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HYDROTHERMAL ASSESSMENT OF MAIN AGRICULTURAL AREAS IN SOUTHERN ROMANIA AND NORTHERN BULGARIA

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Abstract

In these papers, the bioclimatic index de Martonne was used to assess the hydrothermal conditions in some agricultural areas in Southern Romania and Northern Bulgaria during the period 1961-2020. The conditions from October to June were analyzed in view of the cultivation of winter cereals, as well as those from April to October, marking the time for growing spring crops. Additionally, indices were selected during some critical periods for both types of crops. The evaluation of the indices with the Mann-Kendall test and the Sen slope shows a significant (0.01) negative trend or an increase in the degree of unfavorability for growing winter crops in the Danube Plain. The indices during the period for growing rain fed spring crops 1961-2020 also show a negative, but insignificant trend.

Key words: *de Martonne index, Southern Romania, Northern Bulgaria, spring crops, cereal, trends.*

INTRODUCTION

Climate change and especially extreme droughts pose risks to agriculture, and spring crops grown under rainfed conditions are the most vulnerable. Also, due to the nature of its cultivation, winter cereals are not grown with supplemental irrigation and rely on rainfall alone. Dry periods and insufficient rainfall, especially during water-critical phases of crop development, lead to low yields. The relationship between temperature and rainfall, expressed as indices, often gives a good general idea of the hydrothermal conditions of individual regions; of the conditions of favourability as well as of the precise use of irrigation water. In the other hand, indices are mathematically verified indicators directly correlated with biophysical processes (Poggio et al., 2018). In this sense, many different indices and parameters are the subject of scientific interest, including in the regions of Northwestern Bulgaria and Southern Romania where large part of the areas are not irrigated. Studies on droughts show an expansion by the end of the 21st century in the Mediterranean region, and in particular in areas of Southeastern Europe such as Romania and Bulgaria (Charalampopoulos et al., 2023; Gao & Giorgi, 2008). Central Europe has good precipitation in all seasons and a maximum in July, while Eastern Europe has less precipitation distributed throughout the year than Northwestern Europe, but summer amounts are mostly higher (Mikolaskova, 2009). The same author reports that continentality in terms of precipitation increases to the east. A correct quantitative assessment of humidity conditions can be obtained by calculating various meteorological, hydrological and biometeorological indices. Therefore, they are the subject of scientific interest of many researchers studying the climate in different regions of Europe (Koleva & Alexandrov, 2008; Vlăduţ et al., 2017; Prăvălie et al., 2017; Mitkov & Topliyski, 2018; 2019; Radeva et al., 2018; Passarella et al., 2020; Chmist-Sikorska et al., 2022; Shopova et al., 2022. A study for Bulgaria for the period 1979–2023 found that the precipitation-evaporation difference is relatively stable and no increase in the water deficit in Bulgaria is observed on an annual basis (Nojarov, 2024).

Other authors (Drenovski, 2024) pay attention to the continental index during the warm and cold half-year, comparing several climatic periods: 1931-1985, 1995-2010 and 1990-

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2023. The author found very slight fluctuations in the stations with transitional and Mediterranean type of precipitation. A decrease of about 0.1-0.2 on average is observed in the values of the continentality coefficient of precipitation (Cc) for the regions with temperate continental precipitation regime (Pleven). However, the weakening of the continental influence is not defined as a significant change in the precipitation regime during the two half-years. One of the main results of climate change, directly related to the cultivation of agricultural crops, is the occurrence of prolonged periods of meteorological and hydrological droughts and a decrease in soil moisture. The southern, southeastern and eastern parts of Romania are most vulnerable to drought. In very dry years, average yields of various crops barely reach 35-60% of potential yields (Ionita et al., 2016). Changes in Romania and Bulgaria after 1989 have a similar nature and bring many risks and challenges to agriculture and irrigation opportunities (Dumitraşcu et al., 2018; Kolcheva, 2024; Seymenov & Kolcheva, 2025). The anthropogenic factor responsible for the condition of irrigation systems can significantly affect yields through planning and provision of irrigation water. This publication aims to complement the hydrothermal assessment of some agricultural regions of Northwestern Bulgaria and Southern Romania using the de Martonne bioclimatic index during the main and critical periods of crop development. The study period is 1961-2020.

MATERIALS AND METHODS

Research area: The stations Turnu Severin, Craiova, Pitesti and Bucharest for the territory of Romania and Vidin, Montana, Vratsa and Pleven in Northern Bulgaria were analyzed (Figure 1). The climate of the studied agricultural regions is characterized by relatively cold winters and humid and hot summers. The regime of precipitation has a spring-summer maximum and the highest total amounts between April and July. The average summer air temperatures are higher than 22°C, and the precipitation is between 150 mm and >200 mm. The territories near the mountain ranges such as Pitesti and Turnu Severin have higher rainfall and shorter and cooler summers. Both orchards and vineyards are grown there, as well as spring and winter cereals.

Figure 1. The study area

Data used and study period: Average monthly air temperature °C; Monthly Σ precipitation in mm; Study period: 1961-2020. The data are derived from the ERA5 reanalysis (here used at a resolution of 0.5° x 0.5°). Climatological averages and trends should be considered in relation to inter annual variability (https://climateknowledgeportal.worldbank.org).

Methods: The bioclimatic index of De Martonne (De Martonne, 1926) was used, which describes the studied areas quite well (Croitoru et al., 2013). This index is considered of great relevance not only for environmental or climatological applications but also for agriculture and land resources management (Passarella et al., 2020). The equation was modified according to the coefficients proposed by the same authors (Croitoru et al., 2013):

$$IdM = 1{,}714 * \frac{\Sigma R}{T(GSS) + 10}$$

$$IdM = 1{,}333 * \frac{\Sigma R}{T(GSW) + 10}$$

$$IdM = 6 * \frac{\Sigma R}{T(IV + V) + 10}$$

$$IdM = 4 * \frac{\Sigma R}{T(SS) + 10}$$

where:

- T (GSS) represents average air temperature (ºC) during the growing season of spring crops;

- T (GSW) represents average air temperature (ºC) during the growing season of winter wheat;
- T (SS) represents average air temperature (ºC) during the summer season;
- ΣR represents precipitation in mm.

The climate classification of the regions is made according to Passarella et al., 2001, Baltas, 2007, Deniz et al., 2011, Rahimi et al., 2013, Zareiee, 2014, Nistor, 2016 (Table 1).

Table 1. De Martonne climate classification

Climate	Index range	Description
Arid or dry	IDM≤10	Needs continuous irrigation
Semi-arid	10 ≤IDM<20	Needs irrigation
Mediterranean	20 ≤IDM<24	Need supplementary irrigation
Semi-humid	24 ≤IDM<28	Need supplementary irrigation
Humid	28 ≤IDM<35	Need occasional irrigation
Very humid	35 ≤IDM≤55	Need infrequent irrigation
Extremely humid	IDM>55	Water self-sufficient

Statistical assessment of trends: The Excel template MAKESENS of the Finnish Meteorological Institute (Salmi et al., 2002) was applied for data processing. The bioclimatic indices were checked for direction and statistical significance of trends using the non-parametric Mann-Kendall test. The template tests for the presence of a monotonic increase or decrease using the non-parametric Mann-Kendall test and calculates the slope of a linear trend estimated using the non-parametric Sen method (Gilbert, 1987) at statistical significance levels of 0.001***, 0.01**, 0.05* and 0.1^{+}. The Z value indicates whether the trend is positive or negative, as well as whether it is statistically significant, and Q is a characteristic of the slope.

RESULTS AND DISCUSSIONS

In the regions of Northern Bulgaria and Southern Romania, main spring and winter cereal crops are grown. The development of winter wheat from sowing through dormancy to ripening and harvesting takes place during the period from October to June. In October, precipitation provides moisture for the germination and initial development of winter wheat (Croitoru et al., 2012). This month is considered the beginning of the moisture accumulation process, which ends with the resumption of active vegetation in the spring. The months of April and May are critical in terms of moisture conditions, because the reproductive period of crop development takes place in the same month - the processes of flowering, fertilization and milk maturity (Hershkovich, 1984; Georgieva, 2013). The same authors indicate insufficient moisture in May as the main yield-limiting factor. The hydrothermal conditions during the development period of cereals, expressed by the De Martonne dryness index for GSW, are shown in the Figures 2 to 5.

The index values classify the region as humid and very humid, with the best conditions for the development of winter wheat crops being observed in the stations of Pitesti, Montana and Turnu Severin. The period was wetter before 1980, with the most unfavorable conditions for Bulgaria between 1982 and 1994, and for Romania from 1991 to 2002.

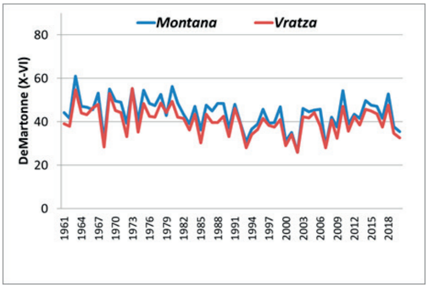

Figure 2. The distribution of the De Martonne index (GSW) Craiova and Bucharest

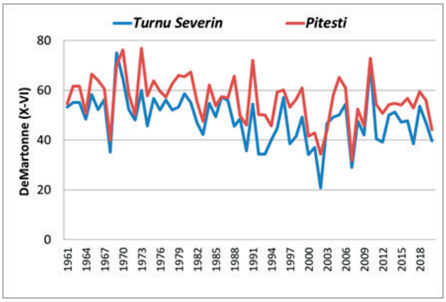

Figure 3. The distribution of the De Martonne aridity index (GSW) Turnu Severin and Pitesti

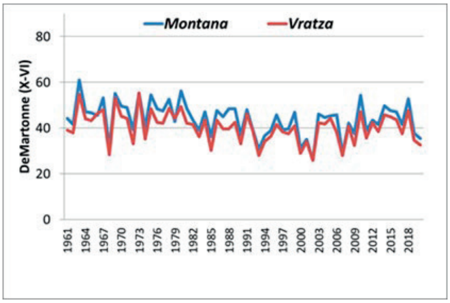

Figure 4. The distribution of the de Martonne aridity index (GSW) 1961-2020 Montana and Vratza

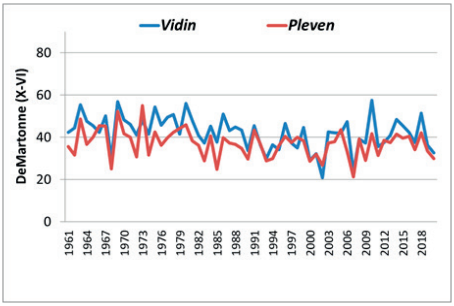

Figure 5. The distribution of the De Martonne aridity index (GSW) 1961-2020 Vidin and Pleven

Table 2. Statistical assessment of the trend (GSW)

Mann-Kendal trend	*Sen's slope estimate*		
De Martonne (IX-VI)	**Test Z**	**Signific.**	**Q**
Turnu Severin	-3.4	***	-0.2
Craiova	-3.0	**	-0.2
Pitesti	-2.7	**	-0,2
Bucharest	-1.2		-0.2

Table 3. Statistical assessment of the trend (GSW)

Mann-Kendal trend	*Sen's slope estimate*		
De Martonne (IX-VI)	**Test Z**	**Signific.**	**Q**
Vratza	-2.2	*	-0.1
Vidin	-2.9	**	-0.2
Montana	-2.5	*	-0,1
Pleven	-1.6		0.0

When growing winter wheat, hydrothermal conditions during the critical periods of flowering and milk maturity are of great importance for biological and total yields. Lower temperatures and the good rainfall are a prerequisite for high yields. Therefore, the index values in this critical period have a pronounced impact on the final yield (Figures 6 and 7).

In the stations of northern Bulgaria, two peaks are observed in the periods around 1979 and 2014. The variations and contrast values are no exception and are characteristic of the periods before and after 2000.

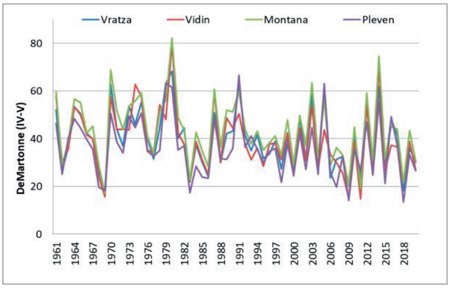

Figure 6. The distribution of the De Martonne aridity index April-May

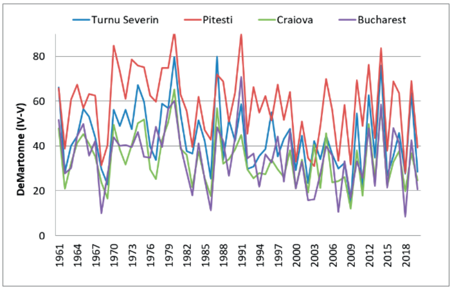

Figure 7. The distribution of the De Martonne aridity index April-May

The period 1991-2000 is the driest. The results show that during this period winter wheat crops develop in conditions ranging from semi-arid to semi-humid, with the most vulnerable being the regions of Craiova and Pleven. Based on some modeling studies (Constantin et al., 2025), in other agricultural regions of northern Romania, irrigation of winter wheat is recommended precisely during the critical months of April to May. Several extreme high values are observed in 1972, 1991 and 2005, with the lowest values in 1962, 1977, 1993, 2000 and 2011. In Southern Romania, the two wettest years were before 1990. The average values of the index define the region as Humid with the exclusion of Pitesti. The assessment of the index trends during the period April-May is similar to that of the index during the period September-June (Table 4).

Except for Vratza, Pleven and Pitesti stations, the trends for the study period are negative and significant at the 0.05 level.

The development of spring crops in the region of study occurs during the period from April to October (Hershkovich, 1984). The De Martonne index for this period is shown in Figures 8 to 11.

Table 4. Statistical assessment of the trend April-May

Mann-Kendal trend	*Sen's slope estimate*		
De Martonne (IV-V)	**Test Z**	**Signific.**	**Q**
Turnu Severin	-2.1	*	-0.2
Pitesti	-1.8	+	-0.2
Craiova	-2.1	*	-0.2
Bucharest	-2.0	*	-0.2
Vratza	-1.9	+	-0.2
Vidin	-2.6	**	-0.3
Montana	-2.1	*	-0.2
Pleven	-1.8	+	-0.2

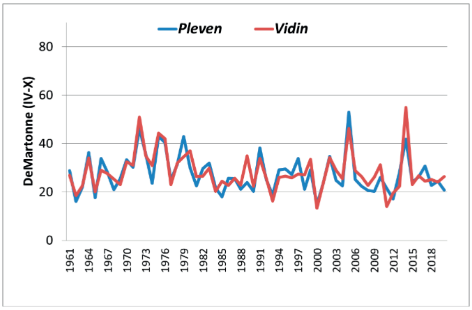

Figure 8. The distribution of the De Martonne aridity index CSS

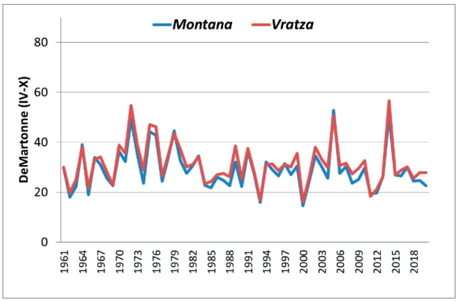

Figure 9. The distribution of the De Martonne aridity index GSS

During the period of growing spring crops, the driest was 2000. The prevailing years were years in which the conditions were Mediterranean and humid and which required irrigation. The exception is the Pitesti station, in which the conditions were very humid. For the period of maize growing before 2010, data series reveal mostly positive slopes, but few of them are statistically significant for the period 1961-2007 (Croitoru et al., 2013).

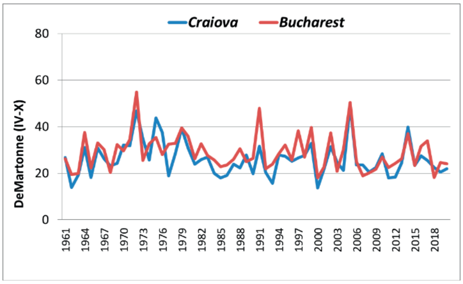

Figure 10. The distribution of the De Martonne aridity index (GSS) Craiova and Bucharest

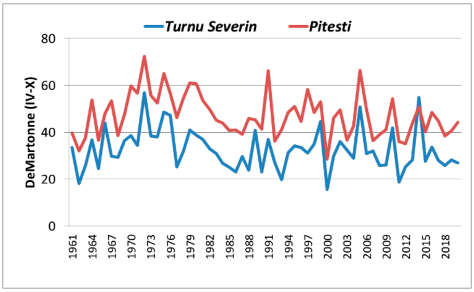

Figure 11. The distribution of the De Martonne aridity index (GSS) Turnu Severin and Pitesti

According to the data (Table 5), the trend reverses in a negative direction, with the slope remaining without statistical significance. The probable reason is the extreme values observed in recent decades.

Table 5. Statistical assessment of the trend (GSS)

Mann-Kendal trend	*Sen's slope estimate*		
De Martonne (IV-V)	**Test Z**	**Signific.**	**Q**
Turnu Severin	-1.6		-0.1
Pitesti	-1.9	+	-0.1
Craiova	-1.3		-0.1
Bucharest	-1.5		-0.1
Vratza	-1.5		-0.1
Vidin	-1.2		-0.1
Montana	-1.2		-0.1
Pleven	-1.4		-0.1

The assessment of the trend slope during the summer season (Table 6) corresponds to that during the vegetation period of spring crops. At stations Pitesti and Bucharest, the negative trend has a significance level of 0.1. According to the index values during the studied period, the climate is classified from semi-arid to humid apart from station Pitesti where the conditions are predominantly humid to very humid (Figures 12 and 13). Two peaks are observed around 1976 and in 2005, better shown in the stations from Northern Bulgaria.

Table 6. Statistical assessment of the trend of the De Martonne aridity index (SS)

Mann-Kendal trend	*Sen's slope estimate*		
De Martonne (IV-V)	**Test Z**	**Signific.**	**Q**
Turnu Severin	-1.2		-0.1
Pitesti	-1.8	+	-0.1
Craiova	-1.4		-0.1
Bucharest	-1.8	+	-0.1
Vratza	-1.5		-0.1
Vidin	-1.1		-0.1
Montana	-1.6		-0.1
Pleven	-1.6		-0.1

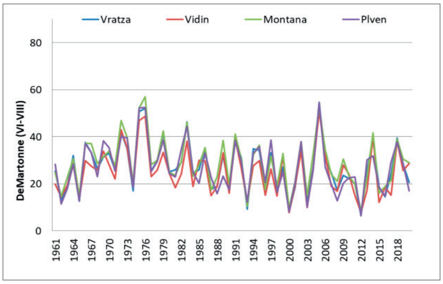

Figure 12. The distribution of the De Martonne aridity index June-August

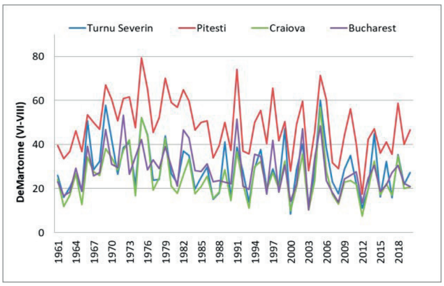

Figure 13. The distribution of the De Martonne aridity index June-August

Additional information related to plant security is provided by the number of cases with different types of climates during the study period (Figures 14 to 17). During the growing season of winter wheat, the conditions are predominantly extremely humid and very humid (Figure 14). In the stations Bucharest and Craiova, in about 40% of the cases the climate is semi-humid, and in the second station a number of years with an index below 20 and semi-arid climate conditions are also recorded. However, the second critical period in terms of humidity shows that even values below 10 - arid or dry conditions (Bucharest) are observed during the period (Figure 15).

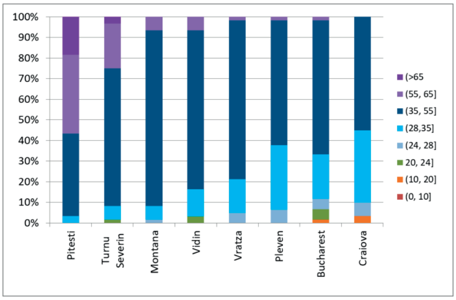

Figure 14. Distribution of climate types 1961-2020 according to De Martonne aridity index September-June

The best conditions are shown by Pitesti, Turnu Severin and Montana, and the most unfavorable years are found in Craiova and Pleven.

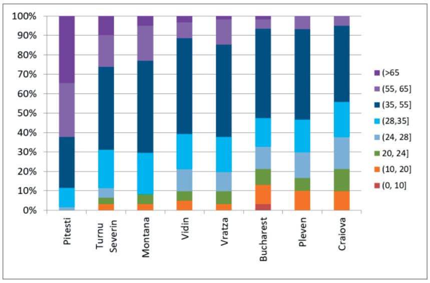

Figure 15. Distribution of climate types 1961-2020 according to the De Martonne aridity index April-May

The results show that the humidity conditions during the growing season are risky in rainy conditions (Figure 16).

Apart from Pitesti, where the climate is humid and very humid, irrigation is necessary in all other stations. Turnu Severin and Montana have predominantly semi-humid to humid conditions and a low need for irrigation. The most unfavorable conditions during the growing season are observed in the stations Craiova and Pleven, where in over 80% of the years the climate is Mediterranean and semi-arid and the need for irrigation for the spring crops is mandatory.

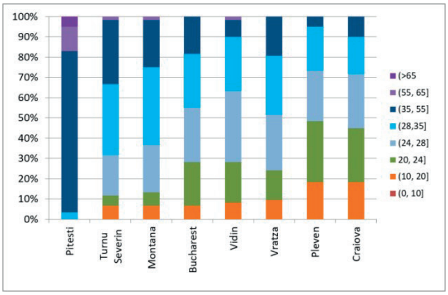

Figure 16. Distribution of climate types1961-2020, according to the De Martonne aridity index April-October

During the summer period, the stations with the most unfavorable conditions, years with an index below 10 and arid or dry conditions are Pleven, Craiova Vidin and Vratza (Figure 17). In the region of Southern Bulgaria, the best conditions during the studied period are observed at Montana station. Conditions range from humid to extremely humid in the Pitești region.

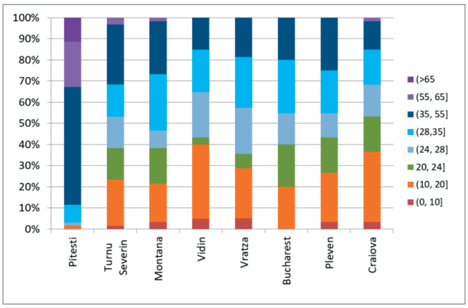

Figure 17. Distribution of climate types 1961-2020 according to the de Martonne aridity index June-August

CONCLUSIONS

An assessment of the hydrothermal conditions in the main agricultural regions of Southern Romania and Northern Bulgaria was made. The results show that the humidification conditions do not ensure the development of spring crops during their growing season and during the summer period. With the exception of Pitesti, where the climate is humid and very humid, irrigation is necessary for all other stations. Turnu Severin and Montana have prevailing semi-humid to humid conditions and a low need for irrigation. The most unfavourable conditions are during the potential growing season in the stations Craiova and Pleven, where in over 80% of the years the climate is Mediterranean and semi-arid and the need for irrigation for the spring crops is mandatory. The assessment of the trends shows a significant decrease in the index during the entire wheat growing period, as well as during the critical stages of earing and flowering in May and June. The observed negative trends during the growth and development of spring crops are not statistically significant. The same is observed during the summer period when only the regions closer to the mountain ranges such as Pitesti and Bucharest tend to be at statistical significance levels of 0.1. Despite the proven high temperatures, the distribution of the summer precipitation manages to maintain a negative insignificant trend for the entire period 1961-2020, most likely due to the higher extreme values in recent decades.

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