# THE IMPACT OF CLIMATE CONDITIONS ON WHEAT YIELD IN OLTENIA (1990-2021)

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**Abstract.** Wheat, one of the most important crops at global level, is both a thermo-sensitive and rain-sensitive plant. As a consequence, any change in the key meteorological parameters determines low yields, especially in rain-fed regions. In order to assess the relationship between wheat yield and climate conditions, we used monthly values of temperature and precipitation amount from 14 meteorological stations located within the study area. The data cover the period 1990-2021. Based on mean values, wheat generally finds proper climatic conditions within most of the region. Southern counties, especially Mehedinţi, Dolj and Olt, display certain thermal and pluviometric risks, as heat sums (interval October-June) exceed the optimum upper value (2300°C) and water deficit generates dry conditions in May-June interval, which corresponds to the maximum water requirements of winter wheat. Drought-prone areas were determined based on Selyaninov's hydrothermal coefficient (HTC) and drought variability was analysed based on the standardized precipitation anomaly (SPA) and Weighted Anomaly Standardized Precipitation (WASP). HTC indicates slightly and moderately dry conditions in the plain area (both annual and monthly values), while northwards, in the piedmont and Subcarpathians, the climate is either slightly or moderately humid, drought risk reducing gradually in this direction. SPA indicates a predominance of normal years (43-45%), followed by dry years (29-31%) without an obvious latitudinal and altitudinal differentiation. According to WASP, most of the months (70-80%) are normal (no risk), but they are not homogenously distributed during the year and dry conditions emerge at higher rates in May-July and September-October (up to 30%), especially in the east of Oltenia. During the interval under study, the lowest wheat yields were registered in 1992, 1993, 1996, 2000, 2002, 2003, and 2007 and, in most of the cases, they were determined by the pluviometric deficit registered during the entire life cycle or during a sensitive phenological stage. In certain years, 2003 and 2007 for example, heat stress was also an important factor for a diminished yield.

**Keywords:** climatic conditions, drought, wheat, yield, Oltenia.

**Rezumat. Impactul condiţiilor climatice asupra producţiei de grâu în Oltenia (1990-2021).** Grâul, una dintre cele mai importante culturi la nivel global, este o plantă cu sensibilitate mare atât faţă de condiţiile termice cât și pluviometrice. În consecință, orice modificare a parametrilor meteorologici cheie determină producții scăzute, în special în regiunile în care producţia se bazează exclusiv pe precipitații. Pentru a evalua relația dintre producția de grâu și condițiile climatice am utilizat valori lunare de temperatură și precipitații de la 14 stații meteorologice situate în zona de studiu. Datele acoperă perioada 1990-2021. Pe baza valorilor medii, grâul găsește, în general, condiții climatice adecvate în cea mai mare parte a regiunii. Județele sudice, în special Mehedinți, Dolj și Olt, prezintă anumite riscuri termice și pluviometrice, întrucât sumele de temperatură (interval octombrie-iunie) depășesc valoarea optimă superioară (2300°C), iar deficitul de apă generează condiții de secetă în intervalul mai-iunie, care corespunde cerințelor maxime de apă pentru grâul de toamnă. Zonele predispuse la secetă au fost determinate pe baza coeficientului hidrotermic al lui Selyaninov (HTC), iar variabilitatea secetei a fost analizată pe baza anomaliei standardizate de precipitații (SPA) și a anomaliilor standardizate ponderate de precipitații (WASP). HTC indică condiții ușor și moderat uscate în zona de câmpie (atât valori anuale, cât și lunare), în timp ce spre nord, în piemont și Subcarpați, clima este fie ușor, fie moderat umedă, riscul de secetă diminuându-se treptat în această direcție. SPA indică o predominanță a anilor normali (43-45%), urmați de anii secetoși (29-31%), fără o diferențiere latitudinală și altitudinală evidentă. Potrivit WASP, majoritatea lunilor (70-80%) sunt normale (fără risc), dar nu sunt distribuite omogen pe parcursul anului, iar condiții de uscăciune apar cu o pondere mai mare în intervalele mai-iulie și septembrie-octombrie (până la 30%), mai ales în estul Olteniei. Cele mai scăzute producții de grâu s-au înregistrat în 1992, 1993, 1996, 2000, 2002, 2003 și 2007 și, în majoritatea cazurilor, au fost determinate de deficitul pluviometric înregistrat pe întreg ciclul de vegetație sau într-o etapă fenologică sensibilă. În anumiți ani, 2003 și 2007 de exemplu, stresul termic a fost, de asemenea, un factor important care a dus la diminuarea producției.

**Cuvinte cheie:** condiții climatice, secetă, grâu, producție, Oltenia.

## INTRODUCTION

Wheat (*Triticum aestivum* L.) represents one of the major cereal crops (the third most important after rice and maize in terms of production, according to FAO, 2020 and the first among cereals in terms of food use and international trade, according to FAO 2022), especially in the Northern hemisphere, and a key element when it comes to food security. Taking into account the present climatic context and the future projections, together with the estimated population growth, increasing the agricultural productions has already become a priority. According to IPCC (2021), Central and Eastern Europe will be subject to one of the most intensive warming, temperature changes also triggering the modification of other climatic parameters, i.e. rainfall amounts and distribution during the year, drought frequency and intensity, torrential rainfalls frequency, etc. Plant phenology is highly dependent on climate conditions. However, the impact on production depends on the severity of the climatic event correlated with the sensitive stages in plants' development, undertaken mitigation measures, etc.

Temperature is considered one of the most important abiotic factors that conditions yield. Wheat is generally considered a cold-loving plant, its temperature requirements depending on the variety and development stage (vegetative, reproductive – inflorescence/spike development, anthesis – flowering, grain set, and senescence). In order to obtain maximum yields, during anthesis and grain fill growth stages, when the plant is highly sensitive to extreme heat, the optimum mean temperatures should range between 12 and 22°C (TEWOLDE et al., 2006) and the mean maximum temperature should not exceed 28-30°C (DRAEGER & MOORE, 2017). Consequently, temperature increase is considered one of the main threats to wheat production as each 1°C above optimum temperatures will be responsible for up to 6% yield reduction (ASSENG et al., 2015; LIU et al., 2016). However, certain studies indicate that higher temperatures determined a two-week shift in winter wheat growth in the last 50 years, thus enabling crops to avoid increasing summer temperatures (REZAEI et al., 2015) and droughts (WEBBER et al., 2018).

In terms of humidity requirements, the annual optimum rainfall amount is 600 mm (MUNTEAN et al., 2001), the lower threshold being 225 mm. The optimum amounts are different during the plant's life cycle. The last phenological stages (May – June), including grain fill growth, require the highest amounts, between 150 and 200 mm. However, water deficit/stress occurring during the earlier phenological stages (vegetative, reproductive) determines the reduction of yield (GOODING at el., 2003) especially in the case of rain-fed crops. When water deficit is also associated with high persistent temperatures, the stress is even higher and detrimental to wheat physiology (DUGGAN et al., 2000) and yield (ANWAAR et al., 2020).

Romania is one of the biggest wheat producers in Europe, as 20% of its arable land is very favourable and 70% favourable for wheat production. Based on Eurostat data (https://ec.europa.eu/eurostat/databrowser/view/apro_cpnh1/), Romania is ranked fourth in terms of wheat production, with 10.433 mil. t in 2021 and 9178.79 mil. t in 2022 after France, Germany, and Poland. The dependency of wheat yield on climate conditions (rain-fed crops) is highlighted by mean production/ha. Thus, if France and Germany obtained between 7 and 7.6 t/ha, Poland 5-5.5 t/ha in the two years, Romania registered a much lower productivity – 4.8 t/ha in 2021 and 4.18 t/ha in 2022. Consequently, climate evolution for the next decades becomes highly important if irrigation systems are not functional, temperature continues to increase, and drought vulnerability follows the same trend.

Oltenia is one of the most vulnerable regions in the country to climate change. Different studies highlight statistically significant increase in temperature and potential evapotranspiration (CROITORU et al., 2013; PRĂVĂLIE, 2014; PRĂVĂLIE et al., 2017; VLĂDUȚ & ONȚEL, 2013; VLĂDUȚ, 2017), heatwaves (CROITORU et al., 2016), drought (mainly during summer and autumn) (BOJARIU et al., 2012; CHEVAL et al., 2014; IONITA et al., 2016), aridity (PRĂVĂLIE, 2013; VLĂDUȚ et al., 2017; RĂDUCĂ et al., 2019; VLĂDUȚ & LICURICI, 2020) and the decline of the water resources (PRĂVĂLIE et al., 2016). Moreover, there are large surfaces covered by sands and sandy soils. The area displaying very favourable conditions for wheat production is limited to the plain area, especially its central and northern part, while favourable conditions characterize the piedmont and the southern Subcarpathian area (mainly within the floodplains of the main rivers).

Taking into account temperature projections, wheat yield might be affected in the region. Thus, according to Ro-Adapt, for the RCP4.5 emission scenario, the mean temperature in May will be 0.8°C higher for the period 2021-2040 and 1.2-1.3°C for the period 2041-2070 than the mean of the reference period 1971-2000. In June, the increase is even higher: 1.1-1.3°C for the period 2021-2040 and 1.6°C for the period 2041-2070 (ANM, http://193.26.129.161/despre-platforma.php). In the case of rainfall amounts (same scenario), projections are not that clear. Annual values are projected to decrease in Mehedinți (-3.5%), Gorj (-2.2%), and Vâlcea (-0.6%) and increase by 1-2% in Dolj and Olt for the period 2021-2040, while for the period 2041-2070, there will be an increase of up to 3.9% (Olt).

The aims of the present study are: (1) to analyse the spatial distribution of temperature and precipitation, as well as of the indices influencing the growth and development of wheat; (2) to present drought occurrence and variability in the region over the past 32 years (1990–2021); (3) to explore the impact of temperature and precipitation deficit/droughts on wheat yield and determine the contribution of each assessed parameter to the yield reduction.

## MATERIAL AND METHODS

**Study area and data**. Oltenia, located in the southwestern part of Romania, is an important agricultural area. Among cereals, wheat finds most suitable conditions mainly in its southern lower part corresponding to the plain and piedmont, but, taking into account the favourable climate and soil conditions, some surfaces are cultivated even in the Subcarpathian region, mostly in depressions and the floodplains of the rivers. For the present study, the following climatic data were used: the mean monthly temperatures and monthly precipitation amounts for the 14 meteorological stations located within the analysed region (Fig. 1; Table 1). The data cover a period of 32 years (1990-2021) and they were provided by the National Meteorological Administration. The statistical data related to the cultivated surface and wheat production were provided by the National Institute of Statistics (NIS, 2023).

**Methods.** The assessment of the importance of the climatic conditions on wheat yield is based on the analysis of different indices taking into account the thermal and pluviometric requirements of the plant. Thus, the *pluviometric potential* of the region was analysed based on the optimum and critical thresholds for different phenological stages – sowing-sprouting period for autumn crops (September-October), water retention in the soil (over the dormant season, November – March), maximum water requirements of winter wheat (May – June) (Table 2). In terms of *thermal requirements*, winter wheat needs certain temperatures during the vernalization – hardening physiological processes, which correspond to the interval October – December, as well as during the phenological phases occurring in spring-summer (Table 3).

As most of the plants cultivated in Oltenia are vulnerable to hydric stress, specific indices highlighting drought risk were also applied.

*Selyaninov's hydrothermal coefficient* (HTC) (SELYANINOV, 1958) is calculated according to the formula: $HTC = \frac{P}{\sum_{T>10}\frac{T}{10}}$ (1), where $P$ is the sum of precipitation amounts (mm) and $T$ is the sum of temperatures (°C) for the months when mean temperatures exceed 10°C, which mostly correspond to the period of April – October, thus emphasizing hydric stress during the last phenological phases of wheat. HTC was applied in different studies related to the determination of moist and dry periods (RIAZANOVA et al., 2016; VLĂDUŢ et al., 2017; VLĂDUŢ & LICURICI, 2020), or to the favourability of climate for the development of different plants (EVARTE-BUNDERE & EVARTS-BUNDERS, 2012; KWIATKOWSKI, 2015; LEBLOIS & QUIRION, 2013). The significance of HTC values is shown in Table 4.

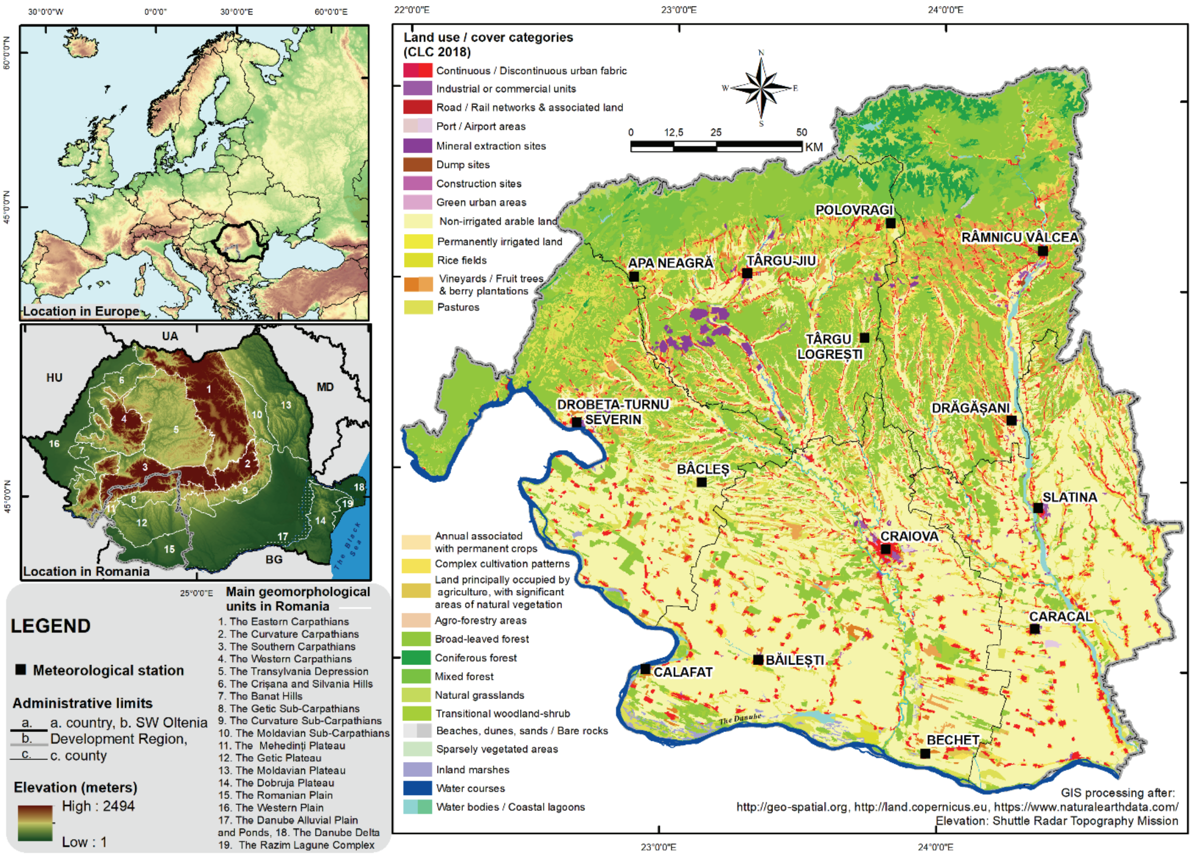



Figure 1. Location of Oltenia Region within Romania and of the considered meteorological stations (original).

Table 1. Geographical coordinates of the considered meteorological stations.

| No. | Meteorological station | Altitude (m) | Latitude | Longitude |
|---|---|---|---|---|
| 1. | Dr. Turnu-Severin | 77 | 44°38` | 22°38` |
| 2. | Calafat | 61 | 43°59` | 22°57` |
| 3. | Bechet | 36 | 43°47` | 23°57` |
| 4. | Băileşti | 57 | 44°01` | 23°20` |
| 5. | Craiova | 192 | 44°19` | 23°52` |
| 6. | Caracal | 106 | 44°06` | 24°22` |
| 7. | Slatina | 172 | 44°26` | 24°21` |
| 8. | Bâcleş | 313 | 44°29` | 23°07` |
| 9. | Târgu Logreşti | 265 | 44°53` | 23°42` |
| 10. | Drăgăşani | 280 | 44°40` | 24°17` |
| 11. | Apa Neagră (Padeș) | 258 | 45°00` | 22°52` |
| 12. | Târgu Jiu | 203 | 45°02` | 23°16` |
| 13. | Polovragi | 531 | 45°11` | 23°49` |
| 14. | Râmnicu Vâlcea | 237 | 45°06` | 24°22` |

Note: The meteorological stations are rendered from west to east, on landforms (the Danube Alluvial Plain, Oltenia Plain, the Getic Piedmont and Subcarpathians)

The *standardized precipitation anomaly* (SPA) is calculated according to the following formula (KUTIEL & PAZ, 1998):

$SPA = \frac{P_i - \overline{P}}{\sigma}$ (2), where $P_i$ is the precipitation amount from a particular year; $\overline{P}$ is the mean precipitation amount for the considered period; σ = standard deviation.

Standard deviation is calculated by extracting the square root of the dispersion ($\sigma^2$) based on the formula: $\sigma^2 = \frac{\sum_i^n (P_i - \bar{P})^2}{n}$ (3), where $n$ is the number of years (for $P_i$ and $\bar{P}$ the significance is rendered above). Precipitation deficit and excess was assessed based on SPA for different regions: Greece (MAHERAS, 2000), Romania (CROITORU et al., 2011; ARBA, 2012), Turkey (KUTIEL et al., 2001).

Table 2. Optimum and critical limits of rainfall amount during the characteristic intervals for the growth and development of wheat.

| Interval | Significance of the precipitation amounts (mm) – thresholds | | | | | |
|---|---|---|---|---|---|---|
| | Extremely dry | Very dry | Dry | Optimum | Humid | Extremely humid |
| September – October | < 40 | 40-60 | 60.1-80 | 80.1-120 | 120.1-150 | >150 |
| November – March | <100 | 100.1-150 | 150.1-200 | 200.1-300 | 300.1-400 | >400 |
| May – June | <50 | 50.1-100 | 100.1-150 | 150.1-200 | 200.1-300 | >300 |

Source: NMA, 2014

Table 3. Thermal requirements of winter wheat.

| Interval | Indicator | Value |
|---|---|---|
| October – December (vernalization) | Sum of positive temperatures (SPT) (∑Tav >0°C) | 550°C |
| November – March | Cold sum (∑Tav < 0°C) | <200 cold units – low intensity / mild winter;<br>200.1-300 cold units – moderate intensity / normal winter<br>300.1-400 cold units – high intensity / cold winter<br>>400 cold units – extremely high intensity / very cold winter |
| October-June | Temperature sum (heat sum, ∑Tav >0°C) | 1800-2300°C |

Source: NMA, 2014

Table 4. Climate classification according to the HTC.

| HTC | Climate classification |
|---|---|
| 0.3 | Very dry or arid |
| 0.31-0.60 | Dry |
| 0.61-0.80 | Moderately dry |
| 0.81-1.00 | Slightly dry |
| 1.01-1.20 | Slightly humid |
| 1.21-1.40 | Moderately humid |
| 1.41-1.60 | Humid |
| >1.61 | Very humid |

Source: VLĂDUŢ et al. 2017 (adapted from SELYANINOV 1930)

The *Weighted Anomaly Standardized Precipitation* (WASP) is computed based on monthly precipitation departures from the long-term mean (1990-2021), which are then standardized by dividing by the standard deviation of monthly precipitation. The resulting standardized monthly anomalies are weighted (multiplication by the fraction of the mean annual precipitation for the given month) (LYON & BARNSTON, 2005). WASP-index was applied in the Iberian Peninsula (ANDRADE & BELO-PEREIRA, 2015; ANDRADE et al., 2021), Romania (CROITORU & TOMA, 2010; VLĂDUŢ et al., 2013), Turkey (AKŞAN & BACANLI, 2021). The types of climate and associated risks are rendered in Table 5.

*Correlation analysis.* The relationship between the wheat yield and the applied climatic indices was also assessed based on the Pearson correlation coefficient. The coefficient can vary between -1 and +1 when the two considered variables are in perfect linear correlation (positive or negative) (HENNEMUTH et al., 2013). If the Pearson coefficient is 0, it means there is no association between the variables. The interpretation of the size of the correlation coefficient also varies from one author to another. For the present study, the classification proposed by Glen was used: very strong positive/negative correlation – ±0.70 to ±1.00; strong positive/negative correlation – ±0.40 to ±0.69; moderate positive (negative) correlation – ±0.30 to ±0.39; weak positive (negative) correlation – 0.20 to ±0.29; negligible correlation – 0.19 to -0.19.

*Interpolation*. Although the key meteorological parameters important for the present research are measured at the stations located in the study area, the development of stochastic models for more refined assessments of climate impact on crops requires the effective determination of the spatial distribution of mean climate variables and derived indices (HUTCHINSON, 1995). Thus, the monthly values of temperature and precipitation amount, and the derived indices were primarily associated to the georeferenced point data set comprising the fourteen meteorological stations in Oltenia. Moreover, we considered that the further addition of support meteorological stations located in the nearest Romanian, Serbian, and Bulgarian areas would lead us to a more accurate estimation of the climate characteristics for the entire area under study and of their impact on wheat development and production. Starting from the spatial and numerical attributes of our area and data set, the Spline regularized method, integrated in the ArcGIS Spatial analyst tools, proved to be a well-suited interpolation method. The data generated during the study and analysed are included in the present paper.

Table 5. Climate classification according SPA and WASP.

| Climate type | SPA | WASP | Associated risk |
|---|---|---|---|
| Extremely dry | ≤ -2.50 | ≤ -2 | Major risk |
| Very dry | -1.51 … -2.49 | -2 … -1.5 | Medium risk |
| Dry | -0.51 … -1.50 | -1.5 … -1.0 | Minor risk |
| Normal | -0.50 … 0.50 | -1.0 … 1.0 | No risk |
| Humid | 0.51 … 1.50 | 1.0 … 1.5 | Minor risk |
| Very humid | 1.51 … 2.50 | 1.5 … 2.0 | Medium risk |
| Extremely humid | ≥ 2.50 | ≥ 2.0 | Major risk |

Source: KUTIEL & PAZ, 1998 (SPA); LOYD & BARNSTON, 2005 (WASP)

## RESULTS AND DISCUSSION

***Temperature and precipitation mean annual values***

Oltenia is one of Romania's regions with a high thermal potential, but also one of the most vulnerable to drought. The analysis of the mean annual temperatures for the period 1990-2021 revealed values ranging between a minimum of 9.9°C, at the foot of the mountains (Polovragi) and a maximum of 12.6°C (at Drobeta Turnu Severin, in the south-western extremity of the region). However, with the exception of the areas located in the proximity of the mountains and at higher altitudes, there are no notable differences between plain and hilly areas, including the Subcarpathians (Slatina – 11.6°C and Râmnicu Vâlcea – 11.4°C). The highest temperatures are registered in the southern half of the plain (mean annual values are above 12°C), while in the northern half of the plain, the piedmont and the Subcarpathians, they vary between 11 and 12°C (Fig. 2). This thermal uniformity is induced by the reduced altitudinal range and the great opening of the region southwards. In terms of monthly mean values, the coldest month, January, displays slightly negative values (around -1.0°C), except for the southwestern extremity where temperatures are positive even in January. In July, the hottest month, mean temperatures oscillated between a minimum of 23.3°C in Craiova and a maximum of 24.4°C in Calafat in the plain area, while northwards values decrease by about 1-1.2°C both in the piedmont and the Subcarpathians, except for the stations located in the northwestern part of the region or at higher altitudes, where the difference reaches 3°C if compared with the mean temperature for the entire plain unit (e.g. Polovragi).

Wheat is sensitive to high temperatures especially during certain phenological phases, such as grain set and filling (ripening and maturation). The optimum temperature required during this phase is between 19°C and 22°C (PORTER & GAWITH, 1999). In Oltenia, this phase corresponds to the end of May and June, when mean temperatures are within the aforementioned limits (slightly greater in the southwestern part of the region). Thus, if considering only the mean values, wheat finds suitable development conditions from the thermal point of view. However, as a heat-sensitive plant, temperature increase already registered in the region (there is an increase between +0.6 and +1.6°C in the mean annual values between the periods 1961-1990 and 1991-2021) or that projected in the near future (1.6-2.5°C for SSP2-4.5, respectively 1.9-3.0°C for SSP2-8.5, period 2041-2060) (IPCC, 2021) may greatly affect wheat productivity.

If from the thermal viewpoint there are no significant differences within the extra-Carpathian Oltenia, in terms of rainfall amount, the difference between the highest (Apa Neagră, 941.2 mm) and the lowest (Bechet, 529.1 mm) mean amounts is quite important. Thus, rainfall amounts decrease significantly both eastwards and southwards. Along the Danube, the decrease is of about 130 mm, while in the Subcarpathians it exceeds 200 mm (Fig. 3).

At monthly level, there emerged certain changes if comparing the mean values of the period 1990-2021 with those of the period 1961-2021, which may highlight an alteration of the annual regime of precipitation. The lowest monthly amounts generally correspond to February (except for Drobeta Turnu Severin, where the minimum amount is registered in March), in case of both periods. When referring to the maximum monthly amounts, however, it was noticed that, in the southwestern and central part of the plain, May registers the highest amount (for the period 1961-2021 May was the month of maximum only in the southwest), while in the eastern sector of the piedmont and the central sector of the Subcarpathians, July became the month with the highest amount instead of June. A potential explanation of this change is related to temperature increase, which intensifies thermal convection and associated rainfalls. This shift in maximum amounts may have a negative impact on wheat productivity as the plant needs greater amounts of water in the period May-June.

***The spatial distribution of the indices influencing the growth and development of wheat***

Wheat yield greatly depends on climate conditions, the plant being however more vulnerable to different climatic variables according to the phenological stage. Thus, yield can reduce substantially in case temperatures registered after the germination and emergence stages (13-18°C according to MUNTEAN et al., 2001) are greater than 8-10°C (AMASINO, 2004) as wheat requires low temperatures to stimulate vernalization. Another sensitive stage is flowering, when the fertilization-pollination processes are affected by high temperatures, as well as after this stage, when temperatures above 20°C determine a defective accumulation of dry substances in the grain (NAM, 2014). Pluviometric deficit may affect the yield during the entire development cycle even if wheat is a plant with medium water requirements. Generally, wheat can develop quite well when annual precipitation amounts are between 600 mm and 225 mm (the lowest threshold), as the plant has a transpiration coefficient of 350-400 mm.

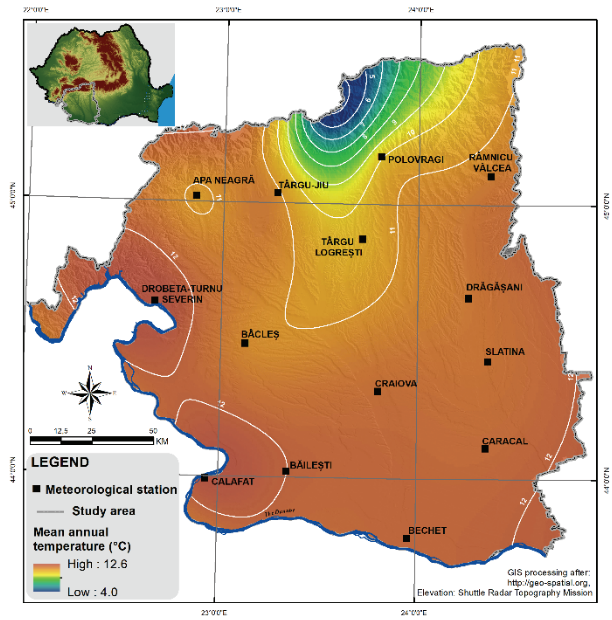



Figure 2. Mean annual temperatures in Oltenia (1990-2021) (original).

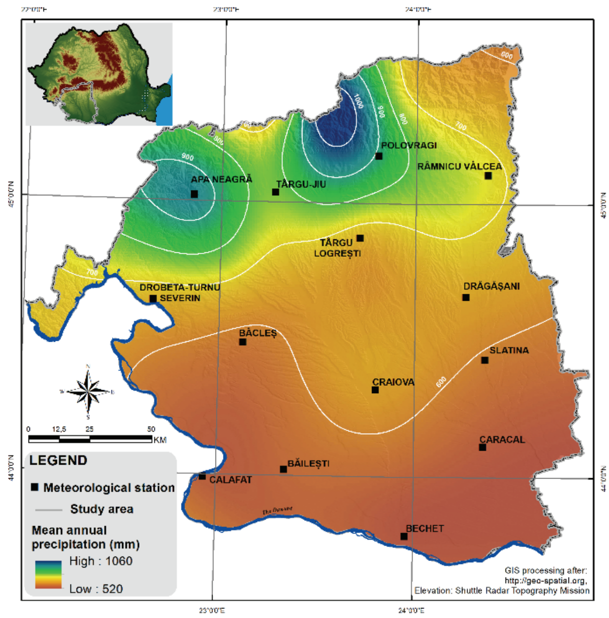



Figure 3. Mean annual precipitation amounts in Oltenia (1990-2021) (original).

In Oltenia, wheat is planted in the beginning of October, when temperatures are in the range 13-18°C, favouring the germination and emergence stages. Mean values are also below 8°C when tillering occurs, but, in the last years, December tends to become a warmer month and a short duration at low temperature could result in a failed or insufficient vernalization in winter wheat (LI et al., 2013). Thus, between October and December, wheat needs about 550°C (SPT), which is registered in all counties except for Gorj (Table 6). The highest values are characteristic to Dolj County, Calafat being the station with the greatest value (692.9°C) in the region. SPT gradually decreases northwards, but values are below this optimum threshold only in the central part of the piedmont and the Subcarpathians. In Oltenia, there are generally mild winters, cold stress having a low intensity. Even in the years with lower values in January (about -5°C) there are no more than 200 cold units. The optimum heat sum (HS) is exceeded in southern counties, Mehedinţi, Dolj, and Olt (in Olt, the value is however almost equal to the upper optimum limit), the southwestern part of the plain displaying the greatest values (>2450°C). None of the stations, including those from higher altitude, are below the 1800°C threshold.

Table 6. Mean values of the considered thermal indices at county level (1990-2021).

| Interval | Index | Optimum / County | Value MH | DJ | OT | GJ | VL |
|---|---|---|---|---|---|---|---|
| Oct.–Dec. | SPT | 550°C | 583.0 | 644.0 | 558.1 | 501.6 | 569.2 |
| Nov.–Mar. | CS | <200 cold u. – mild winter | -10.3 | -19.2 | -33.4 | -26.5 | -11.1 |
| Oct.-June | HT | 1800-2300°C | 2319.2 | 2361.5 | 2300.4 | 2081.2 | 2251.6 |

Most of the region is within the optimum limits in terms of the precipitation amount required during the sowing-emergence, which is between 80 and 120 mm (September-October interval). At the county level, only Gorj is above the upper threshold, but due to greater amounts registered in higher areas, which are not under crops. Thus, in a normal year, water requirements are met even in the plain area, supporting the proper development of plants. During the period of water retention in the soil (mainly corresponding to the dormant season, November – March) dry conditions appear in Olt (Table 7), and the amounts are optimum in the other counties. The most problematic period is May – June, considered the maximum water requirement period of winter wheat. Dry conditions are registered in all three southern counties, which are also the most important wheat producers. In the central and western part of the plain (Calafat, Băileşti), the cumulated amounts do not exceed 115 mm, which is 35 mm below the lower optimum threshold. In fact, all stations located in the plain and piedmont area (except for Târgu Logreşti, which is at a higher altitude) are below this threshold. Consequently, water should be supplemented by irrigations, especially in drier years.

Table 7. Mean values of the considered pluviometric indices at county level (1990-2021).

| Interval | Optimum | Mean value / Significance MH | DJ | OT | GJ | VL |
|---|---|---|---|---|---|---|
| Sept.–Oct. | 80.1-120 | 105.8/O | 96.1/O | 94.0/O | 131.1/H | 112.0/O |
| Nov.–Mar. | 200.1-300 | 217.5/O | 200/O | 181.3/D | 274.5/O | 202.2/O |
| May–June | 150.1-200 | 135.5/D | 125.6/D | 134.5/D | 179.9/O | 163.9/O |

***The spatial distribution and variability of drought***

Drought prone areas were determined based on HTC, while drought variability was analysed based on SPA and WASP. Thus, according to the HTC annual values for the analysed period (1990-2021), the climate is slightly dry (SD) in the southern part of the plain area, the lowest values being registered within the Danube Alluvial Plain (Calafat – HTC: 0.85 and Bechet – HTC: 0.90) and slightly humid (SH) at higher altitudes (the northern and western plain area). In the piedmont, the climate is generally SH, a moderately humid (MH) climate being characteristic only at higher altitudes. MH climate also appears in most of the lower areas of the Subcarpathians (Fig. 4), very humid conditions (VH) being registered only at the contact with the mountains (Polovragi, HTC: 1.80, the highest mean value).

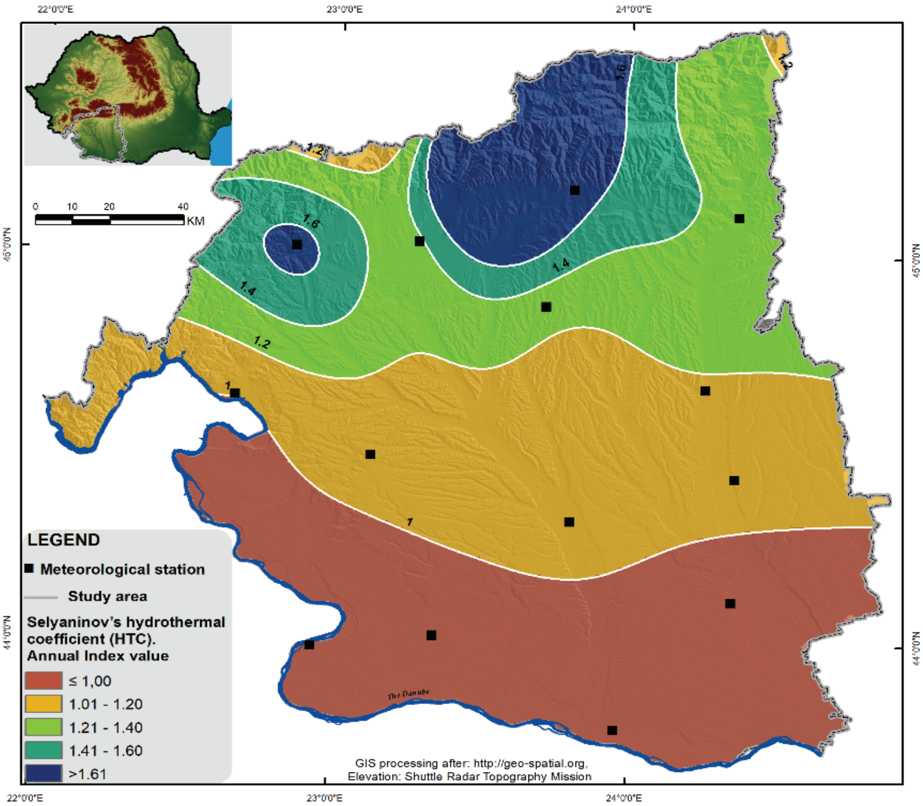



Figure 4. HTC mean annual values in Oltenia (1990-2021) (original).

Dry conditions were also assessed at monthly level for those months with mean temperatures >10ºC overlapping the phenological stages of wheat. Generally, it is about five months i.e. September-October, April-June. The first two months are important as they represent the period when sowing-emergence phases occur and wheat requires a rainfall amount of 80-120 mm. Rainfall deficit characterizes most of the plain in September, as climate is MD along the Danube and in its eastern sector and SD in the rest of the unit. In the piedmont and the Subcarpathians the drought risk reduces as climate is SH, respectively MH and even H, at higher altitudes (Fig. 5a). Spring months, as well as October are characterized by greater humidity, the HTS indicating SH to VH climate all over the considered region, including the extreme south plain area (Fig. 5b, c, d). The most problematic month in terms of drought corresponding to certain critical phenological phases (flowering – end of May-early June, respectively ripening and maturation - June) is June and the most problematic area is represented by the southwestern and central parts of the plain (Fig. 5e). Northwards, the climate is SH to VH, wheat finding proper conditions of development at least in the years with normal rainfall amounts.

In terms of variability, SPA emphasized higher rates of normal years (-0.50 … +0.50) – 43% of the total number of years for the plain area, 44.5% for the piedmont and the Subcarpathians, followed by years characterized by deficit (-0.51 …≤ -2.50) – 30.7% in the plain and about 28.5% for the hilly area (Fig. 6). The first decade of the analysed period is the driest of the period. There were no extremely dry years, but both 1992 and 2000, with few exceptions, are classified as very dry years, which means medium risk for agriculture. At monthly level, there is a clear predominance of no risk months on the whole (between 70 and 80%).

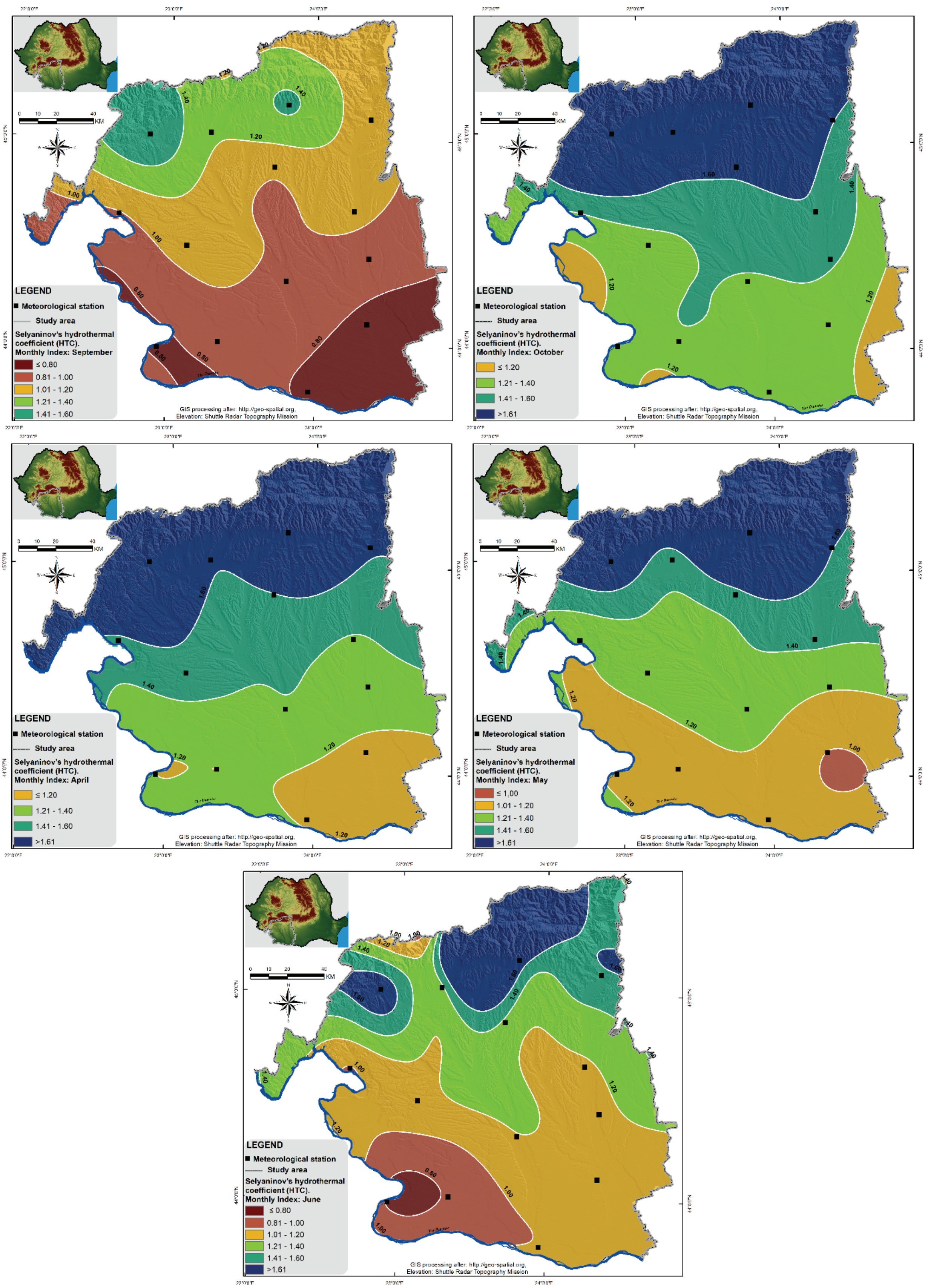



Figure 5. HTC mean monthly values in Oltenia (1990-2021) (original).

Precipitation deficit is registered in 10 to 18% of the months, the share of this category being greater than that of the humid months (Fig. 7), with some exceptions – the south-western and northern part of the plain (Drobeta Turnu Severin and Craiova) and the central and eastern part of the Subcarpathians (Târgu Jiu and Râmnicu Vâlcea). However, dry months are not homogenously distributed during the year, higher rates corresponding to the interval May-July, when plants have greater water requirements. The share of dry months during this interval is also greater in the eastern part of the region – Bechet (31.3% in May and June), Caracal (21.9% in May and 28.1% in June), Slatina (21.9% in June), Târgu Logrești (25% in both months), and Râmnicu Vâlcea (21.9% in June). In the east, the September – October interval also has higher shares of dry months (between 12.5 and 18.8%), which is detrimental to wheat as this is period corresponds to sowing stage and precipitation amounts should range between 80 and 120 mm for proper germination.

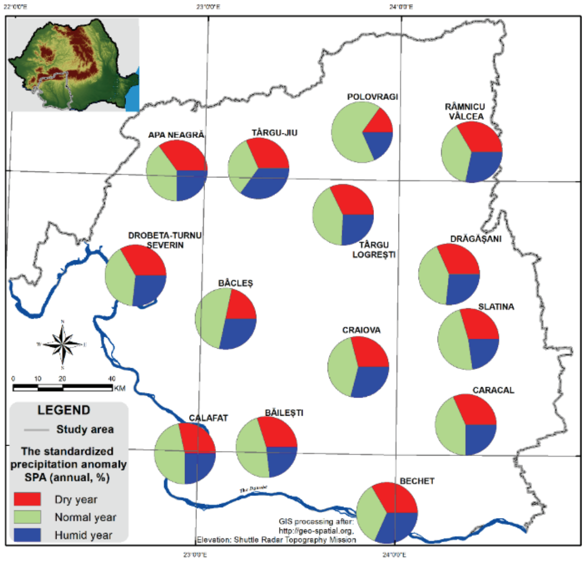



Figure 6. Share of dry, normal and humid years based on SPA in Oltenia (1990-2021) (original).

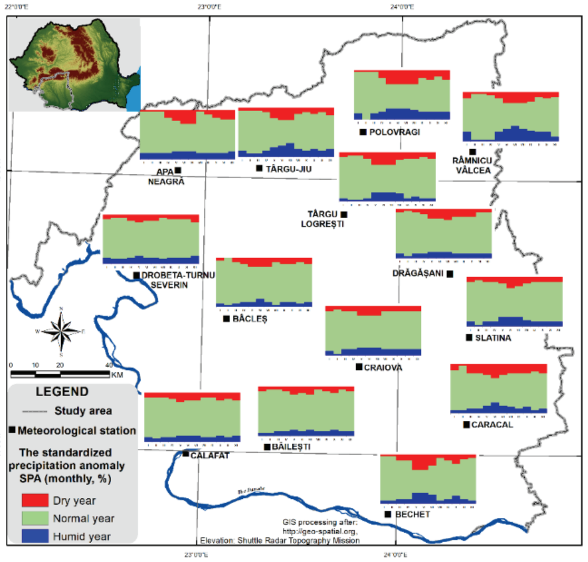


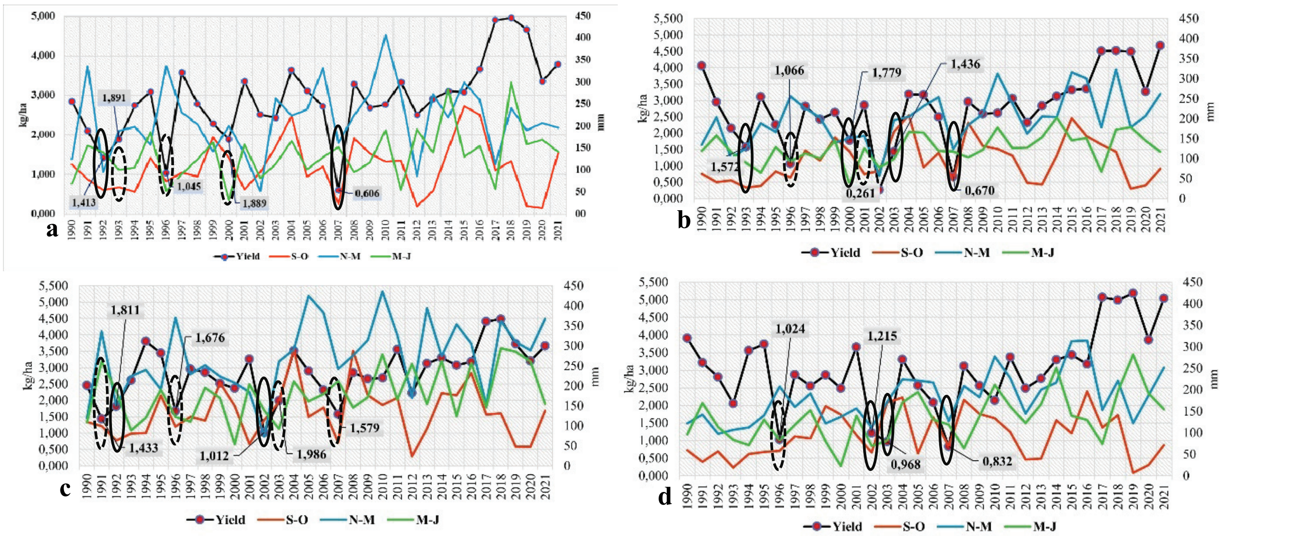

Figure 7. Share of dry, normal and humid months based on WASP in Oltenia (1990-2021) (original).

***The impact of climate conditions on wheat yield (1990-2021)***

In Oltenia, wheat yield greatly varies from one year to another and from one county to the another, mainly depending on climatic conditions. The analysis of the mean yield (kg/ha/county) during 1990-2021 revealed certain years when yields were much lower than the average, at least in two of the five counties of the region. Taking into account that the mean production for the entire period at regional level is of about 3,000 kg/ha, we closely analysed those years when the yield was below 2,000 kg/ha. Such years are 1992, 1993, 1996, 2000, 2002, 2003, and 2007. Starting with 2008 up to 2021, wheat yield was on average greater than 3,000 kg/ha. ***2007*** stands as the most problematic year, the average yield in Oltenia being 1,148 kg/ha (Mehedinți, Dolj, Olt registering 606, 670, respectively 832 kg/ha), followed by ***2002*** with 1,236 kg/ha (Dolj 261 kg/ha), ***1996*** with 1,391 kg/ha, and ***2003*** with 1,809 kg/ha (Olt 968 kg/ha). The driest years were 1992 and 2000 with precipitations amounts below 300 mm in the plain and 300 to 400 mm in the hilly area. The hottest years were 2019-2020, when annual mean temperatures exceeded 14°C in the southwest and north of the plain and 13°C for the rest of the region (except for Târgu Logrești and Polovragi).

However, the lowest productions are not exclusively correlated with the annual lowest precipitation amounts. Such cases can be mentioned for 1992 and 2000 as the driest years in the region, when yield was reduced but not extremely low. In 1992, it varied between a minimum of 1,413 kg/ha in Mehedinți and a maximum of 2,802 kg/ha in Olt, while in 2000, the lowest yield was registered in Dolj (1,779 kg/ha). 1992 yield was mainly affected by the precipitation deficit registered in the previous autumn (S-O dry and very dry conditions), during the dormant season (N-M very dry and extremely dry conditions) and even during the flowering/grain set stages (WASP May-June indicating very dry and extremely dry conditions). In 2000, in spite of extremely dry conditions corresponding to the interval May-June as indicated by M-J, HTC, WASP (Table 8), wheat was not entirely affected as precipitation amounts registered in autumn and winter (S-O, N-M) indicate a humid or optimum year ensuring thus its water requirements during the first phenological stages (Fig. 8).

In 1993, wheat yield was affected in Dolj, Mehedinți, and Olt (below or close to 2,000 kg/ha). The precipitation deficit registered in 1992, including the autumn months, had a major contribution. In September, HTC had a mean value of 0.19, respectively 0.28 (arid) in Dolj and Olt and 0.39 (very dry) in Mehedinți and drought prolonged in October and during the dormant season (N-M), as well. Dry conditions also characterize the critical interval May – June, especially in Dolj (HTC=0.37, WASP=-1.34). Besides the pluviometric deficit, temperature was a key factor for the reduction of yield. In Dolj, the mean temperature exceeded 22°C (higher than the upper limit), but maximum values were particularly high – the mean of daily maximum temperature reached 24.5°C in May and 29°C in June and the maximum value of daily maximum temperature 33.6°C in May and 37.2°C in June (Craiova). Close values were also registered in Mehedinți (Drobeta Turnu Severin) and Olt (Slatina and Caracal).



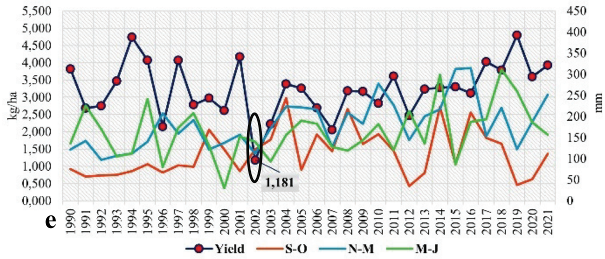




Figure 8. Wheat yield and precipitation amounts (S-O, N-M, M-J) between 1990 and 2021 in Mehedinți (a), Dolj (b), Gorj (c), Olt (d), Vâlcea (e) (original).

Correlated with the precipitation deficit for S-O, N-M, M-J

Correlated with the precipitation deficit for S-O, M-J

The same situation emerged in 1996, when wheat yield was about 1,000 kg/ha in the southern counties (Fig. 9; Table 8). Precipitation amounts were less than 10 mm in the entire region in October 1995 (HTC=0.16-0.25 arid), which means wheat did not have enough water during the emergence stage. Even if during the dormant season (N-M) the amounts indicate an optimum or humid year, the deficit registered in M-J, correlated with high temperatures drastically reduced yield (mean of daily maximum temperature above 30°C in the plain area and 28-29°C in the hilly area both in May and June) as the fertilization-pollination processes were affected, as well as accumulation of dry substances in the grain.

The years 2002 and 2003 also had extremely low productions in certain counties, particularly in Dolj (2002) and Olt (2003). In fact, 261 kg/ha represents the lowest yield in the last 32 years. In 2002, based on the S-O precipitation amount, Dolj and Olt registered very dry conditions, in the other counties the period being optimum or humid. The severe drought is also confirmed by HTC values for October (arid in Dolj: 0.09, Olt: 0.05, Mehedinți: 0.10). Water deficit increased during the dormant season, N-M indicating extremely dry conditions in three counties (Mehedinți, Gorj, Vâlcea less than 75 mm in five months) and very dry in the other two counties. Even if in M-J, precipitation amounts increased, the conditions were dry and very dry and the crop had already been compromised on large surfaces. Moreover, mean temperatures in June exceeded 22°C, in Dolj even 23°C, while the maximum value of daily maximum temperature reached 31.4°C in May and 38.5°C in June (the greatest value for this year) totally compromising wheat yield. Consequently, in Dolj, 27.5% of the total surface cultivated with wheat (about 79,500 ha) were declared under total calamity and 62.9% partially under calamity (Fig. 10). By comparison, in 2003, lower yields were mainly determined by temperature-related issues, as S-O and N-M indicate optimum and even humid conditions. During the period with maximum water requirement (M-J), very dry conditions emerged in Gorj, Mehedinți, and Vâlcea. Water stress (HTC for June indicate extremely dry conditions in four of the counties) was enhanced by high temperatures (mean temperature in June reached almost 24°C in Dolj and Olt), while mean maximum temperatures exceeded 30°C within the entire plain area and maximum value of daily maximum temperatures exceeded 34°C. Accordingly, all counties of the region were mentioned in Decision no. 440/2003 regarding the declaration of the state of natural calamity in agriculture and farmers obtained certain financial compensations.

The year 2007 marks the lowest productions in the time series, the three southern counties registering between 600 and 800 kg/ha. Water deficit started in autumn (S-O) and was maintained during the entire phenological cycle in Dolj and Olt. The only month with high amounts was May, but after the drastic drought registered in April (HTC: 0.06-0.20 arid) within the entire region, wheat crop was compromised on large surfaces. Besides water deficit, heat stress was also increased – in the three counties, the mean temperature in June exceeded 23°C, with maximum values going up to 36-37°C. Consequently, in Dolj alone, 130,000 ha cultivated with cereals were under calamity, but according to the Decision no. 636/2007 regarding the declaration of a state of natural calamity in agriculture for the crops sown in the fall of 2006 and in the spring of 2007, natural calamity was also declared in Mehedinţi and Olt.

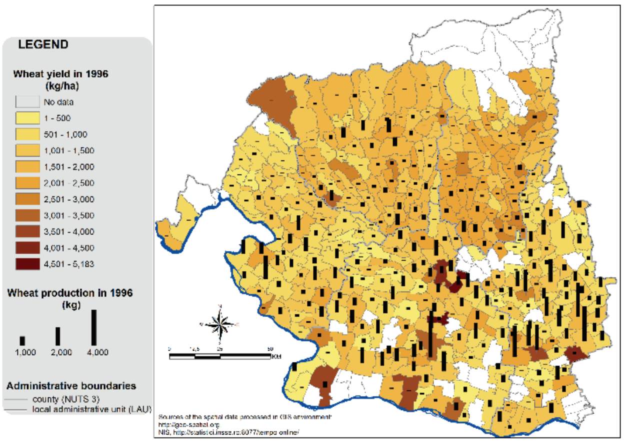



Figure 9. Wheat yield (kg/ha) within the administrative units of Oltenia Region in 1996 (original).

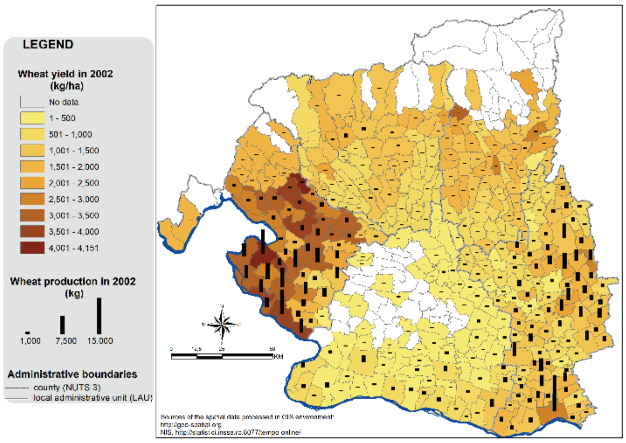



Figure 10. Wheat yield (kg/ha) within the administrative units of Oltenia Region in 2002 (original).

Table 8. Wheat yield and main climatic parameters.

| Year/Index | Yield | S-O | N-M | M-J | Temp. (June) | HTC (av. May) | SPA | WASP (av. May-June) |
|---|---|---|---|---|---|---|---|---|
| | 1992 | | | | | | | |
| MH | 1,413 | 54.6 | 95.1 | 140.5 | 19.6 | 0.51 | -1.49 | -1.97 |
| DJ | 2,151 | 45.0 | 100.2 | 116.0 | 20.5 | 0.65 | -1.71 | -2.23 |
| GJ | 1,811 | 63.6 | 148.9 | 186.5 | 18.3 | 1.10 | -1.38 | -1.85 |
| OT | 2,802 | 56.8 | 97.4 | 113.7 | 20.4 | 0.39 | -1.77 | -2.50 |
| VL | 2,745 | 60.1 | 97.2 | 170.0 | 19.3 | 0.74 | -1.46 | -2.10 |
| | 1993 | | | | | | | |
| MH | 1,890 | 61.4 | 189.8 | 100.4 | 21.1 | 0.52 | -0.75 | -0.98 |
| DJ | 1,572 | 27.4 | 125.9 | 89.1 | 22.2 | 0.37 | -1.16 | -1.34 |
| GJ | 2,618 | 80.6 | 224.4 | 88.2 | 19.3 | 0.49 | -0.93 | -1.04 |
| OT | 2,051 | 19.5 | 106.8 | 83.3 | 21.9 | 0.71 | -1.25 | -1.78 |
| VL | 3,464 | 61.2 | 135.5 | 105.2 | 20.4 | 0.90 | -0.98 | -1.42 |
| | 1996 | | | | | | | |
| MH | 1,045 | 74.8 | 336.7 | 52.3 | 22.1 | 0.09 | -0.45 | -0.15 |
| DJ | 1,066 | 45.2 | 234.2 | 77.3 | 23.0 | 0.49 | -0.14 | -0.17 |
| GJ | 1,676 | 97.8 | 370.6 | 122.4 | 20.3 | 0.57 | -0.02 | -0.02 |
| OT | 1,024 | 58.0 | 207.2 | 82.6 | 22.5 | 0.56 | -0.49 | -0.19 |
| VL | 2,143 | 66.9 | 259.2 | 79.8 | 21.8 | 0.56 | -1.00 | -0.97 |
| | 2000 | | | | | | | |
| MH | 1,889 | 127.8 | 200.6 | 31.4 | 22.6 | 0.11 | -1.78 | -2.30 |
| DJ | 1,779 | 92.5 | 171.0 | 84.0 | 22.9 | 0.33 | -1.89 | -2.49 |
| GJ | 2,370 | 150.0 | 207.6 | 54.0 | 21.3 | 0.24 | -2.04 | -2.70 |
| OT | 2,489 | 142.4 | 137.2 | 22.6 | 22.9 | 0.20 | -1.92 | -2.72 |
| VL | 3,615 | 121.8 | 188.1 | 30.4 | 22.3 | 0.14 | -1.92 | -2.78 |
| | 2002 | | | | | | | |
| MH | 2,508 | 95.5 | 52.6 | 125.2 | 22.8 | 0.58 | 0.17 | 0.24 |
| DJ | 261 | 57.5 | 142.8 | 89.5 | 23.4 | 0.52 | 0.50 | 0.67 |
| GJ | 1,012 | 114.5 | 73.8 | 138.3 | 20.9 | 1.41 | -0.61 | -0.80 |
| OT | 1,215 | 54.2 | 112.2 | 69.1 | 22.8 | 0.46 | 0.46 | 0.65 |
| VL | 1,181 | 121.7 | 72.6 | 140.4 | 21.1 | 1.52 | -0.11 | -0.17 |
| | 2003 | | | | | | | |
| MH | 2,430 | 153.2 | 262.8 | 113.3 | 21.5 | 0.23 | -0.30 | -0.38 |
| DJ | 1,436 | 145.5 | 214.0 | 105.3 | 23.8 | 0.22 | -0.47 | -0.03 |
| GJ | 1,986 | 159.2 | 261.1 | 92.1 | 21.5 | 0.28 | -0.90 | -1.33 |
| OT | 968 | 170.4 | 171.9 | 81.3 | 23.7 | 0.21 | -0.04 | -0.06 |
| VL | 2,222 | 144.8 | 216.7 | 93.0 | 22.2 | 0.60 | -0.57 | -0.83 |
| | 2007 | | | | | | | |
| **Year/Index** | **Yield** | **S-O** | **N-M** | **M-J** | **Temp. (June)** | **HTC (av. April)** | **SPA** | **WASP (av. May-June)** |
| MH | 606 | 23.9 | 162.2 | 152.0 | 23.2 | 0.15 | 0.32 | 0.40 |
| DJ | 670 | 65.1 | 164.5 | 114.3 | 23.9 | 0.06 | 0.33 | 0.42 |
| GJ | 1,579 | 58.4 | 241.7 | 212.0 | 21.2 | 0.19 | 1.28 | 1.69 |
| OT | 832 | 67.8 | 127.2 | 119.0 | 23.5 | 0.13 | 0.92 | 1.31 |
| VL | 2,052 | 117.7 | 140.0 | 127.6 | 22.3 | 0.20 | 0.58 | 0.84 |
| Significance | | Extremely dry | Very dry/ warm | Dry/Warm | Optimum | Humid | Very humid | Extremely humid |

The relationship between yield and different climatic indices was also assessed based on the Pearson correlation coefficient (Table 9). In most of the cases there is a negligible correlation, either positive or negative (especially when referring to annual values, i.e. SPA, MaP). In terms of climatic index, the highest significance was registered for M-J cumulated precipitation amount and the mean annual temperatures (MaT). In the first case, there is a strong positive correlation in Dolj and Olt and a moderate positive correlation in the other three countries, which indicates that rainfall is extremely important during the grain fill and ripening stages. As for MaT, it resulted a moderate or weak positive correlation that support the idea that wheat is a thermal-sensitive plant. However, when yield was correlated with mean temperature of May and June, it emerged a different situation. Dolj and Olt are the counties where temperature-associated risk is higher, especially in May (strong negative correlation), indicating that higher temperature will trigger lower yield. With reference to counties, Dolj seems to be the most climate-dependent county in terms of wheat yield. Thus, it results that yield reduction is not determined by a single climatic parameter/index, but by the combined action of hydric and thermal stress.

Table 9. Correlation between yield and climatic indices based on Pearson correlation coefficient.

| County /Index | Y/S-O | Y/N-M | Y/M-J | Y/SPA | Y/MaP | Y/MaT | Y/T(May) | Y/T(June) |
|---|---|---|---|---|---|---|---|---|
| **Mehedinți** | 0.22/WPR | -0.02/NR | 0.27/WPR | 0.08/NR | 0.07/NR | 0.38/MPR | -0.09/NR | 0.03/NR |
| **Dolj** | 0.14/NR | 0.46/SPR | 0.40/SPR | 0.11/NR | 0.09/NR | 0.25/WPR | -0.46/SNR | -0.35/ MNR |
| **Olt** | -0.07/NR | 0.11/NR | 0.39/MPR | -0.09/NR | -0.09/NR | 0.39/MPR | -0.47/SNR | -0.25/WNR |
| **Gorj** | 0.20/WPR | 0.22/WPR | 0.21/WPR | 0.11/NR | 0.05/NR | 0.34/MPR | -0.11/NR | -0.11/NR |
| **Vâlcea** | -0.16/NR | 0.13/NR | 0.29/WPR | 0.02/NR | -0.10/NR | 0.23/WPR | -0.29/WNR | -0.15/NR |

## CONCLUSIONS

Climate change is expected to pose gradually increasing pressure on crops, as upward temperature trends are obvious, precipitation pattern seems to alter, thus jeopardizing water availability throughout the year, and the frequency and severity of certain climatic risk phenomena are projected to increase in the near future. In this context, the availability and stability of crops might be undermined. Oltenia is one of the most exposed regions to climate change in Romania, and, at the same time, an important wheat-producing area.

The assessment of the current climatic conditions generally indicates a good suitability for wheat, the thermal and rainfall requirements of the plant being met when analysing mean values for the period 1990-2021. However, water deficit emerges on different time scales, in the southern counties, especially in Dolj and Olt, the biggest wheat producers in the region. Dry conditions appear in May-June, which overlaps one of the most sensitive stages in wheat development, namely flowering and grain filling. HTC annual values also indicate the plain area as displaying a slightly dry climate, mainly within the Danube Alluvial Plain. The analysis of year-to-year values also point out to two drought-exposed periods – early autumn (September-October), when rainfall should ensure enough humidity for the plant emergence stage and the aforementioned period, when wheat requires the highest water amounts. The share of the months classified as dry, very dry or extremely dry (based on WASP) is of about 30% in the plain area. A spatial pattern also emerged, as the eastern sector of the region, including all landforms, presents greater values and shares of months with water deficit compared to the central and western sectors.

Moreover, water deficit tends to associate more frequently with high temperatures, thus hydric stress being exacerbated by heat stress. In these cases, winter wheat yield was severely affected, but for the studied period, the main factor that triggered extremely low yields was related to the lack or insufficiency of the precipitation amounts. The importance of the precipitation distribution during the year is highlighted by the yield registered after 2007. In spite of the fact that there were certain years with total amounts below the mean of the period, rainfalls were distributed relatively uniformly or dry months did not overlap wheat sensitive development stages and yield was above the average. The analysis of the years 1992, 1993, 1996, 2000, 2002, 2003, and 2007 (average yield below 2,000 kg/ha) indicate a good correlation with M-J precipitation amount, HTC (June), and lately (2003 and 2007), with June mean temperature and May and June mean maximum temperatures.

Taking into account the projected temperature increase in the region, adaptation is necessary in order to reduce the negative impacts of climate change on yields and to ensure food security. Some of the potential adaptation strategies that can be adopted in the region include: a later sowing date (the end of October – the beginning of November compared to the present situation when wheat is planted in the first decade of October), the use of resistant genotypes (heat-tolerant varieties, varieties with high or moderate vernalization, earlier flowering cultivars to avoid heat stress during reproductive and grain filling stages), the expansion of the irrigation infrastructure and other sustainable land management measures (developing techniques to conserve soil and soil water, intercropping with nitrogen-fixing crops, etc.).

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