

Article

The Impact of Drought Risk on Maize Crop in Romania

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Abstract

This study examines the effects of climate change on maize production in Romania between 2003 and 2024, focusing on yield dynamics, regional disparities, and economic losses. Maize, a key crop in Romanian agriculture, has become increasingly vulnerable to extreme weather events, particularly droughts, which remain the most frequent risk. The analysis highlights a marked decline in maize yields and cultivated area in recent years, strongly correlated with severe droughts in 2020, 2022, and 2024. The results show that western and northern counties display greater resilience, while southeastern regions face significant yield losses. The economic impact is substantial, with losses exceeding EUR 1 billion. These findings underscore the systemic nature of climate-related risks and call for region-specific adaptation strategies, expanded irrigation infrastructure, and index-based insurance schemes to strengthen resilience and ensure sustainable maize production under changing climatic conditions.

Keywords: climate change; agriculture; historical maize yield; maize surface evolution; maize losses; agriculture economics

1. Introduction

Climate change, driven primarily by global warming, is widely recognized as one of the greatest environmental challenges of our time [1]. Its main driver is the increasing concentration of greenhouse gases (GHGs), largely resulting from human activities such as fossil fuel combustion, industrial processes, and land-use changes [2]. Beyond its environmental effects, climate change has profound implications for agriculture, as shifts in temperature, precipitation patterns, and the frequency of extreme weather events directly affect crop yields and livestock productivity. One of the most crucial parameters in this context is the atmospheric concentration of carbon dioxide (CO₂), which influences both plant growth and ecosystem dynamics [3]. These challenges are particularly pressing given the need to ensure global food security in a world where the population is projected to reach nearly 9.5 billion people by 2050. Ensuring stable and resilient agricultural systems in the face of climate change is therefore essential to meeting future food demands and avoiding widespread risks to human well-being [2]. When the concentration of CO₂ in the atmosphere increases, plants produce a greater amount of vegetative matter (the CO₂ fertilization effect). The magnitude of this fertilization effect depends on whether the plant is classified as a C3 or C4 species. C3 plants are more sensitive to elevated CO₂ concentrations and are more likely to benefit from higher atmospheric CO₂ levels [4,5].



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Among all of the plant biotic and abiotic stresses, the most recurrent risk in Europe's climate is drought. The severity and frequency of droughts have increased, especially in southwestern and central parts of Europe. Across most of the continent, studies estimate significant increases in the duration, severity, and frequency of droughts throughout the 21st century, with the exception of the northern regions [6]. Drought is a combination of individual factors, including a lack of precipitation, and is exacerbated by high temperatures and associated with high evapotranspiration. By the year 2100, farms in southern Europe could suffer significant losses induced by drought. These insights are clearly reflected in the work conducted by Mănescu et al. [7]. Drought is one of the major factors accelerating the process of desertification, with profound effects on ecosystems and community livelihoods. The reduction in water resources, the decline in soil moisture, and the loss of land fertility lead to decreased agricultural productivity and land degradation, favoring the expansion of arid areas. Moreover, prolonged drought increases the vulnerability of rural communities dependent on agriculture, undermines food security, and raises the risk of forced migration. According to the United Nations Convention to Combat Desertification (UNCCD), drought and desertification are closely interconnected phenomena, and the sustainable management of land and water resources is essential to reducing their impact and achieving the goals of sustainable development [8]. Minimizing the risks generated by climate change at the global level requires the adoption of specific actions that are adaptable to the effects of climate change. These measures must be adapted to the specifics of each region of Europe [9].

The main objective of this paper is to analyze the impact of climate change on maize production in Romania through a quantitative and territorial assessment of climate risks, with a focus on drought. This study aims to identify trends in production and cultivated area over the past two decades to determine the most vulnerable and high-performing agricultural regions and to explore the relevance of risk transfer mechanisms—particularly agricultural insurance—as adaptation solutions to changing climate conditions. In this regard, we seek to provide an analytical foundation for the development of differentiated public policies and to support the strategic decision-making of both farmers and insurers.

This paper is organized into several sections. The Introduction outlines the research context, objectives, and the study's contribution to the field. The second section reviews the relevant literature, with a focus on the impact of climate change on maize production, emphasizing drought through a quantitative and spatial assessment of climate risks. The following section details the dataset and research methodology. Results are then presented and discussed in relation to findings reported by other scholars. The paper concludes with final remarks, including proposed strategies for addressing the identified challenges.

2. Literature Review

The scientific literature examining the impact of climate change on agriculture has developed significantly over the past two decades. Although there is a growing consensus that climate change is already occurring and will continue to occur, the magnitude of these impacts remains uncertain [10,11]. The multitude of factors playing a significant role in agricultural production and their complex interactions pose a challenge to comprehensive assessments of climate impact. Crop simulation models and other agronomic models used in previous research vary in complexity and in the extent to which they incorporate physiological processes [12]. Methods of integrating GCM (General Circulation Model—Hadley Centre Climate Model, version 2) data into crop simulation models differ considerably [13], with a variety of economic modeling approaches applied (e.g., production function versus the hedonic approach). Consequently, these studies have generated a wide range of esti-

mates regarding expected productivity and variability impacts. Regional temperature and precipitation remain among the most important factors influencing agricultural output.

One of the earliest important studies that analyzed the potential effects of climate change on agriculture [14] used a hedonic approach to estimate the marginal value of climate by regressing land values against climatic, soil, and socioeconomic variables using cross-sectional data. Their findings suggest that increasing temperatures in all seasons (except autumn) will reduce farm productivity, while increased precipitation in all seasons (again, except autumn) will enhance productivity. The authors also acknowledged that irrigation is a key adaptive response. They estimated the impact of climate change on farm productivity by applying these estimations to a climate change scenario involving a doubling of CO₂ emissions by mid-21st century, a 1.62 °C (5 °F) average temperature increase, and an 8% change in precipitation. Their results show that the estimated impact of climate change is lower when using the hedonic approach compared to the production function method. This outcome was expected, since the production function does not account for adaptive responses (such as crop switching), thereby tending to overestimate damages. The reported results vary from a 4–6% decline to a slight increase in agricultural output value.

Criticisms of the hedonic approach in the above-mentioned study concern the inadequate treatment of irrigation, lack of robustness in weighting methods, and difficulties in estimating dynamic adjustment costs due to short-term fixed capital constraints. To address this first issue, Schlenker, Hanemann, and Fisher [15] performed Chow tests to determine whether regression coefficients differ significantly between rain-fed and irrigated regions, also testing for differences in the coefficients of climatic variables. The results indicate that the economic effects of climate change on agriculture should be assessed separately for rain-fed and irrigated areas and that aggregating them may produce misleading estimates. The study also links individual farm productivity with surface water availability, concluding that climate change could significantly impact the value of irrigated land [16].

Temperature increases affect crop responses in a nonlinear fashion. Using a 55-year dataset on crop yields, studies have found that productivity for maize, soybeans, and cotton increases at higher temperatures, up to a certain threshold. Their results show significant yield declines towards the end of the century as temperatures surpass these thresholds. Studies estimate that, by the end of the century, yields for these three crops may decline by 25–44% under the slow-warming scenario (IPCC B1) and by 60–79% under the rapid-warming scenario (IPCC A1). Hence, there could be substantial negative effects on agriculture in the long term if temperatures exceed critical levels [16].

A key aspect of climate change's impact on agricultural insurance lies in crop yield variability because it reflects producer risk. Isik and Devadoss [17] created a framework to determine the impact of climate change on crop yields and variability and on the covariance of yields between different crops. As also mentioned in the literature, meteorological risks have an important impact on crop yields [18,19]; other factors like diseases, pests, and the use of various inputs, such as seeds, fertilizers, and pesticides, may also play a role. [20–22] The distribution of crop yield is directly influenced by inputs, which means that it is not normally distributed [23].

Temperature directly affects plant physiological processes such as photosynthesis, respiration, and evapotranspiration [24]. A high increase in the temperature can reduce yields by accelerating maturation and reducing the time available for biomass accumulation [24–26]. For example, maize is very sensitive to heat stress during flowering, which can significantly reduce yield [27]. Extreme temperatures increase soil water evaporation, inducing water stress in crops.

Water is an important factor for crop growth, and therefore, changes in precipitation can deeply affect the crops [28]. Excess precipitation can cause floods, which affects soil structure and restricts oxygen access to crop roots [29]. Low or no precipitation can reduce soil moisture and negatively affect crops [30]. Changes in rainfall distribution have led to a frequency increase in agricultural droughts in central and southern Europe [31]. The main crops affected are maize and sunflower [32].

The combined effects of high temperatures and low precipitation have an even greater impact on the agricultural systems. This situation is evident for rice and soybeans, where water deficits coupled with heat can cause dramatic yield losses [33].

Romania, located in southeastern Europe, has a temperate continental climate and is increasingly affected by extreme weather events such as heat waves, prolonged droughts, and floods [34,35]. Characterized by arid, semi-arid, and dry subhumid climatic conditions, approximately 30% of the country is classified as desertified [36]; this is a concerning figure given that agriculture, one of Romania's traditional economic sectors, still accounts for about 5% of the gross domestic product. The southern, southeastern, and eastern regions are the most severely impacted, with multiannual precipitation rates of 600 mm or less and temperature increases of up to 1.7 °C since 1997 [37]. As a result, drought in Romania has been the subject of extensive research [38–43].

Based on the above, it can be stated that the effects of climate change on agriculture are complex. For some crops, higher temperatures can positively influence yields within a certain increase range. However, higher temperatures may also increase damage in the flowering period of crops, but the impact also depends on the level of precipitation, water availability, or management practices. When changes occur due to climate change, there are potential mitigation options: (1) the use of irrigation to reduce water deficits; (2) the use of different crops, which are more tolerant to heat, and drought. Successful adaptation will always depend on the availability of such varieties, their yield performance, and the relative costs of seeds and production.

3. Methodology

In order to build a robust and relevant analytical framework, this study has been focused on maize in Romania. Maize holds a central role in Romanian agriculture: it is one of the most widely grown field crops and is highly vulnerable to water scarcity and heat stress [44,45]. The summer period is considered particularly critical due to its sensitivity to drought, making maize an ideal reference crop for analyzing climate risks and evaluating risk transfer mechanisms via insurance [46,47]. The choice is further justified economically and strategically, as Romania is a major producer of maize within the European Union [48]. Because Romania exports significant quantities, every year, large annual production fluctuations caused by climate variability also affect the supply chains, domestic prices, and the budgetary balance of agricultural subsidies. Romania is characterized by climatic diversity, which leads to differences in the frequency and severity of extreme events from county to county. This variability necessitates the adoption of personalized risk management solutions that consider the local characteristics of each region.

The proposed methodology combines a rigorous historical analysis of production and loss data. The analysis is performed at the county level, to identify how climate change affects each region.

Stage I—Analysis of the evolution of maize cultivation in Romania. In this stage, we sought to identify trends in cultivated areas, average yields, and the geographic distribution of maize. Consideration was given to the results at the county and national level over the last 20 years. These data made it possible to assess the production capacity of different regions, highlighting areas with high potential, stagnation, or decline.

All statistical calculations, including the estimation of Olympic averages, burning cost, and yield variability indicators, were performed using Microsoft Excel 365. The software was used both for data preprocessing and for quantitative modeling. Graphical representations (maps and figures) were also generated using Excel's charting tools.

Stage II—Analysis of maize production losses in Romania. In this stage, yield losses caused by climate change were quantified using historical agricultural data series. The analysis was based on data obtained from an official source, the National Institute of Statistics (INS). Each county was analyzed, and all data were aggregated at the national level. The reference period for the dataset was set between 2003 and 2024. In this way, the relevance of historical insights and the accurate identification of trends were ensured. To assess the evolution of maize cultivation in Romania by county, the average maize yield was calculated for several time intervals: 20, 15, 10, and 5 years. The main objective was to identify a potential trend in maize cultivation and provide a comparative basis for assessing territorial performance. The formula used to calculate the average maize yield is as follows:

$$\bar{P}_n = \frac{1}{n} \sum_{i=1}^n P_i, \quad (1)$$

where

$\bar{P}_n$ —Average yield over n years (with $n = 20, 15, 10, 5$);

P_i —Maize yield in year i , expressed in tons/hectare;

n —The number of years included in the analysis.

Annual yields for each county were extracted for the four intervals, and averages were calculated for each time window. This approach enabled the identification of counties with stable or improving performance, as well as those showing significant declines under recent climate change conditions. To assess the variability of maize yield at the county level across different periods, the sample standard deviation (denoted as STDEV.S) was used, which expresses the average squared deviation of individual values from the arithmetic mean. This statistical indicator provides important information about the stability of production and, implicitly, the exposure to agricultural risk.

$$S = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2}, \quad (2)$$

where

S —Standard deviation of the sample (STDEV.S);

x_i —Yield value in year i ;

$\bar{x}$ —Arithmetic mean of production over the analyzed period;

n —The number of years included in the analysis (20, 15, 10 or 5).

Standard deviation was used in this research to highlight the degree of production instability over time and the impact of climate variability on crop yield.

The analysis of the area cultivated with maize serves as a fundamental indicator for assessing farmers' adaptive behavior in the face of climate risks. In this research, the evolution of the cultivated area was analyzed at the national level in order to capture the agricultural interest in this crop. Data on the annual area cultivated with maize were collected from the National Institute of Statistics (INS). These data were centralized and organized both at the country level and disaggregated by county. To determine the total area cultivated with maize in Romania in a given year t , the sum of the areas cultivated at the county level was calculated as follows:

$$S_{total,t} = \sum_{i=1}^n S_{i,t}, \quad (3)$$

where

$S_{total,t}$ —Total area cultivated with maize in Romania in year t ;

$S_{i,t}$ —Area cultivated with maize in county i in year t ;

n —Number of counties (41).

To highlight general trends and eliminate abrupt fluctuations, a 3-year moving average was used, calculated as follows:

$$\overline{S}_t = \frac{S_{t-2} + S_{t-1} + S_t}{3}, \quad (4)$$

where

$\overline{S}_t$ —3-year moving average of the cultivated area;

S_t —Area cultivated in the current year;

S_{t-1} —Area cultivated in the previous year;

S_{t-2} —Area cultivated two years prior.

Based on the results, comparative graphs were developed between the annually cultivated area and the 3-year moving average, at the national level, to highlight periods of expansion or contraction of cultivated areas and their correlation with periods of severe drought.

To determine the level of risk (burning cost) for each county, it was first necessary to estimate the insured production level at the county level. This calculation indicates the average yield that a farmer achieves in that specific county. The method involves using a 7-year Olympic average of county-level data for the period 2017–2023. This method is preferred over the simple arithmetic mean as it eliminates the influence of extreme values, which are frequently caused by exceptionally good or bad agricultural years directly impacted by abnormal climate conditions [49]. This approach is often used in agricultural insurance modeling. While this method provides a more stable and representative baseline for historical yields, under the current evolution of climate change it is important to also take into account the expected increase in frequency and severity of extreme weather events. In this new reality the past yield stability may no longer be a reliable predictor of future variability. Although Olympic averaging remains a useful tool for smoothing historical series, it should ideally be complemented with climate scenario analyses or stress-testing models that capture the potential impact of intensifying droughts and heatwaves on maize production in Romania.

$$\overline{P}_{olimpic\grave{a}} = \frac{1}{n-2} \sum_{i=1}^n P_i \text{ excluding } P_{min} \text{ and } P_{max}, \quad (5)$$

where

$\overline{P}_{olimpic\grave{a}}$ —7-year Olympic average yield, considered the insured production by a farmer;

P_i —Maize yield in year i expressed in tons/hectare;

n —7 consecutive years (2017–2023).

Note: The minimum and maximum values from the dataset are excluded from the calculation. The sum is calculated for the remaining five values.

The research hypotheses are as follows:

H1. Climate change has significantly influenced maize production in Romania over the past two decades, with observable trends in both yield levels and cultivated area.

H2. Drought is the primary climatic factor driving yield variability and production losses in Romania.

H3. There is increasing territorial polarization between high-performing counties, which demonstrate resilience, and vulnerable counties, which experience recurrent declines in productivity due to climate stress.

4. Results

In order to evaluate the dynamics of agricultural production in Romania, a quantitative analysis based on annual data series at the county level is essential. In the case of maize county level, average yield data from the past two decades provide a clear picture of the transformations that have occurred in the agricultural sector. By calculating averages over 20-, 15-, 10-, and 5-year periods, we can observe not only the general trends, but also the level of volatility and regional differentiation (see Figure 1).

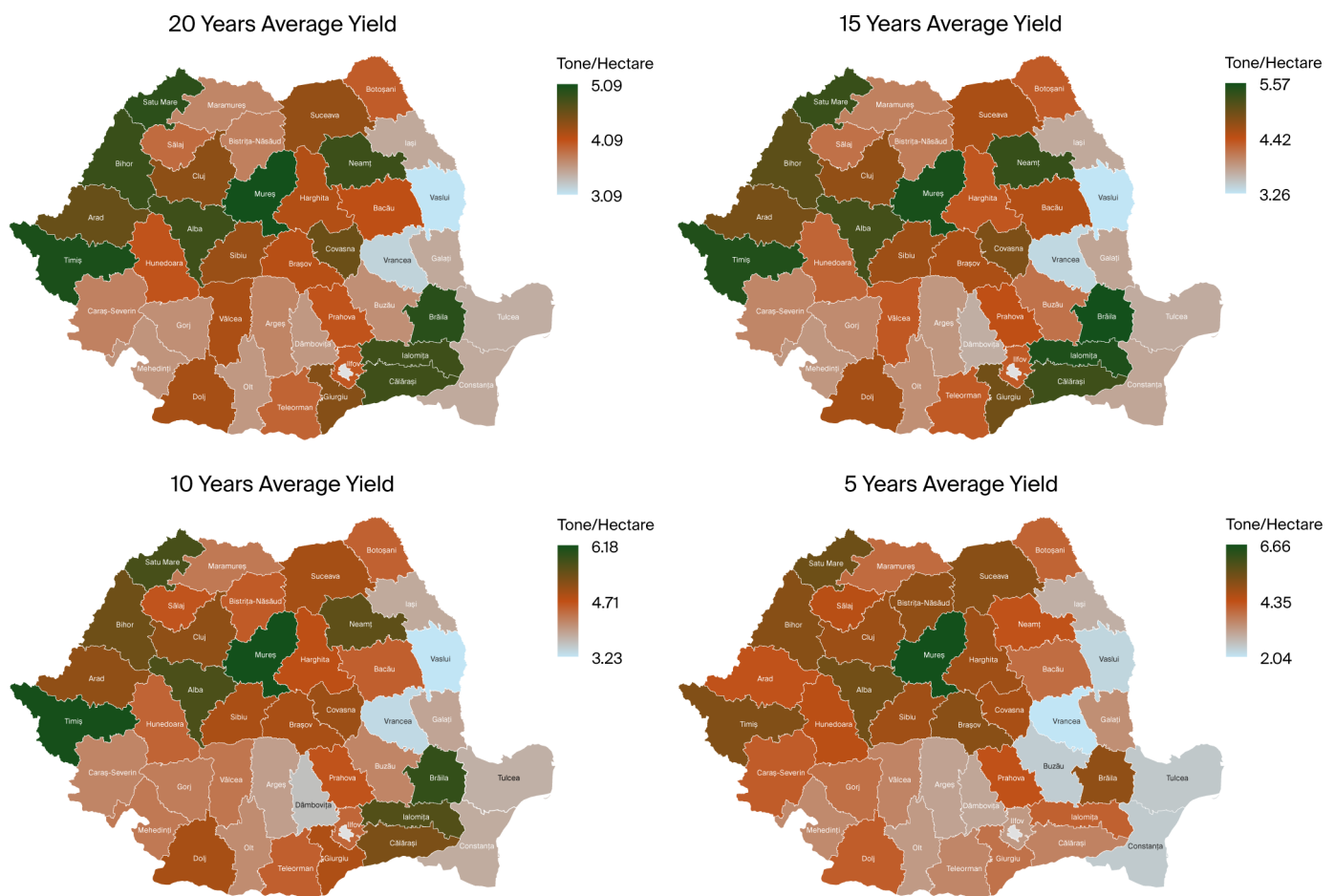


Figure 1. Average maize yields over 20, 15, 10, and 5 years in Romania.

The analysis of average maize yields at the county level in Romania for different number of years reveals an upward trend between 2000 and 2019, followed by a sharp decline in the last five years. The national average yield increased from 4.12 t/ha (20-year average) to a peak of 4.67 t/ha (over the last 10 years) but dropped to 4.02 t/ha in the last 5 years. This trend suggests a recent deterioration in production conditions under the impact of climate change.

In the last few years, an increased frequency of severe droughts and heatwaves was recorded. The impact was severe because it happened during the critical growth period of the maize crops. The most affected years were 2020 and 2022. The effects were particularly visible in the southern and south-eastern regions. These regions are also highly exposed to water stress. These extreme weather conditions significantly reduced yields

despite technological progress. Very important these extreme events combined with a low infrastructure in Romania from the irrigation perspective explain why the upward trend observed until 2015 could not be sustained, resulting in a marked downturn in yields in recent years. This upward evolution, followed by a downturn, is consistent with agricultural dynamics observed across Europe, where partial modernization of agricultural technologies led to higher yields, but the increasing frequency of extreme climate events has offset some of these gains in recent years [31].

As illustrated in Figure 1 above, the largest increases in maize yields over the 20-to-5-year interval were recorded in counties in the northern and central regions of the country:

- Mureș: +1.57 t/ha;
- Bistrița-Năsăud: +1.21 t/ha;
- Brașov: +0.94 t/ha.

Conversely, the most significant yield declines occurred in southeastern counties:

- Călărași: −1.28 t/ha;
- Buzău: −1.25 t/ha;
- Vrancea: −1.17 t/ha.

Figure 2 illustrates the spatial distribution of changes in maize yields in Romania, comparing the five-year average yields with the ten-year average yields. The map highlights counties where yields have significantly increased, as well as areas where yields have stagnated or decreased.

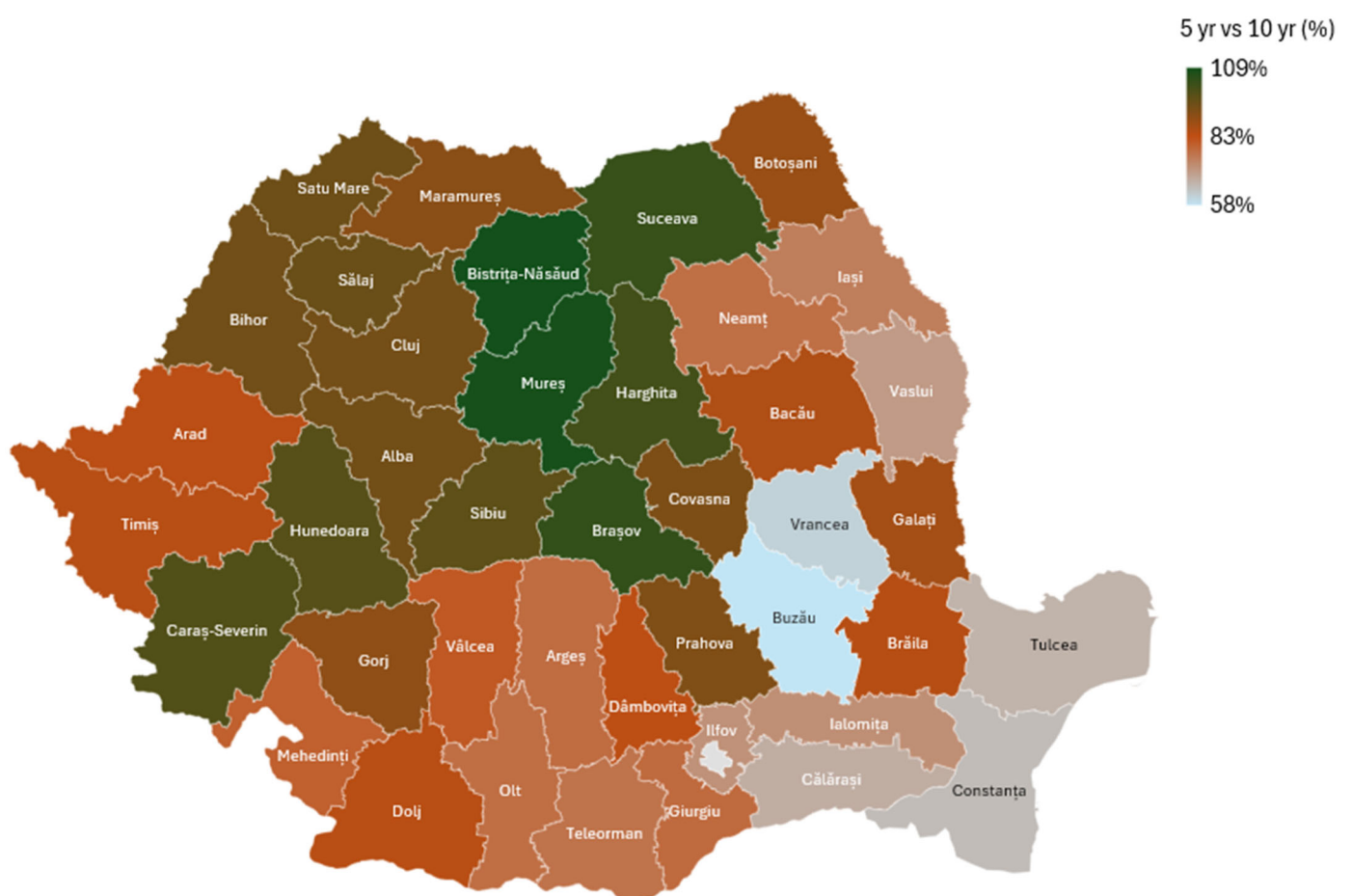


Figure 2. Spatial distribution of changes in maize yields in Romania—5 years vs. 10 years.

The results from Figure 2 show a clear geographical polarization. In several counties from the north and western regions yield levels over the last five years are higher compared

to the ten-year baseline. These results present a trend increase. In the opposite site, parts of the south-eastern and eastern regions show declining or stagnant yields. This reflects higher vulnerability of these areas to drought and other climatic stresses.

This spatial analysis provides evidence that yield dynamics are not homogeneous across Romania. These findings support the need for regional agricultural policies and insurance solutions.

Although these counties have traditionally been strong agricultural areas, they have been severely affected by prolonged droughts and heatwaves and a lack of efficient irrigation systems.

The analysis of spatial maps highlights an increasingly pronounced agricultural polarization between counties that are able to adapt and innovate and those that remain vulnerable to climate change. Regions in Transylvania and northern Romania are consolidating their status as high-performing agricultural centers, while the southeast and southern parts of the country are becoming critical risk zones for agriculture.

To assess the variability of average maize yields across Romanian counties, the standard deviation was used as an indicator of value dispersion relative to the national average. The calculation was deliberately carried out using the sample standard deviation formula (STDEV.S), because—even though the dataset includes all 41 administrative counties—the analysis seeks to capture not just a static description of the internal situation, but also broader trends in agriculture within the context of climate change and regional adaptability. Thus, the statistical approach is not purely descriptive but is aimed at inference and extrapolation in similar contexts.

The standard deviation presented in Figure 3 and Table 1 has shown an interesting evolution as the analysis moves from longer intervals (20 years) to shorter ones (5 years). Twenty years ago, the variation between counties was relatively small, indicating a higher degree of agricultural homogeneity and more balanced production conditions at the national level. In the last 10 years and the more recent 5 years, a consistent increase in value dispersion is observed, culminating in a standard deviation of 1.01 t/ha in the most recent period. This high value reflects a marked polarization of yields. Some counties have managed to maintain or even improve their performance, while others have recorded significant declines. These can be caused by climatic change, lack of infrastructure, or technological constraints.

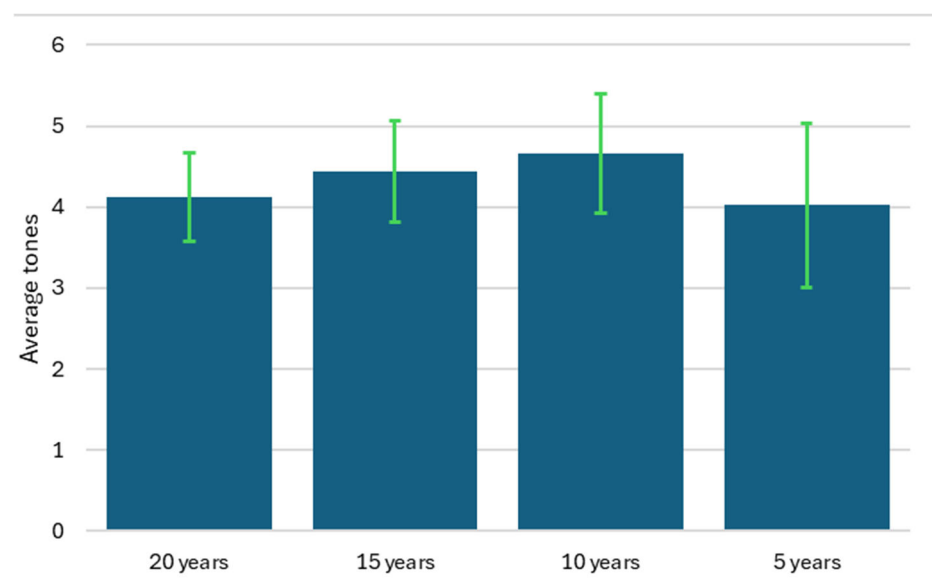


Figure 3. Standard deviation of maize yields over different time intervals.

Table 1. Standard deviation of maize yields over different time intervals.

Standard Deviation	20 Years	15 Years	10 Years	5 Years
STDEV S	0.55	0.63	0.74	1.01

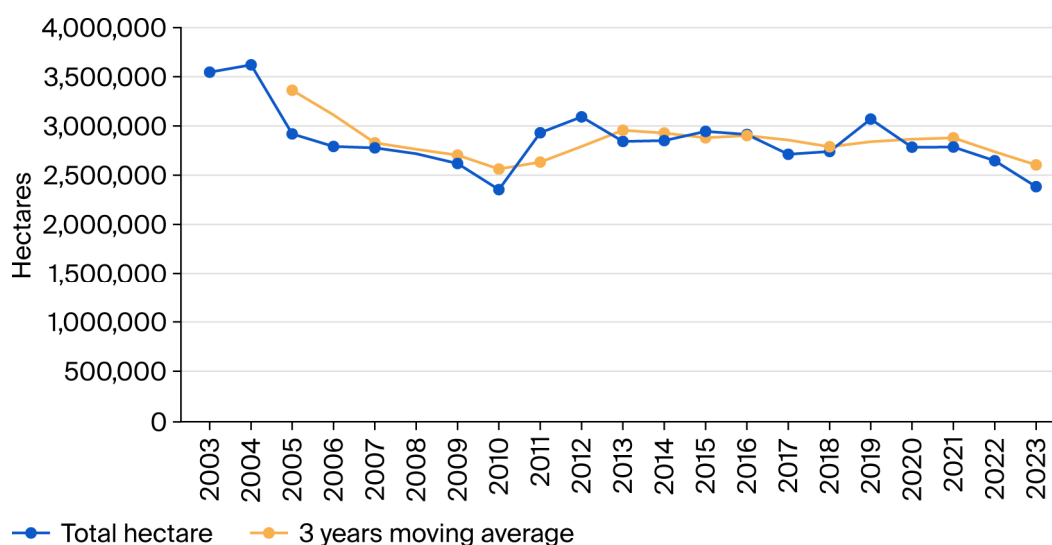
The increase in the territorial variability of maize production becomes a relevant indicator not only of regional imbalances but also of the fragility of the Romanian agricultural system in the face of climate risks. This trend justifies not only the methodological choice of using the sample standard deviation but also the need for differentiated interventions and agricultural policies tailored to the specific characteristics of each region.

In our view, the analyzed data highlight the complex dynamics of maize production in Romania. Although there have been technological advancements and significant yield increases in certain regions, climatic instability and the lack of adequate infrastructure have led to a notable regression in other parts of the country. The results from the last 5 years present some concerns in Romanian agriculture. This situation requires specific state interventions at the county level in order to adapt to the new climate realities.

Based on these results, the development of differentiated agricultural policies tailored to the climatic and agronomic specificities of each region is imperative. At the same time, it is vital to strengthen adaptive capacity through the following:

- Investments in irrigation infrastructure;
- Promotion of climate-resilient crop varieties;
- Development of financial risk mitigation solutions such as agricultural insurance and/or mutual funds.

In a context marked by meteorological instability, the long-term analysis of the maize-cultivated area allows for a better understanding of agriculture's response to climate stress. Figure 4 illustrates the dynamics of the area cultivated with maize during 2003–2023 (hectares) along with the 3-year moving average. We introduced the moving average in order to highlight general trends by smoothing out annual fluctuations.

**Figure 4.** Evolution of the area cultivated with maize in Romania.

The findings presented in Figure 4 indicate that in Romania the lowest level of maize surface was recorder in 2023 and 2010. Important to note is that the reasons for the two years are different: (a) in 2010 the decline was influenced mainly due to economic limitations following a crisis from 2008 to 2009 when input cost increased a lot and selling price of

corn; (b) in 2023 the decreased was mainly influenced because of climate change as there multiple years with drought and heat stress (2020, 2022).

The analysis of Figure 4 reveals three distinct periods. During the 2003–2011 period, there was a gradual decline in cultivated area, reaching a clear minimum around 2010. In this year, values dropped below 2.5 million hectares. This period included years with frequent droughts (2007), which discouraged maize cultivation in favor of crops more resistant to water stress. Another important factor is the underdeveloped irrigation system in Romania. The period from 2012 to 2019 marked a phase of relative stabilization and recovery of cultivated areas. During the period, there was an average of approximately 2.8–3 million hectares of cultivated area. This can be attributed to more favorable weather conditions and a more stable European agricultural policy (CAP), which provided direct financial support to farmers, encouraging the maintenance of maize in crop rotations. It can be observed that agricultural investments generated medium-term stability, even though 2015 was a drought year in Romania. From 2020, we can see that climate change has had a higher impact in Romania. The cultivated surface with maize decreased from approximately 3 mil hectares in 2020 to 2.39 mil hectares in 2023. This evolution shows the impact of climate change in Romania. The most affected areas are the ones from southern and eastern Romania. These regions are very frequently affected by atmospheric drought. This risk, combined with the lack of irrigation infrastructure, has led farmers to abandon maize in favor of more resilient crops or to reduce the area cultivated due to repeated losses.

To better understand the evolution of the area cultivated with maize in Romania and to reduce the influence of abrupt annual variations, we introduced a 3-year moving average, which was used to determine the trend and to provide a more stable picture of the general direction of the agricultural changes. The analysis of the 3-year moving average confirms all the observations mentioned earlier. It outlines a general downward trend in recent years and indicates a deterioration in the conditions of maize cultivation in Romania. Between 2012 and 2019, the moving average remained relatively constant, suggesting a period of equilibrium. After 2020, the moving average began to decline slowly, confirming a trend of maize being gradually phased out of crop rotations. The main factors for this recent trend were the droughts from 2020 and 2022.

Considering all the results, we can observe that the maize-cultivated area in Romania has experienced a significant decline in recent years. In 2023, the level of cultivated maize in Romania was at the lowest level in 20 years from the climate change perspective. In our opinion, some of the measures that can be adopted by stakeholders in the agricultural sector include stimulating irrigation investments, promoting agricultural insurance, advancing digitalization, and transferring innovations, in order to maintain the viability of maize cultivation in an increasingly volatile climate.

After examining the dynamics of the maize cultivated area in Romania, it is equally important to analyze the evolution of maize yields per hectare. The production results are determined by the extent of cultivated land but also by the productivity of that land. Figure 5 presents the annual maize yields between 2003 and 2023, together with the 3-year moving average. This complementary perspective identifies whether changes in total production were mainly driven by shifts in cultivated area, yield performance, or a combination of both.

Figure 5 presents the evolution of maize yields in Romania for the 2003–2023 period, including a 3-year moving average. The results from Figure 5 show a strong sensitivity of maize production to climatic conditions like droughts. The most important drops were recorded in 2007, 2012, 2015, 2020, and 2022.

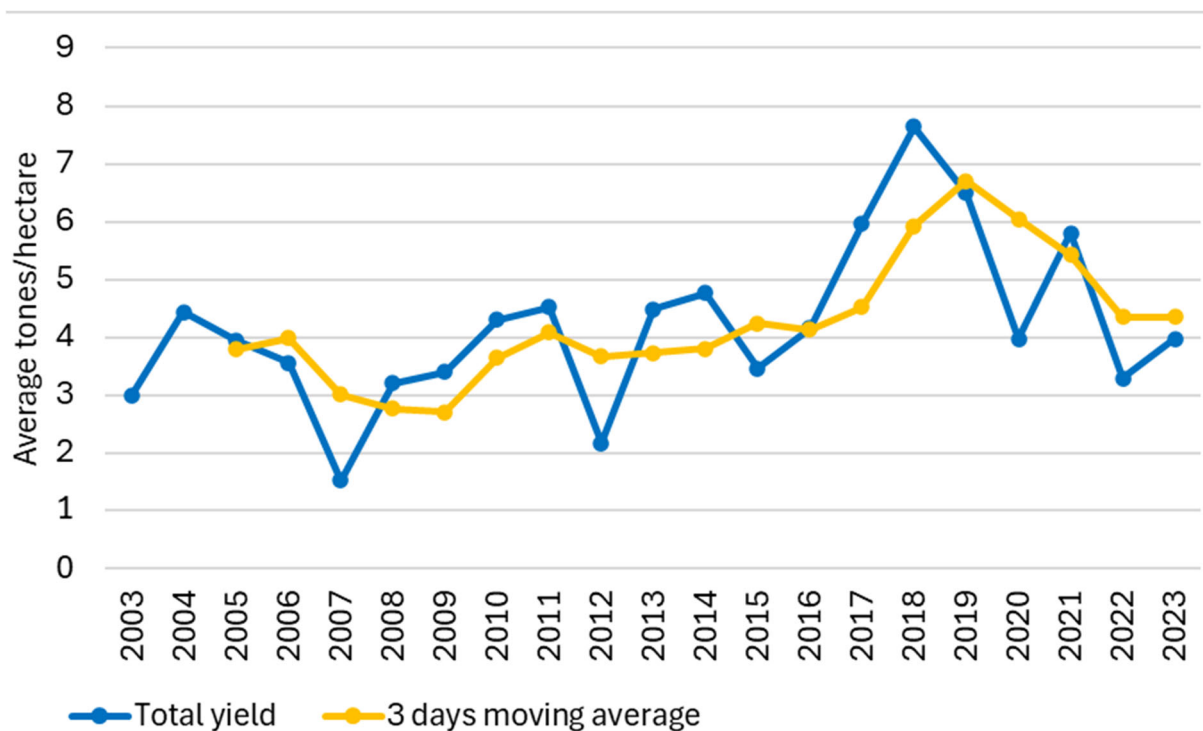


Figure 5. Evolution of the maize yield in Romania.

The yields generally increased during the first half of the analyzed period mainly because of technological improvements and better input use. In the last decade Romania has been marked by significant fluctuations mainly because of climate change corresponding to extreme drought years.

The moving average line provides a clearer picture of underlying trends, confirming that while technological progress and improved farm management contributed to higher yields in the late 2010s, climatic shocks continue to exert significant downward pressure on yield stability in the long run.

In order to better understand how maize is cultivated across Romania, Figure 6 presents the territorial distribution of the cultivated area, highlighting the agricultural structure of Romania and the capacity of each region to maintain this crop in a context increasingly marked by climate risks. The 2023 data show significant differences between counties both in terms of cultivated area and shares of the national total.

Figure 6 shows that the counties with approximately 5% of the total maize-cultivated surface are Brăila, Călărași, and Ialomița. The lowest share (around 0.5%) is recorded in Harghita, Covasna, Ilfov, and Brașov. Mountain regions have limited capacity to support maize cultivation due to altitude, cooler climate, fragmented terrain, and poor accessibility. From this analysis, we can see that approximately 25% of Romania's maize-cultivated area is concentrated in just five counties. This polarization indicates a structural dependency on a few key counties, which makes the system vulnerable to localized risks. We can conclude that a drought in the Bărăgan region can severely affect national production and affect exports. The detailed analysis of maize cultivation areas and yields in Romania at county level over the last 20 years reveals pronounced regional disparities.

In relation to the impact of climate change, maize cultivation has become a barometer of agricultural resilience, reflecting farmers' ability to adapt to an unpredictable environment. The territorial distribution of cultivated areas in 2023 shows a significant dependency on a few key counties, which collectively hold a large share of the national total and record high

yields. At the same time, numerous counties in the southern and eastern regions, such as Teleorman, Dolj, and Galați, are facing a decline in efficiency caused by persistent drought.

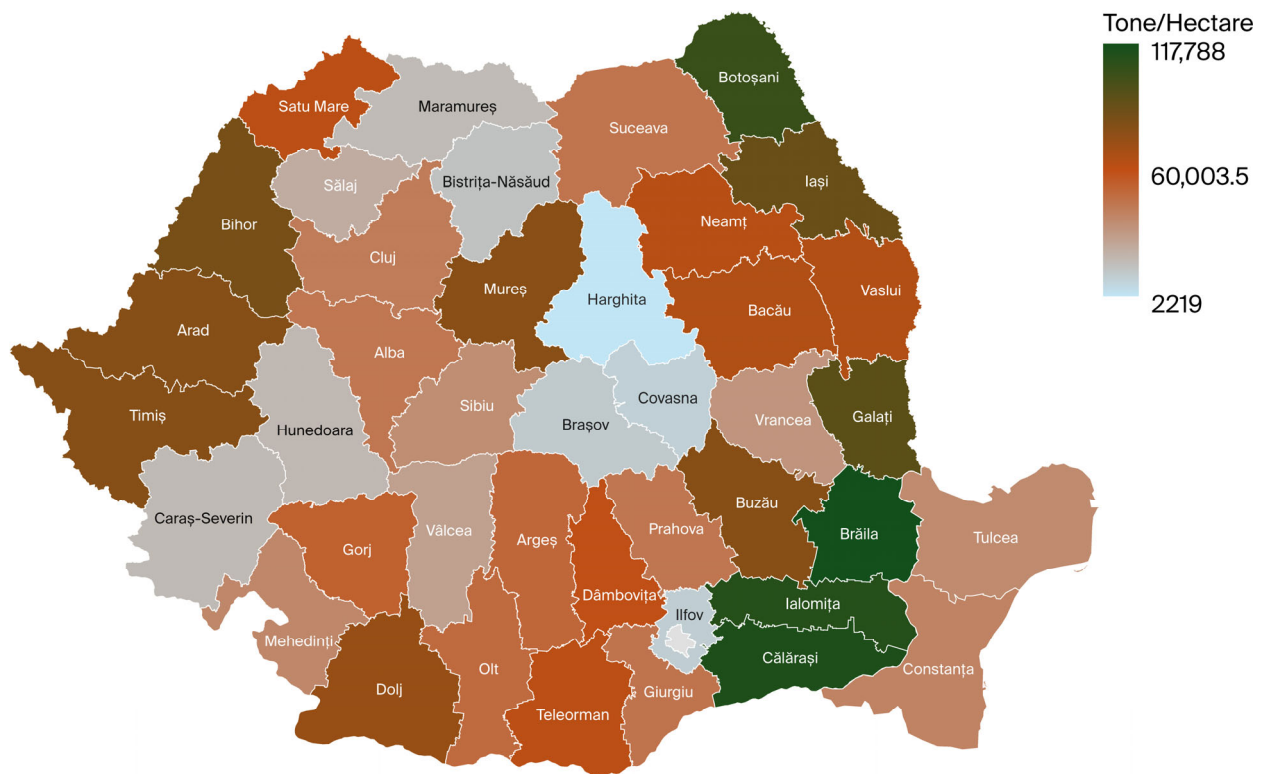


Figure 6. Area cultivated with maize in Romania in 2023.

The estimated yields, when correlated with cultivated areas, confirm the relevance of not only the size of the land, but also its technological adaptability and access to resources (water, inputs, insurance). In this regard, there are counties with relatively small areas but high yields—signs of untapped agricultural potential that could become strategically important in the future.

Based on the analysis, it can be concluded that maize cultivation in Romania depends on a regionally differentiated approach, combining

- Support for high-performing areas to maintain competitiveness;
- Urgent interventions in climate-vulnerable regions;
- Encouragement of sustainable expansion in areas with high yields but limited maize cultivation.

To provide a realistic picture of maize production that can be considered in agricultural insurance processes and climate risk management, an analysis of the average yield at the county level using a methodology adapted to the current climatic context was conducted. A 7-year interval (2017–2023) was selected, a period long enough to capture recent structural and climatic variations yet recent enough to reflect current field realities. To reduce the influence of extreme values, which are particularly frequent in the context of climate change, an adjusted averaging technique was applied, involving the following:

- The maximum and minimum yield values were excluded from the analyzed interval;
- The average was calculated using only the remaining five years, considering them representative of a sustainable and realistic yield from both an agronomic and economic perspective.

In Figure 7, it can be observed that the highest adjusted production values (>6.2 t/ha) were recorded in the counties of Timiș, Mureș, Ialomița, Brăila, Satu Mare, and Bihor, which

are considered as counties with a developed infrastructure and less exposure to drought. In contrast, counties like Vaslui, Vrancea, Galați, Dâmbovița and Tulcea have adjusted yield values below 4.2 t/ha, indicating climatic vulnerability. These counties have been repeatedly affected by severe drought in recent years. The analysis concludes that the western and southeastern regions of the country tend to perform better, while the eastern and southern parts register the lowest values. The central and northern areas remain within a medium range of risk and efficiency, influenced by a milder climate but also by fragmented landholdings.

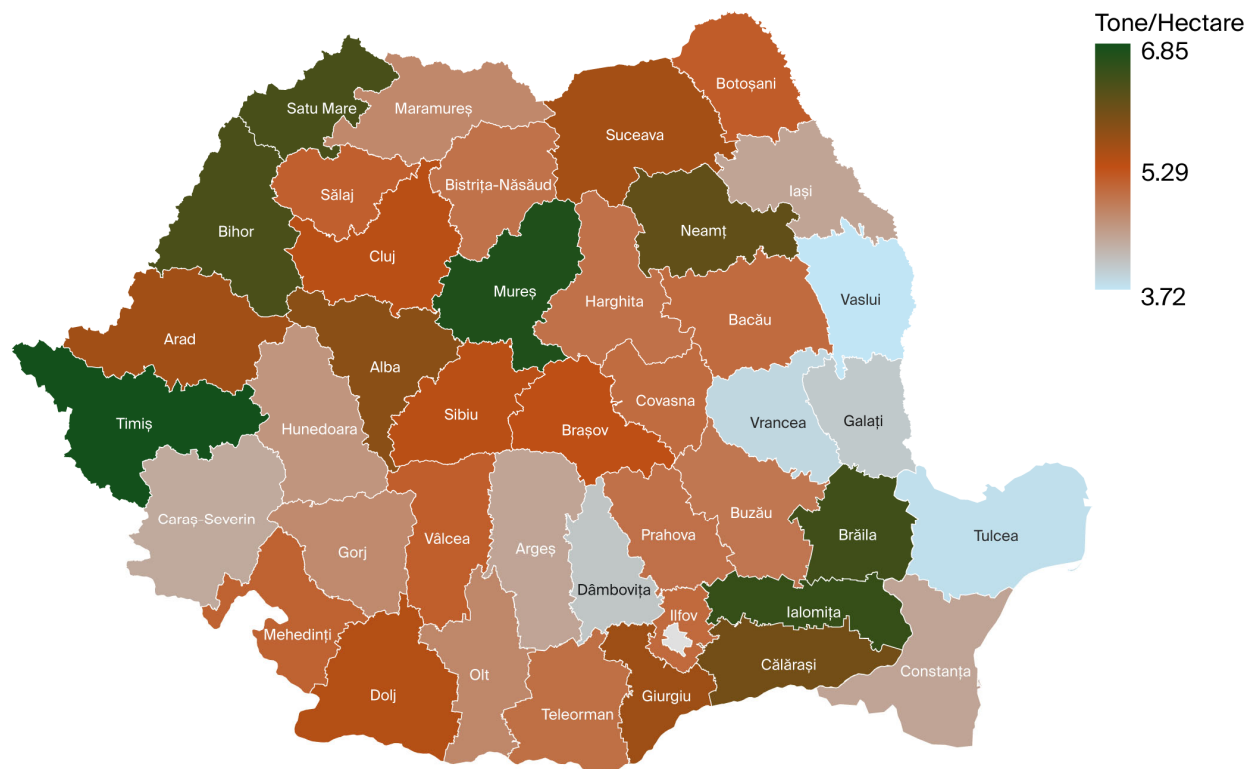


Figure 7. Insured production values used at county level in Romania.

The counties with the highest yield values (Figure 7) correspond to regions with more favorable climatic conditions. According to Romanian National Meteorological Administration and corroborated by previous studies [35,40] the central and north-western counties have on average 600–700 mm of annual precipitation while in the southern and south-eastern counties values often drop below 500 mm per year.

To further support this finding, future research can integrate annual precipitation datasets and different drought indices. This would allow a more detailed spatial mapping of drought exposure in Romania, highlighting counties most affected by water stress and providing a stronger basis for designing regionally adapted risk management strategies.

Establishing the average insurable yield based on an adjusted average (Olympic average) is essential for developing an equitable and sustainable system for transferring agricultural risk. The analysis of these data helps classify regions by performance level, thereby enabling the identification of the optimal method for managing extreme risks such as drought.

To objectively assess the historical exposure of Romanian agriculture to climate risks and the financial impact generated by maize crop losses, the article analyzed the estimated damages over the past 22 years (2003–2024), expressed in absolute value (EUR). This analysis was carried out to better understand the impact of climate variability on Romanian agriculture and to identify high-performing and underperforming agricultural years. The

dataset is relevant for informing decision-making on the development of climate risk management solutions, both through state interventions and through farm-level strategies.

Figure 8 illustrates the evolution of losses in maize crops in Romania between 2003 and 2024, providing a clear view of how climate risks have affected the agricultural sector in the last 20 years. The values presented reflect annual losses caused by extreme weather events based on an estimated agricultural potential derived from the 7-year adjusted average yields and a unit price of EUR 212.75 per ton.

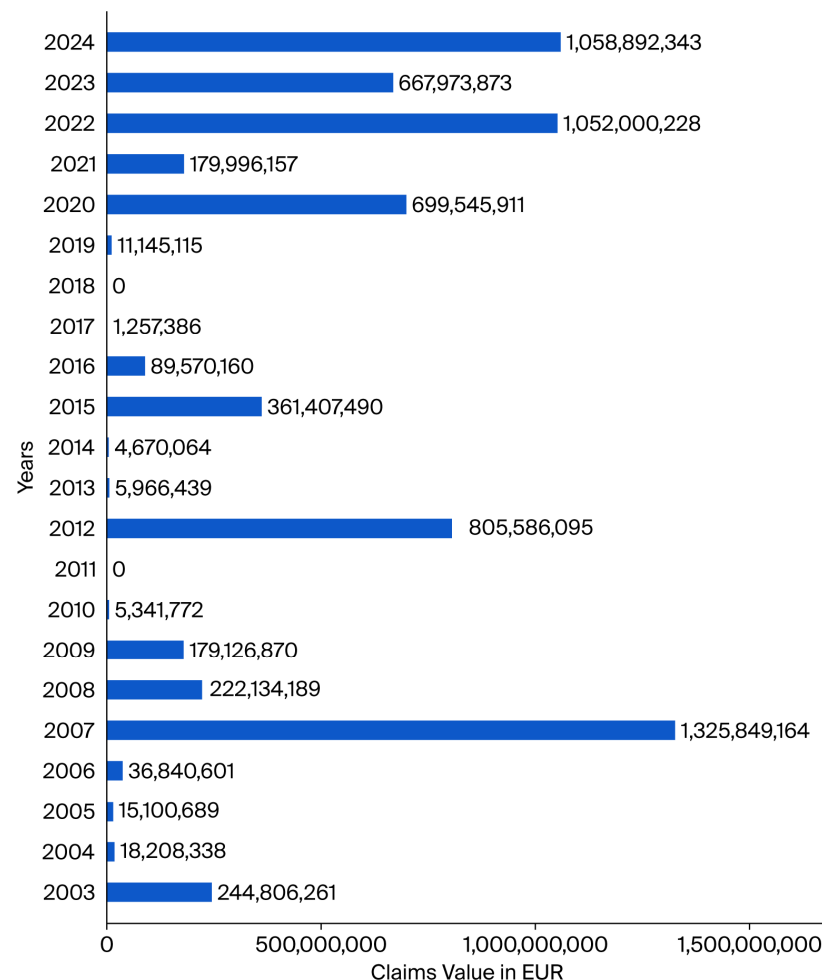


Figure 8. Evolution of maize losses caused by extreme weather risks in Romania (2003–2024).

The analysis highlights that 2007 was the worst year in terms of recorded losses, with an estimated damage of over EUR 1.3 billion due to a generalized drought that affected the entire country. After this event farmers started to reduce sown areas in the following season shifting to less water-demanding crops. The Romanian government introduced emergency support schemes, including partial compensation for affected farmers and subsidies for purchasing inputs for the following agricultural cycle. In addition, 2007 marked the first discussions on the need to rehabilitate irrigation systems and to promote the development of risk transfer mechanisms such as agricultural insurance. However, implementation was limited; for example, even in 2025, Romania does not have a national insurance scheme. This highlights the structural vulnerability of Romanian agriculture to systemic droughts.

Following this critical period, there were relatively stable intervals between 2008 and 2011 and between 2013 and 2019, during which insignificant losses were recorded. This suggests a climatically and agriculturally favorable period. In 2012, we can also observe a critical moment with losses exceeding EUR 805 million.

Starting from 2020, the trend changes and loss values increased significantly, indicating an important climatic pressure on maize production. All years between 2020 and the present, except 2021, have seen critical moments, with losses ranging from EUR 600 million to over EUR 1 billion. In 2022 and 2024, the losses were estimated to have exceeded EUR 1 billion. A similar situation was recorded in 2007. The recent findings illustrate the increase in both frequency and severity of extreme climate events, which increasingly undermine the stability of agricultural production.

Based on the historical loss analysis, it can be stated that maize cultivation in Romania is now facing a period of heightened climate exposure, where potential losses are no longer exceptions but have become recurring and systemic risks. The rising compensation values in recent years confirm the transition to a more unstable climate and reinforce the need for innovative financial solutions such as index-based yield insurance.

5. Discussions

The findings of this study highlight several key aspects regarding the impact of climate change on maize cultivation in Romania. Maize is recognized as a crop of major strategic importance for both domestic consumption and exports within the European Union [46].

First, a strong correlation has been confirmed between climate variability—particularly drought—and yield instability, especially during the last decade. Yield losses of 15–70% under severe drought conditions have been reported in southern Romania, depending on the intensity, duration, and timing of drought events [46]. Experimental data from Șimnic also indicated that grain-filling temperature was negatively correlated with maize yield ($r = -0.973$), while precipitation during the sowing-to-anthesis period was positively correlated ($r = 0.966$) [50]. The use of moving averages and adjusted yield calculations has further revealed a downward trend in national productivity in recent years, despite prior technological improvements.

The examination of average maize yields at the county level in Romania over various years shows an increasing trend from 2000 to 2019, succeeded by a significant drop in the past five years. In recent years, Romania has seen a rise in the occurrence of intense droughts and heatwaves (2020, 2022). There was a high impact as it occurred during the essential growth stage of the maize plants. The impacts were especially evident in the southern and southeastern areas. These areas are likewise significantly vulnerable to water scarcity. These severe weather conditions greatly diminished yields in spite of technological advancements. These crucial extreme events combined with inadequate irrigation infrastructure in Romania affected the rising trend that was seen until 2015 leading to a significant decline in yields in recent years.

The moving average method was introduced in order to smooth short-term fluctuations and highlight the underlying trends in maize yields over time. By introducing a 3-year moving average the analysis reduces the impact of extreme events occurred in a specific year and provides a clearer picture of medium-term yield dynamics. In this way a trend is better captured which may not be immediately visible when analyzing raw annual data.

The analysis of standard deviation in maize production indicates a shift from low variability over the past 20 years to increased disparities in the last decade. Compared to 0.55 for a 20-year period, standard deviation doubled and reached 1.01 for a most recent 5-year period. This change highlights polarization in yields among counties influenced by factors like climate change, infrastructure deficits, and technological barriers. The growing territorial variability signals significant regional imbalances within Romania's agricultural system. Taking these aspects into consideration, we can conclude that there is a need for tailored agricultural policies and interventions specific to each region's characteristics. Some examples of possible next steps are investments in irrigation, promoting climate-

resilient crop varieties and developing financial risk mitigation tools like agricultural insurance. Second, a clear territorial polarization has been observed. Counties in the west and north demonstrate higher performance and resilience, while southeastern counties experience significant production declines due to repeated drought, limited irrigation, and soil degradation. Agroclimatic suitability analyses confirm this regional disparity, showing better climatic suitability in western and northern Romania compared to the southeast [51].

The findings presented in Figure 2 demonstrate that yield variations are not uniform throughout Romania. In various counties from the northern and western areas, yield levels in the past five years have exceeded the ten-year baseline. These outcomes indicate a rising trend. Conversely, areas in the south-eastern and eastern regions exhibit declining or stagnant productivity. This indicates greater susceptibility of these regions to drought and various climate-related pressures. These results emphasize the necessity for local agricultural policies and insurance options.

Third, the use of the Olympic average methodology for estimating insurable yields has proven effective in mitigating the influence of outlier years, ensuring a more stable and equitable foundation for designing agricultural insurance products. This approach also enables the identification of vulnerable regions that require public support or alternative risk management instruments.

This method is preferred over the arithmetic mean because it reduces the impact of extreme values from abnormal climate conditions. Also, it is important to mention that this method is used worldwide in the agriculture insurance/reinsurance sector. While it offers a stable baseline for yields, climate change's increased frequency and severity of extreme events may undermine its reliability for future predictions. Therefore, in order to make more accurate predictions, Olympic averaging should be paired with climate scenario analyses or stress-testing models to evaluate potential impacts on maize production in Romania.

Fourth, historical damage data illustrate a concerning trend whereby extreme losses are no longer isolated events. The impact of climate change on agricultural productivity in Romania reveals that systemic disruptions are now affecting the cultivation of maize, with losses exceeding EUR 1 billion in years such as 2007, 2022, and 2024. This confirms the transition to a new climate regime in which drought is recurrent and systemic [52,53].

The analysis reveals that 2007 was the year with the highest recorded losses. This year holds great significance as the Romanian government has initiated discussions regarding the necessity to restore irrigation systems and to encourage the establishment of risk transfer mechanisms like agricultural insurance. Nonetheless, the implementation was constrained, as even in 2025, Romania lacked a national insurance program. This occurrence emphasized the inherent weakness of Romanian agriculture to extreme events like droughts or heat stress.

The findings of this study demonstrate that maize cultivation in Romania is increasingly shaped by the impacts of climate change, particularly recurrent and systemic droughts. The results confirm a strong correlation between yield instability and extreme weather events, compounded by territorial disparities in infrastructure, resource availability, and adaptive capacity. Recent analyses reveal a downward trend in productivity during the last decade, largely explained by recurrent drought episodes, high evapotranspiration rates, and insufficient irrigation infrastructure [25,54]. Yield data further show an increasing territorial polarization: while western and northern counties exhibit higher resilience, southeastern regions record recurrent yield losses due to extreme climate variability and soil degradation [46]. The growing evidence indicates that extreme droughts are no longer isolated events but part of a systemic climate risk regime, with recent studies documenting losses exceeding EUR 1 billion in some years [53]. This highlights the urgent need for regionally tailored adaptation strategies that include investments in irrigation, the promotion

of drought-resistant maize hybrids, and the expansion of financial risk-transfer instruments such as agricultural insurance [55].

Finally, this study contributes to the literature by demonstrating the need for regionally tailored adaptation strategies and the critical role of data in shaping agricultural risk management. Increasing irrigation capacity and improving water productivity, particularly in the southern lowlands, are among the adaptation pathways highlighted in recent studies [55].

6. Conclusions

Climate risk management in agriculture is an important concern in Europe, as well as at the global level, because of climate change. Agriculture is particularly vulnerable, as shifts in temperature, altered precipitation regimes, and the increased frequency of extreme weather events directly affect crop productivity [56]. Among staple crops, maize is especially sensitive to water scarcity and heat stress, with several studies highlighting yield reductions of up to 70% under severe drought conditions in Southern and Eastern Europe [49,50]. The analysis presented in this study highlights the urgency of the actions needed to adapt agricultural systems to changing climate realities. Both public and private stakeholders can make a difference by developing optimal solutions.

This article demonstrates that climate change has a significant impact on the Romanian agricultural industry. The results confirm international trends pointing to the increasing frequency and intensity of extreme weather events. The results also highlight the systemic vulnerability of agriculture to these recurring risks.

Methodological innovations such as the use of adjusted averages, including the Olympic average, have proven effective in stabilizing yield estimates by reducing the influence of extreme years. This approach has been used to assess climate-related yield failures in European maize and wheat production, confirming that return periods for drought-induced yield losses are becoming shorter, especially for maize [49].

Based on a rigorous methodology and long-term analysis (2003–2024), the report shows that, despite technological progress and yield increases in certain regions, the negative effects of drought, heat stress, and rainfall imbalances are intensifying. The decline in national average production over the past five years, coupled with the reduction in cultivated area, indicates an alarming regression in the sector's ability to maintain stability in the face of climate risks.

The article recommends further research, including a detailed analysis of the implementation of the proposed solutions in Romania at a national level. For example, greater investment in irrigation and digital agricultural technologies requires consideration of economic costs, technical feasibility and water resource sustainability. Similarly, the expansion of risk mitigation solutions such as index-based insurance schemes depends on policy support and support from State through subsidy. Strategic public interventions aimed at strengthening regional resilience should be accompanied by clear policy frameworks and cost–benefit analyses. At the same time, future research should go beyond the 2003–2024 period to better capture the long-term impact of climate change, and it should also integrate information on diseases, pests, and soil fertility into the modeling framework, either through agronomic simulation models or through combined statistical–climate approaches. This would provide a more comprehensive and realistic assessment of production risks and of the effectiveness of adaptation and risk transfer mechanisms.

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