of the agricultural sector but also weakened the country's overall food security and negatively affects the livelihoods of rural communities that depend on livestock production.

The study highlighted the need for a fundamental shift toward more resilient and adaptive agricultural practices. In particular, there is a strong case for expanding the diversity of forage crops, adopting more efficient water management systems, and introducing technologies that enhance soil fertility and moisture retention. Equally important is the implementation of region-specific adaptation strategies that reflect the particular vulnerabilities and ecological conditions of Moldova's agro-climatic zones. In future research, it is planned to assess the potential of alternative and underutilised forage crops better adapted to arid conditions. Additionally, further studies will focus on evaluating the economic feasibility of innovative irrigation systems and forage conservation technologies. Particular attention will be given to the development of predictive models that integrate climate data to optimise forage crop planning and improve the resilience of livestock feeding systems under various climate scenarios.

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CONFLICT OF INTEREST

None.

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Вплив зміни клімату на кормову базу в Республіці Молдова

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Анотація. Зміна клімату визнана зростаючою загрозою для розвитку людства та сталого існування природних екосистем, що має особливо серйозні наслідки для сільського господарства – основи існування сільських громад. Глобальні сільськогосподарські системи зазнали руйнівного впливу через підвищення температури на планеті, збільшення рівня CO_2 в атмосфері та зростання частоти екстремальних погодних явищ, таких як повені та посухи. У Республіці Молдова ці зміни створили все більші виклики для сектору кормів, який відігравав важливу роль у підтримці продуктивності тваринництва та забезпеченні національної продовольчої безпеки. У дослідженні оцінювали вплив зміни клімату на вирощування кормових культур, зосередившись конкретно на тому, як коливання температури та кількості опадів впливали на врожайність біомаси, поживну цінність та продуктивність тваринництва. Було застосовано мультидисциплінарний підхід, що включав аналіз довгострокових кліматологічних даних (1970-2020), огляд наукової літератури та узагальнення експериментальних даних, пов'язаних з фізіологією рослин та складом кормів в умовах абіотичного стресу. Результати показують постійне підвищення середніх температур та значну нерегулярність сезонних опадів, що призводить до зниження врожайності кормових культур на 15-30 % у роки екстремальної посухи. Підвищені температури прискорили дозрівання рослин, але зменшили співвідношення листя до стебла, що призвело до зниження вмісту сирого білка (на 10-20 %) і збільшення концентрації клітковини, особливо лігніну, що негативно вплинуло на перетравність. Ці зміни корелювали з помітним зниженням споживання корму жуйними тваринами і надоїв молока на 12 % у періоди високого стресу. Сукупним ефектом стало зниження ефективності систем тваринництва, що, в свою чергу, вплинуло на прибутковість ферм і стійкість продовольчого забезпечення. Результати дослідження підкреслили нагальну потребу в адаптивних стратегіях, таких як селекція посухостійких кормових культур, впровадження вдосконалених методів зрошення та перегляд національної сільськогосподарської політики. Дослідження пропонує важливі висновки для сільськогосподарських дослідників, тваринників та політиків, які прагнуть розробити стійкі до кліматичних змін системи управління кормовими культурами та тваринництвом у Молдові

Ключові слова: кліматичні умови; кормові культури; географічні райони; врожай; поверхня; кількість опадів

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Modern GIS technologies supporting land management in agricultural land consolidation

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Abstract. Ukraine has not conducted a comprehensive or systematic assessment of the effectiveness of spatial land consolidation processes, and the institutional framework supporting agricultural land integration remains limited. This study investigated the potential for rational land management through the application of agricultural land consolidation, focusing on the Liutenska and Petrivsko Romenska territorial communities. Geographic Information Systems (GIS) were employed to analyse spatial structure, land fragmentation, and opportunities for land-use optimisation. The methodological approach included geospatial analysis, systems analysis, graph-based generalisation, and normative-legal content analysis to evaluate fragmentation levels, ownership patterns, and spatial inconsistencies. The study found that land consolidation contributed to a reduction in land-use fragmentation, adjustments in land tenure structure, and improvements in the spatial configuration of agricultural areas. The integration of GIS tools supported spatial data analysis, enhanced transparency in decision-making processes, and facilitated the incorporation of ecological, economic, and social considerations. Parcel reallocation through equivalent exchange and consolidation planning supported more coordinated land cultivation, reduced transportation distances, and improved access to infrastructure. The findings suggested that spatial, legal, and institutional instruments need to be applied in combination to support land consolidation at the community level. These results can inform land management strategies for local authorities, agricultural producers, and stakeholders involved in rural development, particularly within the framework of ongoing land reform in Ukraine

Keywords: spatial optimisation; rural development; cadastral data; geoinformation analysis; sustainable agriculture; integration; fragmentation

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