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THE CLIMATIC BACKGROUND OF AGRICULTURAL PRODUCTION IN POLAND (1951–2000)

Abstract: This article presents the results of studies conducted on the variability of thermal and precipitation conditions in Poland in the second half of the 20th century, especially taking into consideration periods which were unfavorable for agricultural production. Averaged spatial temperatures and precipitation totals from consecutive years 1951 to 2000 were used. A significant increase in spring temperatures was noted, while the winters also became warmer. This had a significant effect upon the change of the thermal vegetation period's duration. No changing trends were noted with regard to the amount of precipitation.The analysis of the seasonal structure during the anomalous years, with regard to temperature and the amount of precipitation, made it possible to pinpoint years particularly unfavorable for agricultural production. There was a certain repeatability of unfavorable conditions, tied to the existence of a relatively stable 8-year cycle of temperature change, which was especially noticeable during the wintertime. During the last two decades of the 20th century, high temperature values, occurring also in the summertime, in combination with insufficient precipitation, contributed to the occurrence of dry spells and even periods of drought. The occurrence of dry spells during the vegetation period and the extreme shortening of the vegetation period have a significant effect upon the amount of grain crop production.

Key words: air temperature, atmospheric precipitation, variability, crop production, Poland.

One of the most important problems in climatology is the definition of variability and the assessment of climatic changes on various scales of time and space. An additional incentive for the undertaking of studies concerning this problem is the currently noted “signal” of global warming. The main directions of research include the definition of the “share” of natural and anthropogenic conditions in climate variability, the past evolution and the prognosis of climatic conditions, and the assessment of the possible consequences of climate change in the natural environment, as well as in various domains of human economic and social activities. In recent years, a lot of emphasis has been given to the study of extreme meteorological (climatic) phenomena. This is due to the noticeable change in their frequency, as well as, in the case of air temperature, an increase in mean value, and also to the significant and generally negative effect of these phenomena upon the economy. The intensification of these phenomena is spatially varied, which is why these problems are being solved mainly on a regional scale.

The aim of this paper is to define climatic element variability in Poland during the second half of the 20th century, and also to pinpoint periods especially unfavorable for agricultural production. Climatic conditions present during the vegetation period are the most significant for the growth, development and harvesting of cultivated plants. Some factors important for crop production include air temperature and atmospheric precipitation. Given the climatic conditions in Poland, the latter factor was judged to be especially significant during periods critical to the development of cultivated plants (Dzieżyc, Nowak, Panek, 1987). The set of meteorological factors associated with the winter and early spring, notably temperature (e.g. freezing) and the amount of and type of precipitation, also constitute a potential danger to vegetation. Meteorological elements in Poland exhibit not only seasonal variability, but also great variability from one year to the next. Variability and diversity in the course of meteorological events during particular years often leads to overly shortened crop production and vegetation periods. A delay in the beginning of these periods is especially detrimental to agricultural production. The recent contemporary observation of the current warming trend – its extent and seasonal spread in Poland – is also a significant challenge for agricultural production.

The data used for the analysis of climatic variability in Poland were the average monthly air temperature values, and the totals of atmospheric precipitation, collected at 45 and 50 meteorological stations of the IMGW,[1] respectively; located less than 300 m above sea level, for each year from 1951 to 2000. Average values were obtained from all the stations included, producing series representing temperature and precipitation throughout the area of Poland. The spatially averaged series obscure the local characteristics of specific climatic element areas and are often used for the assessment of climatic conditions from the standpoint of various sections of the economy, including agriculture.

The direction and rate of change in temperature and precipitation, as well as their fluctuation and the occurrence of anomalous seasons, was defined. Temperatures/precipitation amounts considered anomalous (extremely anomalous) for particular seasons of the year were those above the 90% quantile (95%), and those falling below the 10% quantile (5%) (Klein Tank et al., 2002). The aim of the analysis was also to define the effect of seasonal changes in temperature upon the duration of the thermal vegetation period. The amount of moisture insufficient for plants during the vegetation period (April – October), with reference to central Poland, was defined on the basis of the Selyaninov hydrothermal coefficient $K = P/0,1\Sigma\, t$, where P = total precipitation in the given period, expressed in mm, and t = average daily air temperature in °C (Radomski, 1973). Coefficient values lesser than 1.0 indicate the presence of a dry spell. A period during which K is less than 0.5 is classified as an extreme dry spell (drought).

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[1] IMGW – Instytut Meteorologii i Gospodarki Wodnej (The Institute of Meteorology and Water Management).

VARIABILITY IN AIR TEMPERATURE AND ATMOSPHERIC PRECIPITATION

In the years 1951 – 2000, on average, a significant increase in spring air temperatures was noted in Poland (Table 1). Winters became milder; the mean winter temperature in the last decade of the 20th century was approaching 0°C. The strongest temperature growth-trend occurred on the turn of winter and spring (in February and March) (Fortuniak, Kożuchowski, Żmudzka 2001). Some cooling was also characteristic of June and the period from September to December. However, only the temperature growth-trends in March and May were statistically significant (Kożuchowski, Żmudzka, 2002).

Table 1.

Trend ranking (τ = Mann-Kendall statistic values) and the linear trend coefficients a, of changes in the seasonal and yearly, regionally averaged temperatures [°C per year] and atmospheric precipitation totals [mm per year] in Poland from 1951 to 2000 (* the trend is significant at the 0.05 level) (Żmudzka, 2004)

	Air temperature					Atmospheric precipitation				
	Dec.– Feb.	Mar. – May	Jun.– Aug.	Sep.– Nov.	Jan.– Dec.	Dec.– Feb.	Mar.– May	Jun.– Aug.	Sep.– Nov.	Jan.– Dec.
a	0.04	0.04*	0.00	-0.00	0.02*	-0.03	0.33	-0.24	0.24	0.28
τ	0.18	0.30*	-0.03	-0.09	0.17	-0.00	0.12	-0.02	0.09	0.05

The last two decades of the 20th century deserve particular attention. This was when the rate of climatic warming increased, what was noticeable not only during the winter/spring season (Jan. – May), but also during the warm part of the year. As it was shown (Fortuniak, Kożuchowski, Żmudzka, 2001), halfway through the period studied, i.e. during the 1970s, relatively warm winters were accompanied by cool summers. Toward the end of the 20th century, high temperature values started to appear during the summers as well. At the end of the 20th century only the autumns were somewhat cooler than the 50-year temperature average.

In the second half of the 20th century, the amount of precipitation throughout the area of Poland did not undergo a significant changing trend (Żmudzka, 2002). The directional coefficients of simple regressions indicate a slight increase in the amount of precipitation during the spring and autumn, and a decrease during the summer and winter (Table 1). The individual seasons were not homogeneous with respect to the rate or the direction of change (Żmudzka, 2002). During the spring the increase in precipitation took place in March and April; in May, it was found, the amount of precipitation decreased. June was characterized by an increase, and July and August by a decrease. During the autumn, the greatest increase in the amount of precipitation was determined to be in September; in November the tendency was negative. The slightly negative shift during the winter was caused by a decrease in the amount of precipitation in January and February and an upward trend in December. It is worth mentioning here that during the long--term period studied, the length of time that the snow cover remained on the ground has decreased significantly (e.g. in Warsaw, the coefficient for the linear trend of change in the snow cover duration time was –1.1 days per year); the snow cover's thickness has also decreased.

The highest yearly average amount of precipitation in a 10-year period was shown for the years 1961–1970, while the lowest was shown for the years 1981–1990. The 10-year period 1981–1990 was also atypical due to the fact that the highest monthly precipitation during the course of the year was shifted from July to June (Żmudzka, 2002). The period, in which the average yearly precipitation total most closely resembled the long-term average, was the last 10 years of the 20th century. However, this "normalcy" was the result of significant variations during different seasons compensating for each other during the course of the year – excessive precipitation in the spring and low precipitation in the summer.

A fuller picture of the temperature and precipitation fluctuations, averaged throughout the area of Poland, is provided by the curves, illustrating their cumulative deviation from the averages of the long-term period 1951–2000 (Fig. 1). In the case of temperature, the shape of the curves for the winter, spring and the whole year follows a rising trend – in the first half of the long-term period, the dominant type of deviation is negative, while after 1988, it is positive. The cumulative deviations for the spring and the year are greater than the value of three standard deviations, indicating the presence of ordered fluctuations in the time series (Drozdov, Grigoreva, 1972 per Fortuniak, Kożuchowski, Żmudzka, 2001). Summer temperatures experienced an increase of the changing trend in the second half of the long-term period.

The seasonal structure of the long-term precipitation pattern is somewhat more complicated. However, aside from the winter season, there are two clearly marked periods when negative deviations dominate: in the 1950s and in the 1980s/early 1990s; and then two when positive deviations dominate: in the 1960s/1970s and from the mid-1990s onwards. On the turn of the 1980s and 1990s deserves particular attention. This was when temperatures rose and the amount of precipitation dropped significantly, what resulted in the occurrence of dry spells, and even periods of drought (Bobiński, Meyer, 1992). A similar situation also took place in the early 1980s.

Taking into consideration the seasonal structure of the anomalous temperature values and precipitation totals (Fig. 2), one can note that conditions unfavorable for agricultural production reoccur every 7 – 8 years on average, in association with particularly cool winter/spring periods. Such cold (and generally dry) winters occurred for example in: 1954, 1963, 1970, 1985 and 1996. This is an indication of the existence of a relatively stable 8-year cycle of temperature change, which is particularly noticeable in the wintertime (Żmudzka, 1999; Fortuniak, Kożuchowski, Żmudzka, 2001). At the beginning of the second half of the 20th century, several exceptionally warm and dry spring/summer periods occurred (in 1951 and in 1953). The 1970s

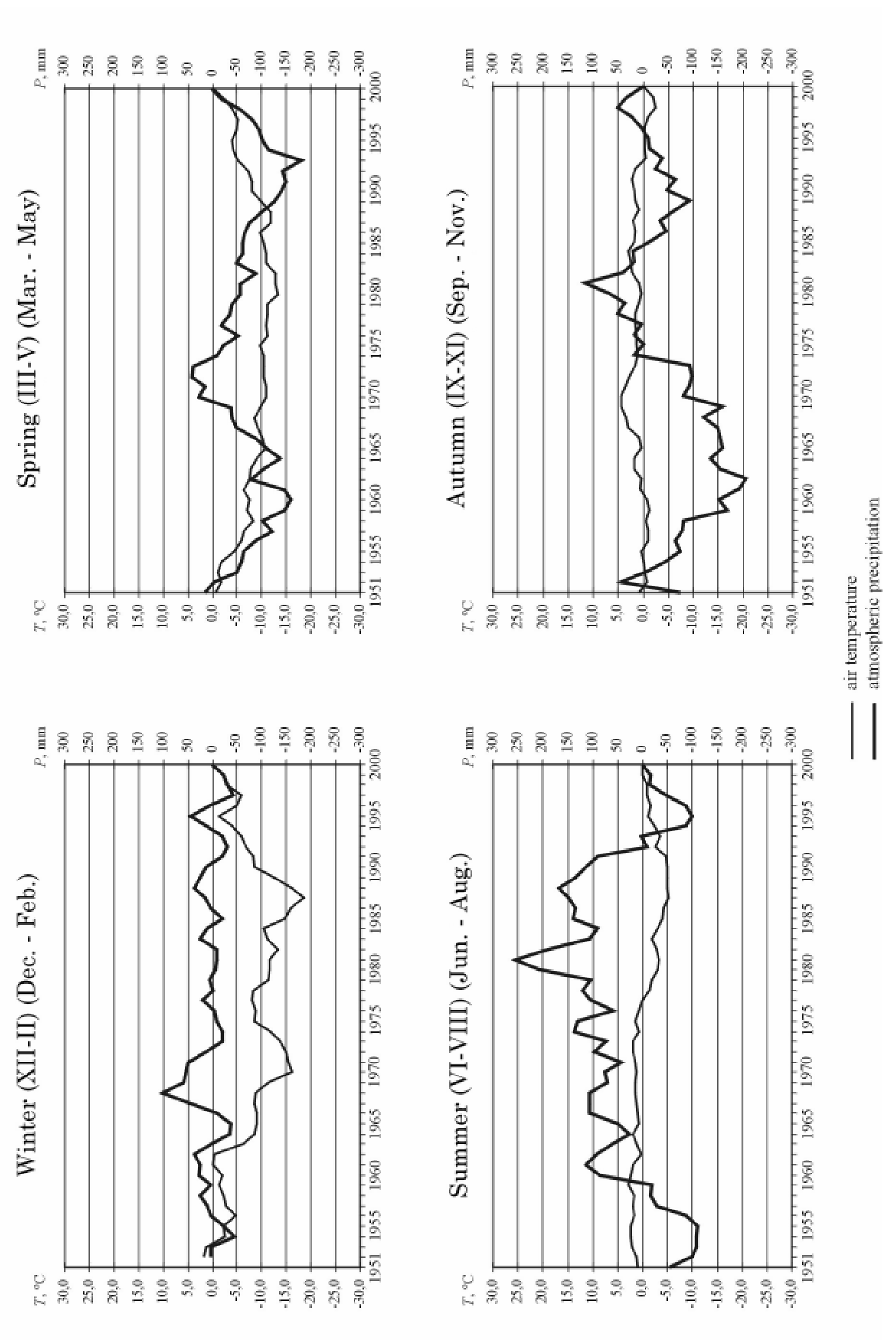

Fig. 1. The cumulative deviations from the averages, of the seasonal, spatially averaged air temperature values and atmospheric precipitation totals in Poland, from 1951 to 2000 (Żmudzka, 2004)

on the other hand were a period of extremely wet and cold years. The turn of the 1980s and 1990s (1989 – 1994) was a period of several years with abnormally warm and dry winter/spring as well as summer seasons. Concluding the 20th century, the year 2000 was the warmest year in Poland out of the entire preceding half-century, and probably also out of the entire period during which uninterrupted instrumental measurements have been conducted, beginning in Warsaw in 1779 (Kożuchowski, Żmudzka, 2002; Lorenc, 2000). In 2000, the average air temperature for the entire area of Poland was 9.5°C. The spring, autumn and winter were exceptionally warm, and the turn of spring and summer was dry as well. At this point, it is worth noting that two particularly warm periods were separated by years that were relatively cool, and in 1997 and 1998 intense precipitation and flooding regionally occurred: in the summer of 1997 and in the spring and summer of 1998 in the south, and in the autumn in the south and coastal areas of Poland. These years did not however stand out as anomalous in the series of spatially averaged precipitation totals analyzed.

From an agricultural production standpoint, certain detailing of the assessment of climatic conditions can be obtained by defining dry spell periods on the basis of the monthly values of the Selyaninov hydrothermal coefficient *K*. Years considered to be especially unproductive, due to the length and intensity of dry spells in central Poland, are assembled in Table 2.

Table 2.

Years of dry spell occurrence in central Poland
(*K* – the Selyaninov hydrothermal coefficient) (Żmudzka, 2004)

Year	*K*		Year	*K*	
	Apr. – Oct.	<1		Apr. – Oct.	<1
1951	0.7	Jun. – Aug.	1979	0.9	May – Jun.
1953	0.8	Apr. – May, Aug.	1983	1.0	Jun. – Jul.
1954	1.0	May – Jun., Aug.	1988	1.0	Apr. – May, Sep.
1963	1.0	Jun. – Jul.	1992	0.9	May – Aug.
1964	0.9	Apr. – May, Jul.	1993	1.0	Apr. – May, Aug.
1967	0.9	May, Jul. – Aug.	1994	1.4	Jun. – Aug.
1969	1.0	May, Jul.	1999	1.1	Jul. – Sep.
1976	0.8	Apr., Jun. – Aug.	2000	1.0	Apr. – Jun.

In most cases, dry spells during the vegetation period were associated with anomalously low precipitation totals; towards the end of the 20th century they were also caused by exceptionally high temperatures.

Quantile (%) 1951-2000	Dec. - Feb.		Mar. - May		Jun. - Aug.		Sep. - Nov.			
	t	*R*	*t*	*R*	*t*	*R*	*t*	*R*	temperature *t*	*R*
>95.00	>1.76	>136.60	>9.36	>179.30	>18.16	>281.40	>9.80	>205.40	extremely warm	extremely wet
90.01÷95.00	1.05÷1.76	133.61÷136.60	8.76÷9.36	162.21÷179.30	18.02÷18.16	275.21÷281.40	9.26÷9.80	188.11÷205.40	anomalously warm	
80.01÷90.00	0.51÷1.04	126.81÷133.60	8.35÷8.75	150.61÷162.20	17.71÷18.01	254.61÷275.20	8.83÷9.25	167.41÷188.10		
60.01÷80.00	-0.71÷0.50	111.01÷126.80	7.73÷8.34	131.01÷150.60	17.21÷17.70	231.01÷254.60	8.51÷8.82	145.41÷167.40	warm	wet
40.01÷60.00	-1.57÷-0.72	101.01÷111.00	7.13÷7.72	116.01÷131.00	16.87÷17.20	212.01÷231.00	8.27÷8.50	125.61÷145.40	NORMAL	NORMAL
20.01÷40.00	-3.33÷-1.58	76.81÷101.00	6.19÷7.12	102.01÷116.00	16.29÷16.86	187.01÷212.00	7.41÷8.26	108.81÷125.60	cold	dry
10.01÷20.00	-4.59÷-3.34	67.01÷76.80	5.80÷6.18	94.91÷102.00	15.90÷16.28	163.81÷187.00	7.10÷7.40	102.81÷108.80		
5.01÷10.00	-5.47÷-4.60	63.21÷67.00	5.39÷5.79	84.61÷94.90	15.76÷15.89	141.96÷163.80	6.86÷7.09	76.46÷102.80	anomalously cold	
≤5.00	≤-5.48	≤63.20	≤5.38	≤84.60	≤15.75	≤141.95	≤6.85	≤76.45	extremely cold	extremely dry

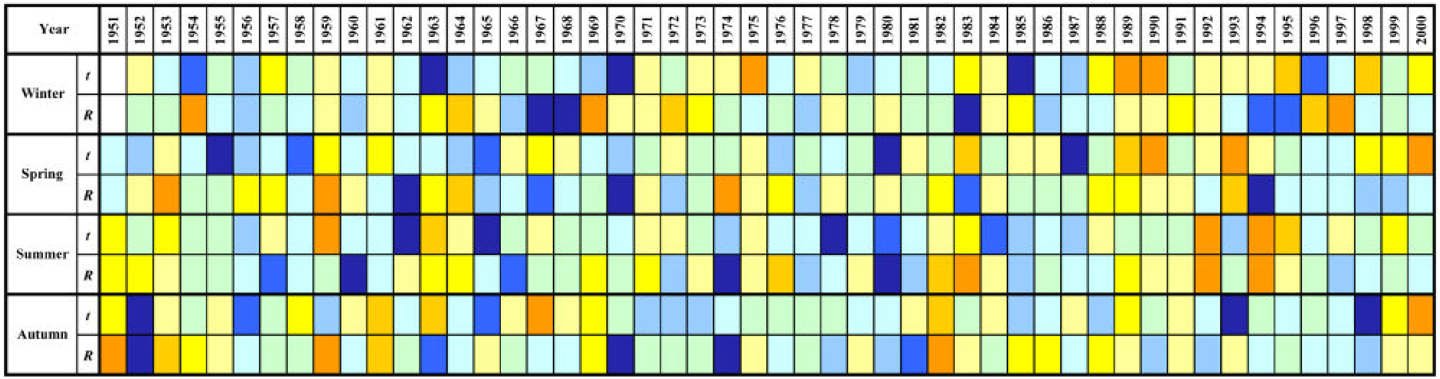

Fig. 2. The thermal t and precipitation R classification (according to quantile values for the period 1951–2000) and the seasonal calendar for Poland.

THE THERMAL VEGETATION PERIOD

The seasonally varied trend of air temperature change resulted in the changing of the starting and ending times and the length of the thermal vegetation period. The average starting and ending dates and the average duration of this period corroborate the norms acknowledged in the literature, regarding the spatial layout of these time parameters throughout Poland, calculated based on data from earlier long-term periods (Żmudzka, 2001). Although the general outline of the spatial structure of images obtained is similar, there are some noticeable differences, especially with regard to the beginning of the vegetation period. This indicates the earlier beginning of this period, especially in the western part of Poland. A slight increase in the average duration of the vegetation period is also noticeable in this region. During the last two decades of the 20th century, the starting dates for the vegetation period in Poland had, on average, "moved" from the beginning of April to the last five days of March. The close of the vegetation season had also been accelerated slightly (on average, in Poland, it falls on the first five days in November), in association with a cooling trend observed during the period lasting from September to December.

The change in the duration of the vegetation period, defined for the 20-year-period from 1981 to 2000, in relation to the years 1951 to 1980, averaged 5 days in Poland (by advancing 6 days in the beginning and one day towards the end). Despite the warming, the relatively small changes in the duration of the thermal vegetation period in the second half of the 20th century, were caused by changes in the thermal regimen: winter became shorter, while it was predominantly early spring and early winter, and spring itself as well – but to a lesser degree, which became longer (Fortuniak, Kożuchowski, Żmudzka, 2001; Kożuchowski, Żmudzka, 2002).

In most cases, the results of studies pertaining to climate change prognoses suggest the further lengthening out of the thermal vegetation period (mainly due to the acceleration of its onset), as well as increasing spatial variability of the thermal vegetation period throughout the area of Poland. However, depending upon which probable climate change scenario one accepts, assessments of the predicted rate of increase in vegetation period duration vary significantly – ranging from several days (a version of the HadCM2 GS atmospheric general circulation model, taking into account the increase of greenhouse gasses and sulfate aerosols; Liszewska, Osuch, 1999; Fortuniak, Kożuchowski, Żmudzka, 2001), to several dozen days (and even exceeding 100 days in some regions) over the second half of the 21st century (the GISS and GFDL models which assume the doubling of the amount of carbon dioxide in the atmosphere; Kędziora, 1995; Demidowicz et al., 1999; Deputat 1999).

THE CONNECTIONS BETWEEN CROPS AND THERMAL/PRECIPITATION CONDITIONS

During their successive developmental phases, different species of cultivated plants exhibit significant differences with regard to the optimal thermal and precipitation conditions which they require. In different phases crops also vary with regard to sensitivity to changes in temperature and precipitation. Although the assessment of thermal and precipitation conditions – based on monthly (seasonal) averages; does not exhaust the entire spectrum of factors significant for plant growth and development, and does not always correspond to the agricultural assessment, one can observe that quite often, years deemed unfavorable according to the accepted criteria, were the years during which low crop production was determined (Żmudzka, 2004). For instance, values of the Selyaninov hydrothermal coefficient *K* for the vegetation period, and the starting dates of this period (calculated by the Huculak-Makowiec method, based on daily temperature values) (Huculak, Makowiec, 1977) account for the dozen percent of variation in the amount of grain crop production in central Poland (Table 3).

Table 3.

Linear correlation coefficients (*r*), regression equation coefficients (*a*) and multiple correlation coefficients (*R*) for the average oat harvest, with hydrothermal coefficient *K* values (Apr. – Oct.) and period of vegetation beginning dates (*Bvp*) for the Warsaw region (according to data from 1955 to 2000).

	r	*a*	*R*
K	0.28	4.05	0.43
Bvp	-0.31	-0.10	

CONCLUSIONS

1. The presently observed, seasonally variable changes in air pressure and atmospheric precipitation create qualitatively variable agricultural production conditions in Poland, e.g. an earlier beginning of the vegetation period resulting from the significant rise in temperature during the winter/spring season, the recession of the thermal winter, and a significant increase in summer temperatures during the last two decades of the 20th century.

2. In the context of the advancing warming trend, one can observe the significant fluctuation of thermal conditions which, in conjunction with variable precipitation amounts, determine the presence of conditions unfavorable for plant growth and development. The coincidence of anomalously low precipitation totals with exceptionally high temperatures towards the end of the 20th century had determined, among other things, the occurrence of dry spells and even droughts, which then persisted for several years.

3. A certain recurrence of conditions unfavorable for agricultural production is also tied to the existence of a relatively stable 8-year cycle of temperature variation, which is most clearly marked in the wintertime.

4. Despite uncertainties regarding the future extent and direction of climatic changes, due to the significant influence of the factor of climate upon the development and harvesting of cultivated plants, introducing adaptive processes into agriculture may prove to be necessary.

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