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Identifying climatic risk to soybean cultivation in the transitional type of moderate climate in Central Poland

Identyfikacja klimatycznego ryzyka uprawy soi w klimacie umiarkowanym typu przejściowego w Polsce Centralnej

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Abstract

Meteorological measurements carried out in 1986-2015 were used to evaluate the climatic risk for soybean cultivation in the transitional type of moderate climate in Poland, as well the directions and the significance of changes in the meteorological indices were considered. Their analysis led to determination of the following unfavourable climatic conditions for soybean cultivation: shortening of the active growth period, a delay of the date on which the soil warms up to 8 °C at a depth of 5 cm, occurrences of meteorological and agricultural droughts and of late spring ground frosts. All indices of the climatic risk in soybean cultivation demonstrated high temporal variability. Significant trends of changes for the following indices were observed: an increase in the number of moderate and strong frosts and an earlier start of the period when soil reaches 8 °C at a depth of 5 cm. For 2000-2015, in relation to the previous 15-year period of 1986-2000, it was found that temporal variability increased for the number of moderate and strong late spring frosts and for the date of the last late spring frost. On the other hand, variability was reduced in regard to the beginning and the length of the period of active growth of plants, as well as precipitation shortages and surpluses in the period when soybean water needs are intensified.

Keywords: active growth period, drought, frost, temporal variability, trend of change

Streszczenie

Pomiary meteorologiczne przeprowadzone w 1986-2015 zostały wykorzystane do oceny ryzyka klimatycznego uprawy soi w klimacie umiarkowanym typu przejściowego w Polsce, pod uwagę wzięto także kierunki i znaczenie zmian wskaźników meteorologicznych. Ich analiza doprowadziła do ustalenia następujących niekorzystnych warunków klimatycznych dla uprawy soi: skrócenie okresu aktywnego wzrostu, opóźnienie dnia, w którym gleba nagrzeje się do 8 °C na głębokości 5 cm, wystąpienia susz meteorologicznych i rolniczych oraz przymrozków późnowiosennych. Wszystkie wskaźniki ryzyka klimatycznego w uprawie soi wykazały dużą zmienność czasową. Zaobserwowano istotne tendencje zmian dla następujących wskaźników: wzrost liczby umiarkowanych i silnych przymrozków oraz wcześniejsze rozpoczęcie okresu gdy gleba osiągnie 8 °C na głębokości 5 cm. Dla 2000-2015, w stosunku do poprzedniego 15-letniego okresu 1986-2000, stwierdzono, że zmienność czasowa wzrosła dla liczby umiarkowanych i silnych przymrozków późnowiosennych oraz oraz daty ostatniego przymrozku późnowiosennego. Z drugiej strony, zmienność została zredukowana w odniesieniu do początek i długość okresu intensywnego wzrostu roślin, jak również niedoborów opadowych i nadwyżek w okresie, w którym potrzeby wodne soi są zintensyfikowane.

Słowa kluczowe: aktywny okres wzrostu, przymrozek, susza, zmiana trendu, zmienność czasowa

Introduction

In spite of long-term comprehensive research on climate change (JRC Scientific and Technical Reports, 2009; Moss et al., 2010; Ciscar et at., 2011), there are still many doubts related to scenarios and assumptions concerning the effects of those changes on agriculture (International Panel on Climate Change, 2014a, 2014b; JRC Scientific and Political Reports, 2014). Crop productivity and soil water balance were studied in various models of plant growth using parameters from different climate models. Their results show, that impact of climate change on agriculture and water conditions can be very different in the various regions of Europe, increasing regional disparities. There may be some advantages and new opportunities for farmers in some regions of Europe, but also a lot of losses and difficulties in others (Behrens et al., 2010). Impact on Central European agriculture generally might be negative, although there are differences between countries even within the region. Due to the increase in temperature, decrease in rainfall and elongation in growing seasons, there may be an improvement in crop productivity in countries such as Poland, the Czech Republic, Hungary, Bulgaria, and Romania (Stuczyński et al., 2000; Commission of European Communities Working Document, 2009). Climate variability is one of the most important factors that influence each year on the effects of agricultural production, even in high-performance and technologically advanced agricultural areas (Kang et al., 2009). Therefore, some studies were done to determine the limitations for agricultural crop cultivation resulting from temporal variability of climate elements (Ault et al., 2016; Żarski et al., 2016). This will help to adapt particular plant cultivars to projected changes in thermal conditions and water balances in the area of the Central Europe.

A discussion on the possibility of soybean cultivation in the transitional type of moderate climate has been going on in Poland for several years (Kościelniak, 2015; Nawracała, 2015). In the opinion of Kozyra et al. (2009) and Żmudzka (2012), the observed climate changes in Poland are characterized by a lengthening of the vegetation period, which makes it possible to introduce the cultivation of plants with higher thermal requirements, such as soybean. An analysis of FAOSTAT reports (2016) shows that the cultivation area, as well as the volume of soybean yield in Poland, has been constantly growing over the period of the last 10 years, yet with no significance for the global market. In spite of constant progress concerning its varieties, the cultivation scale of this plant largely depends on climatic conditions. Weather conditions in the vegetation period are of extreme importance for the development of soybean, which is one of the thermophilic plants (Kumagai and Sameshima, 2014). Two critical periods can be distinguished as regards its high thermal requirements. The first period occurs from sowing to the peak of germination. The optimum germination temperature fluctuates around 10-15 °C. The blooming phase constitutes another critical period. When the temperature drops below 10 °C, the plant does not enter the blooming phase and, consequently, it may not mature before autumn frosts, to which it is very sensitive (Zarychta, 2014). The most important condition is soil temperature which, according to Woynarowska (1972), should amount in the sowing period to between 8 °C and 10 °C. The optimum date in the climatic conditions of Poland is between 20th April and 5th May. Sowing too early causes unsatisfactory plant spacing. On the other hand, late sowing results in extending the vegetation period until autumn (Jasińska and Kotecki, 1993). Soybean also demonstrates high water requirements in the blooming period (Nowak and Wróbel, 2010). Germination and pod filling also included as periods of particular demand for water (Zarychta, 2014). According to Kołodziej and Pisulewska (2000), the most favourable conditions for growth, development and yielding of soybeans can be found in the south-eastern part of Poland. According to Bujak and Frant (2009), obtaining varieties with a shorter vegetation period (125-135 days), which are more tolerant to the length of the day and lower temperatures in the initial growth phase, could also make it possible to carry out soybean cultivation in other regions of Poland.

This paper evaluates the climatic risk of soybean cultivation in the transitional type of moderate climate in the period of 1986-2015 on the example of Central Poland. Particular emphasis is put on the direction and significance of changes in the meteorological indicators under analysis. It has been assumed that, according to the global warming theory, the length of the period of the active growth of plants significantly increased. Additionally, the research involves examination of another hypothesis resulting from climatic changes concerning an increase in the variability of occurrence (extremity) of unfavourable climatic conditions.

Material and methods

The meteorological data used in the paper are the result of measurements originating from the Research Station of the University of Science and Technology in Bydgoszcz located in Central Poland (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 meteorological observations and measurements since 1949. The study is based on homogenous series of the period 1986-2015. The paper uses average monthly air temperatures and sums of precipitation for the months of the soybean vegetation period. Minimum daily ground temperatures in May and June were used to establish the dates of late spring frosts. On the basis of meteorological data, unfavourable factors increasing the risk for soybean cultivation were determined:

– shortening of the period of active growth of plants determined for each year by a calculation method using the delayed settling of temperature at a level above 10 °C in spring or from a too early end of this period in autumn;
– the occurrence of agricultural droughts resulting from a shortage of actual precipitation in relation to the optimum precipitation (Schwarz, 1970), specified for the entire period of soybean vegetation (May-September), as well as for periods of intensified demand for water in May and July-August;
– the occurrence of periods of atmospheric droughts determined on the basis of the relative precipitation index (RPI), describing the percentage ratio of precipitation for a vegetation period in a year to the multi-annual average for a given period; according to criterion proposed by Kaczorowska (1962) and Dembek et al. (2015) (Table 1):

Table 1. Relative precipitation index (RPI) classes

Type of period	Month	Two-month period	Vegetation season
	% to the multi-annual average		
Extremely dry	<25	<37	<50
Very dry	25-49	37-62	50-74
Dry	50-74	63-82	75-89
Average	75-125	83-118	90-110
Wet	126-150	119-137	111-125
Very wet	151-200	138-175	126-150
Extremely wet	>200	>175	>150

– the occurrence of late spring (May and June) ground frosts, taking account of their intensity classes;
– delayed warming of the soil to 8 °C at a depth of 5 cm, resulting in worse emergence and germination.

The analysis conducted led to determination of mean and extreme values of the examined factors, standard deviations (SD) and the frequency of a given phenomenon. The trend method, linear regression equations and correlation coefficients (CC) were used to determine changes occurring in time (Garnier, 1996). The critical value of the correlation coefficient for number of paired observations n-2=28 at the significance level P<0.05 is r=0.361. In order to determine changes in temporal variability, the periods of 1986-2000 and 2001-2015 were compared with the application of standard deviations and ranges.

Results and discussion

The results of the research demonstrate the high frequency of unfavourable conditions of climatic conditions for soybean cultivation in the Bydgoszcz area. It is worth emphasizing that this frequency in 1986-2015 depended on the type of the factor under analysis and, first of all, on the criterion chosen for determining unfavourable conditions (Table 2). Late spring frosts occurred in 83.3% of the years, but moderate and strong frosts were recorded in only 30% of the years. Unfavourable water shortage in soybean cultivation was found in 20-30% of the years, depending on the balancing period. The period of the active growth of plants was reduced by at least ten days on average once per six years and the date when the top soil reached 8 °C was delayed by at least seven days in 13.3% of the years.

All unfavourable weather factors under analysis demonstrated high temporal variability in the examined multi-annual period of 1986-2015. Taking into consideration the thermal period of active plant growth, it was found that it lasted 162 days on average. However, in 2000 its length was 193 days and in 1991 it was only 143 days. The average date of the beginning of this period was 26th April. It started five times at least a week later. An early (by at least seven days) end of the active growth of plants, which on average fell on 4th October, was also observed with a frequency of 16.7%. As the average dates related to the beginning and the end of the active growth show, they overlap the soybean vegetation period. Unfavourable phenomenon occurred on average every six years, when the period under analysis lasted less than 152 days. In 1986-2015, a tendency was observed in the examined area, consisting in lengthening the period of active growth of plants by 0.88 per 10 years, although it was not significant (Table 2). This resulted from the tendency of this period to start earlier, by 1.71 days per 10 years (Figure 1). In 2001-2015, reduced temporal variability was recorded for the date of the beginning, the end and for the length of the period of active growth of plants in relation to the previous 15-year period (Table 2).

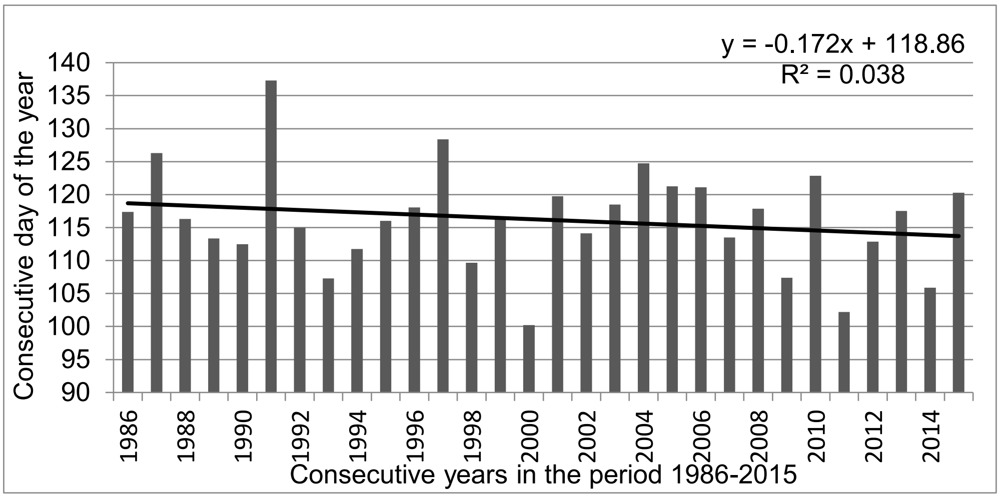

Figure 1. The beginning of the period of active growth of plants with the tendency of earlier start in the multi-annual period 1986-2015

Table 2. Characteristics of selected parameters of climatic risk to soybean cultivation in the multi-annual period 1986-2015

Parameters	Mean	Max (year)	Min (year)	SD	Criterion for determining unfavourable factors	Frequency of unfavourable factors (% years)	Change per 10 years	CC	SD		Range (max-min)		Temporal variability
									1986-2000	2001-2015	1986-2000	2001-2015	
Beginning of the period of active growth of plants	26 Apr.	17.05 1991	10.04 2000	8	Delay ≥ 7 days	16.7	-1.71	-0.196	9	7	37	23	↓
End of the period of active growth of plants	4 Oct.	19.10 2000	23.09 1996	7	Earlier start ≥ 7 days	16.7	-0.83	-0.102	8	7	26	22	↓
Length of the period of active growth of plants	162	193 2000	143 1991	11	Shortening ≥ 10 days	16.7	0.88	0.068	13	10	51	35	↓
Deficiency/excess of rainfall in the growing season (V-IX) (mm)	-18	148 2001	-219 1992	92	Deficiency > 100 mm	20	20.8	0.198	92	91	326	282	↓
Deficiency/excess of rainfall in May (mm)	-1	56 1996	-54 1988	34	Deficiency > 20 mm	30	11.2	0.299	35	32	110	90	↓
Deficiency/excess of rainfall in July-Aug. (mm)	-13	98 2010	-135 1994	56	Deficiency > 50 mm	20	16.3	0.254	60	49	195	184	↓
Total number of days with late spring frosts	2.93	8 1999 2011	0 5 years	2.5	Occurrence of phenomena	83.3	0.66	0.234	3	3	8	8	→
Number of days with moderate, and severe late spring frosts (<-2 °C)	0.63	5 2011	0 21 years	1.2	Occurrence of phenomena	30	0.51	0.377*	1	2	2	5	↑
Date of the last late spring frost occurrence	14 May	6.06 1991 2009 2012	3.04 2003	17	Delay ≥ 14 days	26.7	0.62	0.033	16	17	51	54	↑
Beginning of the period of 8 °C soil temperature at 5 cm depth	14 Apr.	25.04 1987 1997	1.04 2014	6	Delay ≥ 7 days	13.3	-3	-0.422*	6	6	22	22	→

Source: own data and elaboration. ↑ increase; ↓decrease; → no change of temporal variability; CC - correlation coefficients; *significance level $P<0.05$

The conducted analysis of water conditions for soybean revealed very high variability, both as regards time and intensity of the examined parameters. Water conditions were determined with the use of two parameters. The first parameter was the relative precipitation index (RPI), determining the moisture level for individual months and periods in the multi-annual period. The second index concerning agricultural drought was illustrated with shortages or surpluses of precipitation in relation to its optimal value.

The measurement results concerning the weather drought index, RPI (Table 3) for individual months of May-Sept. show high temporal variability of unfavourable weather conditions. In the thirty-year period under analysis, the months with an average moisture level according to RPI prevailed, with their total number amounting to 47 (31.3%). On the other hand, highly unfavourable conditions, i.e. extremely dry, occurred nine times (6%) in total. The greatest number of such cases was recorded in May – 13.3% of the analysed period. This is an adverse phenomenon, since May is a very important month in soybean development in view of the germination phase, which is a critical period for plants as regards water demand.

Table 3. Type of periods in months and periods in soybean vegetation according to the RPI index in multi-annual period 1986-2015

Type of period	V	VI	VII	VIII	IX	V-IX	VII-VIII
Extremely dry	4	0	2	2	1	2	2
Very dry	5	5	4	3	6	6	4
Dry	3	8	5	6	4	4	4
Average	8	9	7	13	10	8	14
Wet	3	3	7	3	3	5	2
Very wet	6	3	4	1	3	4	3
Extremely wet	1	2	1	2	3	1	1

Water conditions for soybean in terms of the agricultural drought index over the entire period of May-Sept. in the Bydgoszcz area revealed a large range of 367 mm. In 2001, excessive precipitation of 148 mm was recorded, while in 1992 there was a precipitation shortage of 219 mm. On the other hand, the mean recorded shortage was 18 mm. Unfavourable conditions with a shortage exceeding 100 mm occurred with the frequency of 20%. Shortages exceeding 50 mm in the critical period in soybean cultivation, occurring in July-August, were observed with the same frequency. The average shortage for this time over the thirty-year period amounted to 13 mm. In 1994, a precipitation shortage of 135 mm was observed. Another critical period for the plant under discussion was May, which revealed a 30% frequency of unfavourable water conditions (Table 2).

As Figure 2 shows, an improvement in water conditions for soybean was observed over the 30-year period. Water conditions improved by 20.8 mm per 10 years in the vegetation period, i.e. May - September, and as regards critical months – by 11.2 mm in May and 16.3 mm in July and August. All three periods under analysis revealed a positive correlation between the examined feature and the passage of subsequent years of the multi-annual period. In comparing fifteen-year periods, it was observed that temporal variability of water conditions of soybeans in the assumed balancing periods in 2001-2015 was reduced in relation to the previous 15-year period (Table 2).

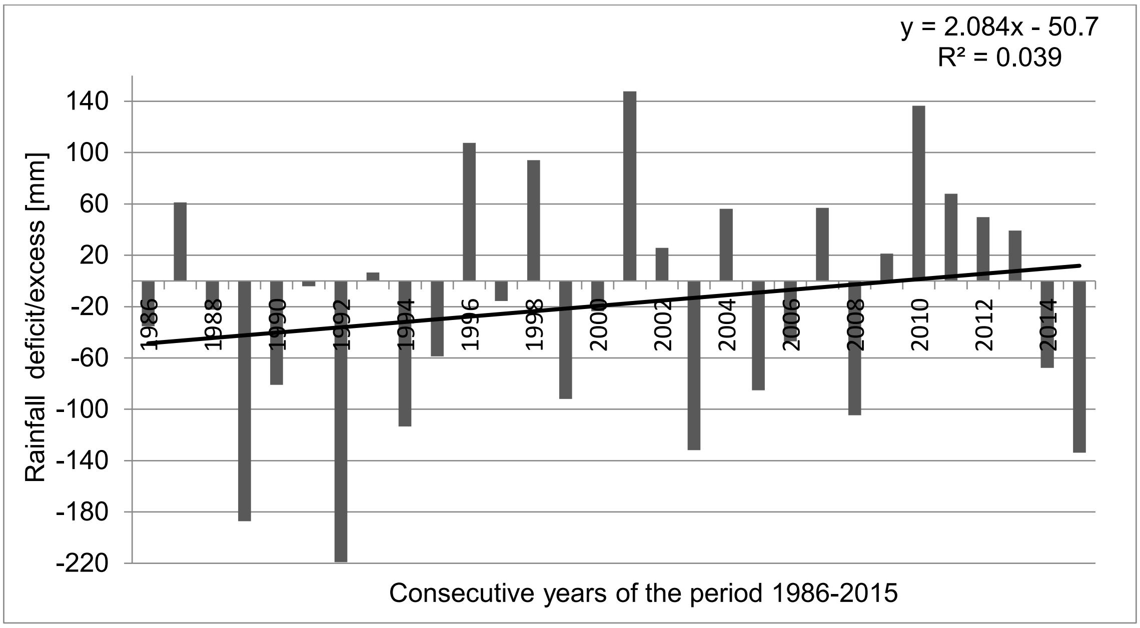

Figure 2. Deviations from the average water conditions in soybean cultivation in the period V-IX and a rising tendency in the multi-annual period 1986-2015

Soybean is a plant that is sensitive to late spring frost occurring in the Polish climate (May and June). In 1986-2015, temperatures below 0 °C were recorded in 25 years, i.e. 83.3% of the total number of years. Eight days of frost were found in 1999 and 2011. Most serious frosts, moderate and strong, characterized by a ground temperature below 2 °C, occurred with a definitely lower frequency. This weather event was recorded nine times in the multi-annual period (30%). May 14th was the average date for the occurrence of frost in the period under analysis. In 1986-2015, a strong positive correlation occurred in the number of strong and moderate frosts (an increase) by 0.51 per 10 years (Figure 3). Additionally, the total number of all spring frosts increased by 0.66 per 10 years. It was also observed that the last frost occurred later, although it was not a significant trend of changes. In the course of the analysis of the 15-year period, a high increase of temporal variability was found for moderate and strong frost. An increase in variability was also recorded for the date of the last frost occurrence. Nevertheless, no changes were recorded in the number of all late spring frosts (Table 2).

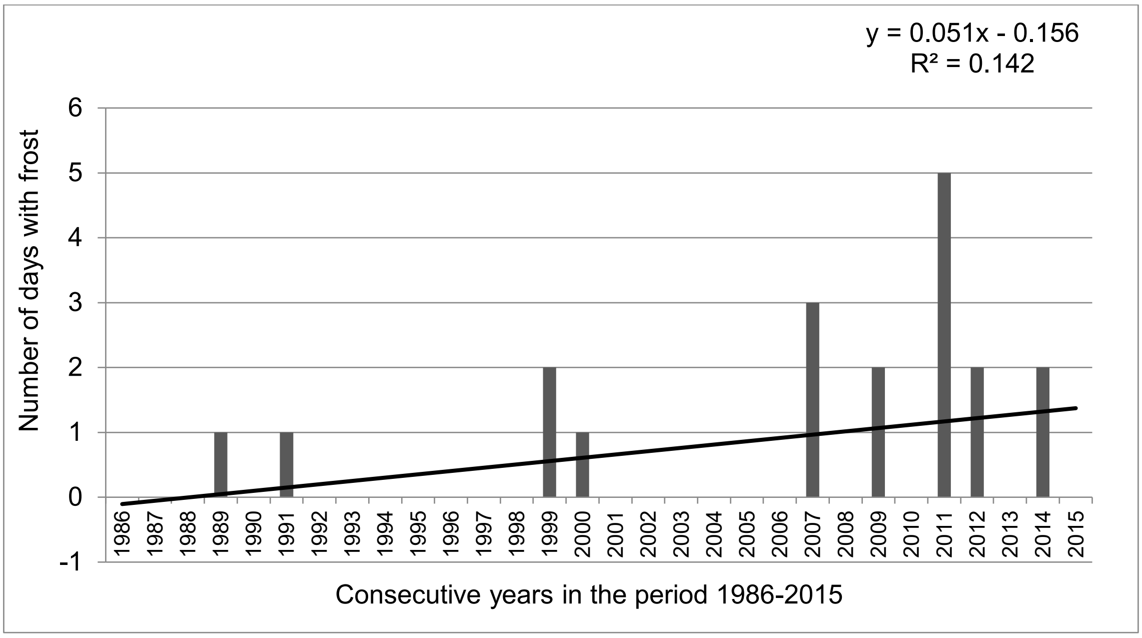

Figure 3. The number of days with moderate and strong frosts during late spring and a rising tendency in the multi-annual period 1986-2015

In 1986-2015, the soil reached a temperature of 8 °C at an average depth of 5 cm on 14th April. The greatest delay, until 24th April, was found for 1987 and 1997. Apart from the above-mentioned years, two more unfavourable cases of such a delay were observed, which resulted in the expected frequency of the delayed possibility of soybean sowing amounting to 13.3% for all of the years. A negative correlation was found between the value of the index and the year. Over time, the beginning of a period with a temperature of 8 °C at a depth of 5 cm (Figure 4) occurred earlier. This is a favourable phenomenon. In 2001-2015, no changes in the extremity of the discussed index were observed in relation to the previous 15-year period (Table 2).

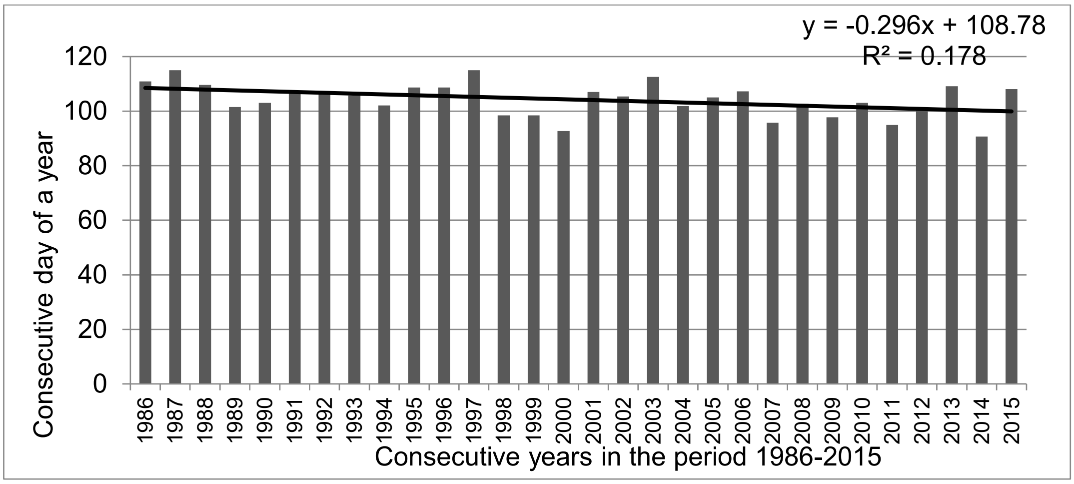

Figure 4. The beginning of the period of 8 °C soil temperature at a depth of 5 cm with the tendency of an earlier start in the multi-annual period 1986-2015

Due to the rising temperatures associated with predicted climate change the possibility of adapting crops to the environmental conditions of an area may change. Studies on the effect of climate and adaptation policies are becoming more serious area of scientific interest, for instance, the effect on the production of crops such as corn, wheat and rice (Hoogenboom, 2000; Challinor and Wheeler, 2008) A dynamic crop model the IBSNAT-ICASA (International Benchmark Sites Network for Agro-technology Transfer) used by Parry et al. (1999) to estimate climate potential changes in major cereals and soybean crop yield, shows that climate change will increase yields at high and mid-latitudes and decrease yields at lower latitudes. A data analysis for 1986-2015 confirmed the strong effect of the temporariness of the climate in Poland on the climatic risk for soybean cultivation in the Bydgoszcz area which, in most cases, corresponds to the results obtained by other researchers. The tendency of thermal conditions to improve (as demonstrated by a longer period of soybean vegetation with an earlier beginning of the period of active growth of plants and an earlier date on which the soil at a depth of 5 cm reached the temperature of 8 °C in the multi-annual period) confirms the opinion that an increase in temperature and lengthening of the vegetation period was observed all across Poland (Stuczyński et al., 2000; Kozyra et al., 2009; Żmudzka, 2012).

As reported by Doroszewski et al. (2012), the intensity of extreme, adverse meteorological phenomena is increasing. This claim is supported by the results obtained for the occurrence of moderate and strong frosts in the Bydgoszcz area. On the other hand, Wibig and Glowicki (2002) confirmed that with rising minimum temperature, Poland experienced a prolongation of the frost-free season.

The observed improvement in water conditions for soybean cultivation in the period under analysis and the reduction of their variability disprove the thesis put forward by Stuczyński et al. (2000) and Kundzewicz et al. (2006) of an intensified occurrence of drought, being the result of periods without precipitation or with low precipitation. The obtained image of changes in the climatic risk for soybean cultivation in the area of Central Poland is generally consistent with the evaluation made by Januszewska-Klapa (2016). At the same time, it confirms certain aspects of the theses related to climate warming presented by Starkel and Kundzewicz (2008). As verified by studies of many authors' scenarios of projected climate change in Central Europe, especially on precipitation, are ambiguous (Giorgi et al., 2004; De´que´et al., 2007; Wibig, 2012; Anders et al., 2014). Models indicate precipitation decreasing in the south and increasing in the north Europe. The position of the exact border line at which the positive or negative climate change signal starts is not certain - it varies over a broad band somewhere between mid-Scandinavia and the Alps, within which Poland is located (Christensen et al., 2011). It is very important to be able to recognize and evaluate this uncertainty by examining the temporal variability of climatic and agro-climatic indicators in terms of agricultural production in this area. This is essential for the consideration of the adaptation to the future climatic conditions in these regions. As a result of changes in the global climate the zones for cultivation of specific plants can be shifted. For governments and land managers it is important to understand these changes in order to develop adaptation strategies for resources and development planning (Holzkämper et al., 2013).

Conclusions

This paper summarizes results of the study on unfavourable factors increasing the risk for soybean cultivation in the transitional type of moderate climate in Central Poland. On the basis of the conducted analysis of adverse weather factors in soybean cultivation occurring in 1986-2015 the following conclusions can be drawn. Unfavourable conditions for the climatic conditions of soybean cultivation in the Bydgoszcz area in the multi-annual period under analysis demonstrated a high frequency and very high variability in individual years. Significant trends were observed for the following indices: an increase in the number of moderate and strong frosts – an unfavourable phenomenon, earlier beginning of the period in which the top soil reaches 8 °C at a depth of 5 cm – a favourable phenomenon. Other factors did not reveal any significant changes over time. In 2000-2015, as compared to the previous 15-year period, it was found that temporal variability concerning the number of late spring moderate and strong frosts and the date of the last late spring frost increased. The tendency of favourable climatic changes, such as an improvement of water conditions, earlier beginning of the active growth period, with its simultaneous lengthening and earlier dates when appropriate thermal conditions for soybean sowing are reached, suggests the possibility of developing cultivation of this plant in the area of the central part of Poland.

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