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IMPACT OF CLIMATE CHANGE ON CROP LAND AND TECHNOLOGICAL RECOMMENDATIONS FOR THE MAIN CROPS IN TRANSYLVANIAN PLAIN, ROMANIA

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ABSTRACT

The Transylvanian Plain (TP) is an important agricultural production area of Romania that is included among the areas with the lowest potential of adapting to climate changes in Europe. Thermal and hydric regime monitoring is necessary to identify and implement measures of adaptation to the impacts of climate change. Soil moisture and temperature regimes were evaluated using a set of 20 data logging stations positioned throughout the plain. Each station stores electronic data regarding ground temperature at 3 depths (10, 30, 50 cm), humidity at a depth of 10 cm, air temperature (at 1 m) and precipitation. For agricultural crops, the periods of drought and extreme temperatures require specific measures of adaptation to climate changes. During the growing season of crops in the spring (April - October) in the south-eastern, southern, and eastern escarpments, precipitation decreased by 43.8 mm, the air temperature increased by 0.37°C, and the ground temperature increased by 1.91°C at a depth of 10 cm, 2.22°C at a depth of 20 cm and 2.43°C at a depth of 30 cm compared with values recorded for the northern, north-western or western escarpments. Water requirements were ensured within an optimal time frame for 58.8-62.1% of the spring row crop growth period, with irrigation being necessary to guarantee the optimum production potential. The biologically active temperature recorded in the TP demonstrates the need to renew the division of the crop areas reported in the literature.

Key words: climate change monitoring; temperature regimes; soil moisture; adaptation technologies; Transylvanian Plain.

INTRODUCTION

The effects of climate change are currently a pressing issue in the scientific community (Fuhrer, 2003; Eastwood et al., 2006; Cassardo, 2009; Casas-Prat & Sierra, 2012; Barkhordarian et al., 2012, 2013; Qadir et al., 2013). The monitoring of the affected environment thus proves necessary to establishing directions of evolution and adaptation measures (Fowler et al., 2007; Hemadi et al., 2011; Ramirez-Villegas et al., 2012; Liu et al., 2012; Lereboullet et al., 2013; Beck, 2013; Bisaro et al., 2013). The Transylvanian Plain (TP), with an area of 395,616 hectares, is an important agricultural production area of Romania characterised by a climate that is extremely diverse and unstable due to the fact it is a plain-type climate, and from an orographic point of view, the plain exhibits a hilly relief (Baciu, 2006). Autumn crop sowing in the TP follows the schedule considered optimal for this area and specific to the cultivated species according to the inhabitants' knowledge of the microclimates of their lands (Gus et al., 2004; Rusu, 2005). Climate changes over the past few years have significantly altered the calendar periods considered optimal and have led to the introduction of new species, and other species considered to be traditional are becoming increasingly compromised, thus becoming risky crops (Ranta et al., 2008; Coman & Rusu, 2010; Moraru & Rusu, 2010; Halbac-Cotoara-Zamfir & Miranda, 2012; Saeed et al., 2013).

Romania is classified among the areas with the lowest capacity to adapt to existing climate changes and likely to generate crops, and the TP is one of the most affected areas (ESPON, 2011). Currently (and in the future), a series of strategies and plans to counter climate change are being (will be) put forward, but their implementation requires a strict monitoring of the area's thermal and hydric regime to identify the measures for adaptation to the impact of climate change (Sun et al.,

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2012; Oury et al., 2012; Boe, 2013; Diffenbaugh & Scherer, 2013).

In Romania, there has been a significant increase in the average annual temperature. Over the last century, the temperature has increased by approximately 0.5°C. The pronounced thermal growth over the last decades, beginning with the second half of the 20th century, has reached values of 0.8°C-1°C over extended areas in Romania. Concerning precipitation, a slight reduction (50 mm) in the amount of annual rainfall at the national level has been reported for the period 1901-2007 (NMA, 2011).

The National Meteorological Agency (NMA, 2011) forecasts for Romania, compared with that reported for the period 1980-1990, the same average annual warming projected for Europe, namely, an increase in temperature between 0.5-1.5°C for the period 2020-2029 and between 2.0-5.0°C for 2090-2099. For the period 2090-2099, scientists estimate a pluviometric deficit during the summer (10-30%) and an increase in rainfall during the winter (5-10%). Because the scarcity of water will become increasingly marked, agriculture will be greatly affected, but at the same time, the population will suffer from an inability to adapt to extreme temperatures that will very likely manifest themselves over several consecutive days (Bogdan & Niculescu, 1999; Moraru & Rusu 2010).

The latest research on the evolution of the climate within the Carpathian Basin indicates an approximately 0.7°C increase in the air temperature over the last one hundred years. This increase is also supported by the fact that six of the warmest years of the 20th century were registered in the 1990s. Contrary to its name, the TP is not a geographically flat plain but rather a collection of rolling hills lying approximately 300 m to 450 m above sea level in the south and 550 to 600 m above sea level in the north (Baciu, 2006). The climate of the TP is highly dynamic, ranging from hot summers with high temperatures above 30°C to very cold winters with low temperatures near -10°C (Climate Charts, 2007).

For the period 1967-2000, the TP was characterised by multiannual average temperatures of 9.2°C in the south (Turda station) and 9.1°C in the north (Targu Mures station), with average multi-annual precipitations of 510 mm/year in the south (Turda station) and 567 mm/year in the north (Targu Mures station). Within this context, the purpose of the research conducted was to monitor the climate, the thermal and hydric regime of the soils in the TP and to elaborate measures of adaptation to climate change.

The aim of monitoring the soil thermal and hydric regime, air temperature and rainfall in the TP is to determine the impact of climate change, characterise the properties of soils, understand crop reaction and identify specific technological adaptation measures.

MATERIAL AND METHODS

Analysis of the crop structure of the TP reveals high statistical shares of the following crops, which are considered the main crops: winter wheat, maize, soybean, sunflower and sugar beet. These 5 main crops were identified by analysing the cultivated areas over the last 20 years, as well as from the recommendation of a crop rotation system that should include an annual leguminous plant, i.e., soybean.

The thermal and hydric regime of the TP (soil temperature and humidity, air temperature and precipitations) was monitored during the period 2008-2012. Twenty data-logging HOBO Micro Stations (H21-002, On-set Computer Corp., Bourne, MA, USA) were deployed across the TP on various soil types, slopes, and aspects (Figure 1). The soil types where the stations were located included the following: chernozem (Caianu), Phaeozem (Balda, Band, Craiesti, Triteni, Dipsa, Jucu, Ludus, Cojocna, Voiniceni), eutricambosoil (Matei, Silivasu de Campie, Branistea, Unguras, Zau de Campie), districambosoil (Filpisu Mare), preluvosoils (Taga, Nuseni, Sic, Zoreni). The majority of the soils have a loam-clay texture, pH between 6 to 8.69 and humus content of 2.5 to 4.15 in the 0-20 cm horizon. The stations were placed to cover the three subunits of the TP: Low Hills Plain, High Hills Plain and Bistrita-Sieu Hills Plain. HOBO Smart Temp (S-TMB-M002) temperature sensors and Decagon EC-5 (S-SMC-M005) moisture sensors were connected to HOBO Micro Stations.

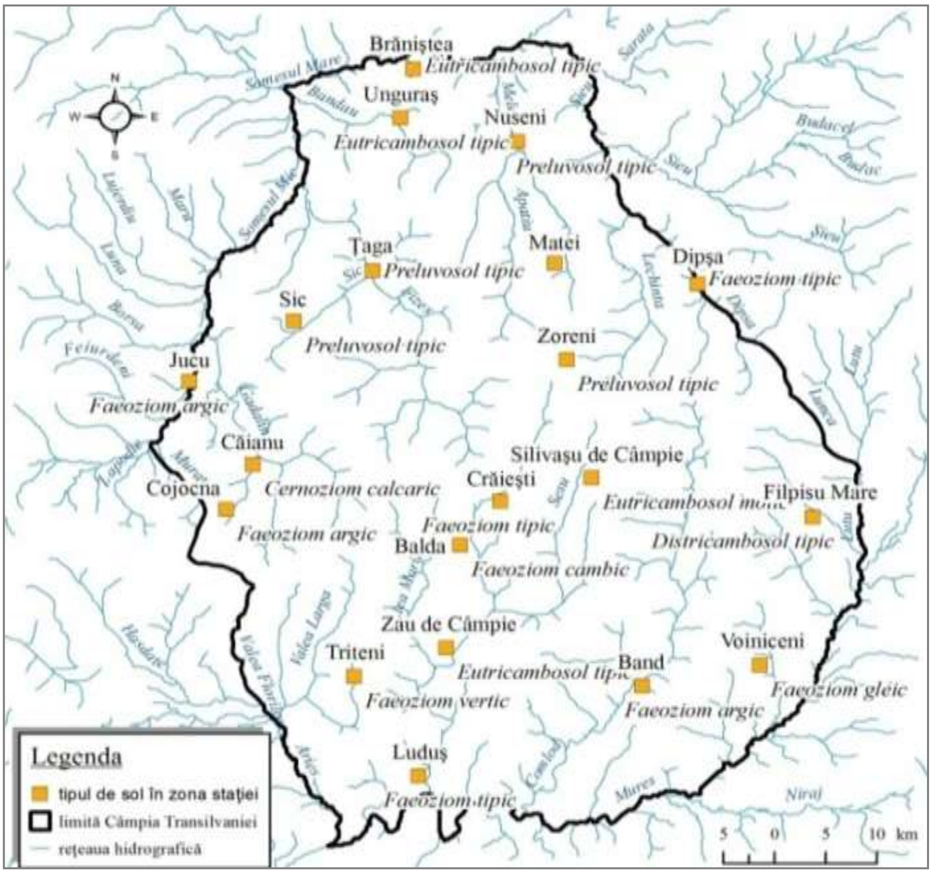

Figure 1. Types of soil where the stations were located in TP

Additionally, at 10 of the 20 sites, tipping bucket rain gauges (RG3-M) were deployed to measure precipitation (On-set Computer Corp., Bourne, MA, USA). Each station stored electronic data regarding ground temperature at 3 depths (10, 30, 50 cm), humidity at a depth of 10 cm, air temperature (1 m) and precipitation. Data were downloaded from the Micro Stations every two months via a laptop computer using HOBOware Pro Software Version 2.3.0 (On-set Computer Corp., Bourne, MA, USA). Table 1 shows the configuration of the stations (Weindorf et al., 2009; Haggard et al., 2010).

Table 1. Station configuration in the Transylvanian Plain

Station number	Station name	Latitude	Elevation, m/ Exposition	Rain gauge
1	Balda (MS)	46.717002	360 / NE	No
2	Triteni (CJ)	46.59116	342 / NE	No
3	Ludus (MS)	46.497812	293 / NE	Yes
4	Band (MS)	46.584881	318 / SE	No
5	Jucu (CJ)	46.868676	325 / V	Yes
6	Craiesti (MS)	46.758798	375 / N	No
7	Sillivasu de Campie (BN)	46.781705	463 / NV	Yes
8	Dipsa (BN)	46.966299	356 / E	Yes
9	Taga (CJ)	46.975769	316 / N	No
10	Caianu (CJ)	46.790873	469 / SE	Yes
11	Cojocna (CJ)	46.748059	604 / N	Yes
12	Unguras (CJ)	47.120853	318 / SV	Yes
13	Branistea (BN)	47.17046	291 / V	Yes
14	Voiniceni (MS)	46.60518	377 / SE	Yes
15	Zau de Campie (MS)	46.61924	350 / S	Yes
16	Sic (CJ)	46.92737	397 / SE	No
17	Nuseni (BN)	47.09947	324 / SE	No
18	Matei (BN)	46.984869	352 / NE	No
19	Zoreni (BN)	46.893457	487 / NV	No
20	Filpişu Mare (MS)	46.746178	410 / S	No

NE = northeast; SE = southeast; V = west; N = north; NV = northwest; E = east; SV = southwest; S = south; MS = Mures County; CJ = Cluj County; BN = Bistrita-Nasaud County

RESULTS AND DISCUSSION

Monitoring the soil thermal and hydric regime, air temperature regime and precipitation allowed us to observe how, and if, the optimal sowing period of crop plants has been modified over the years due to climate changes that have taken place. The data recorded from the 20 stations were compared with the data specified in the literature concerning the optimal sowing period in the TP; the following were taken into account: the first and last frost date, the minimum germination temperature recorded, the biologically active temperature, the optimal soil humidity and the days with temperatures higher than 30°C.

According to the literature (Cacovean, 2005), the first autumn frost in the TP occurs on the 19th of October. For the monitored period, 2008-2012, the earliest autumn frost, at a soil depth of 10 cm, was recorded on November 13, 2011 at Triteni (-1.07°C.) and Taga (-0.68°C), followed by first autumn frosts recorded on November 18, 2008 at Band (-0.14 °C) and November 18, 2011 at Zoreni (-0.20°C). There were stations where the first frost did not appear until the end of the year; in such cases, we recorded the date of the first frost the following year at the latest: February 17, 2010 at the Silivasu de Campie (-0.06°C), February 16, 2011 at Triteni (-0.12°C) and February 5, 2010 at Branistea (-0.06°C).

The last spring frost usually appears, according to the specialty literature, before the 10th of May. The latest spring frost recorded for the period 2008-2012 took place on March 13, 2011 (-0.06°C) at the Taga, Triteni and Zoreni stations, followed by the frosts on March 7, 2009 at the Dipsa station (-0.26°C) and March 3, 2009 at Caianu (-0.31°C) and Silivasu de Campie (-2.28°C). There were stations where the last frost, at a depth of 10 cm depth, was recorded on January 26, 2011 (-0.12°C, Craiesti), and at most stations, the last frost, at a depth of 10 cm, occurred in February.

The analysis of the data regarding the first and last frost for the monitored period, 2008-2012, indicates that these values do not affect the optimal sowing period for the monitored crops. Thus, there are no risks in this respect. Throughout the period and at all stations, the last frost was recorded in spring on the 13th of March and the first one in autumn, on the 13th of November. The extent of freezing of the soil decreased significantly compared with that indicated by the statistical data of the area.

To analyse the data concerning the optimal sowing period, we took into account the moment at which the minimum seed germination temperature occurred, which remained above this value for 3 consecutive days and had a tendency to increase during the following days. These temperatures were 8°C for maize, 7.5°C for soybean, 7°C for sunflower, and 6°C for sugar beet. The analysis of the data recorded at the stations showed that the minimum germination temperature for the main crops in the area was recorded up to 15 days earlier, and these data were compared with the known data from the literature (Table 2). The sowing temperature was recorded 15 days earlier for soybeans, 10-12 days earlier for maize, and 2-3 days earlier for sunflower and sugar beet. Significant differences were recorded from one station to another; for example, for maize (Figure 2), the minimum germination temperature was registered 25 days earlier at the southern and south-eastern stations and 10 days earlier at the northern and north-western stations in the TP.

Table 2. The optimum sowing periods recorded in the Transylvanian Plain

No	Crop	Area (ha)			MTG, °C	OSP	OSP, 2008-2012		
		CJ	MS	BN			Caianu, CJ	Ludus, MS	Branistea, BN
1	Maize	42063	60822	28316	8	10-30.IV	07.IV	26.III	02.IV
2	Soybean	725	1075	39	7.5	10-20.IV	27.III	24.III	25.III
3	Sunflower	2727	2972	1388	7	25.III-15.IV	25.III	22.III	22.III
4	Sugar beet	1721	3038	103	6	20.III-15.IV	23.III	20.III	18.III

OSP - optimum sowing period (Gus, P. et al., 2004); OSP, 2008-2012 – the date when the optimum germination temperature was registered. CJ-Cluj, MS-Mures, BN-Bistrita Nasaud; MTG - minimum temperatures for germination (°C).

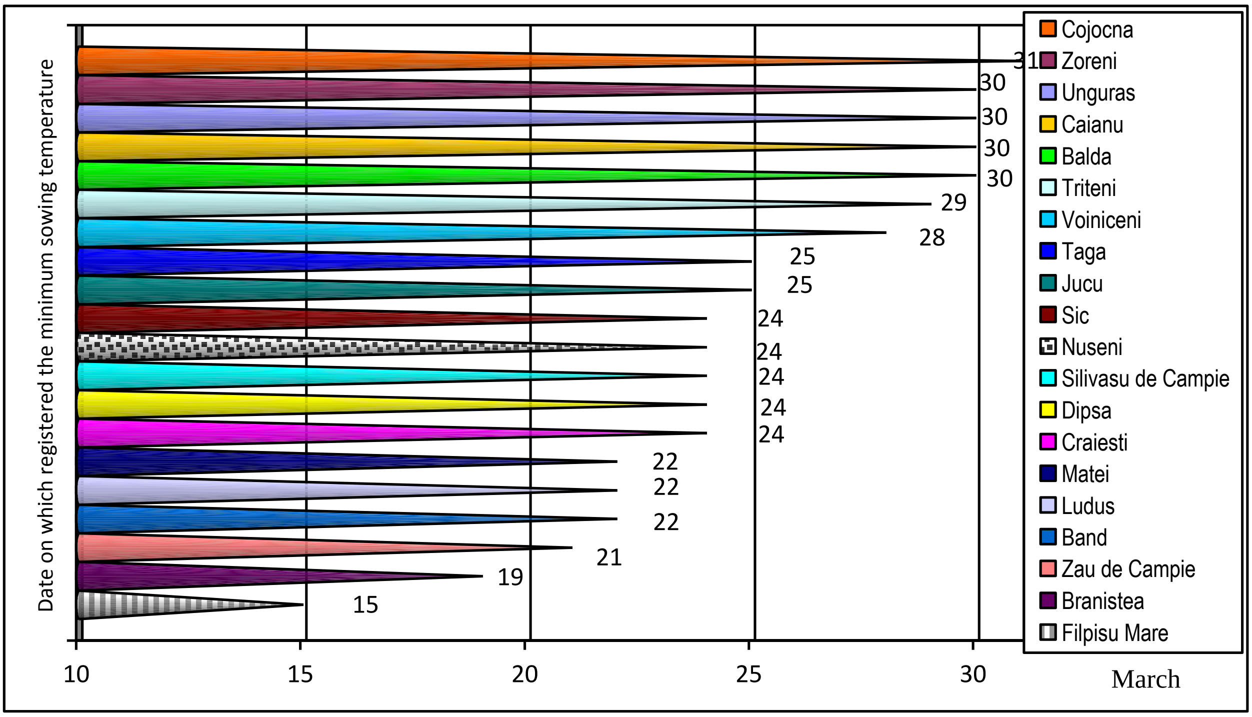

Figure 2. Dates on which the minimum sowing temperature for maize was recorded in the Transylvania Plain (2008-2012)

The biologically active temperature, or thermic constant (CT), was calculated by taking into account the specific vegetation areas of hybrid/late or semi-late varieties, and the basic temperatures, or the biological threshold (temperature below which visible growths are no longer recorded) were 0°C for wheat-290 days; 8°C for maize-150 days; 10°C for soybean-150 days; 70°C for sunflower-140 days; 0°C for sugar beet-183 days.

In the case of wheat, during the vegetation period (September 25 - July 12), the plant requires temperatures of 1800-2300°C to develop. At all of the stations, during all of the monitored years, the biologically active temperature required for wheat reached the maximum recorded level or exceeded the limits specified in the literature, namely, temperatures between 2182-2874°C.

With respect to maize, TP is classified, in the literature, as being in the IIIrd zone, in which the biologically active temperature is 800-1200°C. At most stations, during the vegetation period over the monitored years, 2008-2012, the biologically active temperature required for maize exceeded the limits specified for the IIIrd culture zone. The registered CT ranged between 1229 and 1868°C, thus positioning the TP in the Ist and IInd culture zones. The stations with CT values above 1400°C included the Filpisu Mare (1599-1868°C), Craiesti (1513-1708°C) and Triteni (1339-1508°C) stations, as well as the central and southern stations of the TP, which were consequently situated in the Ist culture zone. The stations with CT values below 1400°C included the Sic (1296-1344°C) and Zoreni (1229-1416°C) stations, as well as the stations in the western and northern TP, which were consequently situated in the IInd culture zone.

In the case of soybean, TP is situated, according to the literature, in the IVth zone, with a thermic potential of 1100-1250°C. The sum of the biologically active temperatures registered for soybeans for the period 2008-2012 lied between 1044 and 1568°C, thus positioning the TP in the IInd, IIIrd and IVth culture zones. The Filpisu Mare station showed values specific to the IInd culture zone (1430-1568°C); the Craiesti station showed values specific to the IIIrd culture zone (1221-1396°C); and the Zoreni and Sic stations showed values specific to the IVth culture zone (1126-1183°C and 1044-1193°C, respectively).

With respect to sunflower, the TP is situated in the II[nd] culture zone, in which the biologically active temperature is 1400-1600°C. The sum of the biologically active temperatures registered for sunflower during the period 2008-2012 lied between 1250 and 1890°C, indicative of culture zones I, II and III. Zone I temperatures were recorded at the Filpisu Mare (1582-1890°C) and Craiesti stations (1487-1763°C); zone II temperatures were recorded at the Triteni station (1387-1562°C); zone III temperatures were recorded at the Sic (1250-1463°C) and Zoreni (1250-1463°C) stations. The disposition area of sunflower is similar to that of maize, with the central and the southern parts of the TP being more favourable to semi-late hybrids and the northern part, a more hilly area, being more favourable for early hybrids.

In the case of sugar beet, we took into account a vegetation period of 183 days, during which the plant required biologically active temperatures of 2400-2900°C in the first growing year and 1800°C in the second year. At all stations, the necessary CT was summed over the sugar beet growth period, resulting in values between 2954°C at Sic and 3857°C at Filpisu Mare.

The Optimal Humidity Interval for Plants (OHIP) represents the time frame during which plants develop properly, and it is equal to 60-90% of the Active Moisture Interval (AMI,%). The average assured OHIP rates for the period 2008-2012 at all stations of the TP showed the best values for winter wheat, namely, 63.8% of the vegetation period, with humidity levels below the optimum range observed during 15.4% of the wheat growing season and humidity levels above the optimal range observed during 20.8% of the season. Spring crops presented a much larger moisture deficit, between 37.9 and 38.9% for sugar beet and soybean and between 40.9 and 41.2% for sunflower and maize, during the growth period, the time frame during which the soil moisture is below the OHIP (Figure 3). Water requirements within the optimal interval, were recorded during only 58.8-62.1% of the growth period, for row spring crops. It is concluded that the risk of water scarcity for spring crops is notably high. Thus, additional measures are required to ensure water (irrigation) and soil water conservation (conservation tillage systems, with minimum tillage and a mulch layer, as well as specific technological adaptations).

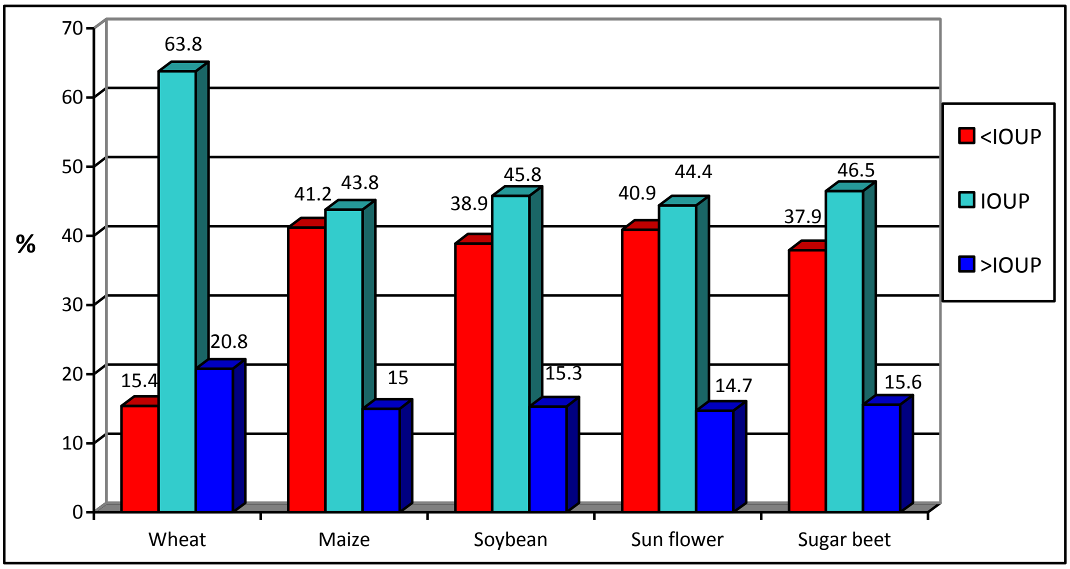

Figure 3. Assured optimal humidity interval for plants (%) at the 20 stations in the Transylvania Plain during 2008-2012

To determine the periods during which the humidity requirements were not met, periods of drought were taken into account. A drought is defined as a lack of rainfall for a period of at least 14 consecutive days during the cold time of the year (October - March) and at least 10 days during the warm period (April - September). The analysis of the drought periods reveals a total of 36 (Branistea) to 86 (Caianu) days without rainfall in 2009, 15 (Branistea) to 40 (Silivasu de Campie) days in 2010, 57 (Caianu) to 83 (Dipsa) days in 2011 and 45 (Branistea) to 76 (Balda) days in 2012. The periods of drought occurred during the summer months, from June to August, but showed a high frequency in September - October as well.

Temperatures above 30°C during the flowering season, accompanied by atmospheric drought (dry winds and reduced relative air humidity), inflict significant damage on both maize (optimal 18-24°C) and sunflower (optimal 16-20°C) production, because pollen loses its viability and thus significantly reduce grain and seed production, as well as the amount of sunflower oil produced. The average numbers of days with temperatures above 30°C recorded at the 20 stations were: 16.33 days in 2008, 58.04 days in 2009, 47.8 days in 2010, 53.96 days in 2011 and 54.63 days in 2012. Of these days, 20-25% were recorded in June, but they mostly represented days in July and August.

Temperature amplitudes spanning from above 30°C to below 10°C at night, which occur during flowering and grain filling, prevent the formation of anthers, thus indirectly hindering the development of pollen grains and the natural deployment of fertilisation processes. Thermal shocks following fertilisation adversely affect the accumulation of reserve substances inside grains, and thus, the phenomenon of degeneracy in maize emerges. High temperature amplitudes have a negative impact on the crops during the summer months, June - August, particularly during growth, flowering and grain formation, when the drought periods are the most frequent and soil humidity exhibits extremely deficient levels. The maximum temperature amplitudes were registered at the Filpisu Mare station located on a southern slope in the south-eastern part of the TP, where the following differences between the daily maximum and minimum temperature were recorded: on June 28, 2009: 9.83-47.97°C (38.14°C); on June 7, 2010: 13.74-48.44°C (34.7°C); and on June 1, 2011: 11.3-49.31°C (38.01°C). The Branistea station, located on a hillside with a western exposure and representative of the northern and north-western parts of the TP, registered the following maximum temperature amplitudes over 24 hours intervals: on June 15, 2009: 7.98-42.4°C (34.42°C); on 7 June 2010: 10.36-41.23°C (20.87°C); and on August 22, 2011: 8.58-42.16°C (33.58°C).

CONCLUSIONS

The monitoring of the soil thermal and hydric regime, the air temperature and rainfall in the TP revealed a transition from a moderate continental climate to an excessive climate with a poor distribution of rainfall and in which many extreme phenomena overlap. Periods of drought and extreme temperatures require specific adaptations to climate change for agricultural crops.

From the analysis of the data recorded in the TP, we recommend hastening the optimal sowing periods reported in the literature by 7 days for maize and soybeans and by 5 days for sunflower and maintaining the same periods for sugar beet. The optimum sowing periods are now as follows: for maize: April 5-25, for sunflower: March 25 - April 10, for sugar beet: March 20 - April 10, for soybeans: April 5-15. Highly significant differences were recorded from one station to another, the results being influenced by soil type and exposure conditions. Therefore, in practice, it is very important to take into account differences in escarpment morphology. During the growing season of the crops in spring (April - October), the south-eastern, southern, and eastern escarpments presented an approximately 43.8 mm decrease in precipitation, a 0.37°C increase in air temperature, and increases in ground temperature of 1.91°C at a depth of 10 cm, 2.22°C at a depth of 20 cm and 2.43°C at a depth of 30 cm, as compared with the values recorded for the northern, north-western and western escarpments.

Water requirements are ensured within the optimal time frame of 58.8-62.1% of the spring row crop growth period. Thus, irrigation is necessary to ensure the optimum production potential. In June - July and August, 36-83 days of drought were recorded, which overlapped with days exhibiting temperatures above 30°C; a total of 47.8-58.04 days exhibiting both were recorded during 2008-2012.

The biologically active temperatures recorded in the TP demonstrated the need to renew the division of the crop areas reported in the literature. For the analysed crops, wheat, maize, soybean, sunflower and sugar beet, superior areas of redistribution should be ensured with a view to the possibility of cultivating a higher percentage of semi-late or late varieties/hybrids.

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