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Research Article

# Zoning of sunflower fields based on climatic variables: A case study in the Republic of Moldova

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## Abstract

Climate change has a significant impact on the entire agricultural sector, including sunflower cultivation. In the Republic of Moldova, alongside the applied agricultural techniques and the cultivated areas, the variations of climatic variables have a substantial importance in determining yield. In this study, the evolution of climate conditions during 2003-2021 period, the relationships between these variables and sunflower yield trends, as well as the territorial favourability of the Republic of Moldova for sunflower cultivation were evaluated. The analysis was based on the correlation coefficients between the average annual yield and the temperature values during the April-August period, the precipitation from the cold and the growing period. The results showed that the climatic conditions in the northern part of the country are more favourable for sunflower cultivation compared to the southern part. This difference can be explained by the uneven distribution of precipitation and temperatures across various regions of the country, highlighting the importance of adapting agricultural technologies to regional contexts to optimize agricultural production under the conditions of climate change.

***Keywords:*** correlations; favourable areas; precipitation; sunflower; temperature; yield

## Introduction

Conservation and integrated management of agricultural areas affected by climate change is a key priority within the global agenda for implementing the principles of sustainable agriculture (Agovino *et al*., 2019; Kumari *et al*., 2022). The impact of climate change on agriculture has been addressed by the Food and Agriculture Organization of the United Nations and Intergovernmental Panel on Climate Change (IPCC, 2023), which promote an integrated approach to adapt agricultural sectors to new climate realities (Lipper *et al*., 2014).

For the Republic of Moldova climate change represents a major threat to sustainable development and one of the most significant environmental problems, with negative consequences for various socio-economic activities. Agriculture plays a significant role in the national economy, and its strong dependence on climate conditions underscores the necessity for a comprehensive, continuously updated scientific and methodological framework capable to respond promptly and effectively to the challenges posed by climate change (Bojariu *et al*., 2021). Sustainable agriculture is based on practices that maintain ecological balance, prevent soil

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degradation, and ensure efficient resource use, particularly considering current climate challenges. Rising temperatures and decreasing water resources exert considerable pressure on agricultural production, directly affecting yield and indirectly leading to the emergence of new threats, such as pest populations increase and distribution with increased temp, appearance of new pests and diseases (Singh and Reddy, 2013; Robinson, 2024).

Sunflower (*Helianthus annuus* L.) is an important oilseed crop predominantly cultivated in European countries (approximately 70% of the total areas), including the Republic of Moldova, with more than 22% of agricultural fields occupied by this crop (FAOSTAT, 2024; NBS, 2023). Although sunflower plants are considered drought-resistant due to their well-developed root systems, that penetrate deep into the soil to access water reserves, they remain susceptible to the effects of heat and water stress (Duca *et al.*, 2022). This vulnerability is particularly pronounced during crucial growth phases, such as germination, anthesis (Debaeke *et al.*, 2021). Thus, insufficient water supply might significantly reduce germination rate and vigor of sunflower seeds, resulting in non-uniform germination and crop stand (Wen, 2015; Santos *et al.*, 2024). Heat stress during the reproductive stage causes a decrease in seed number, seed weight and oil characteristics, ultimately leading to crop yield loss (Mehmood *et al.*, 2023). It is anticipated that the frequency, duration, and intensity of heat and drought stress events will rise in the future, posing significant risks to agricultural productivity and food security (Mirzabaev *et al.*, 2023).

According to the Fourth National Communication of the Republic of Moldova under the United Nations Framework Convention on Climate Change (NCCC, 2018), there is a risk that in the absence of adequate adaptation measures, the cultivation of sunflower crop will become impossible or economically unprofitable in the most region of the country by the end of the 21st century.

In this context, sustainable management of agricultural resources and the identification of areas favourable for crops cultivation become imperative. To optimize sunflower production, it is essential to conduct rigorous assessments of temperature and precipitation distribution across the country during the cold and growing period (April-August), and to identify correlations between yield and relevant climatic characteristics, which can cause water and thermic stress and affect productivity (Bateri *et al.*, 2024). Thus, the aims of this research were to analyze the evolution of climate conditions during 2003-2021 period (i), and the relationships between these variables and sunflower yield trends in Moldova (ii), as well as to evaluate the favourability of the territory of the Republic of Moldova for sunflower cultivation (iii). These insights will support the development of effective measures for adapting to climate change and sunflower zoning while ensuring the economic viability of sunflower production.

## Materials and Methods

*Investigation area and analyzed particularities*

To identify optimal regions for sunflower farming in the Republic of Moldova, various characteristics of interest were assessed from 2003 to 2021. Thus, the yield of sunflower crops and climatic data, including the amount of annual atmospheric precipitation (i), precipitation during the cold period (ii) and growing periods (iii), as well as the average daily temperatures (iv) for this period were analyzed comparatively to the period of 1961-1990, recommended as a reference by the World Meteorological Organization. Sunflower yield data were retrieved from the National Bureau of Statistics (NBS, 2023) and contain the average annual sunflower yields in 35 administrative territorial unit (ATU). The climate data were obtained from the State Hydrometeorological Service (SHS, 2023).

*Evaluation methods*

To calculate the correlation between agricultural production and climatic variables, the spatial interpolation methods, which allow the extraction of values for climatic variables by administrative-territorial units were used. Climate data collected from 16 meteorological stations were interpolated employing the Spline method. From the resulting raster, polygons were extracted for each ATU and the average values of climatic parameters were calculated for each of them. Correlation coefficients between the average sunflower yield and the average of daily temperatures from April to August, amount of precipitation from the vegetation and cold period were calculated. The correlation coefficients provide a statistical measure of the strength and direction of the relationship between these variables, allowing the identification of the climatic factors with the greatest influence on agricultural yield.

*Data processing*

To assess the influence of each climatic factors, the rasters resulting from the multiplication of district-specific climatic values were overlaid with the obtained correlation coefficients in QGIS. This approach allows for a more rigorous and objective evaluation of the impact of each climatic variable on production, emphasizing the importance of temperature and precipitation during different periods.

The trends of climatic variables and yield were analyzed using non-parametric Mann-Kendall (MK) test and Sen's slope (SS) estimator. MK test indicates trends in the studied time series, while the Sen slope calculates the magnitude of the change (slope) (Koudahe *et al*., 2018; Fernández-Luqueño *et al*., 2014).

Calculations and verification of statistical significance (p=0.05) of the obtained results were performed using the XLSTAT tools available in Microsoft Excel with the generation of graphical representations.

## Results and Discussion

*Evolution of climate conditions on the territory of the Republic of Moldova during 2003-2021 period*

The greatest economic losses in agriculture are generated by the overlapping of extreme weather conditions to the critical periods of crop development, which are essential for yield determination (Povară, 2001). This issue becomes particularly relevant in the context of climate change, which lead to changes in the structure, intensity and frequency of extreme weather events, thereby increasing risks for agricultural crops, including sunflower. Temperature and rainfall are primary climatic factor affecting the rate of plant development.

Thermal resources, assessed and interpreted according to different biological thresholds characteristic of plant species and various phases of their growth cycle, provide an understanding of the thermal potential available to a region and the degree of favourability for normal vegetation, depending on the thermal requirements needed to complete the biological cycle.

When calculated above biological thresholds specific to different crops (5 °C, 7 °C, 10 °C), the thermal resources are considered useful for plant growth and development and are called effective temperatures (Povară, 2001). For sunflower the total heat consumption, expressed by the sum of temperatures ≥ 7 °C throughout the entire growing season, ranges between 1400 and 1800 °C. From this point of view, the heat requirements of the sunflower are satisfied on the entire territory of the Republic of Moldova and the sum of effective temperatures does not pose a limiting factor for the development of this crop in Moldova.

Annual temperature variations can lead to significant discrepancies in grown phases occurrence, directly impacting the rate of plant growth and development. For example, in the years characterized by elevated temperature, the vegetation phases occur earlier and the physiological processes in plants are more accelerated, while in the years with lower temperatures, development can be delayed, which negatively affect the yield (Enache, 2009).

Although sunflower does not have very high temperature requirements, immediately after sowing the plant requires a substantial amount of heat for normal growth. The optimal temperature for sunflower development (from germination to flowering) is 20-30 °C. On the other side, temperatures exceeding 20 °C during the flowering stage and 22 °C during the seed-filling stage can result in a reduction in seed yield (Ştefan and Constatinescu, 2022). An average temperature of approximately 18 °C from April to August is considered optimal for the development of this crop (Enache, 2009).

During the reference period of 1961-1990, the average temperatures from April to August indicated on a thermal deficit for sunflower throughout the country, while in the recent decades, due to the current global warming trend, this scenario has been altered. Growing season average temperature in the most regions of the country is optimal for sunflower development. The exception is the northern part of the Republic of Moldova, where average temperature values still remain below the optimal threshold of 18 °C (Figure 1).

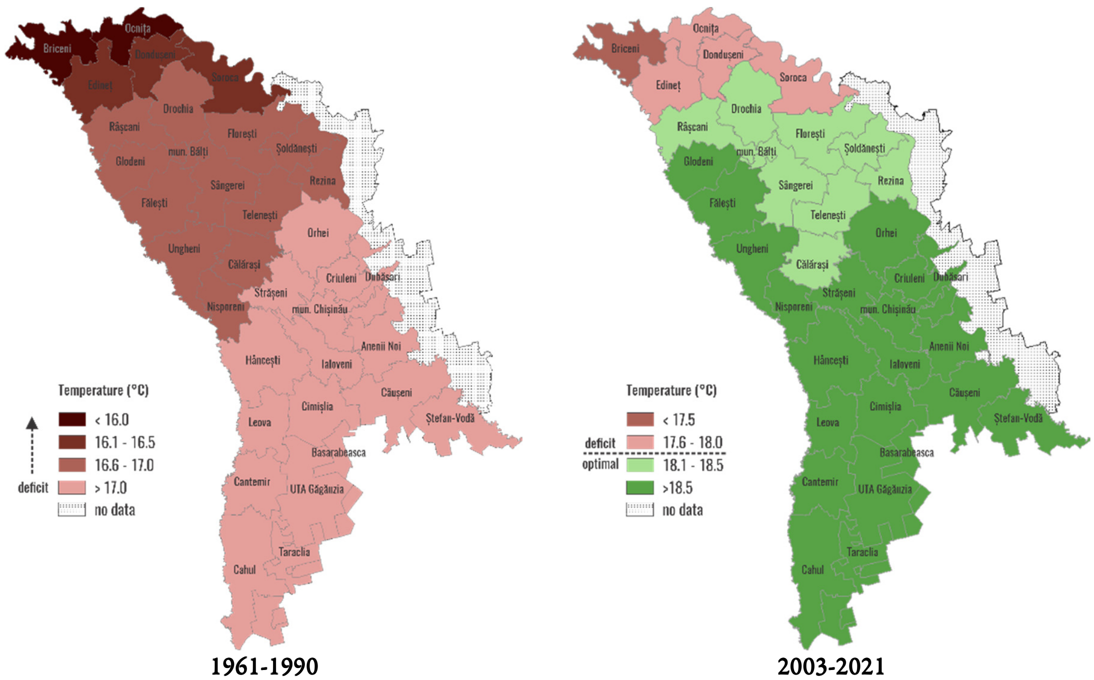



**Figure 1.** Average temperature from the growing season

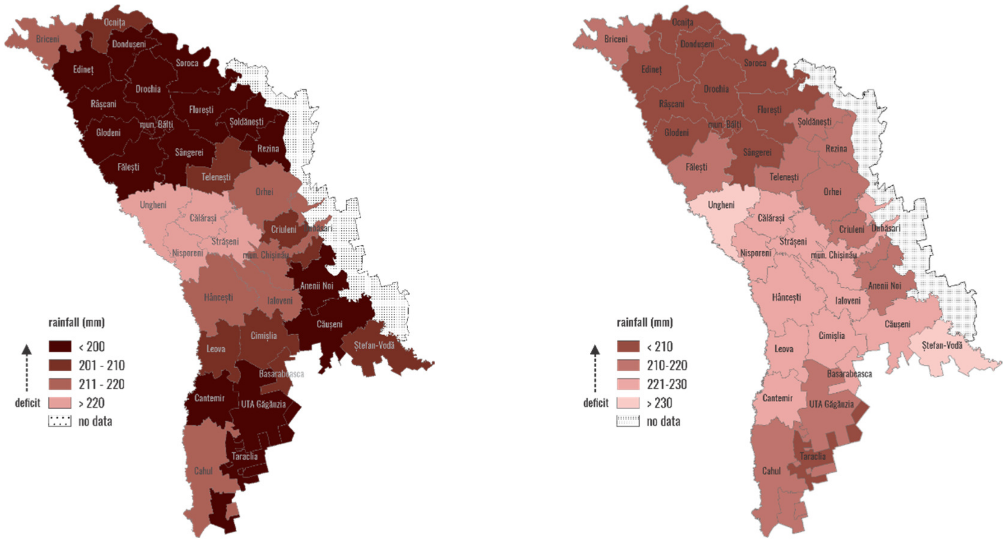
These observations underscore climate change as a complex factor that can both expand favourable areas for agricultural crops in certain regions and limit them in others, depending on the specific interactions between temperature, precipitation, and other climatic variables. In this context, analyzing the evolution of thermal resources in the Republic of Moldova is essential for assessing the territory's future capacity to support agriculture, particularly as climate change continues to shape conditions for agricultural development.

According to the data collected from Briceni meteorological station in the period of 2003-2021, the average temperature during growing season (April to August) did not exceed the 18 °C threshold in the 85% of analyzed years. This finding underscores the limiting nature of thermal resources in the northern part of the Republic of Moldova for this crop. At the national level, the years 2004 and 2021 were identified as the coldest within the analyzed interval, with temperatures less than the 18 °C threshold in almost all regions, excepting Cahul and Chisinau meteorological stations. Interestingly, although there is a spatial correlation between temperature distribution and sunflower production, this correlation does not always hold in the temporal dimension. In regions where the average temperature is below 18 °C, production is generally lower, but no significant reduction in yield was observed in cold years at the national level. This discrepancy can be attributed to the use of average values, which tend to “smooth out” local variations and mask extreme fluctuations. For instance, lower yields in certain regions are often compensated by higher yields in areas with average temperatures above 18 °C.

In addition to temperature, the amount of precipitation from October to April, as well as during the growing season, plays a critical role for growth and development of sunflowers. The moisture accumulated in the soil during the cold semester is one the main source of water supply for plants throughout the growing season and, therefore, largely determines the conditions for crop formation. For sunflower, it is required 400–450 mm of precipitation during the cold period. The plant is notably adaptable to the climatic conditions of semi-arid regions, being able to develop efficiently in areas with annual rainfall ranged from 500 to 650 mm. On the other hand, even the moisture is essential for plant growth, abundant rainfall can create conditions conducive to disease outbreaks and dispersion of pathogens, such as fungi and bacteria, which negatively impact agricultural production. Due to this fact sunflower is often cultivated in drier and warmer regions, with annual rainfall around 650 mm and relative low air humidity, where the risks of phytopathogen infestations are reduced (Debaeke *et al*., 2017).

During the growing season, soil moisture reserves gradually decrease as they are consumed through evaporation and transpiration. A lack of moisture during the flowering and seed-filling periods can delay flower formation and reduce the number of achenes. So, adequate moisture supply during this period is crucial for achieving a high yield. In the study region, total water consumption throughout the growing season varies between 300 and 400 mm (Tabără, 2005). Recent researches in the field of climate science indicate a general trend of decreasing precipitation in southern European countries, along with more frequent episodes of severe droughts (Duca *et al*., 2022). This shift poses a significant challenge to agriculture (NCCC, 2018). In regions most vulnerable to high temperatures, it is essential to implement innovative technologies for water conservation, such as effective irrigation systems and the integration of technological resources, such as climate-control equipment, to mitigate the negative impacts of climate variability.

The average annual precipitation in the Republic of Moldova, during the period 1961–1990, ranged from 520 to 640 mm, which met sunflower water requirements. Analysis of data from 2003 to 2021 revealed significant variability in the amount of precipitation, with values ranging between 403 mm and 715 mm. These values generally ensured the minimum necessary for the growth and development of sunflower on almost the entire territory of the country. However, in the regions, such as the Cahul Plain, the Cogalnic Plain and the Lower Cuboltei Plain the average annual precipitation was below the optimal threshold of 500 mm. Even if the amount of annual precipitation in the majority of cases corresponds to the value necessary for a good development of sunflower, its contribution in yield determination was not statistically significant, suggesting that other climatic or agronomic factors may have a more substantial influence on yields. As a result, this parameter was excluded from the assessment of the degree of favourability of area for sunflower cultivation.

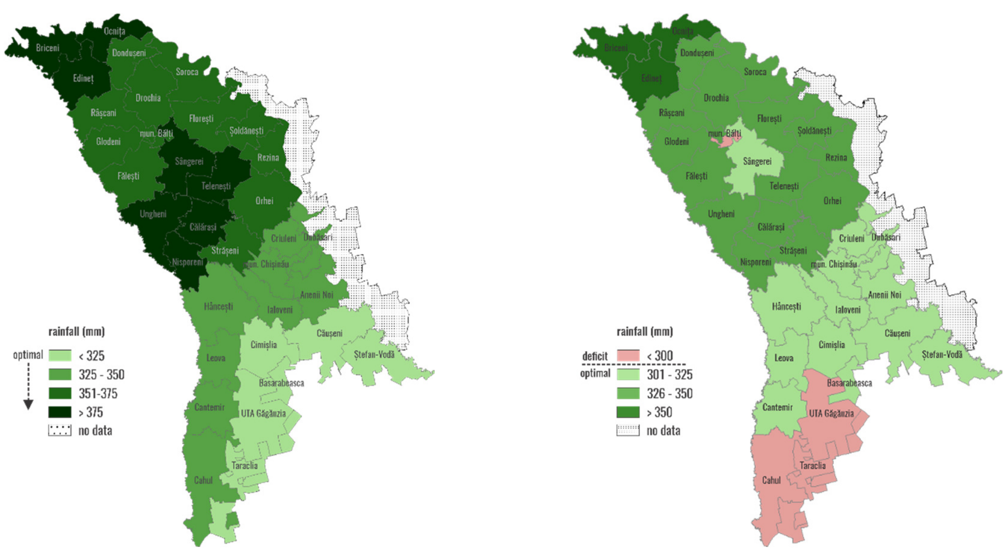



**Average for 1961-1990** **Average for 2003-2021**

**Figure 2.** Distribution patterns of total precipitation from the cold season

The total amount of precipitation during the cold period was below the minimum requirements throughout the country, the deficit being most pronounced in the northern part. While a slight increase in average precipitation during the cold period has been observed in recent years, these values still do not reach the optimal levels needed to maintain adequate soil moisture (Figure 2). Thus, the deficit of precipitation during the cold period constitutes a significant limiting factor for achieving optimal sunflower yield, a statement also supported by the values of the correlation coefficients with the average yield from 2003-2021.

During 1961-1990 years, the total amount of precipitation for the vegetation season was in the limits of requirements for sunflower growing throughout the country, while in the period of 2003-2021 significant variations, especially in the southern part of the country, were found. Thus, in the Autonomous Territorial Unit of Gagauzia (ATUG) and Cahul district the amount of rainfall was below the minimum threshold of 300 mm. On the other side, in the northern districts, excepting Balti municipality the water supply was optimal for this crop (Figure 3).




**Average for 1961-1990** **Average for 2003-2021**

**Figure 3.** Distribution patterns of total precipitation from the growing season

The Mann-Kendall test analysis of datasets indicated the absence of statistically significant trends both on the level of entire country and development region (North, Center and South).

*The relationships between climate variables and sunflower yield trends in the Republic of Moldova*

The dynamics of the sunflower yield from 2003 to 2021 showed an increasing trend in all administrative regions of the Republic of Moldova (a number of examples are presented in Figure 4).

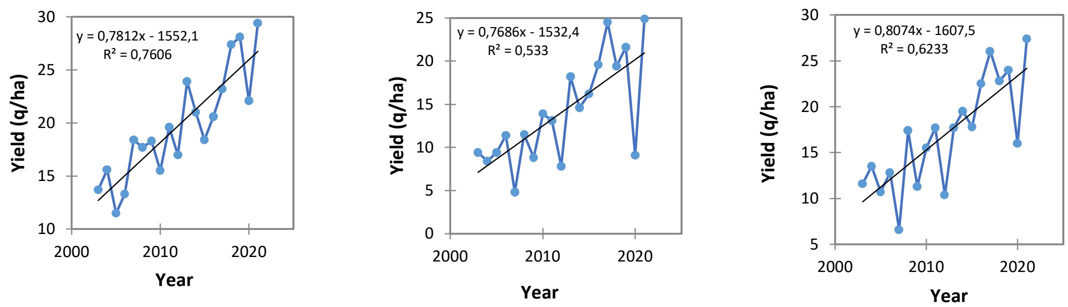



**Figure 4.** Trend of sunflower yield evolution in three administrative-territorial units of the Republic of Moldova, 2003-2021 (Ocnita, Ialoveni and Cantemir, presented selectively)

According to the Mann-Kendall test, the trend of the yield is positive, statistically significant ($p \leq 0.05$), in all ATU, excepting Calarasi and Nisporeni districts, where it is insignificant. The values of the Sen slope, excluding the mentioned districts, ranged from 0.383 q/ha per year in Singerei to 1.044 q/ha/year in Dubasari. High Sen slop values (0.908-1.014 q/ha/year) were also revealed in Leova, Cimislia and Taraclia from the southern part of the country. In contrast, the lowest Sen slope values were recorded in the districts of Basarabeasca (0.493), Orhei (0.517), Fălești (0.553), Telenești (0.563), and in the municipality of Bălți (0.500), indicating a more moderate increase in yield during the analyzed period.

The highest average values of sunflower yield were revealed, especially in the northern region of the country. Thus, in the northern districts, yield values ranged from 14.9 to 19.7 q/ha, while in the center and south, they were between 9.8 to 18.1 and 11.9 to 16.9 q/ha, respectively. The interannual variability of sunflower yields was high, with coefficients of variation (CV%) ranging from 23.4% to 48.2%. It is also noted that yield values in the northern part of the country were more stable, with CVs ranging from 23.4% to 33.6%, compared to 28.4% to 45.8% in the center and 33.1% to 48.2% in the south (Table 1).

**Table 1.** Descriptive statistics for sunflower production during the study period, in three regions of the Republic of Moldova with different analyzed areas

| Parameter | Northern part (ATU*: 12 areas) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Average yield (q/ha) | 16.9 | 18.0 | 18.5 | 18.9 | 18.5 | 18.2 | 19.7 | 14.9 | 19.7 | 18.3 | 17.2 | 17.6 |
| Minimum yield (q/ha) | 8.6 | 9.6 | 7.9 | 11.0 | 6.5 | 6.9 | 12.5 | 3.0 | 11.5 | 10.9 | 8.0 | 8.5 |
| Maximum yield (q/ha) | 24.3 | 28.9 | 28.6 | 26.5 | 28.0 | 30.7 | 27.5 | 24.5 | 29.4 | 26.3 | 25.2 | 25.8 |
| CV% | 29.2 | 28.7 | 27.6 | 25.7 | 28.4 | 32.7 | 23.4 | 33.6 | 24.9 | 25.6 | 25.7 | 26.4 |

ATU (administrative territorial unit): 1 – Briceni; 2 – Donduseni; 3 – Drochia; 4 – Edinet; 5 – Falesti; 6 – Floresti; 7 – Glodeni; 8 – mun. Balti; 9 – Ocnita; 10 – Rascani; 11 – Sangerei; 12 – Soroca

| Parameter | Central part (ATU*: 14 areas) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Average yield (q/ha) | 13.1 | 9.8 | 15.3 | 14.4 | 14.7 | 14.0 | 12.0 | 12.1 | 14.9 | 13.2 | 16.0 | 13.8 | 13.7 | 18.1 |
| Minimum yield (q/ha) | 5.4 | 4.0 | 5.4 | 4.0 | 4.5 | 4.8 | 4.3 | 3.8 | 5.7 | 6.3 | 8.5 | 4.6 | 6.4 | 7.5 |
| Maximum yield (q/ha) | 26.4 | 19.7 | 28.2 | 27.4 | 27.1 | 24.9 | 21.3 | 24.0 | 24.6 | 24.6 | 25.0 | 25.5 | 24.0 | 28.6 |
| CV% | 41.6 | 39.4 | 35.1 | 45.8 | 39.1 | 41.1 | 38.6 | 43.5 | 31.2 | 37.1 | 28.4 | 38.6 | 34.0 | 31.7 |

ATU (administrative territorial unit): 1 – Anenii Noi; 2 – Calarasi; 3 – Criuleni; 4 – Dubasari; 5 – Hancesti; 6 – Ialoveni; 7 – mun. Chisinau; 8 – Nisporeni; 9 – Orhei; 10 – Rezina; 11 – Soldanesti; 12 – Straseni; 13 – Telenesti; 14 – Ungheni

| Parameter | Southern part (ATU*: 9 areas) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Average yield (q/ha) | 11.9 | 15.2 | 16.9 | 14.3 | 14.3 | 16.3 | 14.5 | 15.2 | 14.2 |
| Minimum yield (q/ha) | 2.0 | 3.4 | 6.6 | 4.4 | 2.8 | 5.5 | 4.5 | 3.5 | 3.2 |
| Maximum yield (q/ha) | 21.7 | 25.5 | 27.4 | 26.1 | 27.7 | 26.3 | 24.5 | 26.9 | 25.0 |
| CV% | 44.1 | 38.8 | 33.1 | 39.0 | 48.2 | 40.9 | 36.1 | 40.0 | 40.2 |

ATU (administrative territorial unit): 1 – Basarabeasca; 2 – Cahul; 3 – Cantemir; 4 – Causeni; 5 – Cimislia; 6 – Leova; 7 – Stefan Voda; 8 – Taraclia; 9 – ATUG Gagauzia

In the southern part of the Republic of Moldova, the highest production levels were found in the districts of Leova and Cantemir (Figure 5), although these values were lower than those in the north. This variability in production is influenced by several factors, including the availability of water resources, soil type, and the applied cultivation technologies. For example, the northern districts benefit from more stable water resources, while the southern districts, although they may have certain advantages, such as a warmer climate, often face challenges related to precipitation deficits. These observations highlight the importance of adopting agricultural policies that take into account the specific characteristics of each region.

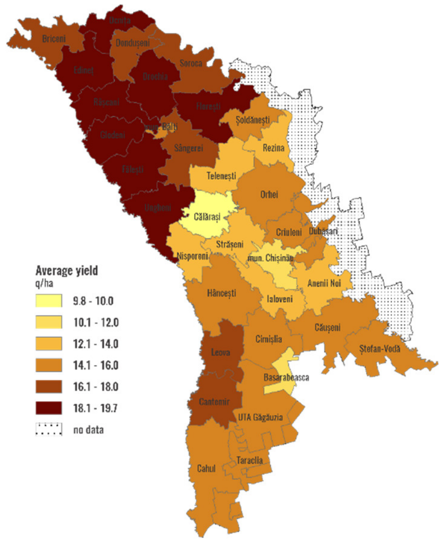



**Figure 5.** The average yield for the period 2003-2021

To estimate the degree of favourability of the country's territory for sunflower cultivation based on analyzed climate variable, we calculated their correlation with the yield. The correlation analysis of sunflower yield from all ATU, in different years, and climate variables (Table 2) showed that seed yield was significantly positively correlated with the amount of precipitation during the growing season. Thus, positive moderate correlations were found in 2005 and 2020 (r = 0.47; r = 0.34) and strong (r = 0.51–0.76) in 2007, 2009, 2014, and 2019. At the same time, negative correlations were revealed between the average temperature during the sunflower growing period: moderate – in 2003, 2008, 2011, 2013, 2014, 2016, and 2019 (r = -0.42 to -0.48) and strong – in 2007, 2009, 2012, 2018, and 2020. The maximum values of the Pearson correlation coefficients (r) were observed in years with severe droughts: 2007 (r = -0.83), 2012 (r = -0.72), and 2020 (r = -0.75).

**Table 2.** Relationship between average annual sunflower yield and climate variables from 2003 to 2021 (r – Pearson correlation coefficient)

| Year | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|
| I[1] | **-0.46*** | 0.25 | 0.17 | 0.13 | **-0.83*** | **-0.44*** | **-0.69*** | 0.02 | **-0.46*** | **-0.72*** |
| II[2] | 0.21 | 0.13 | **0.47*** | 0.03 | **0.76*** | 0.27 | **0.58*** | 0.08 | 0.32 | 0.04 |
| III[3] | **-0.57*** | -0.25 | **-0.52*** | 0.25 | **-0.34*** | **-0.66*** | 0.29 | -0.19 | -0.20 | -0.28 |
| **Year** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | |
| I[1] | **-0.42*** | **-0.43*** | 0.19 | **-0.44*** | 0.17 | **-0.49*** | **-0.48*** | **-0.75*** | 0.04 | |
| II[2] | 0.30 | **0.51*** | 0.10 | 0.32 | 0.01 | 0.08 | **0.56*** | **0.34*** | 0.13 | |
| III[3] | -0.13 | -0.03 | -0.14 | **0.61*** | 0.27 | **-0.60*** | **0.34*** | **0.52*** | -0.14 | |

[1]I – average monthly temperature during growing season; [2]II – total amount of precipitation during growing season;
[3]III – total amount of precipitation during cold season; * – statistically significant correlations ($p<0.05$)

On the other hand, a greater number of statistically significant correlations were observed when the dependence of sunflower yield on bioclimatic factors per administrative-territorial unit were analyzed, this is probably due to a higher degree of environmental factor homogeneity. Thus, moderate (r = 0.45–0.48) to strong (r = 0.51–0.78) positive correlations were found between sunflower yield and the amount of precipitation during the growing season in more than half (54%) of the administrative-territorial units. In ten of the ATU, sunflower yield also positively correlated with the amount of precipitation during the cold season. Specifically, Cahul, Cimișlia, Leova, and Ungheni showed moderate correlations ranging from 0.46 to 0.48, while Basarabeasca, Fălești, Nisporeni, Telenești, the municipality of Bălți, and UTA Găgăuzia had strong correlations, ranging from 0.51 to 0.69.

At the level of the entire dataset (all analyzed period), the correlation coefficients indicated the following values:

- *Yield versus temperature from April to August:* The correlation coefficient is -0.498989, suggesting a moderate inverse relationship between high temperatures during the growing season and sunflower yield.
- *Yield versus amount of precipitation during the cold season:* The correlation coefficient of 0.463994, indicated on a positive relationship, confirming the importance of precipitation from the cold season in accumulation of water reserves available for growing season and sunflower development.
- *Yield versus amount of precipitation during the growing season:* The correlation coefficient is 0.375163, indicating a relatively weak, but significant direct relationship between precipitation during the growing season and sunflower yield. This suggests that additional rainfall during this period may somewhat alleviate the effects of high temperatures.

The correlation coefficients indicate that heat stress during the growing season has a considerable negative impact on yield, while precipitation, both during the cold and the growing season, plays an important role in supporting agricultural production. Similarly, Osman et al. (2021) found a strong positive correlation of annual rainfall with yield of sunflower (r = 0.75), sorghum (r = 0.64) and sesame (r = 0.58) in Sudan, whereas the relationships among the temperature-based variables and crop yield were negative. According to Milosevic et al. (2015) precipitation showed a significant positive correlation with sunflower yields only in July and August, confirming the importance of summer month's precipitation for plant development and yield size. In contrast, temperature showed a significant positive correlation with crop yields only in March, when higher temperatures promote plant development.

This fundamental approach can be used to inform decisions related to climate change adaptation strategies, highlighting the need for the implementation of integrated water resource management and agricultural technologies. The evaluation of climate dynamics and its impact on agricultural production should be a central element in agricultural policy planning, thus contributing to increased crop resilience to climate change.

Based on these coefficients, we have developed a formula to calculate the degree of favourability, which is presented as follows:

$$Fv = P\_grow*0.375163 + P\_cold*0.463994 + T\_Apr\text{-}Aug*(-0.498989) \quad (1)$$

where: *Fv – favourability degree; P_grow – precipitation during the growing season; P_cold – precipitation during the cold season; T_Apr-Aug – average air temperature from April to August.*

By applying formula (1) to calculate the degree of favourability, values ranging from 185 to 236 units were obtained. According to Zăvoianu (2007), the number of classes or intervals into which the set of values is divided is determined based on the following formula:

$$k=1+3{,}33*\log_{10}n \quad (2)$$

where: *K – the number of classes; n – the values of the set.*

In the current analysis, considering n = 35, the result is k = 6. Thus, the degree of favourability was divided into six classes, ranging from "slightly favourable" to "favourable" (Figure 6).

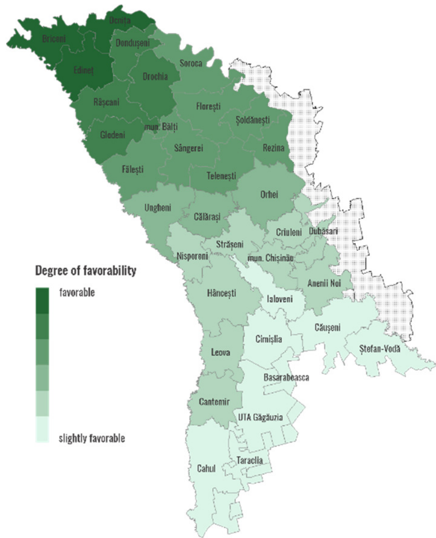



**Figure 6**. The degree of favourability of the territory of the Republic of Moldova for sunflower cultivation

The map of the degree of favourability for sunflower cultivation on the territory of the Republic of Moldova, considering both thermal and precipitation factors, highlights two distinct zones. On one hand, the northern part of the country is classified as a favourable area, while the southern part is considered slightly favourable. It is important to note that within the southern region, only the Leova and Cantemir districts have relatively more favourable conditions compared to the rest of the region. This discrepancy is also reflected in the distribution of average yields from 2003 to 2021.

Knowing the favourable areas and those with limited potential can guide decisions regarding cultivation strategies, the adaptation of agricultural techniques, zoning of sunflower hybrids, and the optimal management of resources, thereby contributing to increased agricultural production under variable climatic.

*General considerations on the main factors influencing sunflower production*

The analysis of the relationships between climatic conditions, especially temperature and precipitation and sunflower yield in the Republic of Moldova during the period of 2003-2021, highlighted some significant factors influencing agricultural production.

Temperatures: The cumulative temperatures exceeding the biological threshold of +7 °C, as well as the monthly average temperatures from April to August, indicate favourable conditions for sunflower cultivation across most of the country. However, in years when the average temperatures are below 18 °C (e.g., 2004, 2005, and 2006), particularly in the northernmost districts (Briceni, Ocnița, Edinet, Donduseni, Soroca), sunflower yield were lower compared to warmer years.

Precipitation and its impact: Although precipitation during the cold season is insufficient across the entire country, the deficit is more pronounced in the northern part. However, under certain conditions, higher amounts of precipitation during the growing season can partially compensate for this deficit.

Central Region: In the central part of the Republic of Moldova, climatic conditions, characterized by adequate precipitation during the growing season and optimal average temperatures, are optimal for sunflower cultivation. However, the fragmented terrain in this region limits the areas available for arable land, which explains the lowest values of yield observed in the Calarasi district.

Cahul Plain and Ialpug Depression: Although these regions meet the thermal requirements for optimal sunflower cultivation, the precipitation deficit both in the cold season and during the growing season limited the production. As a result, these areas are classified as “slightly favourable”, according to the applied calculation methodology.

## Conclusions

The current research findings suggest that, despite the favourable climatic potential for sunflower cultivation in the Republic of Moldova, there are climatic variables that can significantly influence yields. Farmers and decision-makers need to implement strategies for adapting to climate change, including water management technologies and sustainable agricultural practices, to maximize production and ensure the long-term viability of this crop.

## Authors' Contributions

Conceptualization - MD; Data curation – RD, SC; Formal analysis - RD, SC; Methodology - RD; Writing original draft – RD, SC; Writing review and editing – MD, SC. All authors read and approved the final manuscript.

**Ethical approval** (for researches involving animals or humans)

Not applicable.

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## Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

## References

Agovino M, Casaccia M, Ciommi M, Ferrara M, Marchesano K (2019). Agriculture, climate change and sustainability: The case of EU-28. Ecological Indicators 105:525-543. *https://doi.org/10.1016/j.ecolind.2018.04.064*

Bateri J, Lyimo JG, Msinde JV (2024). The influence of climatic and environmental variables on sunflower planting season suitability in Tanzania. Scientific Reports 14(3906):1-13. *https://doi.org/10.1038/s41598-023-49581-5*

Bojariu R, Nedealcov M, Boincean B (2021). Ghid de bune practici întru adaptarea la schimbările climatice și implementarea măsurilor de atenuare a schimbărilor climatice în sectorul agricol [Good practice guide for climate change adaptation and implementation of climate change mitigation measures in the agricultural sector]. Chisinau.

Debaeke P, Casadebaig P, Flénet F, Langlade N (2017). Sunflower crop and climate change: vulnerability, adaptation, and mitigation potential from case-studies in Europe. OCL Oilseeds and Fats Crops and Lipids 24(1):15. *https://doi.org/10.1051/ocl/2016052*

Debaeke P, Casadebaig P, Langlade NB (2021). New challenges for sunflower ideotyping in changing environments and more ecological cropping systems. OCL Oilseeds and Fats Crops and Lipids 28:29. *https://doi.org/10.1051/ocl/2021016*

Duca M, Boian I, Domenco R (2022). The impact of droughts on sunflower production in the Republic of Moldova. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 50(4):13040. *https://doi.org/10.15835/nbha50413040*

Enache L (2009). Agrometeorologie [Agrometeorology]. University of Agricultural Sciences and Veterinary Medicine, Bucuresti, Romania.

FAOSTAT (2024). Food and agriculture data. Retrieved 2024 September 7 from: *http://www.fao.org/faostat/en/#data/QC*

Fernández-Luqueño F, López-Valdez F, Miranda-Arámbula M, Rosas-Morales M, Pariona N, Espinoza-Zapata R (2014). An introduction to the sunflower crop. In: Arribas JI (Ed). Sunflowers: Growth and Development, Environmental Influences and Pests/Diseases. Valladolid, Spain: Nova Science Publishers, pp 18.

IPCC (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Lee H, Romero J (Eds)]. IPCC, Geneva, Switzerland, pp 184. *https://doi.org/10.59327/IPCC/AR6-9789291691647*

Koudahe K, Djaman K, Kayode JA, Awokola SO, Adebola AA (2018). Impact of climate variability on crop yields in Southern Togo. Environment Pollution and Climate Change 2(1):1000148. *https://doi.org/10.4172/2573-458X.1000148*

Kumari A, Lakshmi GA, Krishna GK, Patni B, Prakash S, Bhattacharyya M, Singh SK, Verma KK (2022). Climate change and its impact on crops: A comprehensive investigation for sustainable agriculture. Agronomy 12(12):3008. *https://doi.org/10.3390/agronomy12123008*

Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, Bwalya M, Caron P, Cattaneo A, Garrity D, Henry K, Hottle R (2014). Climate-smart agriculture for food security. Nature Climate Change 4:1068-1072. *https://doi.org/10.1038/nclimate2437*

Mehmood M, Qamar R, Joyia HA (2023). Effect of high temperature stress on pollen grains in sunflower (*Helianthus annuus* L.) inbred lines. Brazilian Archives of Biology and Technology 66(e2322097):1-11. *https://doi.org/10.1590/1678-4324-2023220927*

Milošević D, Savić SM, Stojanović V, Popov-Raljić J (2015). Effects of precipitation and temperatures on crop yield variability in Vojvodina (Serbia). Italian Journal of Agrometeorology 3:35-46.

Mirzabaev A, Bezner Kerr R, Hasegawa T, Pradhan P, Wreford A, von der Pahlen TMC, Gurney-Smith H (2023). Severe climate change risks to food security and nutrition. Climate Risk Management 39:100473, *https://doi.org/10.1016/j.crm.2022.100473*

NBS (2023). National bureau of statistics of the Republic of Moldova. Retrieved 2023 May 4th from: *https://statistica.gov.md*

NCCC (2018). Fourth National Communication of the Republic of Moldova to the United Nations Framework Convention on Climate Change. Ministry of Agriculture, Regional Development and Environment of the Republic of Moldova / United Nations Environment Programme. Coord: Apostol I, Lekoyiet S *et al.* (2018) 470 p.

Osman MAA, Onono JO, Olaka LA, Elhag MM, Abdel-Rahman EM (2021). Climate variability and change affect crops yield under rainfed conditions: A case study in Gedaref State, Sudan. Agronomy 11:1680. *https://doi.org/10.3390/agronomy11091680*

Povară R (2001). Particularități climatice ale Câmpiei Române [Climatic peculiarities of the Romanian Plain]. Annals of Spiru Haret University, Geography Series (4):61-66.

Santos JRP, dos David AMS, de S Custodio DCS, Borges JB, Ribeiro RCF, Amaro HTR, Freitas HKC, Barbosa RS, Santos HSN, da Silva BS (2024). Physiological quality of sunflower seeds under water stressed conditions. Contribuciones a las Ciencias Sociales 17(5):e6831. *https://doi.org/10.55905/revconv.17n.5-138*

SHS (2023). State Hydrometeorological Service of the Republic of Moldova. *https://old.meteo.md/newsait.htm*

Singh RP, Reddy KR (2013). Impact of climate change and farm management. Climate Change and Environmental Sustainability 1:53-72. *https://doi.org/10.5958/j.2320-6411.1.1.006*

Ştefan IO, Constantinescu E (2022). Research on the behavior of some sunflower cultivations of the north area of Olt County. Annals of the University of Craiova, Agriculture, Montanology, Cadastre Series 52(2):170-173. *https://doi.org/10.52846/aamc.v52i2.1404*

Tabără V (2005). Fitotehnie Vol I: Plante tehnice oleaginoase și textile. Editura Brumar, Timişoara.

Wen B (2015). Effects of high temperature and water stress on seed germination of the invasive species Mexican sunflower. PLoS ONE 10:e0141567. *https://doi.org/10.1371/journal.pone.0141567*

Zăvoianu I (2007). Prelucrarea datelor hidrometeorologice. București, Romania.