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The frequency of occurrence of extreme and detrimental meteorological conditions for vegetation of crops in Poland (1971–2010)

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Abstract: *The frequency of occurrence of extreme and detrimental meteorological conditions for vegetation of crops in Poland (1971–2010).* The subject, and aim of this study is the comparison of the frequency of occurrence of thermal, precipitation and pluvio-thermal conditions detrimental to agriculture in Poland during two periods: 1971––2000 and 1981–2010, constituting the former, and the current climate normal, respectively. Each month of the vegetation period (April–October) was, in accordance with the current accounts carried out by agriculture correspondents, assigned to one of the following categories: favorable for vegetation, dry, dry and cool, cool, cool and humid, humid, dry and hot. An identical classification of meteorological vegetation conditions was also carried out for months characterized by extreme air temperature and precipitation values. Extreme values were defined as those monthly temperature mean values, and monthly precipitation totals, the probability of exceeding of which is lower than 10%, i.e. their probability of occurrence, or the so-called recurrence interval, is once every 10 years. The differences existing between the analyzed 30-year periods, can be attributed to the present day climate change – a significant increase in air temperature in April, June, July, and August, with a lack of significant precipitation trends. In the two compared periods, an increase in the number of extreme months from 74 to 82 was stated. The biggest changes during the extreme months were observed for precipitation deficits combined with hot air temperatures, namely, an increase from 15 to 29 months. In general, all the analyzed months of the vegetation period showed an increase in dry months (90 to 105 cases) and a decrease in cool months (44 to 24 cases).

Key words: meteorological vegetation conditions, extreme values, climate change, Poland

INTRODUCTION

Most of the information regarding climate characteristics pertain to average conditions. These, in turn, are most often understood as the 30-year periods recommended by the World Meteorological Organization (WMO). However, as early as 1956, the WMO recommended that each of its member states should update their 30-year normals every 10 years, but this practice was not employed by every member state (Arguez and Vose 2011). Only the 1961–1990, 1971–2000, and, recently, 1981–2010 climate normal, became commonly used whilst preparing subsequent climate characteristics. This particular issue is especially important in the light of global warming clearly progressing in recent decades (Jarraud 2013).

One of the vital characteristics of the Polish climate is its high variability in subsequent years, which results mainly from the country's location in the temperate climate zone. In this particular climate zone the clashing of polar air masses (from the Atlantic Ocean) with the more dry masses (from the continent) occurs quite frequently. Significant weather anomalies, manifesting themselves by large deviations of meteorological elements, are related to some

synoptic situations. Among the latter there are the extreme values. From a formal, and statistical point of view, phenomena are considered extreme, when their recurrence is equal to 1.5, and most often 10 times per 100 years (Kundzewicz and Matczak 2010). There is a common belief, that with the ongoing climate change the frequency of extreme weather phenomena will be increasing (Kundzewicz and Kowalczak 2008).

Despite the increasing level of agricultural engineering, and progress achieved in the selection of adequate cultivated plants, the highly diversified weather pattern is still the principle cause of highly variable meteorological vegetation and crop yield conditions in particular years. The synthesis of these phenomena, above all the ones that are detrimental and extreme in terms of spatial variability in Poland, has been elaborated in the following works: *The Climatic Atlas of Elements and Phenomena Detrimental to the Polish Agriculture* (Koźminski et al. 1987), *The Atlas of the Climatic Risk of Cultivating Plants in Poland* (Koźminski and Michalska 2001), and *The Atlas of the Extreme Meteorological Phenomena and Synoptic Situations in Poland* (Ustrnul and Czekierda 2009).

The aim of this study is the evaluation of the pluvio-thermal conditions of the vegetation of key crops in Poland, during the extreme years in the light of general vegetation conditions in the 1971–2010 period. In particular this article will attempt to answer the following questions: What is the relation of the frequency of occurrence of extreme and detrimental weather conditions during the vegetation period? What is the trend of weather conditions for the vegetation of key crops in Poland in the light of the global warming?

MATERIAL AND METHODS

This study is based on mean monthly temperature values, and monthly precipitation totals collected from 53 weather stations evenly distributed throughout Poland. The obtained values were averaged for the entire country, so it is important to emphasize that further discussion pertains to area values. This particular method was also used by authors such as: Kożuchowski (1996), Kożuchowski and Żmudzka (2001), and Żmudzka (2004). The studied period included 40 years of data (1971–2010), which basically encompasses two climate normals recommended by the WMO: 1971–2000 and 1981–2010. Due to the fact that information about cultivated plants was available at the end of each month, the authors limited themselves to analyzing only the vegetation period, which lasts from April until October. Extreme weather values were defined on the basis of the work written by Niedźwiedź et al. (2004), and include mean values of air temperature and precipitation totals, whose probability does not exceed 10%, which basically means that their recurrence period is once every 10 years. Our analysis shows that such conditions included four the coolest years, four the warmest years, four the driest years and the most humid years.

At the same time, on the basis of agricultural and meteorological bulletins concerning the status of key crops in Poland, published successively in the

years 1971–1999 (*Monthly Agrometeorological Review*, and *Decadal Agrometeorological Bulletins*, as well as other agricultural and statistical materials), the authors determined the pluvio-thermal conditions for the vegetation of the key cultivated plants in each of the 280 months of the period under research, in total in production conditions. In accordance with the content of the agrometeorological bulletins on the state of the cultivated plants, both favorable and detrimental weather conditions as outlined below, were distinguished: excessively low air temperature, insufficient precipitation, excessive precipitation, low air temperature coupled with insufficient precipitation, and high air temperature coupled with insufficient precipitation (Zawora 1993). Among the possible combinations of the thermal and precipitation conditions, I never noted the results of excessively high temperatures, and excessively high temperatures coupled with excessive precipitation, detrimental to the vegetation of plants.

The subsequent stages of this study included: distinguishing sequences of extreme months in a given vegetation period, analyzing the occurrence of cases where a given month was simultaneously extreme in terms of precipitation and temperature, the determination of the number of extreme months in particular years, the comparison of the structure of extreme weather phenomena in the periods 1971–2000 (the former climate normal) and 1981–2010 (the current climate normal), as well as the comparison of the pluvio-thermal conditions of vegetation of the key cultivated plants, during the years defined as extreme, in the light of the entire period under research. This study does not take into account any aspects of the regional diversity of the analyzed phenomenon. It is not concerned with the particular plant species of the cultivated plants, not to mention their varieties. In addition, it does not pertain to the amount of obtained crop yield, which is largely dependent on the current state of agricultural engineering, above all on the amount of mineral fertilization. This study attempts to evaluate the application of formal, and statistical criteria to the analysis of extreme meteorological vegetation conditions, as well as to provide a brief evaluation of the selected features and trends in the Polish agro-climate in the era of a significant global warming.

RESULTS AND DISCUSSION

The period under research (1971–2010) is characterized by a significant increase in annual temperature amounting to 0.3°C a decade, and statistically significant temperature increases amounting to $\alpha = 0.05$, for April, June, July, and August. The values of the decadal temperature increase in the aforementioned months equal to 0.74, 0.37, 0.68, and 0.34°, respectively. In the remaining months (except December) the increase in temperature is not relevant. In December a decreasing air temperature trend is observed. In the 1971–2000 period the mean area air temperature value amounted to 8°C and in the subsequent period (1981–2010) to 8.3°C. The annual precipitation totals in the two time periods did not differ much, and amounted to 601 and 604 mm, respectively.

The occurrence of extreme thermal or precipitation conditions in the vegetation period of the particular months from April to October, was observed in almost every year except 1981 and 1998. In 14 cases simultaneous occurrences of extreme thermal and precipitation conditions were observed in the same month. In 13 of the analyzed years, extreme months occurred during 2–4 consecutive counts. The longest (four months) sequences occurred from April to July (1974, 1980) and from May until August (1984, 1992). In 1974, they were primarily extremely cool months, in 1980 extremely humid, in 1984 there were various extreme months, and in 1992 mainly warm and dry. Additionally, in the year 1992, a fifth extreme month occurred in October, which was independent of the aforementioned extreme month sequences. A significant number of extreme months was also observed in 2001 (April, June, July, September and October), however, in this case they were mainly humid, and cold months with the exception of the dry October. Another such case came to pass in 1993 with extreme months occurring from April to June and also August and October. With the exception of October, the aforementioned months were hot and dry.

The comparison of two 30-year periods, officially regarded as climate normals (1971–2000 and 1981–2010), indicates clear changes in the structure of extreme meteorological phenomena. In the former period, a total of 74 extreme months was observed, whilst in the latter (1981–2010) 82 months were recorded. What is interesting, is the fact that an increase in the frequency of occurrence of favorable months for vegetation (from 8 to 12) was noted, despite the occurrence of extreme thermal and/or precipitation conditions in the compared 30 year periods. If we summed up the number of months with extremely low precipitation, and the number of months with extremely low precipitation, and high temperatures combined, we would see, that the number of occurrences of extreme months increased from 34 to 41. What is more, the number of cases with extremely low precipitation combined with extremely high temperature increased from 15 to 29, in other words almost twofold (Table).

The presented considerations pertained to the characteristics of the meteorological conditions during the vegetation period, taking into account the months that were defined as extreme in accordance with the adopted formal and statistical criteria. A slightly different picture is provided by the analysis of meteorological conditions in every single month of the vegetation period (April–October), and, in particular, when we compare these conditions in the two analyzed 30--year meteorological periods constituting the former and current climate normals. The number of months considered as favorable for agriculture by agricultural correspondents, remained practically unchanged. The most significant decrease was observed in the number of months with low air temperatures, combined with excessive precipitation (from 20 to 8). In contrast, the number of months with high temperatures, and insufficient precipitation increased significantly from 27 to 39 (Table). The above-mentioned changes in the frequency of the extreme, and detrimental to agriculture meteorological phenomena, between the compared

TABLE. The number of occurrences of favorable and detrimental meteorological conditions to the vegetation of crops in Poland in the periods 1971–2000 and 1981–2010 (April–October)

Meteorological conditions during vegetation period	Extreme		Total	
	1971–2000	1981–2010	1971–2000	1981–2010
Favorable	8	12	58	59
Insufficient precipitation	19	12	54	61
Low air temperature combined with insufficient precipitation	5	4	9	5
Low air temperature	4	6	15	10
Low air temperature with excessive precipitation	10	5	20	8
Extreme precipitation	13	14	27	28
High air temperature with insufficient precipitation	15	29	27	39

30-year periods, show relevant differences amounting to $\alpha = 0.01$.

The relationship between the detrimental pluvio-thermal vegetation conditions, based on the accounts of the agricultural correspondents, regarding the state of the cultivated plants and extreme values, based on the arbitrary formal and statistical criteria, presents an interesting picture. A question arises at this point, whether the extreme values designated in this study, take into account every possible combination, or at least most possible combinations, of unfavorable conditions of the vegetation of most cultivated plants in production conditions. Taking into account only the last 30-year period (1981–2010), it can be stated, that out of 210 months that were analyzed, according to the accounts of agricultural correspondents, only 59 exhibited favorable meteorological conditions for vegetation of cultivated plants. The remaining 151 months indicated detrimental conditions, which compared to the 70 cases of unfavorable and extreme conditions, enables me, at the same time, to state that in the Polish climate, such extreme pluvio-thermal conditions constitute merely 46% of months with detrimental conditions. Similarly, the number of extremely dry months (including the combination of insufficient precipitation and high air temperatures) constitutes only 43% of cases of all precipitation deficits.

Summing up, the changes that occurred in the last 40 years in the agro-climate of Poland, enable me to state that the Polish climate is warming annually at a rate of 0.3°C a decade. These results are in accordance with those presented by Żmudzka (2004) and Wójcik and Miętus (2014) for the 1981–2010 period. The most significant temperature increases (0.7°C a decade), were observed in April and July. If we assume that the precipitation totals remain the same, or increase slightly due to increased evaporation, we can observe an increasing aridity of the climate, which is manifested by the increasing frequency of extremely dry months (from 39 to 45), and generally dry months (from 90 to 105), in the two compared climate normals: 1971–2000,

and 1981–2010, as noted by agricultural correspondents.

In comparison to Żmudzka's study (2004), which encompasses the 1951––2000 period, my work shows an increase in the number of months with a statistically significant temperature increase (from 2 to 4). These months were not, March, and May, however, but: April, June, July, and August. In a study by Michalska (2011), encompassing a slightly longer 1951–2005 period, the months with statistically relevant air temperature increase that occurred at the most weather stations in Poland were: March, May, February and August. The coincidence of extremely low precipitation, and monthly precipitation totals insufficient for vegetation, coupled with extremely high, and increasing temperature values, results in the occurrence, and increase in the frequency of dry periods. The dry months, and other unfavorable months, determined on the basis of the formal, and statistical criteria applied here, constitute only half of the cases of the unfavorable pluvio-thermal conditions stated by the agricultural correspondents, dealing with the state of cultivated plants in production conditions.

The presented study is, in principle, a preliminary one, and does not exhaust all the possible aspects of the impact of the present day climate change on the diversity of the meteorological vegetation conditions of cultivated plants in Poland, and the changes in these conditions. The adopted simplifications, do not allow me to draw more detailed conclusions. You have to realize, that the study does not include the winter break in the vegetation period, and the wintering conditions, shaped by air temperature values, the lie of snow cover, and the frequency of thaw. This problem requires a separate study, and a slightly different research methodology. This study does not take into account the doubtlessly great spatial variety of the analyzed phenomena favorable to vegetation, which, for various reasons, are detrimental, or extreme. I have also generalized about the diverse thermal and precipitation requirements of the particular species of cultivated plants, not to mention their varieties. From the point of view of plant physiology, and cultivation, it would be recommendable to adopt an attitude based on the phenological phases, or critical periods of the particular cultivated plants, rather than an attitude based on the calendar. The adopted criterion of the values of meteorological elements stated to be extreme, is also controversial. Despite the above-mentioned limitations adopted on purpose, this study should be treated as a preliminary attempt at evaluating the application of the formal, and statistical criteria in the analysis of the extreme, and detrimental vegetation phenomena in Poland in production conditions, and a brief evaluation of the selected features, and trends in the agro climate of Poland, in the period under research, characterized by a clearly notable warming of the climate.

CONCLUSIONS

1. The period 1971–2010 in Poland is characterized by an annual temperature mean increase, equal to 0.3°C a decade, which is statistically relevant in April and during the summer months (June–August). The largest temperature increase was observed

in April (0.74°C) and July (0.68°C). Precipitation has not exhibited relevant increasing trends, and equaled 601 and 604 mm, respectively (1971––2000 and 1981–2010).

2. An increase in air temperature, coupled with a lack of clear precipitation trends, caused a change in the number of cases, and in the structure of the extreme pluvio-thermal conditions of the vegetation of key cultivated plants, whose probability of exceeding was lower than 10%. In the two compared climate periods: 1971––2000, and 1981–2010, the number of extreme months increased from 74 to 82. The number of months with extremely low precipitation combined with extremely high air temperature (hot and dry) increased from 15 to 29, in other words, it almost doubled.
3. In the two compared climate periods: 1971–2000, and 1981–2010, the number of months with low air temperature and excessive precipitation decreased the most (from 20 to 8). In contrast, the number of months with high air temperature and insufficient precipitation increased significantly (from 27 to 39).
4. In the Polish realities, that is the majority of light alluvial soils, extreme thermal, precipitation and pluvio-thermal conditions constitute merely 46% of all months, which are evaluated as detrimental for the vegetation of crops in productive conditions.

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Streszczenie: *Częstość ekstremalnych i niekorzystnych warunków meteorologicznych wegetacji roślin uprawnych na obszarze Polski (1971––2010)*. Przedmiotem i celem opracowania jest porównanie częstości występowania na obszarze Polski niekorzystnych dla rolnictwa warunków termicznych, opadowych i pluwiotermicznych w dwu okresach: 1971–2000 i 1981–2010, stanowiących starą i nową 30-letnią normę klimatyczną. Każdy miesiąc okresu wegetacyjnego (kwiecień–październik), zakwalifikowano zgodnie z bieżącymi relacjami korespondentów rolnych o stanie upraw jako: korzystny dla wegetacji, suchy, suchy i jednocześnie chłodny, chłodny, chłodny i jednocześnie wilgotny, wilgotny, suchy i jednocześnie upalny. Takiej samej kwalifikacji meteorologicznych warunków wegetacji dokonano również dla miesięcy o ekstremalnych wartościach temperatury powietrza i opadów. Za wartości ekstremalne przyjęto te wartości średniej miesięcznej temperatury powietrza i miesięcznych sum opadów atmosferycznych, których prawdopodobieństwo przekroczenia jest mniejsze od 10%, czyli szansa ich wystąpienia lub tzw. okres powtarzalności wynosi raz na 10 lat. Zaistniałe różnice między analizowanymi 30-leciami można uznać za efekt zachodzących współcześnie zmian klimatycznych – istotnego wzrostu temperatury powietrza w okresie roku i w miesiącach: kwiecień, czerwiec, lipiec i sierpień, przy braku istotnych trendów opadów atmosferycznych. Stwierdzono w porównywanych 30-leciach wzrost liczby ekstremalnych miesięcy z 74 do 82 przypadków. Największe zmiany w miesiącach ekstremalnych wystąpiły dla warunków niedoboru opadów i jednocześnie upalnych, których liczba wzrosła z 15 do 29 przypadków. Ogólnie we wszystkich analizowanych miesiącach okresu wegetacyjnego stwierdzono wzrost miesięcy suchych z 90 do 105 przypadków i zmniejszenie się liczby przypadków miesięcy chłodnych z 44 do 24.

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