Influence of climate conditions on maize yield in Oltenia (1990-2021)

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Abstract

Maize, the most important cereal crop at global level, is a climate-sensitive plant. Consequently, the changes of the key meteorological parameters, namely temperature and precipitation amount, determine low yields, especially in rain-fed regions. The dependency of maize yield on climate conditions was assessed based on monthly values of the considered meteorological parameters (data from 14 meteorological stations for the period 1990-2021). The mean values of the analysed interval generally reveal proper conditions for the development of maize. However, starting with June until September, mean temperatures are 1 to 2°C above the optimum thermal threshold, as mentioned in the specialized literature. The growth degree days index (GDD) emphasizes Oltenia as a region with a very good thermal potential for maize, all mean values exceeding 1600°C, but the southwestern sector of the plain area has already exceeded 2000°C, underlining the increase in heat stress. The water deficit generates dry conditions, especially in Mehedinti, Dolj, and Olt, mainly in the interval July-August, which also corresponds to the maximum water requirements of maize. Drought prone areas were determined based on Selyaninov’s hydrothermal coefficient (HTC), which indicates slightly dry conditions in the growing season in the plain area, while northwards, in the piedmont and Subcarpathians, the climate is slightly humid, respectively moderately humid, drought risk decreasing gradually in this direction. At monthly level, August is the most problematic period as, except the northeastern part (Polovragi and Râmnicu Vâlcea), the entire region displays dry, moderately dry, and slightly dry conditions. The lowest maize yields correspond to the years 1993, 2000, 2002, 2007, and 2012. If in the first three years, the drastic yield reduction was mostly determined by a severe water deficit registered during the entire life cycle of the plant, in the last two years, the main restrictive factor was represented by temperature, mean monthly values exceeding 27°C and mean maximum values 35°C, especially in the plain area. Taking into account the projected increase in temperature and water deficit, the impact of climate conditions on maize crops may also be gradually higher in Oltenia and certain adaptation measures should be taken.

Keywords: temperature, precipitation deficit, maize, yield, Oltenia

Introduction

Maize (Zea mays L.) represents the most important cereal crop, the first in terms of production, according to FAO (2022). In 2021, at global level, maize production reached 1,210,235 thousand tons (on average 5,878 kg/ha), 141,847 thousand tons being produced in Europe, and 14,820 thousand tons in Romania (FAOSTAT, 2023). Worldwide, maize production comes second after sugar cane and it registered a gradual increase during the last two years, three times faster than that of wheat or rice, mainly due to its wide range of uses – food and feed, ethanol fuel production, livestock fodder, etc. (Erenstein et al., 2022). This is possible as maize is a crop characterized by a great phenotypic plasticity (Liu et al., 2021), which enables its production in a wide range of conditions – from 50°N to about 45°S (Vâtcă et al., 2021), from 0 to over 3800 m.a.s.l. (Ramirez-Cabral et al., 2017), and in different climates. However, despite the fact that it tolerates less favourable climatic conditions, including hot and dry periods, yield drastically decreases under such circumstances, as the metabolic processes of the plant are affected.

Temperature and precipitation amounts registered during the growing season are the climatic factors that greatly condition maize yield and quality. As a thermophilic plant, maize tolerates well high temperatures compared to other cereal crops, but its productivity is greatly affected by extreme temperatures. The optimal thermal conditions depend on the phenological phase (germination phase: 15-25°C, leaf development: 18-23°C, inflorescence: 18-23°C, flowering, which is also considered the critical phase: 18-24°C, fruit development: 18-22°C, ripening: 15-16°C) (Vâtcă et al., 2021), but, generally, values below 10°C and above 32°C are detrimental (Bilteanu et al., 1983; Waqas et al., 2021). Besides the direct effects on the plant, high temperatures also determine the increase of evapotranspiration and, thus, the reduction of the available water resources, concomitantly with a higher plant water requirement (Lobell et al., 2014). The optimum rainfall amount for the interval May – August ranges between 280 and 380 mm (Muntean et al., 2001), but its distribution during the growing season is equally

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The increase in temperature and potential evapotranspiration (Bîrsan et al., 2019; Prăvălie, 2014; Prăvălie et al., 2017; Prăvălie et al., 2019), drought (mainly during summer and autumn) (Angeau et al., 2020; Cheval et al., 2014; Onțel et al. 2021), and aridity (Vlăduț & Licurici, 2020).

The aims of the present study are: (1) to analyse the spatial distribution of temperature and precipitation amounts during the growing season; (2) to render the impact of temperature increase and precipitation deficit on maize yield and determine the contribution of each assessed parameter to the yield reduction.

### Material and methods

#### Study area and data

Oltenia is an important agricultural area located in southwestern Romania. There is a notable altitudinal range, almost 2500 m, between the Danube Floodplain and Parângul Mare Peak (Badea, 1983), which induces temperature and precipitation differences (mean annual temperatures of 12°C in the south and below 0°C at high altitudes, respectively mean precipitation amounts of about 550 mm in the south and 1000 mm in the north). The present study considers the extra-Carpathian region, which corresponds to the Getic Subcarpathians, the Getic Plateau, and Oltenia Plain. Most of the cereal crops find proper conditions in the region. However, southern Oltenia, where sands and sandy soils prevail, is considered a less favourable region for maize. The study is based on the mean monthly temperatures, the maximum and minimum mean temperatures, and monthly precipitation amounts for the 14 meteorological stations located within the region (Table 1, Fig. 1). The data cover a period of 32 years (1990-2021) and they were provided by the National Meteorological Administration (continuous data series with no missing values). The statistical data related to the cultivated surface and maize yield were provided by the National Institute of Statistics (NIS, 2023).

#### Table 1: Geographical coordinates of the considered meteorological stations

<table>
<thead>
<tr>
<th>No.</th>
<th>Meteorological station</th>
<th>Altitude (m)</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Dr.-Turnu  Severin</td>
<td>77</td>
<td>44°38'</td>
<td>22°38'</td>
</tr>
<tr>
<td>2.</td>
<td>Calafat</td>
<td>61</td>
<td>43°59'</td>
<td>22°57'</td>
</tr>
<tr>
<td>3.</td>
<td>Bechet</td>
<td>36</td>
<td>43°47'</td>
<td>23°57'</td>
</tr>
<tr>
<td>4.</td>
<td>Băilești</td>
<td>57</td>
<td>44°01'</td>
<td>23°20'</td>
</tr>
<tr>
<td>5.</td>
<td>Craiova</td>
<td>192</td>
<td>44°19'</td>
<td>23°52'</td>
</tr>
<tr>
<td>6.</td>
<td>Caracal</td>
<td>106</td>
<td>44°06'</td>
<td>24°22'</td>
</tr>
<tr>
<td>7.</td>
<td>Slatina</td>
<td>172</td>
<td>44°26'</td>
<td>24°21'</td>
</tr>
<tr>
<td>8.</td>
<td>Băcăleș</td>
<td>313</td>
<td>44°29'</td>
<td>23°07'</td>
</tr>
<tr>
<td>9.</td>
<td>Târgu Logrești</td>
<td>265</td>
<td>44°53'</td>
<td>23°42'</td>
</tr>
<tr>
<td>10.</td>
<td>Drăgășani</td>
<td>280</td>
<td>44°40'</td>
<td>24°17'</td>
</tr>
<tr>
<td>11.</td>
<td>Apa Neagră (Padeș)</td>
<td>258</td>
<td>45°00'</td>
<td>22°52'</td>
</tr>
</tbody>
</table>
Methods

The influence of climatic conditions on maize yield is rendered by the analysis of different specific indices resulting from the thermal and pluviometric requirements of the plant. The pluviometric potential is assessed based on the precipitation amounts registered during the growth cycle (May-August) and the critical stage, namely flowering and grain filling (July-August) (Table 2). The thermal requirements were also considered and they were assessed based on thermal thresholds for distinct phenophases (Table 2) and on the growth degree days (GDD).

Table 2: Precipitation and thermal requirements of maize

<table>
<thead>
<tr>
<th>Interval</th>
<th>Precipitation amounts (mm) – thresholds (NMA, 2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May – Aug.</td>
<td>Optim. &lt; 280 280-380 Humid: &gt; 380</td>
</tr>
</tbody>
</table>

Optimum precipitation thresholds by month (mm) (Muntean et al., 2001)

<table>
<thead>
<tr>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td>60-80</td>
<td>100-120</td>
<td>100-120</td>
<td>20-60</td>
</tr>
</tbody>
</table>

Optimum temperature thresholds (°C) (Vâtcă et al., 2021 apud. Dincă & Moscalu, 1967)

<table>
<thead>
<tr>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-20</td>
<td>16-20</td>
<td>19-21</td>
<td>20-23</td>
<td>19-20</td>
<td>14-17</td>
</tr>
</tbody>
</table>

GDD is calculated according to the following formula:

$$ GDD = \sum_{i=1}^{n} \frac{(T_{max}+T_{min})}{2} - Tb \ (1), $$
where $T_{\text{max}}$ is the daily maximum temperature, $T_{\text{min}}$ is the daily minimum temperature and $T_b$ is the base temperature, 10°C in case of maize (Croitoru et al., 2020; Vâtcă et al., 2021 apud. Bilteanu et al., 1974). The index is calculated for values above 10°C threshold, which generally correspond to the interval April – October. Based on GDD, it is considered that values below 800°C indicate an area as unsuitable for maize production, while values above 1600°C indicate favourability for maize production.

As maize is a crop highly sensitive to hydric stress, precipitation deficit was assessed based on Selyaninov’s hydrothermal coefficient (HTC) (Selyaninov, 1958). The index has the following formula:

$$HTC = \frac{P}{\sum_{T>10°C}(T) - \sum_{T<10°C}(T)} \quad (2),$$

where $P$ is the sum of the precipitation amounts (mm) and $T$ is the sum of temperatures (°C). There are considered those months with mean temperatures above the 10°C threshold, which generally correspond to the period of April – October. HTC was applied in different studies related to the determination aridity (Cherenkova et al., 2013; Chmist-Sikorska et al., 2022; Devyatova et al., 2022; Gudko et al., 2021; Vlăduț & Licurici, 2020), or to the favourability of climate for the development of different plants (Babushkina et al., 2018; Evarte-Bundere & Evarts-Bunders, 2012; Leblois & Quirion, 2013). The significance of the HTC values is rendered in Table 3.

<table>
<thead>
<tr>
<th>HTC</th>
<th>Climate classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>Very dry or arid</td>
</tr>
<tr>
<td>0.31-0.60</td>
<td>Dry</td>
</tr>
<tr>
<td>0.61-0.80</td>
<td>Moderately dry</td>
</tr>
<tr>
<td>0.81-1.00</td>
<td>Slightly dry</td>
</tr>
<tr>
<td>1.01-1.20</td>
<td>Slightly humid</td>
</tr>
<tr>
<td>1.21-1.40</td>
<td>Moderately humid</td>
</tr>
<tr>
<td>1.41-1.60</td>
<td>Humid</td>
</tr>
<tr>
<td>&gt;1.61</td>
<td>Very humid</td>
</tr>
</tbody>
</table>

Source: Vlăduț et al., 2017 (adapted from Selyaninov, 1930)

### Correlation analysis

The relationship between the maize yield and the climatic indices was also assessed based on Pearson correlation coefficient. According to the correlation coefficient $r$, values between +0.7 and +0.9 indicate high positive/negative correlation, +0.5±+0.7 moderate positive/negative correlation, +0.3±+0.5 low positive/negative correlation, and 0±+0.3 negligible correlation (Maitah et al., 2021).

### Interpolation

It is increasingly important to have more accurate information regarding the climatic conditions even in data-scarce regions. To address this issue, interpolation techniques are used to supply meteorological data estimates for areas lacking monitoring infrastructure (Amini et al., 2019). Interpolation of precipitation and temperature data is a common practice for generating continuous, spatially-distributed layers, which can be used in various applications, including climate modeling and agricultural planning (Konca-Kedzierska et al., 2023).

Oltenia is characterized by a relatively homogeneous spatial distribution of the fourteen meteorological stations primarily considered for the study. However, the evaluation of the rainfall and thermal conditions and of their complex effects on maize development and yield, requires the generalization of the available data and the estimation of the corresponding values within the entire region, which covers more than 29,000 km² (NIS, 2023).

To this end, several key steps have been taken, the data generated during the study and further analyzed being included in the present paper. In order to achieve a more accurate estimation of the climatic characteristics of the region, support meteorological stations located in the nearest Romanian, Serbian, and Bulgarian areas were added to the georeferenced data set already comprising the meteorological stations in Oltenia. The available rainfall and thermal data, as well as the values corresponding to the derived indices were associated to the stations in the database. Considering the spatial characteristics of the area under study and the attributes of the data set, the chosen spatial interpolation routine, which uses the Spline regularized method, integrated in the ArcGIS Spatial analyst tools, allowed for gap filling of missing data in order to analyze long-term effects of climatic variables on maize development at regional level.

### Results

#### Spatial distribution of mean temperature values and precipitation amounts: growing season and critical months

The thermal potential of Oltenia region is one of the greatest in Romania. The mean annual values for the period 1990-2021 range between a minimum of 9.9°C, at Polovragi, which is in the submontane area, and a maximum of 12.6°C, at Drobeta-Turnu Severin, in the south-western part of the region. The mean temperatures for the growing season (April-September) exceed 19°C in the plain area, reaching even 20°C at Calafat, while in the hilly region (the piedmont and the Subcarpathians), they vary between 17.5°C and 18.4°C (Fig. 2). Lower values are characteristic to the areas located in the proximity of the mountains, such as Apa Neagră, and at higher altitude, such as Polovragi. In the southern and eastern parts of the Subcarpathians, the values are generally 1°C below the mean value registered in the plain area, this reduced difference northwards being induced by the small altitudinal range, as well as by

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the presence of large valley couloirs, such as the one of the Jiu and of the Olt.

The pluviometric potential of the region is less favourable for different crops, mainly in the southern plain area. In this respect, the differences between the landforms are greater compared to temperature, annual precipitation amounts decreasing both eastwards and southwards. Thus, the mean precipitation amounts range between a maximum of 941.2 mm at Apa Neagră and a minimum of 529.1 mm at Bechet. With regard to the growing season (April – September), the cumulated precipitation amount is between 300 and 360 mm in the plain area, the lowest amounts corresponding to the area located in the proximity of the Danube (at Calafat the amount is below 300 mm). In the piedmont area, the values oscillate between 350 and 400 mm, while in the Subcarpathians they range between 450 and 550 mm, with greater values in the western and northern sectors (Fig. 3). The amounts indicate slightly dry to dry conditions mainly in the plain and southern piedmont area.

The favourability of the climatic conditions for maize was also assessed based on temperature values for the months of the growing season. In April, temperatures are about 2°C below the optimum value as indicated by specialized literature. Generally, maize is sowed in the first part of the month in southern Romania, when soil temperature at a depth of 10 cm reaches 8-10°C (Popescu & Popescu, 1995). May, when maize emerges and starts its development, displays optimum values within the entire region. Starting with June until September, temperature is above the optimum upper threshold in all plain counties (Table 4). Vâlcea registers higher values only in August and September and Gorj is the only county with optimum values, but this is mainly determined by the lower temperatures registered at Polovragi and Apa Neagră. If we exclude the northern part of the county, the values registered in August and September would be above the upper limit.

**Figure 2:** Mean temperatures during the growing season (1990-2021)

**Figure 3:** Mean precipitation amount during the growing season (1990-2021)

**Table 4:** Mean values of the considered thermal indices at county level (1990-2021)

<table>
<thead>
<tr>
<th>Interval</th>
<th>Optimum (°C) / County</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>14-20</td>
<td>MH 12.0/C</td>
</tr>
<tr>
<td>May</td>
<td>16-20</td>
<td>MH 17.1/O</td>
</tr>
<tr>
<td>July</td>
<td>20-23</td>
<td>MH 23.4/W</td>
</tr>
<tr>
<td>August</td>
<td>19-20</td>
<td>MH 23.2/W</td>
</tr>
<tr>
<td>September</td>
<td>14-17</td>
<td>MH 17.9/W</td>
</tr>
</tbody>
</table>

W-warm C-cold O-optimum
With regard to the precipitation amounts, there were considered three intervals: April, which is the month when maize is sowed, July-August, the interval with maximum water requirements, and May-August that represents the most important part of the vegetation period. Mean precipitation amounts corresponding to April are optimum in all the counties, except Gorj that displays humid conditions on the whole, but the amount is optimum in the lower part of the county where maize is cultivated (Table 5). As for the July-August interval, there are optimum amounts only in Gorj, all the other counties displaying dry conditions. The lowest amounts are in Dolj and Mehedinți, where the values are 50 mm below the lower optimum threshold, which means water shortage may affect maize development, even if maize is considered a drought-resistant plant. Thus, in order to obtain good productions, the crops should be irrigated. Studies indicate that, in the climatic conditions of Romania, the minimum precipitation amount for the entire period of vegetation should be about 250-300 mm, while the optimum amount is between 280 and 380 mm (Muntean et al., 2001). On average, optimum amount is reached only in Gorj, but, in all the other counties, except Dolj, the amount is close to the lower threshold, namely 250 mm.

Table 5: Mean values of the considered pluviometric indices at county level (1990-2021)

<table>
<thead>
<tr>
<th>Interval</th>
<th>Optimum (mm)/County</th>
<th>MH</th>
<th>DJ</th>
<th>OT</th>
<th>GJ</th>
<th>VL</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>40.1-60</td>
<td>54.2/O</td>
<td>45.8/O</td>
<td>44.4/O</td>
<td>63.6/H</td>
<td>53.5/O</td>
</tr>
<tr>
<td>July-Aug.</td>
<td>150.1-200</td>
<td>108.3/D</td>
<td>100.3/D</td>
<td>115.0/D</td>
<td>165.0/O</td>
<td>146.8/D</td>
</tr>
<tr>
<td>May-Aug.</td>
<td>280-380</td>
<td>242.9/D</td>
<td>225.9/D</td>
<td>249.5/D</td>
<td>309.9/O</td>
<td>245.9/D</td>
</tr>
</tbody>
</table>

GDD represents one of the most commonly used methods to assess temperature requirements of specific crops. Considering the entire growing season (April – October), most of the region displays GDD values above the 1600°C threshold, which indicates high thermal potential. Only the north-eastern extremity of the Getic Piedmont and the western and northern sectors of the Subcarpathians register lower values (Fig. 4). However, the southwestern sector of the plain tends to become hotter, GDD reaching 2000°C at Calafat. Considering that GDD is calculated based on temperature values (maximum and minimum temperatures), it registered a continuous and significant increase in the last decades, following the same pattern within the entire region. For maize, the suitability limits are between 800°C and 1600°C and the mean GDD values (May-August) indicate that the southern counties are included in suitability I class (1401-1600°C), while the northern counties fall in suitability II class (1201-1400°C).

Figure 4: Mean values of the growth degree days (GDD) (1990-2021)

Water deficit during the growing cycle may also drastically reduce yield. HTC mean values indicate an area characterized by moderately dry conditions in the proximity of Calafat, while most of the plain displays slightly dry conditions. Slightly humid conditions emerge in the northern part of the plain, large areas of the piedmont, and the eastern sector of the Subcarpathians, while moderately humid and humid conditions are in the central and western sectors of the Subcarpathians (Fig. 5).
At monthly level, adequate pluviometric conditions are registered in May – from slightly humid conditions in the southern plain area to very humid conditions in the Subcarpathians (Fig. 6a). On the whole, in June, as well, water deficit is not problematic, but in the western part of the plain (Calafat, D.T. Severin) drier conditions emerge, the climate being characterized as slightly and moderately dry (Fig. 6b). Water deficit in the last two summer months, but especially in August, affects most of the region (Fig. 6c,d), including higher hilly areas. In July, the plain area is slightly to moderately dry, while in the hilly area, due to higher precipitation amounts, the climatic conditions are from slightly humid to very humid. In August, the plain area registers dry conditions, except the northern extremity (Craiova and Slatina), where climate is moderately dry; the hilly area has slightly dry conditions, a moderately humid climate being characteristic only in the higher northern sector of the Subcarpathians. Water deficit maintains in the plain area in September as well (slightly to moderately dry conditions) (Fig. 6e), but it reduced northwards on the background of temperature decrease (slightly humid to humid conditions).
The variability of thermal and pluviometric resources and their impact on maize yield

Temperature and precipitation represent key climatic parameters for maize yield. Generally, from the thermal viewpoint, maize finds proper conditions in Oltenia, but, in certain years, maximum daily temperatures above 32°C (threshold considered detrimental to maize) are recorded for longer periods and reduce yield. Water requirements are not met in most of the plain area, especially during the critical stages – flowering and grain filling, namely July-August interval, when water availability plays the most important role for yield (Butts-Wilmsmeyer et al., 2019).

The average maize yield for the entire period under study places Oltenia below the national corresponding value, with 3534.9 kg/ha as compared to 3743.7 kg/ha. An average value lower than in Oltenia was recorded only in the North-East Region (i.e. 3444.3 kg/ha), while three other regions (i.e Centre, Bucharest-Ilfov, and West) were above the 4000 kg/ha threshold; the most significant average yield for the entire period corresponded to the West Region (4112.0 kg/ha). During 20 of the 32 analysed years, the annual yield values in Oltenia were lower than the national ones. This situation became more frequent after 2010, when Oltenia recorded annual values higher than the national yield only in 2017 and 2020 (NIS, 2023).

The year 1993 registered extremely low productions in all three southern counties, less than 650 kg/ha, while in Gorj and Vâlcea yield varied between 2000 and 3000 kg/ha. From the thermal point of view, temperatures were within the optimum limits in all the months, except August, which was hotter than July and about 3°C above the upper optimum threshold. The main factor that determined these extremely reduced productions is represented by the precipitation amounts. Thus, April was an extremely dry month in Dolj and a very dry month in the other two counties, while during the period with maximum water requirements (July-August), as well as during the growing season, extremely dry conditions characterized all the three counties (almost -100 mm
compared to the lower optimum threshold in the first case and -150 mm in the second). The greatest negative deviations correspond to Dolj County (Fig. 7), which also registered the lowest yield in 1993, this year also marking the negative record for the last 32 years.

Also, 2000 was an exceptionally dry year during the warm season. Yield was very reduced in Dolj and Olt (about 500 kg/ha), northern counties being less affected. Besides low precipitation amounts, temperatures were higher than the optimum both in July and August, and there were several strong heatwaves during summer. The most severe water deficit was registered in Olt (-113 mm in July-August and -220 mm in May-August compared to the lower optimum threshold). Thus, the total amount gathered during the four months of the growing season reached only 60 mm in Olt, 92 mm in Dolj, and 113-114 mm in Mehedinți and Vâlcea (Fig. 8). Drought started in May, which according to HTC is an arid month in Dolj and Olt, a dry month in Mehedinți and Vâlcea, and moderately dry in Gorj. June was arid in four of the counties, except Dolj, where it was dry, as well as August, in this case, the exception (dry month) corresponding to Gorj County. In July, slightly humid conditions were registered only in Mehedinți, drought persisting in the other counties. Even if it was the month with the highest precipitation amounts from the growing season, maize crops had already been compromised on large surfaces. Mean maximum values exceeded 32°C in July and almost reached 34°C in August at all the stations from the plain area and the southern part of the piedmont, heat stress being also increased.

Low yields were also recorded in 2002, maize and wheat crops being totally compromised on large surfaces in Mehedinți and Dolj (Fig. 9). In this case, the main limiting factor was represented by excessive precipitation amounts registered during the July-August interval. Thus, in July, there were 146 mm at Bâcleș, 134.4 mm at Craiova, 131.9 mm at Băilești, and more than 100 mm at the other meteorological stations, as well as in August. The amount increased northwards, reaching 188 mm at Apa Neagră and more than 200 mm at Polovragi.
Influence of climate conditions on maize yield in Oltenia (1990-2021)

Figure 7: Spatial differences of maize production in Oltenia in 1993

Figure 8: Spatial differences of maize production in Oltenia in 2000

Figure 9: Spatial differences of maize production in Oltenia in 2002
For 2007 and 2012, besides the water deficit registered during certain periods, the main problem was represented by extremely high temperatures. In 2007, all three southern counties recorded less than 550 kg/ha, the most affected being Mehedinți with 317.9 kg/ha, the lowest production registered in Oltenia in the last 32 years. Thus, mean temperature of July was above 25°C, while mean maximum values in the plain area exceeded 35°C in the east (Bechet, Caracal) and were between 34 and 35°C in the rest of the unit. Even in the Subcarpathian region, the values were above the 32°C threshold, higher values being considered detrimental for maize crops. Dry conditions were registered in Mehedinți and Dolj for the July-August interval, as well as for the entire growing season (Fig. 10).

Figure 10: Maize yield and the precipitation amounts registered in the interval 1990-2021 in Mehedinți (a), Dolj (b), Olt (c), Gorj (d), and Vâlcea (e)
The year 2012 is by far the hottest year in Oltenia. Temperatures were particularly high during the summer months, in the three aforementioned counties the mean exceeding 27°C, while the mean maximum temperature was above 35°C. August also was a hot month, mean temperatures ranging between 25.1 and 25.4°C, except Vâlcea, which registered 23.8°C. Water deficit was also increased especially in the July-August interval. Even if crops were affected, they were not entirely compromised, 2012 marking the lowest production for Vâlcea County.

From the thermal point of view, the most problematic months are July and August. Even if maize tolerates well higher temperatures, when diurnal values exceed 32°C, the plant is affected and the yield reduces. Starting with 2007, the warming trend has increased both in July and August, mean monthly values frequently exceeding 24°C. Thus, even if the years with July and August mean values below 23°C register the highest shares overall, the three southern counties also have significant shares of temperatures above 24°C (Fig. 11).

Figure 11: Share of July and August mean temperatures above certain thresholds

When analysing the entire period in terms of precipitations amounts for the considered intervals, it results that dry, optimum, and humid conditions have almost similar shares only in April, the most homogenous distribution (about 33%) being registered in Mehedinți and Vâlcea counties (Fig. 12).
Dry conditions have greater shares in Dolj and Olt (40.6%, respectively 46.9%), while in Gorj, the humid conditions display the highest share. Dry conditions clearly predominate in the July-August interval especially in the plain area (Fig. 12). Thus, in Dolj and Mehedinți, more than 80% of the years have precipitation amounts below the optimum thresholds (dry) and the corresponding value for Olt is 75%. Lower shares (53% to 56%) are registered in the other two counties, namely Gorj, which has the greatest share of humid conditions (28.1% of the years), and Vâlcea, which displays the highest share of optimum conditions (31.3% of the years). The same distribution pattern also emerges in case of the precipitation amounts for the interval May-August. Dry conditions prevail in the south (between 71.9% in Mehedinți and 81.3% in Dolj), the share of the years classified as dry decreasing northwards. The greatest share of optimum conditions characterizes Gorj and Vâlcea (31.3%, respectively 37.5%; if in terms of optimum conditions, there is not a significant difference between the two northern counties, in case of humid conditions, Gorj registered the greatest share of such years – 37.5%, followed by Vâlcea with 15.6%.

Discussions

Temperature, precipitation amounts, and evapotranspiration rates are the main climatic drivers for maize yields (Prăvălie et al., 2020). Generally, Oltenia has a good thermal potential, mean temperatures and GDD values for the period 1990-2021 indicating that most of the region is within the optimum limits. However, if taking into account the significant temperature increase (Prăvălie et al., 2017; Vlăduț, 2017), as well as the fact that Oltenia is among the regions very prone to drought especially in summer (Nagavciuc et al., 2022), maize crops are under an ever-increasing pressure. The GDD increase is obvious especially in the south of the region, the 2000°C threshold being exceeded four or three times in the last 10 years. The northwards shift of the 2000°C GDD isoline is also mentioned by Charalampopoulos (2021) when analysing the Balkan Peninsula. Thus, if in 1980 this isoline overlapped northern Greece, in 2000, it shifted considerably, up to southern Romania, and in 2020, it entirely included the Romanian Plain, Dobrogea and the southern part of the Moldavian Plateau. Thus, there can be assumed a high warming rate characteristic to the growing season, with potentially greater negative
impact, both direct and indirect, on maize yield in the near future. The direct impact relates to heat stress (>32°C) that causes the deterioration of different metabolic processes in maize, while temperature increase indirectly determines evapotranspiration acceleration and increase in water deficit, which is also very detrimental to plants.

The quantification of maize response to temperature variability and increasing trends concerned scientists in the last decades. Thus, Lobell et al. (2011) highlighted a total decrease of 3.7% in global maize yield between 1980 and 2008, 3.1% because of temperature and only 0.7% due to precipitation amounts. According to more recent studies, a 1°C temperature increase will trigger 7.4% yield loss in maize (Kraus et al. 2022). Yield loss related to air temperature increase has also been identified in southern Romania, including Oltenia. According to Prăvălie et al. (2017), after 1990, an average 1.2 t/ha/yr loss was recorded for 1°C increase. However, the reduction of the region maize yield is even higher when related to water deficit, namely 1.7 t/ha/yr (Prăvălie et al., 2016).

According to Pearson coefficient \( r \), in most cases, there are negligible negative correlations between yield and temperature (Table 6). This is the case in May, June, and August. A low negative correlation between yield and mean temperature of June was identified in Dolj. In July, the hottest month, low negative correlations were identified in four counties, while in Vâlcea, there is a moderate negative correlation. In this case, temperature determined yield reduction in the region, as higher values during sensitive phenophases are detrimental to maize. As July temperature is significantly increasing, we may assume that maize crops will be even more affected as exposure to high temperature during the grain-filling phenophase shortens this period and determines greater rates of senescence and, consequently, lower yields (Hatfield, 2016; Dawood et al. 2020). Low to moderate negative correlations between July mean temperature and maize yield were also identified in South-Eastern Europe (Lopes, 2022), Serbia (Petrović et al., 2020; Petrović et al., 2023), the Czech Republic (Maitah et al., 2021), while in Hungary, Czibolya et al. (2020) highlighted a strong positive correlation with August mean temperature. In Romania, different researchers emphasized the negative impact of high summer temperatures on maize yield (strong negative correlation) – Bonea & Urechean (2020) in the central part of Oltenia and Șimon et al. (2023) in the Transylvanian Plain.

### Table 6: Pearson correlation between maize yield, temperature, and precipitation amounts

<table>
<thead>
<tr>
<th>County/Climatic parameter</th>
<th>Temperature</th>
<th>Precipitation amounts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>May</td>
<td>June</td>
</tr>
<tr>
<td>MH</td>
<td>-0.28</td>
<td>-0.15</td>
</tr>
<tr>
<td>DJ</td>
<td>-0.23</td>
<td>-0.30</td>
</tr>
<tr>
<td>OT</td>
<td>-0.28</td>
<td>-0.27</td>
</tr>
<tr>
<td>GJ</td>
<td>-0.19</td>
<td>-0.21</td>
</tr>
<tr>
<td>VL</td>
<td>0.01</td>
<td>-0.10</td>
</tr>
</tbody>
</table>

In reference to the correlation between maize yield and GST, respectively GGD, there were identified only negligible negative correlations (except for GDD in case of Mehedinți – negligible positive correlation), which highlight the fact that mean values for the entire growing cycle cannot explain yield reduction. However, when the analysis was made for different phenophases, there were identified significant positive/negative correlations. Thus, in Oltenia, according to Bonea & Dunăreanu (2021), a strong positive correlation with GDD was identified for the emergence and physiological maturity stages, while for tasseling and silking stages, higher GDD values reduced yield (strong negative correlation).

Generally, precipitation amounts correlate positively with maize yield, meaning greater amounts determine better crops. Pearson coefficient highlighted low positive correlation for the precipitation amount registered during the growing cycle (May-August) in four of the counties, except for Gorj, where the correlation was moderate. In the same county, there was identified a low positive correlation for the precipitation amount registered during the water maximum requirement period (July-August), while in the other counties the positive correlation is negligible. At monthly level, positive low and moderate correlations were identified in all five counties in June and July, while in April, May and August, most of the correlations are positive but negligible. In July, moderate and high positive correlation with precipitation is also mentioned in the Czech Republic (Maitah et al., 2021). In Vojvodina, Milošević et al. (2015) identified a low positive correlation for July and August, while in Hungary, a moderate positive correlation emerged for all summer months (Czibolya et al., 2020). Ceglar et al. (2016) highlight a significant dependence of maize yield on monthly precipitation amounts in France; an increasingly negative impact of precipitation anomalies during the summer was also emphasized (Ceglar et al., 2020). July precipitation amount positively correlated with maize yield in Rostov region and the amount cumulated during the entire growing season was considered the dominant factor that explains up to 75.7% of the interannual variability of maize yield in

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Influence of climate conditions on maize yield in Oltenia (1990-2021)
Zimovnikovsky, Russia (Gudko et al., 2022). In Oltenia (Craiova area), Bonea & Urechean (2020) highlighted a strong positive correlation between maize yield and June precipitations, respectively precipitations cumulated in the sowing to anthesis period, while for the other months or phenological phases, precipitations amounts were reported as having an insignificant influence on maize yield, which is consistent with the present study at county level.

Taking into account that none of the analysed variable can entirely explain low yields registered in the region, we may assume that the drastic production reductions are the result of the combined effects of water deficit / drought and heat stress. Recent studies revealed that these combined effects are more detrimental to maize compared to individual stresses (Nelimor et al., 2020), as they restrain fundamental physiological processes, such as respiration and photosynthetic activity (Yousaf et al., 2022). High temperature accelerates potential evapotranspiration and amplifies climate stress, maize being particularly affected as such events usually occur during the most sensitive phenophases – tasseling and grain-filling. In the plain area of Oltenia, it was determined that water deficit is on average responsible for 60–64% of the variation of maize productivity (Prăvălie et al., 2016), 1 mm deficit increase resulting in a reduction of 13 kg/ha/year in the east of the plain and to 20 kg/ha/year in the west. After 2000, the extremely low productions (less than 1000 kg/ha) generally correspond to years characterized by high mean and mean maximum temperatures during summer correlated with reduced precipitation amounts during the entire or part of the growing cycle. Low or extremely low precipitation amounts registered during the sowing month (April in the region) do not compromise yield if there is enough water supply in the soil to support the plant emergence. Such an example is 2018, the year with the highest yield in the analysed period, when April registered moderately dry and dry conditions. Thus, irrigations are necessary in the region to ensure an adequate water amount, as presently maize crops greatly depend on natural conditions. According to the National Agency for Land Improvements, the irrigation systems cover a total surface of 450,973 ha in Oltenia in 2023 (47.5% in Dolj, 35.9% in Olt, and 16.6% in Mehedinți). However, the irrigated surface was much lower, namely 100,779 ha (mostly in Dolj and Olt), which represents only 22.3% of the total surface, even if it increased compared to the previous years. A potential explanation for this low share of the irrigated surfaces is related to the costs, as most of the farmers do not afford to pay for this service.

Conclusions

Cereals are among the most vulnerable crops cultivated in Romania as temperatures are increasingly higher and the water deficit characteristic in the summer coincides with the period of maximum requirements. Based on mean values – temperature, precipitation amounts, GDD, Oltenia displays proper conditions for maize cultivation. However, mean values are not relevant when assessing the relationship between yield and climate as plants are particularly sensitive to different meteorological variables according to growing stage.

Thus, with regard to temperatures, mean monthly values are already 1 to 2°C above the optimum thermal threshold of maize in the interval June-September. Moreover, the repetitive episodes of high and extremely high temperatures registered during flowering and/or grain-filling phases proved to have a great negative impact on maize yields in the last 10 years, particularly in the southern counties, which are also the main maize producers in the region. GDD values for the growing season (April-October) emphasizes Oltenia as a region with a very good thermal potential for cereals. In the case of maize, southern counties have suitability I class (GDD for the interval May-August between 1401 and 1600°C), while the other two counties are in suitability II class. However, values are gradually increasing based on a higher maximum temperature increase compared to the minimum temperature. If this trend maintains, heat stress will also increase, especially in the southwestern part of the plain area, where the average of the last ten years gets close to the 1600°C threshold (Calafat 1588.9°C, D.T. Severin 1584.4°C).

Besides temperatures, precipitation amounts and their distribution during the growing season are equally important. HTC mean values indicate slightly dry conditions in the growing season in the plain area, while northwards, in the piedmont and Subcarpathians, the climate is slightly humid, respectively moderately humid, drought risk decreasing gradually in this direction. The water deficit affects Mehedinți, Dolj, and Olt, mainly during July-August interval, which corresponds to the maximum water requirements of maize. The extremely low yields obtained in 1993 were mainly induced by water deficit. When precipitation shortage combines with hot periods, the negative impact is even greater, as it was the case of 2000, 2007, and 2012, when yield was 50-60% lower compared to the previous year at national level, but in southern Oltenia, especially in Mehedinți and Dolj, the share was much lower (8.7%, respectively 14.8% compared to the previous year production and 9.5%, respectively 15.2% compared to the average production of the entire period).

Maize and wheat represent the main cereal crops based on which Romania is a major international grain exporter. Taking into account the average values of cereal production for the 1990-2021 period, Oltenia represents the third largest regional producer of the country (after the South-Muntenia and South-East regions), with an average annual share of 14.5% (i.e. 2.71 mil. t/year of the total of 18.63 mil. t/year). The corresponding maize production values place Oltenia on the fourth position.
among the Romanian regions, with 13.6% of the total production obtained during the 32-year interval under study (i.e. 1.38 mil. t/year of the national average production of 10.12 mil. t/year). Compared to these average figures, there is also to be mentioned the significant difference between the highest values (i.e. 20% of the national cereal production was obtained in Oltenia in 1994) and the lowest ones (8.5% in 1993 and even 7.8% in 2002) (NIS, 2023). These values highlight both the very important productive potential of Oltenia, as well as the negative influence of unfavorable weather conditions correlated with the insufficient infrastructure necessary for a competitive agriculture in the region.

Consequently, maximizing production efficiency is a priority and, taking into account the projected climate changes, there is an acute need to implement different adaptation measures in due time. Re-establishing the irrigation system in southern Oltenia is mandatory if taking into account the climate projections that indicate a significant overall increase in temperature, but, more important in case of maize, the increase in maximum daily values over summer and in the frequency and intensity of heatwaves. It is also recommended to have earlier sowing dates – the end of March compared to the present period, as projected temperatures will reach the proper values in last decade of the month and it will also be avoided water deficit, as well as extremely high temperatures (above the 32°C threshold which is detrimental to maize) characteristic to the July-August interval. The introduction of new heat and drought-tolerant hybrids is also considered a good solution for the next period and researchers are already working in this direction.

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**Author contribution**

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**Conflicts of interest**

The authors declare no conflict of interest.

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