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TRENDS OF CHANGES IN CLIMATE RISK OF GRAIN MAIZE CULTIVATION IN THE BYDGOSZCZ REGION

Jacek Żarski, Renata Kuśmierek-Tomaszewska, Stanisław Dudek
University of Science and Technology in Bydgoszcz

Abstract

This paper analysed the direction and the degree of significance of changes in selected indicators of climate risk for grain maize in the long-term period of 1985-2014 for the Bydgoszcz region. On the basis of meteorological data originating from the Research Station of the Bydgoszcz University of Science and Technology in Mochełek, the following unfavourable weather factors for maize cultivation were determined: a shortened period of plant active growth, the occurrence of late spring ground frosts, meteorological droughts and agricultural droughts. On the basis of the research conducted, a high temporal variability was found for weather conditions that are unfavourable for maize cultivation, as such conditions occurred with varied frequency, depending on the type of the adverse factor and the assumed criterion for its determination. No significant trends were found regarding the changes in the examined climate risk indicators for production of maize grain over the period between 1985 and 2014, apart from an increase in the number of moderate and strong late spring frosts. The research demonstrated an increase in temporal variability of the length of the plant active growth period and the occurrence of moderate and strong late spring frosts, as well as a clear decrease in temporal variability of maize water supply in 2000-2014 as compared to the previous 15-year period of 1984-1999.

Keywords: grain maize, climate risk, heat shortages, frosts, droughts, Bydgoszcz region

INTRODUCTION

The growing importance of maize in domestic farming can be seen in the enlargement of the grain maize crop area, which in 2012-2015 amounted to about 625,000 ha and was almost twice as large as in 2005-2011. According to the data of the Central Statistical Office (GUS), in 2014 grain maize was cultivated in the province of Kujawsko-Pomorskie on an area of 95,400 ha. In terms of the crop area and yield, this region was ranked second after Wielkopolskie and before Dolnośląskie (GUS 2016).

Maize grain production in the traditional cultivation regions, despite significant progress in cultivation of varieties, still depends to a great extent on weather conditions, particularly on thermal and precipitation factors (Żarski et al. 2004, Sulewska 2007). Heat deficiency is the reason why grain does not reach appropriate technological maturity and, consequently, it leads to a reduction in yield and lower production profitability (Ptaszyńska and Sulewska 2008, Spurtacz et al. 2008). Lack of precipitation also results in irregular growth and the development of plants during the vegetation period. In extreme cases, their shortage in the phase of increased water needs leads even to the drying up of plants, particularly on light and very light soils (Dudek et al. 2009, Żarski et al. 2013). Another unfavourable weather factor in maize cultivation is late spring frost, whose negative impact increases along with the tendency of bringing forward the time for sowing (Koźmiński and Michalska 2010, Sulewska 2007).

The aim of the paper was to provide a climatologic evaluation with determination of the direction and the degree of significance of changes in selected indicators of the climate risk for grain maize cultivation between 1985 and 2014 in the Bydgoszcz region. It was assumed that in relation to the observed and particularly forecasted global climate changes (Kundzewicz and Kozyra 2011), in the Bydgoszcz region in the 30-year period under examination there were symptoms indicating an increase in temporal variability concerning the occurrence of unfavourable weather conditions and, therefore, a climatic risk to grain maize cultivation.

MATERIAL AND METHODS

The research was based on the results of meteorological measurements satisfying the principle of comparability, conducted in a standard manner at the Research Station of the Bydgoszcz University of Science and Technology in Mochełek, situated about 20 km from the city centre (53°13'N, 17°52'E, 98 m above sea level). The measurement station, located in an open, agriculturally used area, has been carrying out standardized meteorological observations and measurements since 1949. Data from the multi-year period of 1985-2014,

concerning monthly average air temperatures, monthly sums of precipitation for individual months of the maize vegetation period and daily minimum air temperatures at ground level between May and June to determine late spring frosts were used for the study. On the basis of the data, the following unfavourable weather conditions in maize cultivation were found:

- shortening of the plant active growth period (the period with air temperature established above the threshold of 10.0^0C), determined for each year with the use of the calculation method;
- occurrence of late spring ground frosts (May and June), taking into account their intensity class;
- occurrence of meteorological droughts based on the RPI index, expressing the percentage ratio of precipitation in a given period of a given year in relation to the multi-year norm for this period);
- occurrence of agricultural droughts based on the actual precipitation shortage in relation to optimal Klatt precipitation, performed for the entire period of maize vegetation (V-IX) and the period of intensified plant water needs (VII-VIII).

Statistical methods typical for the agroclimatological research were applied, with determination of mean and extreme values, standard deviation for each factor and (based on the criterion assumed – its frequency in the multi-year period). Changes over the period of 1985 to 2014 were determined using the trend method, with linear regression equations and correlation and determination coefficients (Garnier 1996, Kossowska-Cezak et al. 2000). In order to determine an increase or a decrease in temporal variability, standard deviations and ranges of its factor for the period of 2000-2014 were compared to the previous 15-year period of 1985-1999.

RESULTS AND DISCUSSION

On the basis of the research conducted, a high temporal variability was found for weather conditions unfavourable for maize cultivation, occurring with varied frequency, depending on the type of the adverse factor and the assumed criterion for its determination (Tab. 1).

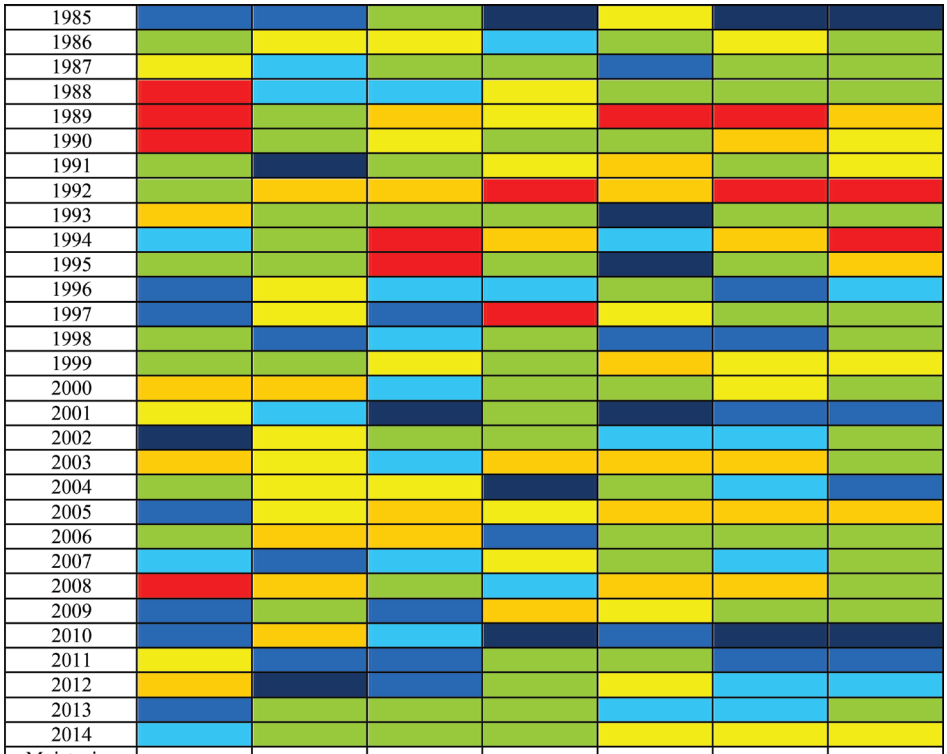
The average thermal period of the plant active growth, corresponding to the maize vegetation period, started in the Bydgoszcz region on 26 April and ended on 4 October. With a mean duration of 162 days, the extreme periods were 193 days long (the longest period in 2000) and 143 days (the shortest period in 1991). A delay in the beginning of the period of plant active growth, unfavourable for the growth and development of maize (heat shortage at the beginning of vegetation) occurred once per 6 years (16.7% frequency). An earlier end, by at least one week, of this period was observed with the same frequency, which

indicated heat shortage in the final phase of maize vegetation. The frequency of unfavourable shortening of the period of active plant growth by at least 10 days also amounted to 16.7% (once per 6 years).

Late spring frosts, unfavourable for the growth and development of maize, occurred in 25 out of 30 examined years (83.3% frequency). The highest numbers of frost days (a total of 8) were observed in May and June 1999 and 2011. Particularly dangerous moderate and strong frosts, involving a temperature drop at the ground level below 2.0°C, occurred with 30% frequency, in 9 years out of 30 years under analysis. In 2011, there were even 5 such days. The average date of the occurrence of the last late spring frost in the Bydgoszcz region was 14 May for the 30-year period under examination. However, during three years, the last late spring frost was recorded on 6 June.

Table 1. Characteristics of selected indicators of climatic risk to grain maize cultivation in the Bydgoszcz region between 1985 and 2014

Index	Mean	MAX	MIN	Standard deviation	The frequency of unfavourable conditions (% of years)	The criterion for determining the adverse conditions
Beginning of the period of active growth of plants	26.04	17.05 1991	10.04 2000	8	16,7	The delay of at least 7 days
The end of the period of active growth of plants	4.10	19.10 2000	23.09 1996	7	16,7	Earlier at least 7 days
The length of the period of active growth of plants	162	193 2000	143 1991	11	16,7	Shortening at least 10 days
The total number of late spring frosts	2,9	8 1999, 2011	0 5 years	2,5	83,3	The occurrence of frost
The number of late spring frosts moderate, and severe (<-2,00C)	0,6	5 2011	0 21 years	1,2	30,0	The occurrence of frost
Date of the last late spring frost	14.05	6.06 1991, 2009, 2012	13.04 2003	17	26,7	Later at least 14 days
Deficiencies and excess of precipitation during the growing season (V-IX) in mm	-7	201 1985	-219 1992	98	16,7	Deficiencies larger than 100 mm
Deficiencies and excess of precipitation during the period of increased water needs (VII-VIII) in mm	-5	137 1985	-135 1994	61	16,7	Deficiencies larger than 50 mm



Moistening degree	V	VI	VII	VIII	IX	V-IX	VII-VIII
Extremely dry	4	0	2	2	1	2	2
Very dry	4	5	4	3	6	5	3
Dry	3	7	4	5	5	4	4
Average	8	9	8	13	9	8	14
Wet	3	3	7	3	3	5	2
Very wet	7	4	4	1	3	4	3
Extremely wet	1	2	1	3	3	2	2

Figure 1. Moistening degree of individual months and periods in the maize vegetation period according to the RPI index in subsequent years of 1985-2014 in the Bydgoszcz Region

Water conditions for maize cultivation, determined with the use of the variability of meteorological drought index RPI (Fig. 1) and agricultural drought index in the form of shortage or excess of precipitation in relation to their optimum amount, revealed a very high temporal variability. At medium deficiency of precipitation in a maize vegetation period of 7 mm, even a 201 mm excess of precipitation was observed in 1985, and up to a 219 mm precipitation deficiency was recorded in 1992 (with a range of 420 mm). Precipitation deficiency ex-

ceeding 100 mm in the grain maize vegetation occurred in the Bydgoszcz region with 16.7% frequency. A very large temporal variability of water conditions of the maize and a similar frequency of unfavourable, significant precipitation deficiency also concerned the period of intensified water needs of plants, i.e. July and August.

No significant trends were found in the changes in the examined indicators of climate risk for production of maize grain over the period between 1985 and 2014, except for an increase in the number of moderate and strong late spring frosts (Tab. 2). There was a tendency of lengthening the period of active plant growth observed by 1.58 days per 10 years (Fig. 2), resulting from the tendency of this period to begin earlier in spring. It was also found that the number of late spring frosts tends to increase and the last frosts tend to occur at a later date (an unfavourable phenomenon). The number of moderate and strong late spring frosts with a temperature drop below – 2.0°C significantly grew by 0.59 per 10 years (Fig. 3). It was also observed that water conditions for grain maize cultivation tend to improve, as regards both the entire vegetation period (by 14.6 per 10 years) and the period of intensified water needs, covering the months of July and August (Fig. 4).

Table 2. Changes in selected indicators of climate risks of grain maize cultivation in the Bydgoszcz region in the period between 1985 and 2014, with correlation and determination coefficients characteristics for linear dependency

Index	Change for 10 years	Coefficient of determination (%)	Correlation coefficient
Beginning of the period of active growth of plants	-2.13	5.94	-0.244
The end of the period of active growth of plants	-0.55	0.46	-0.068
The length of the period of active growth of plants	+1.58	1.51	0.123
The total number of late spring frosts	+0.64	5.27	0.229
The number of late spring frosts moderate, and severe (<-2,00C)	+0.59	19.40	0.440*
Date of the last late spring frost	+1.32	0.48	0.069
Deficiencies and excess of precipitation during the growing season (V-IX) in mm	+14.6	1.73	0.131
Deficiencies and excess of precipitation during the period of increased water needs (VII-VIII) in mm	+11.7	2.86	0.169

In 2000-2014, in relation to the previous 15-year period of 1984-1999, the research demonstrated an increase in temporal variability of the length of the plant active growth period and the occurrence of moderate and strong late spring frosts, as well as a clear decrease in temporal variability of maize water supply

(Tab. 3). For the other indicators of maize cultivation climate risk, no growth or decrease in extremity was found.

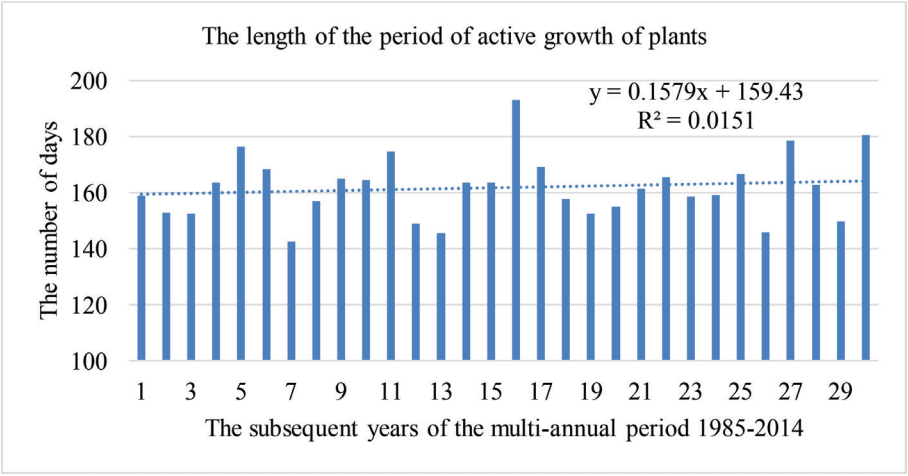


Figure 2. Temporal variability of the period of active growth of plants in the Bydgoszcz region, with a growth tendency in 1985 to 2014

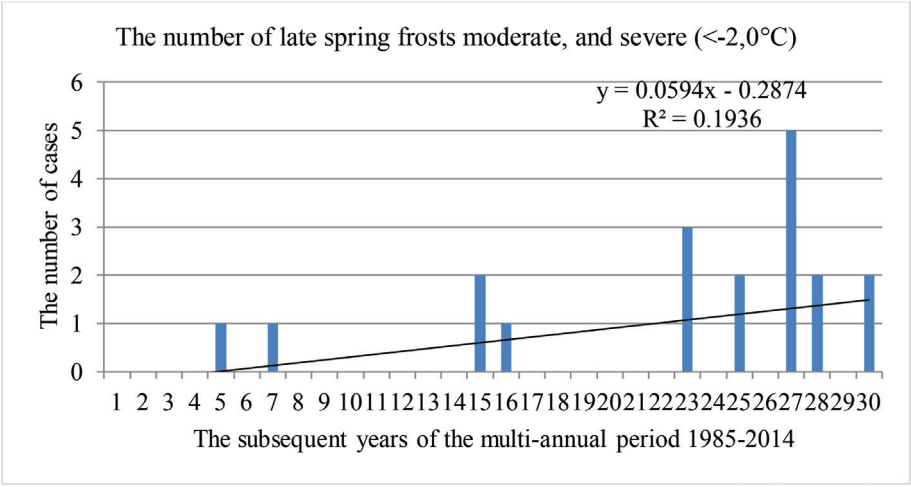


Figure 3. Temporal variability of the number of late spring frosts <-2.0°C in the Bydgoszcz region, with a growing trend in 1985-2014

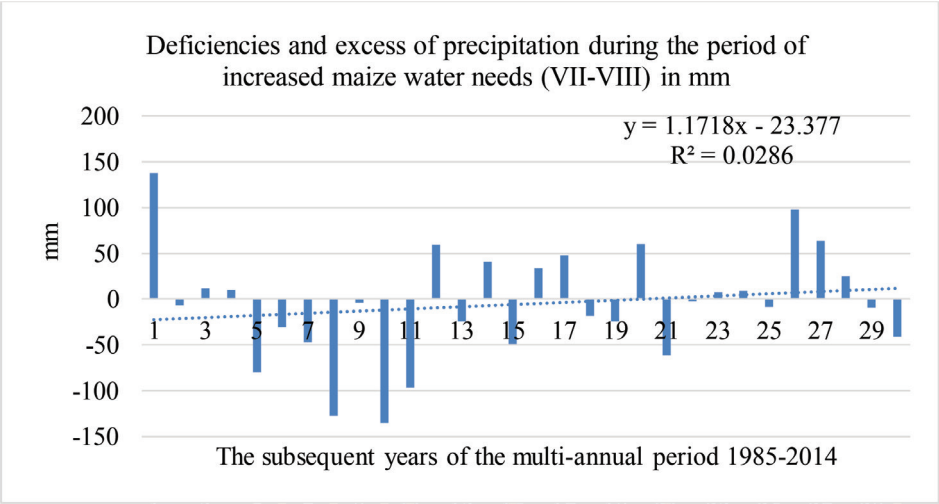


Figure 4. Temporal variability of water conditions of maize in the period of intensified water needs in the period of Bydgoszcz with an improving tendency in 1985-2014

The above-presented picture of climate risks in grain maize cultivation in the Bydgoszcz Region is consistent with the results presented by Koźmiński and Michalska (2010) with regard to the entire country and Żarski (2012) and Januszewska-Klapa (2016) with reference to the region of Bydgoszcz and selected localities of the Kujawsko-Pomorskie Province. This results from a very high temporal variability of the climate of Poland, expressed in the occurrence of weather conditions close to the norm in about 30-35% years (Fig. 1-2, 4). In the context of global warming theory and related climate change scenarios (Starkel and Kundzewicz 2008, Kundzewicz and Kozyra 2011), the results of this research in some aspects confirmed the published projections of changes, while some other aspects were not consistent with those projections.

Certainly, the significant growing trend in the number of frosts, particularly moderate and strong frosts, and an increase in the extremeness of their occurrence, can be considered a symptom of the climate changes taking place and, therefore, also of the climate risk of grain maize cultivation in the Bydgoszcz region. The improvement of thermal conditions for maize cultivation is also demonstrated in a tendency to extend the period of active growth of plants, resulting from earlier dates of its beginning. However, a tendency to improve water supply conditions for maize cultivation over the period of 1985-2014 and an established decrease in the extremeness of the occurrence of precipitation deficiencies and excesses, contrary to the climate change projections, can also clearly be observed.

Table 3. Comparison of temporal variability of selected indicators of climate risk for grain maize cultivation in the region of Bydgoszcz in 1985-1999 and 2000-2014

Index	Standard deviation		Range (MAX-MIN)		Temporal variations
	1985-1999	2000-2014	1985-1999	2000-2014	
Beginning of the period of active growth of plants	8	8	30	24	
The end of the period of active growth of plants	7	8	24	26	
The length of the period of active growth of plants	10	13	34	47	+
The total number of late spring frosts	2.5	2.5	8	8	
The number of late spring frosts moderate, and severe (<-2,00C)	0,6	1,5	2	5	+
Date of the last late spring frost	17	17	51	54	
Deficiencies and excess of precipitation during the growing season (V-IX) in mm	111	84	420	280	-
Deficiencies and excess of precipitation during the period of increased water needs (VII-VIII) in mm	73	43	273	160	-

+ increase, – decrease of temporal variability

CONCLUSIONS

1. Weather phenomena and elements unfavourable for grain maize cultivation in the Bydgoszcz region are characterized by a very high irregularity and temporal variability of their occurrence. Depending on the type of the unfavourable factor and the assumed criterion of its determination, they occurred over the 30-year period under analysis with the frequency of 16.7-83.3% of years.
2. No significant trends were found as regards changes in the examined indicators of climate risk for production of maize grain over the period between 1985 and 2014, except for an increase in the number of moderate and strong late spring frosts.
3. For 2000-2014, in relation to the previous 15-year period of 1984-1999, the research demonstrated an increase in the temporal variability of the length of the plant active growth period and the occurrence of moderate and strong late spring frosts, but also a clear decrease in the temporal variability of water supply for maize cultivation.

REFERENCES

Dudek S., Żarski J., Kuśmierek-Tomaszewska R. (2009). *Reakcja kukurydzy na nawadnianie w świetle wyników wieloletniego eksperymentu polowego.* Infrastruktura i Ekologia Terenów Wiejskich, nr 3, 167-174.

Garnier B.J. (1996). *Podstawy klimatologii.* IMGW Warszawa, 97-114.

GUS www.gov.stat.pl, dostęp 30.03.2016.

Januszewska-Klapa K. (2016). *Tendencje zmian klimatycznego ryzyka uprawy roślin w wybranych miejscowościach województwa kujawsko-pomorskiego.* Rozprawa doktorska. UTP Bydgoszcz, 1-125.

Kossowska-Cezak U., Martyn D., Olszewski K., Kopacz-Lembowicz M. (2000). *Meteorologia i klimatologia. Pomiary, obserwacje, opracowania.* Wydawnictwo Naukowe PWN Warszawa-Łódź, 88-108.

Koźmiński C., Michalska B. (2010). *Niekorzystne zjawiska atmosferyczne w Polsce. Straty w rolnictwie.* W: Klimatyczne zagrożenia rolnictwa w Polsce pod red. C. Koźmińskiego, B. Michalskiej i J. Leśnego. Uniwersytet Szczeciński, 2010, 9-54.

Kundzewicz Z.W., Kozyra J. (2011). *Ograniczanie wpływu zagrożeń klimatycznych w odniesieniu do rolnictwa i obszarów wiejskich.* Polish Journal of Agronomy, 7, 68-81.

Ptaszyńska G., Sulewska H. (2008). *Zmienność plonowania mieszańców kukurydzy o różnej wczesności w warunkach klimatycznych środkowej Wielkopolski.* Acta Sci. Pol., Agricultura, 7(3), 93-103.

Spurtacz S., Pudełko J., Majchrzak L. (2008). *Opłacalność uprawy kukurydzy na ziarno w warunkach produkcyjnych w latach 2005-2007.* Acta Sci. Pol., Agricultura, 7(4), 117-24.

Starkel L., Kundzewicz Z. W. (2008). *Konsekwencje zmian klimatu dla zagospodarowania przestrzennego kraju.* Nauka, nr 1, 85-101.

Sulewska H. (2007). *Wymagania środowiskowe kukurydzy.* W: Integrowana produkcja kukurydzy, pod red. Z. Kaniuczak i S. Pruszyńskiego, Instytut Ochrony Roślin Poznań, 6-9.

Żarski J., Dudek S., Grzelak B. (2004). *Rola czynnika wodnego i termicznego w kształtowaniu plonów ziarna kukurydzy.* Acta Agrophysica, 3(1), 189-195.

Żarski J. (2012). *Tendencje zmian agroklimatu rejonu Bydgoszczy w latach 1981-2010.* Rozdział w pracy zbiorowej „Bydgoskie Kolokwium Wiedzy o Ziemi 2002-2012" pod red. M. Bielińskiego. BTN Bydgoszcz, 85-103.

Żarski J., Dudek S., Kuśmierek-Tomaszewska R., Januszewska-Klapa K. (2013). *Potrzeby i efekty nawadniania kukurydzy uprawianej na ziarno w regionie kujawsko-pomorskim.* Infrastruktura i Ekologia Terenów Wiejskich, nr 3/IV, 77-90.

Prof. dr hab. inż. Jacek Żarski
Dr inż. Renata Kuśmierek-Tomaszewska
Dr inż. Stanisław Dudek
Katedra Melioracji i Agrometeorologii
Wydział Rolnictwa i Biotechnologii UTP w Bydgoszczy
85-029 Bydgoszcz
ul. Bernardyńska 6
zarski@utp.edu.pl
rkusmier@utp.edu.pl

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