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EFFECTS OF AGRICULTURAL DROUGHTS IN THE PROVINCE OF KUJAWSKO-POMORSKIE AND POSSIBILITIES OF MINIMIZING THEIR IMPACT

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Abstract

The aim of the research was an evaluation of the frequency and intensity of agricultural droughts and their effects in the province of Kujawsko-Pomorskie as well as to indicate ways of increasing productivity in such drought periods by applying irrigation. It was found that the drought periods around Bydgoszcz occurred in 17 vegetation seasons out of 30 analysed. They were differentiated by intensity and duration but were also characterized by high irregularity of their occurrence. In the past 30-year period, droughts were especially intensified in the years 1989-1995. In the years 2001-2005 droughts were rare (36%), as compared with the previous 15-year period of 1986-2000 (64%). Crop production of some selected agricultural cultivations in the province of Kujawsko-Pomorskie depended to a large extent on the degree of precipitation shortages in the periods of intensified water demand. The best correlations and determination coefficients exceeding 80% concerned maize cultivations. The occurrence of droughts, expressed by the degree of atmospheric precipitation shortages in June and July, led to a decrease in grain crops in the province by 13%, on average. In the extremely dry year of 2006, a decrease by 27%, in relation to average crops, was observed. Active methods of minimizing effects of agricultural droughts are connected mainly with the development of irrigation systems. In the experiments conducted in the years 2006-2016, it was shown that the application of irrigation of barley and maize in the drought periods not only prevented 40-45% decrease in crops but also provided higher cropping level (by 33-40%) than the one obtained on average without irrigation.

Keywords: agricultural droughts, province of Kujawsko-Pomorskie, irrigation

INTRODUCTION

Dry periods (droughts), also called agro-meteorological or soil droughts, constitute main and unavoidable element of climatic risk of plant cultivation in central Poland. They are characterized mainly by irregularity of occurrence, which results from time changeability (volatility) of Polish agroclimate ranging between maritime and continental climate. Łabędzki (2009a) defines agricultural drought as a shortage of soil water in a specific soil for some plant species in a determined period or a moment, which results in decreasing crops of arable plants. Dudek *et al.* (2009) assumed duration of successive number of days with run-out supplies of easily accessible water for plants in the root layer of the soil as the basic criterion of determining an agricultural drought. According to them, an agricultural dry period starts when such continuous conditions last for at least 7 days. When it is at least 2 weeks, there is an intensive drought; when such a period exceeds 20 days, then the drought is considered “very intensive”.

Increased interest in agricultural droughts, which can be observed since the beginning of the 21st century, is connected with the main scientific problem of contemporary climatology that is becoming more and more important, i.e. research into climate change and their effects, also in agriculture (Kundzewicz and Kozyra 2011). According to the theory of global greenhouse effect and according to Łabędzki (2009a), Doroszewski *et al*. (2012), the results of measurements and meteorological observations indicate that in Poland the frequency and intensity of droughts has increased as well as that they are more and more probable to occur in the future. However, the research by Czarnecka and Nidzgorska-Lencewicz (2012) concerning precipitation conditions of the whole country, as well as those by Żarski *et al*. (2014) conducted in regional aspect, have not revealed any considerable trends of change, especially the decrease of atmospheric precipitation. Also the research by Żarski (2011) and Januszewska-Klapa (2016) show the lack of agricultural drought intensification in the years 1981-2010 in some selected places of Kujawsko-Pomorskie province. Obviously, it does not mean that in the future the frequency of agricultural droughts and their intensity will not be on the increase. According to predictions and simulations of climatic changes for years 2050-2060, the calculated probability of the occurrence of extremely dry periods in central Poland show a two-fold, three-fold and even four-fold increase, depending on the assumed scenario of such climatic changes (Kuchar *et al*. 2015).

The aim of the research was the evaluation of the frequency of occurrence and effects of agricultural droughts in Kujawsko-Pomorskie province as well as to indicate ways of increasing productivity in drought periods by applying irrigation.

MATERIALS AND METHODS

The meteorological data used by the authors in the research were derived from standard measurements of air temperature and atmospheric precipitation, carried out in the years 1986-2015 at the Research Station of the University of Science and Technology (UTP) in Bydgoszcz, located about 20 km away from the city in Mochle (φ= 53°13'N, λ=17°51'E, h=98.5 m above sea level). The station's area is free from the influence of city anthropogenic factors and may be treated as representative for Bydgoszcz region. In order to evaluate drought occurrence, a relative precipitation index – RPI (atmospheric drought) was used, as well as the Klatt's index of shortages of actual atmospheric precipitation in relation to optimal precipitation for soils of medium compactness (agricultural drought – NO) (Dembek *et al.* 2015). RPI is the ratio of precipitation sum for the given period *P* and the long term average for the same period expressed as a percentage.

In order to evaluate the effects of agricultural droughts, data concerning crop volumes of some selected species and arable plants in the production circumstances of Kujawsko-Pomorskie province were used. The data were derived from regional databases of the Main Statistical Office (GUS 2016). Crop production in the years 2004-2015 of the following agricultural cultivations were taken into account: barley, maize for grain, legumes, cereal straw and green maize mass being raw material for the production of renewable energy (Żarski 2012). Short period of observation (years 2004-2015) resulted from the lack of data from other years (maize, legumes) or the need to avoid crop increase changes due to biological and agrotechnical development (maize). Straw crops were calculated based on maize crop volumes as well as indicators of the relation between straw crops and grain crops, as quoted in the work by Ludwicka and Grzybek (2010). A simple model of weather-crop was utilized, which allows for determining the influence of atmospheric precipitation shortages on crop volumes of the above cultivations. The basic statistical tools applied in the work were Pearson's correlation index as well as the method of polynomial regression. The relation between crop volume and shortage of atmospheric precipitation was tested in various time intervals. The paper presents only the most significant relations that were characterized by the highest correlation and determination coefficients.

The third set of data was acquired using the results of precise, long-term field experiments with irrigation of malting spring barley and maize for grain carried out in the years 2006-2016 at the UTP Research Station in Mochełek near Bydgoszcz. The experiments were carried out on lessive soil comprising fluvio-glacial sands on shallowly deposited middle clay, classified as soil quality class IVa and as regards rye agricultural usability complex – as very good. Considering its compactness degree, the soil is light on a compact base. It represents the group of soils typical for luvisols of Kujawsko-Pomorskie province, according to WRB classification.

RESULTS AND DISCUSSION

EVALUATION OF THE OCCURRENCE OF AGRICULTURAL DROUGHTS

As presented in Figure 1, drought periods in Bydgoszcz region were detected in 17 vegetation seasons, out of 30 analysed. They were differentiated by intensity and duration and occurred very irregularly. Totally, in 120 selected fragments of the vegetation season, covering three periods of two months and one four-month period in each of the 30 years tested, the following periods were identified: 21 very dry and 18 dry ones. There were 5 extremely dry periods, including one in late spring and early summer (2008), one in June-July (2006), two in the middle of summer (1992 and 1994) and one in the whole period of active plant growth (1992). In some years, drought periods affected only one part of the vegetation season (1991, 2004, 2014), in others, they were long-term and comprised the whole spring-summer period. The most acute in this respect were the vegetation seasons in the years 1992, 1989, 2015, and secondly in the years 1994, 1995, 1990, 2008. In the past 30-year time span, droughts were mostly intensified in the years 1989-1995, and they were not detected in vegetation seasons of 2009-2013. Even a perfunctory analysis of the data set presented in Figure 1 does not allow for concluding that in Bydgoszcz region there has been any increase in frequency of occurrence and in intensity of drought periods in recent years, unless we consider „the recent years" as the whole analysed 30-year time span, without relating to even earlier times. On the contrary, it is easily discernible that in the years 2001-2015 there were fewer droughts than in the previous 15-year period of 1986-2000 (64%).

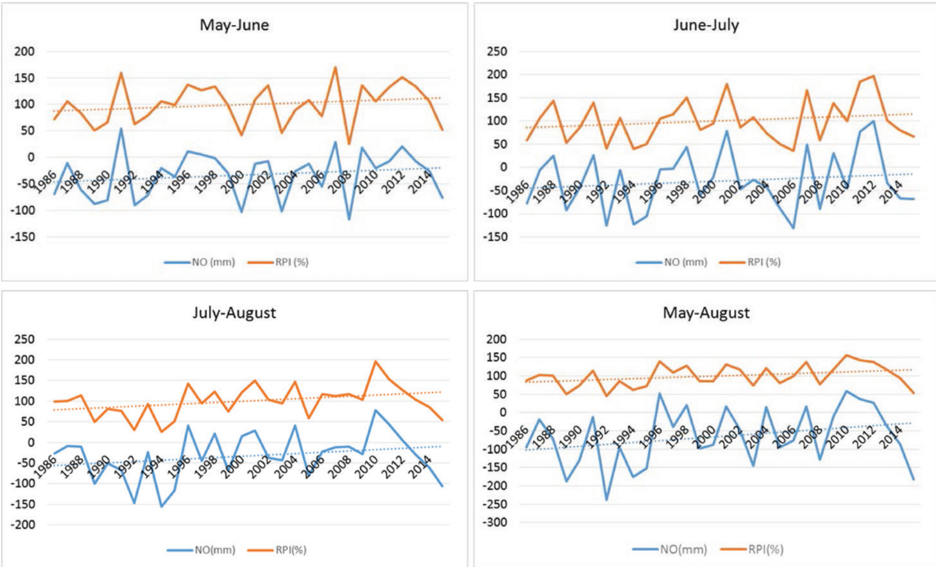
The confirmation of no increase in drought occurrence intensity year by year in the analysed period 1986-2015, are the results of correlation and regression calculations, which reveal lack of significant trends of change as well as tendencies of atmospheric moisture content increase and precipitation deficiency in plant cultivation decrease (Figure 2). Worth noting is the very high correlation between the values of relative index of precipitation (RPI) and the index of agricultural drought (NO) that shows quantitative shortages of actual precipitation in relation to Klatt's optimal precipitation. The first of these indexes is based only on rainfall data, whereas the other one takes into account also air thermal conditions. Other studies (Łabędzki and Bąk 2015, Tokarczyk 2008, Tokarczyk and Szalińska 2013) indicate that there are many indicators for quantitative evaluation and monitoring of droughts, all of them, however, have a high degree of compliance, despite their identifying and expressing drought intensity in various units.

Years	Parts of vegetation season			
	V-VI	VI-VII	VII-VIII	V-VIII
1986	dry period	very dry period		dry period
1987				
1988				
1989	very dry period	very dry period	very dry period	very dry period
1990	dry period		dry period	very dry period
1991			dry period	
1992	dry period	very dry period	extremely dry period	extremely dry period
1993	dry period			dry period
1994		very dry period	extremely dry period	very dry period
1995		very dry period	very dry period	very dry period
1996				
1997				
1998				
1999		dry period	dry period	dry period
2000	very dry period			dry period
2001				
2002				
2003	very dry period			very dry period
2004		dry period		
2005		very dry period	very dry period	dry period
2006	dry period	extremely dry period		
2007				
2008	extremely dry period	very dry period		dry period
2009				
2010				
2011				
2012				
2013				
2014		dry period		
2015	very dry period	dry period	very dry period	very dry period

extremely dry period
very dry period
dry period

Source: own data and elaboration

Figure 1. Occurrence of extremely dry, very dry and dry periods in various parts of the vegetation season of arable crops in Bydgoszcz region in the years 1986-2015



Explanations: NO – index of agricultural drought (quantitative shortages of actual precipitation in relation to Klatt's optimal precipitation)
RPI – relative precipitation index
Source: own data and elaboration

Figure 2. Variability of indicators of drought occurrence in Bydgoszcz region in the period 1986-2015; year by year tendency of change

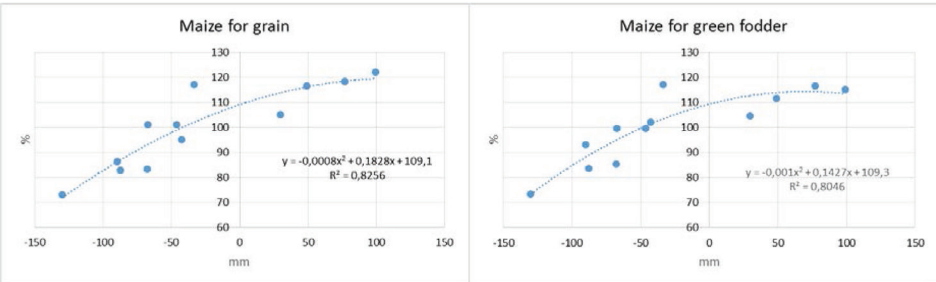
EFFECTS OF AGRICULTURAL DROUGHT OCCURRENCE

The effect of drought periods is the decrease in crop production and deterioration of its quality. Chmura *et al.* (2009), based on many years of field experiments by COBOR, determined the percentage fall of crops during rainfall shortages that fluctuated within very wide limits ranging from 2 to 73% and depended mainly on the user group and plant species, soil complex, and, most of all, on the intensity of such a drought period. In the State Monitoring System of Agricultural Drought operated by The Institute of Soil Science and Plant Cultivation (IUNG) in Puławy (Doroszewski *et al.*2012), it is assumed that agricultural drought results in crop reduction of plant groups and species by 20%, and on that basis critical values of climatic water balance (CWB) are quoted. They are an indicator of agricultural drought of similar category as shortages of atmospheric precipitation presented in the present work.

Table 1. Descriptive statistics of the relation between crop production and atmospheric precipitation shortages in Kujawsko-Pomorskie province (years 2004-2015)

Crop	Period of increased water needs	Average yield (100 kg·ha^{-1})	Average rainfall shortage (mm)	Coefficient of determination R^2 (%)	Average (and maximal) yield drop in dry periods (%)
Barley	V-VI	33.2	-23.2	43	14 (23)
Maize for grain	VI-VII	56.9	-25.7	83	13 (27)
Legumes	V-VIII	25.0	-38.4	43	17 (22)
Biomass - cereal straw	V-VI	29.3	-23.2	46	10 (13)
Biomass - green fodder	VI-VII	436.0	-25.7	80	11 (27)

Source: own data and elaboration



Source: own data and elaboration

Figure 3. Relation between index of grain and green fodder yield expressed in percentage and atmospheric rainfall shortages in the period of VI-VII in Kujawsko-Pomorskie province (mm)

Statistical calculations based on data reported by Main Statistical Office (GUS) indicated that crop yields in Kujawsko-Pomorskie province depend significantly on rainfall shortages in the periods of increased plant water needs (Table 1). In the case of cereal crops, yield of barley grain and cereal straw depended mostly on the sum of precipitation in May and June. Maize crops cultivated both for grain and green fodder correlated best with the sum of precipitation in June and July, whereas yield of legumes - on the sum of precipitation comprising the period from May to August. The best correlations and determination coefficients exceeding 80% concerned maize. As presented in Figure 3, the occurrence of drought periods, expressed in the shortage of rainfall in June and July, lead to decreasing crops in Kujawsko-Pomorskie province by 13%, on average. In the extremely dry year of 2006, a decrease by 27%, in relation to average crops, was observed. Similar percentage crop decreases concerned maize green fodder, barley grains and legumes, and lower - straw of basic cereals. It is worth noting that the period in question (2004-2015) in relation to the past 30 years did not abound with agricultural droughts. In the years 2007 and 2009-2013 they were not found to occur in the vegetation season, and in 2004 and 2014 only in one period (VI-VII) an agricultural drought of the lowest intensity was identified.

POSSIBILITIES OF MINIMIZING LOSSES

In order to minimize the negative effects of some weather phenomena on agriculture, including agricultural droughts, passive, preventive or active measures can be applied (Koźmiński and Michalska 2010). The passive method means insuring plantations. Preventive measures in the case of mitigating drought effects comprise, inter alia, regionalization of crops cultivations (Dzieżyc 1989), making use of biological development in order to limit water demands and increase plants' resistance to droughts, as well as agrotechnical development in order to increase in soil water supplies, accessible for the plants. Active methods are connected most of all with the development of crops irrigation being an activity that can efficiently prevent effects of agricultural drought. The results of various research works dealing with agricultural and horticultural plants indicate that irrigation contributes to a proper rhythm of growth and development of plants as well as to intensification of their physiological processes. As a result, it contributes also to crop growth and its stabilization over the years, and favourably influences quality features of such crops (Łabędzki 2009b, Rzekanowski *et al*. 2011, Żarski *et al*. 2013).

Table 2 presents effects of plant irrigation in field experiments conducted continuously for 11 years at the Mochełek Research Station in the neighbourhood of Bydgoszcz. The absolute, relative, and unitary average increment of barley and maize grain yield cultivated under irrigation treatment show the potential for increased crop productivity in optimal water conditions. Moreover, the irrigation also contributed to the stabilization of cropping in the case of the cultivations in question. As a result of applied irrigation, the variability coefficient of barley yield decreased from 36 to 19%, and in the case of maize - from 50 to 18%.

Application of irrigation in drought seasons not only prevented crop drops of 40-45%, but also provided higher cropping volume (by 33-40%) than that obtained on average without the use of irrigations. Absolute and relative production effects were obviously significantly higher than the average ones, while, the unitary effects were higher on barley, and comparable to the averages in maize cultivation. The productivity effects constitute a basis for evaluating economic productivity that is a decisive factor for potential introduction of irrigation into the process of arable plant production. In the light of the analysis as conducted by Kledzik *et al*. (2015), the results obtained by means of calculation of direct surplus increase have shown that in the case of malting spring barley and maize cultivated for grain, the introduction of this measure was economically justifiable.

Table 2. Effects of crops irrigation on lessive soil in the region of Bydgoszcz in the years 2006-2016

Crop	Years	O ($Mg \cdot ha^{-1}$)	CV (%)	W ($Mg \cdot ha^{-1}$)	CV (%)	Effects of crops irrigation		
						($Mg \cdot ha^{-1}$)	(%)	($kg \cdot mm \cdot ha^{-1}$)
Malting barley	On average	4.35	36	6.01	19	1.66	39	20.3
	Drought seasons	2.58	22	6.07	20	3.49	136	25.9
Maize for grain (d. m.)	On average	8.03	50	11.84	18	3.81	48	35.0
	Drought seasons	4.42	88	10.61	25	6.19	140	34.6

Explanations: O - yield without irrigation, W - yield under irrigation, CV - coefficient of variation of the yield
Source: own data and elaboration

CONCLUSIONS

1. In the 30-year time span of 1986-2015, drought periods in the region of Bydgoszcz occurred in 17 vegetation seasons with the greatest intensification that took place in the years 1989-1995. In the years 2001-2015 there were definitely fewer droughts (36%) as compared with the previous 15-year period of 1986-2000 (64%). Therefore, one cannot claim that this unfavourable phenomenon is increasing as regards its frequency and intensity.
2. Crop volumes of some selected agricultural cultivations in Kujawsko-Pomorskie province depended to a large extent on the size of precipitation shortages in periods of increased water demands. Occurrence of drought periods led to the crops decrease by 10-27% in relation to average crops, depending on the cultivated plants and drought intensity.
3. Application of irrigation in drought period on experimental scale not only prevented crops drop of 40-45%, but also provided 33-40% higher yield than that obtained on average without irrigation.

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