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Possibilities of Early Sowing of Maize in Croatia with Respect to Climate Change

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Abstract: Maize is the main field crop grown on arable land in Croatia. In the 2001-2010 period, maize was grown on 333,736 ha, with yearly yield variations from 3.86 to 7.98 t ha⁻¹. Climate change and global warming have considerable impacts on maize growing. The aim of this study was to investigate the temperature and heat unit sum ([daily Tmin + daily Tmax] : 2 - 10: calculated only for days with Tmin above 10 °C) trends (comparison of 1961-1990 and 2010-2016 periods) at five localities: Osijek, Slavonski Brod, Krizevci, Zagreb in the Pannonian region (PR) and Gospić in the mountain region (MR). Mean soil temperatures in April, at 5 cm depth for, 1961-1990 were 11.6 °C and 8.6 °C, for PR and MR, respectively. However, mean temperatures for 2010-2016 increased by 2.2 °C and 2.4 °C, respectively. Heat unit sums from April 25 to October 10 (expected frost-free period in Osijek, 90 % probability) were 1301 and 1554, for 1961-1990 and 2010-2016, respectively. Analogous data for Gospić were 882 and 1147, respectively. In the 1961-1990 period, the last spring frost occurred in Osijek and Zagreb on May 12 1968 and in Gospić on May 29, 1967. In that period, the last spring frost appeared on April 15 and later for 14 years in Osijek, 15 years in Zagreb and each year in Gospić. However, in the 2001-2015 period, the last spring frost appeared on April 19, 2015 in Osijek, April 22, 2005 in Zagreb and May 25, 2005 in Gospić. In that period, the last spring frost appeared on April 15 and later in two years in Osijek, three years in Zagreb and eight years in Gospić. Based on these findings, April 5 is the recommended date for the beginning of maize sowing in the eastern part of PR. However, because of the possible risks due to weather excesses, particularly delayed last spring frost, only between 20 and 30 % of the studied area is recommended for "earlier sowing", with a tendency to somewhat decreased yield of earlier sowing in the western part of PR. However, there is practically the same level of risk for early maize sowing in MR and the recommended date for beginning maize sowing is May 10.

Keywords: maize sowing date, climate change, global warming, soil temperature, maize heat units, Croatia

Introduction

Global warming and more frequent extreme weather events are often connected with climate change. Climate change, particularly precipitation quantity and its distribution as well as temperature regimes, have often adverse effects on field crop yields (Parry et al., 2005). Lobell and Field (2007) estimated that about 30 % variation of global average yields of the world's six most widely grown crops (wheat, rice, maize, soybeans, barley and sorghum) are a result of precipitation and temperature variations in the growing season.

Maize is the main field crop on arable land in Croatia. In the 2001-2010 period, maize was grown on 333,736 ha, with yearly yield variations from 3.86 to 7.98 t ha⁻¹. Most maize growing areas are situated in the Pannonian region because of its relatively more favorable soil and climate characteristics compared to the remaining part of the country. General characteristics of the climate, relief, soil and water resources were in detail elaborated in the monograph Geography of Croatia (Magas, 2013). Lower precipitation and higher air temperatures, especially in July and August, are usually closely associated with lower maize yields (Shaw 1988; Kovacevic et al., 2013; Rastija et al., 2012).

The frost-free period is important for maize growing because the maize growing season could be included between the last spring frost and the first autumn frost since maize can tolerate temperature up to -3 °C. Based on this criterion, the recommended time of maize sowing in PR of Croatia is the second half of April and after May 10 in MR (Gotlin and Pucaric, 1979; Pucaric, 1992; Pospisil, 2010; Kovacevic and Rastija, 2014). In the Corn Belt of the USA, the recommended maize sowing time is, depending on the area, from February 1 to 11 in the southernmost area and moves later in the northward direction to the first half of May near to the border area with Canada (Sprague and Dudley, 1988). Expected appearance of the last spring frost is the main criterion for determination of the sowing time. Affected by the recent climate change, maize sown at this time under the conditions of southeastern Europe (Croatia, B&H, Hungary, Romania, Serbia and Bulgaria) is more liable to be exposed to drought and heat stress in the period between just before flowering and the beginning of grain formation. Namely, at this stage of development, maize is most susceptible to water deficit and high temperature. Earlier sowing of maize, for example ten days before the usual time, has some advantages because of more favorable weather conditions for maize growth prior to the flowering stage, particularly lower temperatures. Lower risk of weather stress at the critical stage of maize growth could contribute to the probability of higher and more stable yields.

The aim of this study was to test soil and air temperatures and heat unit sum (HUS) trends (comparison of 1961-1990 and 2010-2016 periods) at five localities in Croatia – four in the Pannonian region (PR) and one in the Mountain region (MR) - with regard to the possible recommendation for earlier beginning of maize sowing.

Material and methods

Climatological reports of the Meteorological and Hydrological Service from 1961 to 1990 and from 2010 to 2016 (SHS, 2016) were used as sources of weather data for this study. Five towns were selected to study the weather conditions: four towns (Osijek, Slavonski Brod, Krizevci and Zagreb) are situated in PR (lowland part of northern Croatia) and the fifth town (Gospic), situated in the Lika province, is part of MR.

Temperature at 5 cm and 20 cm of soil depth, mean (Tmean), maximum (Tmax) and minimum (Tmin) air temperatures, as well as the date of the last spring frost were taken from the mentioned climatological reports. Mean air temperature was calculated as the sum of temperatures measured at 7:00 a.m., 14:00 p.m. and doubled temperature at 21:00 p.m. divided by 4 (equation = $[(T_{7h} + T_{14h} + 2 \times T_{21h}) : 4]$). Heat unit sum (HUS) was calculated from the equation: $HUS = [daily\ Tmin + daily\ Tmax] : 2 - 10$. Only days with Tmin above 10 °C were taken into consideration for HUS calculation. HUS was calculated for the period from April 25 to October 10. This period was selected because it is estimated to be frost-free (90 % probability) based on meteorological data for Osijek (Radic et al., 1981). However, due to the impact of recent climate change, recalculation of the frost-free period is required.

Results and discussion

Mean soil temperatures at 5 cm and 20 cm depth (3-month means: March-May) for 1961-1990 in four towns of PR were 11.6 °C and 10.9 °C pointing out that in the eastern part of the region (Osijek) these temperatures were 12.2 °C and 11.3 °C, respectively. At the same time, soil temperatures in MR (Gospic) were 8.8 °C and 8.3 °C at 5 cm and 20 cm soil depths, respectively. In the 2010-2016 period, the temperature at 5 cm soil depth was by 1.8 °C higher (PR) and 2.0 °C higher (MR) compared to 1961-1990 averages. A similar trend was found for soil temperature at 20 cm depth (Table 1).

Monthly values of soil temperatures at 5 cm depth in the 1961-1990 period were 6.0 °C, 11.6 °C and 17.3 °C (means of four towns in PR, 3.7 °C, 8.6 °C and 14.2 °C (MR) for March, April and May, respectively. In general, soil temperatures at 20 cm depth were between 0.4 °C and 1.1 °C lower compared to the temperature at 5 cm. In more eastern Osijek, soil temperatures were somewhat higher than in the remaining three towns of PR. In the 2010-2016 period, these temperatures were by 1.7 °C, 2.2 °C and 1.3 °C (PR), by 1.9 °C, 2.4 °C and 1.5 °C (MR) higher than in the 1961-1990 period. A similar trend was found for soil temperature at 20 cm depth (Table 1).

Air temperatures in the period 1961-1990 (3-month averages: March-May) in PR (means of four towns) were 5.1 °C (Tmin), 16.5 °C (Tmax) and 10.8 °C (Tmean) and in MR 2.5 °C, 13.7 °C and 8.2 °C, respectively. Like soil temperature, air temperatures in the eastern part of PR (Osijek) were somewhat higher compared to the remaining part of the region. Monthly air temperature values in PR were 0.9 °C, 5.1 °C and 9.4 °C (Tmin), 11.4 °C, 16.6 °C and 21.6 °C (Tmax), 5.9 °C, 10.8 °C and 15.6 °C (Tmean) for March, April and May, respectively. Under mountainous climate (MR), these values were on average 2.7 °C lower: -1.3 °C, 2.6 °C and 6.3 °C (Tmin), 8.9 °C, 13.5 °C and 18.6 °C (Tmax), 3.6 °C, 8.1 °C and 12.8 °C (Tmean), respectively (Table 2).

Table 1. Soil temperature

Weather Bureau	Soil temperature (°C) at two soil depths for two periods											
	1961-1990						2010-2016					
	Soil depth 5 cm			Soil depth 20 cm			Soil depth 5 cm			Soil depth 20 cm		
	March	April	May	March	April	May	March	April	May	March	April	May
a) Pannonian region (lowland part of northern Croatia)												
Osijek	6.5	12.2	18.0	5.7	11.3	16.9	7.4	13.6	18.9	7.4	13.0	17.9
Slav. Brod	6.0	11.7	17.2	5.8	11.3	16.2	8.1	14.3	19.1	7.9	13.6	18.1
Krizevci	5.6	10.9	16.6	5.1	10.2	15.4	7.3	13.5	18.0	7.0	12.7	17.2
Zagreb	5.9	11.7	17.5	5.8	11.0	16.4	7.8	13.9	18.4	7.5	13.3	17.8
Average	6.0	11.6	17.3	5.6	10.9	16.2	7.7	13.8	18.6	7.5	13.2	17.8
b) Lika province (part of the mountain region of Croatia)												
Gospic	3.7	8.6	14.2	3.3	8.2	13.4	5.6	11.0	15.7	5.2	10.4	14.8

Table 2. Air temperatures

Means of air temperatures (°C): means of minimum (Tmin), maximum (Tmax) and mean (Tmean)										
	Tmin (°C)			Tmax (°C)			Tmean (°C)			
	March	April	May	March	April	May	March	April	May	
A: The 1961-1990 period										
a1) Pannonian region (lowland part of northern Croatia)										
Osijek	1.0	5.6	10.3	11.9	17.5	22.5	6.1	11.3	16.5	
Slav. Brod	0.8	4.9	9.3	12.0	17.0	22.1	6.2	10.9	15.9	
Krizevci	0.8	4.7	8.8	10.5	15.7	20.5	5.5	10.2	14.8	
Zagreb	1.1	5.1	9.2	11.3	16.3	21.1	5.9	10.6	15.3	
Average a1	0.9	5.1	9.4	11.4	16.6	21.6	5.9	10.8	15.6	
a2) Lika province (part of the mountain region of Croatia)										
Gospic	-1.3	2.6	6.3	8.9	13.5	18.6	3.6	8.1	12.8	
B: The 2010-2016 period										
b1) Pannonian region (lowland part of northern Croatia)										
Osijek	2.9	6.9	11.0	12.8	19.6	22.3	7.5	12.9	16.7	
Slav. Brod	2.5	5.9	9.7	13.3	19.7	22.3	7.6	12.8	16.2	
Krizevci	2.9	6.6	10.5	12.3	18.4	21.2	7.3	12.2	15.7	
Zagreb	3.3	6.8	10.8	12.8	18.9	21.7	7.9	12.9	16.4	
Average b1	2.9	6.5	10.5	12.8	19.1	21.9	7.1	12.2	15.7	
b2) Lika province (part of the mountain region of Croatia)										
Gospic	0.8	4.2	7.4	10.5	16.6	19.4	5.3	10.4	13.4	

Air temperatures in the 2010-2016 period (3-month averages: March-May) in PR (means of four towns) and in MR (Gospic) were higher than in 1961-1990 as follows: 6.6 °C (Tmin), 17.9 °C (Tmax) and 11.7 °C (Tmean), 4.1 °C (Tmin), 15.5 °C (Tmax) and 9.7 °C (Tmean), for PR and MR, respectively. Average increases of air temperatures were 1.2 °C (PR) and 1.7 °C (MR). Monthly values of air temperatures in PR were 2.9 °C, 6.5 °C and 10.5 °C (Tmin), 12.8 °C, 19.1 °C and 21.9 °C (Tmax), 7.1 °C, 12.2 °C and 15.7 °C (Tmean) and in MR 0.8 °C, 4.2 °C and 7.4 °C (Tmin), 10.5 °C, 16.6 °C and 19.4 °C (Tmax), 5.3 °C, 10.4 °C and 13.4 °C (Tmean) for March, April and May, respectively. Average increases of air temperatures in the 2010-2016 period were + 1.5 °C (March), +1.8 °C (April) and +0.5 °C (May) in PR and + 1.8 °C (March), +2.3 °C (April) and +0.8 °C (May) in MR (Table 2). Differences in both soil and air temperatures between the two regions are in accord with their climatic characteristics (Magas, 2013), while differences between the two periods are associated with the recent climate change (Cindric et al., 2009).

The period from April 25 to October 10 is with 90 % probability expected to be a frost-free period in the area of Osijek. In the 1961-1990 period, precipitation quantities in PR were lower (average 417 mm) than in MR (506 mm) with a tendency to grow from the east (Osijek 342 mm) toward the west (Zagreb 480 mm). Absolute minimum (aTmin) and absolute maximum (aTmax) temperatures in PR were recorded in Slavonski Brod (-3.8 °C and 39.5 °C) and mean temperature (Tmean) in Osijek (18.3 °C). These values were lower in MR (-5.6 °C, 37.0 °C and 37.0 °C, respectively). HUS value in this period was, on average, 1301 in PR with a decreasing trend from

the east toward the west (Osijek 1440, Krizevci 1177, and Zagreb 1267). HUS in MR was by 419 units, or 32%, lower than the average value in PR. The 2010-2016 period was characterized by increases in temperature. For example, aTmin, aTmax and Tmean mean were higher in PR by 1.3 °C, 1.3 °C and 2.9 °C, respectively. In MR, these values in the 2010-2016 period were higher by 3.0 °C (aTmin) and by 2.9 °C (Tmean), while aTmax was similar to the 1961-1990 period. HUS for the 2010-2016 period was higher than for the 1961-1990 period by 253 units, or about 20%, in PR and by 265 units, or about 30 %, in MR (Table 3).

Table 3. Heat unit sum (HUS), precipitation and air temperatures in the expected frost-free period

Period from April 25 to October 10: Heat unit sum (HUS), precipitation (Prec.) and air temperatures: absolute minimum (aTmin), absolute maximum (aTmax) and mean (Tmean)										
Town	1961-1990					2010-2016				
	mm Prec.	HUS	Temp. (°C)			mm Prec.	HUS	Temp. (°C)		
			aTmin	aTmax	Tmean			aTmin	aTmax	Tmean
a) Pannonian region (lowland part of northern Croatia)										
Osijek	342	1440	-2.6	38.6	18.3	404	1607	-1.0	40.3	19.7
Slav. Brod	412	1318	-3.8	39.2	17.7	413	1534	-2.5	40.5	19.5
Krizevci	432	1177	-3.0	37.6	16.7	437	1492	-1.6	38.5	18.7
Zagreb	480	1267	-2.5	37.5	17.3	467	1579	0.0	38.6	19.5
Average	417	1301			17.5	431	1554			19.4
b) Lika province (part of the mountain region of Croatia)										
Gospic	506	882	-5.6	37.0	15.1	573	1147	-2.6	37.2	17.0

Table 4. Dates of the last spring frost

Date of the last spring frost (code = day. month); bolded = the last date in the decade										
1961-1990										
Year	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
Osijek	no data	02.05	26.03	25.03	02.04	01.04	20.04	12.04	19.04	05.04
Zagreb	no data	02.05	05.04	09.04	03.04	31.03	24.04	12.04	20.04	02.05
Gospic	no data	16.05	06.05	29.04	01.05	24.04	05.05	10.05	20.04	25.05
Year	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Osijek	16.04	27.04	23.03	16.04	26.03	28.03	22.04	12.05	21.04	13.04
Zagreb	16.04	29.04	23.04	14.03	26.03	01.05	18.04	12.05	06.05	13.04
Gospic	16.04	30.04	14.05	10.05	30.04	04.05	29.05	15.05	06.05	30.04
Year	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
Osijek	20.04	24.04	28.03	29.04	25.04	15.04	24.03	25.04	25.03	18.03
Zagreb	22.04	25.04	14.04	28.04	30.04	15.04	24.03	26.04	25.03	11.04
Gospic	6.05	03.05	17.04	28.04	04.05	21.04	23.05	24.04	09.05	14.04
2001-2015										
Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Osijek	15.04	08.04	10.04	31.03	03.04	08.04	05.03	27.03	27.03	16.03
Zagreb	15.04	08.04	09.04	28.03	22.04	08.04	22.03	26.03	27.03	16.03
Gospic	18.04	28.04	10.04	25.05	09.05	14.04	06.04	14.04	27.03	16.04
Year	2011	2012	2013	2014	2015	2016				
Osijek	12.03	10.04	28.03	12.03	19.04	21.02				
Zagreb	22.03	10.04	08.04	26.02	19.04	27.02				
Gospic	06.05	18.05	03.04	06.05	20.04	27.02				

In the 1961-1990 period, the last spring frost occurred in Osijek and Zagreb on May 12, 1968 and in Gospic on May 29, 1967. In that period, the last spring frost appeared on April 15 and later in 14 years in Osijek, in 15 years in Zagreb and each year in Gospic. However, in the 2001-2015 period, frost appeared on April 19, 2015 in Osijek, April 22, 2005 in Zagreb and May 25, 2004 in Gospic. In that period, the last spring frost occurred on April 15 and later in two years in Osijek, in three years in Zagreb and eight years in Gospic (Table 4).

Based on these findings, April 5 is the recommended date for the start of maize sowing in PR. However, because of possible risks due to extreme weather events, particularly delayed last spring frost, only between 20

and 30 % of the studied area is recommended for earlier sowing, with a tendency of slightly less sowing in the western part of PR. However, there is practically the same level of risk in MR and the recommended date to begin maize sowing is May 10.

Cindrić et al., (2009) observed climate variations and changes in air temperature and precipitation throughout Croatia since the beginning of the 20th century (1901), including Osijek and Zagreb. During the 20th century, annual amounts of precipitation showed a downward trend in all parts of Croatia (10-year decreasing trend: -1.3 % in Osijek and -0.3 % in Zagreb). Two growing seasons (2010 and 2012) are typical examples of the climate trend characterized by deviation of precipitation and temperature regimes in a short period in the same areas compared to standard averages of the 1961-1990 period. Regarding maize water requirements, the growing season of 2010 was especially favorable. However, the growing season of 2012 was characterized by both dry and hot stresses for maize. The 2012 drought devastated non-irrigated maize yields in the region (Serbia by 53 %, Hungary and Croatia by 38 %, B&H by 40 %) compared to the normal 2010 growing season (Kovacevic et al., 2013). By applying adequate fertilization and soil reclamation by liming it is possible to alleviate drought and hot stresses in maize (Komljenovic et al., 2010, 2015; Markovic et al., 2008; Stojic et al., 2012).

Conclusion

Comparison of weather data for the 1961-1990 period and recent seven years (2010-2016) revealed increases in soil and air temperatures, HUS and earlier occurrence of the last spring frost. Based on these findings, it is possible to recommend ten days earlier beginning of maize sowing in the Pannonian region (April 5). However, more frequent weather deviations, particularly delayed last spring frost, are the reasons why only 20 to 30 % of the maize sowing area could be sown before the until now usual time of maize sowing (April 15). Furthermore, maize sowing before May 10 is risky in the mountain region.

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