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EVALUATION OF NEEDS AND EXPECTED EFFECTS OF SPRINKLER IRRIGATION IN POTATO CULTIVATED IN THE KUJAWSKO-POMORSKIE REGION

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Summary

The study was carried out in order to determine the frequency of droughts in the period of increased water needs in potato, and to assess the needs and expected productive effects of the plants grown under irrigation on the basis of temporal variation of the standardized precipitation index SPI in the Kujawsko-Pomorskie district. Rainfall data were derived from standard measurements of atmospheric precipitation in between 1 July and 31 August in the multi-annual period 1981-2010.These data were obtained from the branches of COBORU in Chrząstowo, Głębokie and Głodowo, and the University of Technology and Life Sciences Research Centre in Mochełek. The results of carried research showed that the frequency of occurrence of dry spell during the period of increased needs for water of potato amounted to 26.7-40.0% in the region, depending on the locality. Strong droughts occurred in the year 1983, 1989, 1992 and 1994, moderate drought in 2005 and weak droughts in 1982, 1984 and 1999. Great irrigation needs of potato which corresponded to periods of strong and moderate droughts (SPI $\leq$ -1.0) have been identified in 5 years of the 30 years examined. The expected increase in the yield of potato tubers grown on light soils under irrigation during those years exceeded 15.7t·ha^{-1}. In the 9 years of the 30 have occurred medium-level irrigation needs, which in the period of July-August, corresponded to SPI values between 0 and -1.0.

Key words: potato, the region of Kujawsko-Pomorskie, SPI index, irrigation needs, production results of irrigation

INTRODUCTION

In terms of environmental criteria, the desirability of potato irrigation due to water shortages which on one hand reduce the production potential of the environment determined by the energy reserves of solar radiation and on the other hand they eliminate the benefits of bio-and agro-technical progress. According to the study by Ostrowski and Łabędzki [2008] water shortages in potato production in Poland are characterized by great temporal and spatial diversity, arising from the variation of precipitation and types of soil.Water shortages are greatest in central part of Poland, including the Kujawsko-Pomorskie district, amounting in the whole period of potato vegetation on average 80-160 mm while in dry years 120-200 mm depending on the type of soil. The average needs for irrigation of potato grown on light soils, which correspond to the rainfall shortages during the period of increased water requirements, in central Poland are estimated at the level of 50-75 mm, while the maximum needs in extremely dry years exceed 150 mm [Rojek 2006, Żarski et al. 2011]. The advisability of potato irrigation in areas of particular water shortage also argues the significant effect of production.According to the synthesis numerous studies irrigation leads to a significant stabilise and increase in tuber yields, improvement of their quality [Żarski et al. 2004, Smith 2006; Rolbiecki et al. 2009] and is an economically cost effective treatment [Jankowiak, Rzekanowski 2006].

Due to the great variability of precipitation in time, irrigation of crops cultivated in central Poland on soils typical for them is of the intervention that complements periodic water shortages [Rzekanowski et al. 2011]. The needs for irrigation occur during meteorological and agricultural droughts which appear in this region with the frequency of approximately 30% [Łabędzki 2007]. One of the quantitative indicators used to identify meteorological drought and indirectly also the agricultural one is the standardized precipitation index SPI. Normalization and standardization of a series of rainfall measurements, carried during the calculation, allows the assessment of meteorological drought in different climatic conditions and time intervals [Łabędzki 2006]. The SPI index is also used in the monitoring of meteorological and agricultural drought in Kujawy region, implemented by the Kujawsko-Pomorski Regional Research Centre ITP [Bąk, Łabędzki 2009].

The cognitive aim of the study was a meteorological characteristic of the frequency of droughts in the period of increased water needs of medium-early potato, grown on light soil. The utility goal was the assessment of needs and the expected effects of the production of these plants under the influence of irrigation in the Kujawsko-Pomorskie region on the basis of temporal variability of the standardized precipitation index (SPI).

MATERIALS AND METHODS

The paper is based on the results of standard rainfall measurements taken in the multi-annual period 1981-2010 during the increased water needs of medium-early potatoes (from 1 July to 31 August). The rainfall data were obtained from branches of the Research Centre for Cultivar Testing (COBORU): Experimental Station in Chrząstowo and two Experimental Departments in Głębokie and Głodowo. Also used data derived from measurements carried out in the Research Station of the University of Technology and Life Sciences, located in Mochełek. All the measuring points of rainfall are located in the Kujawsko-Pomorskie Voivodship.Experimental Station in Chrząstowo and the Research Station in Mochełek are situated in the northern part of the Krajeńskie Lakeland. Two other Experimental Departments are located in the southern part of the region: Głębokie in the Gnieźnieńskie Lakeland (Inowrocławska Plain) and Głodowo in the Dobrzyńskie Lake District (Płońska Upland) (Table 1).

Standardized precipitation index was calculated separately for each locality and also for the whole region (based on the average rainfall in these areas); 30-year series of two-month rainfall totals were normalized by the function f (P) = (P) 1/3 [Łabędzki 2006].On the basis of the SPI values were defined categories of rainfall conditions according to the 9-point scale which is used for monitoring rainfall conditions in Poland by the Institute of Technology and Life Sciences in Falenty (www.itep.edu.pl).

Needs and expected effects of irrigation of potato were determined by the general formula derived by Grabarczyk [1987] as:

$$Q = (P_{OPT} - P_{RZ}) \cdot q$$

where:

- Q – an increase of tuber yield due to irrigation ($t \cdot ha^{-1}$);
- P_{OPT} – optimal rainfall during the increased water needs of plants (mm);
- P_{RZ} – actual rainfall during the increased water needs of plants (mm);
- q – per unit increase of yield under the influence of irrigation in $t \cdot ha^{-1} \cdot mm^{-1}$ of rainfall deficiency.

Needs for irrigation, which is equal to the shortages of rainfall during the period from 1 July to 31 August, were calculated as the difference between optimal and actual rainfall. A detailed formula developed for medium-early potato by Żarski et al. [2011] was applied. The formula was based on results of many years of research with irrigation of crops in the region of Bydgoszcz on light soil with concise subsoil (good rye complex).This formula is as follows:

$$Q = (190 - P_{RZ}) \cdot 0.15$$

Apparent from this that the optimal rainfall for potatoes, i.e. those for whose are not found increments of tuber yields under the influence of irrigation, are at the level of 190 mm. For the case of rainfall below the optimum, irrigation causes yield increase of up to 150kg·ha^{-1}per 1 mm of rainfall deficiency in relation to the optimal quantity.

In the paper were also used data concerning crop acreage and harvest of potato in the Kujawsko-Pomorskie voivodship, built on the databases from the website of the Central Statistical Office (www.stat.gov.pl).

RESULTS AND DISCUSSION

The average long-term rainfall in the specific locations in the Kujawsko-Pomorskie voivodship, especially air temperature during the increased water requirements of potatoes, were similar to those recorded in the reference station of Polish National Hydrological and Meteorological Service (IMGW) in Toruń (Tab. 1). In particular, a large convergence concerned the rainfalls in August. The highest rainfall in the region and the most similar to those recorded in the reference station, occurred in Głodowo while the lowest in Chrząstowo. The comparison of the average actually recorded rainfall with optimum rainfall indicates that on light soils in the region of Kujawsko-Pomorskie there are needs of irrigation of medium-early potato, which, depending on the location, are on average at the level of 50-60 mm. It must be concluded their great compliance with results provided by Rojek [2006] in his paper, despite a different methodology adopted by the author.

Table 1. Long-term average (1981-2010) of rainfall totals and air temperature during the period of July-August in the selected measuring locations in the region of Kujawsko-Pomorskie

Locality Institution	Latitude	Longitude	Rainfall totals (mm)			Air temperature (°C)		
			VII	VIII	VII-VIII	VII	VIII	VII-VIII
RSHM Toruń IMGW	53°03‘	18°36‘	84.2	67.3	151.5	18.8	18.2	18.5
SDOO Chrząstowo COBORU	53°11‘	17°35‘	64.7	62.3	127.0	18.5	17.8	18.2
Stacja Badawcza Mochle UTP Bydgoszcz	53°13‘	17°51‘	69.8	62.6	132.4	18.6	17.9	18.3
ZDOO Głodowo COBORU	52°50‘	19°15‘	80.5	62.9	143.4	18.6	17.8	18.3
ZDOO Głębokie COBORU	52°39‘	18°27‘	76.4	60.5	136.9	18.8	18.3	18.5

Source:own elaboration

In the multi-annual period 1981-2010, depending on the locality were recorded 9-14 periods of increased water needs of potatoes in rainfall conditions classified as normal (Table 2). In the 8-12 years of 30 analyzed occurred periods of drought, and in five years it was an extreme, strong or moderate drought. In the remaining 8-11 years, depending on the locality, in July and August was humid or wet. Noteworthy is the high frequency of droughts (30%) compatible with results for the central Poland presented by Łabędzki [2007], which was based on a long-term series of measurements of rainfall in Bydgoszcz.

In the entire region of Kujawsko-Pomorskie, the values of SPI index calculated for the four sites of measurements on the basis of the average rainfall totals in July and August were characterized by very high temporal variability (Fig. 1).The multi-annual period 1981-2010 values of this index ranged from 2.09 in 2010 (extremely wet) to -1.81 in 1989 (strong drought). However, studies showed no significant trend of the SPI values with time from 1981 to 2010, since the coefficient of determination for this dependence equaled $R^2 = 0.0839$.This result is generally consistent with the conclusion drawn in the work of Czarnecka and Nidzgorska-Lencewicz [2012]. Based on the analysis of 60-year observations in Poland, there were no statistically significant trends of seasonal rainfall and was not confirmed their increasing volatility.

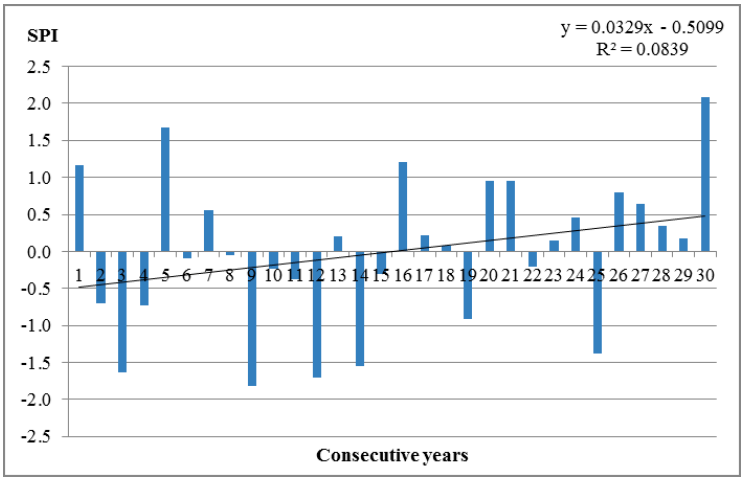
Table 2. The number of categories of rainfall conditions during the period of July-August in the multiannual period 1981-2010 in the selected locations in the region of Kujawsko-Pomorskie

Category of rainfall conditions	Value of SPI	Chrząstowo	Mochle	Głodowo	Głębokie
Extreme drought	≤ –2.00	1 [1983]	2 [1994, 1992]	1 [1989]	1 [1989]
Strong drought	(-2.00; -1.50]	2 [1994, 1992]	1 [1983]	2 [2005, 1992]	0
Moderate drought	(-1.50; -1.00]	2 [1989, 1999]	2 [1989, 1995]	2 [1982, 1983]	4 [2005, 1999, 1983, 1994]
Weak drought	(-1.00; -0.50]	4	3	5	7
Regular conditions	(-0.50; 0.50)	10	14	10	9
Humid	[0.50; 1.00)	6	4	5	4
Moderately wet	[1.00; 1.50)	3	2	4	3
Very wet	[1.50; 2.00)	2 [1985, 2010]	2 [1985, 2010]	0	2 [1985, 2010]
Extremely wet	≥ 2.00	0	0	1 [2010]	0

Source: own elaboration

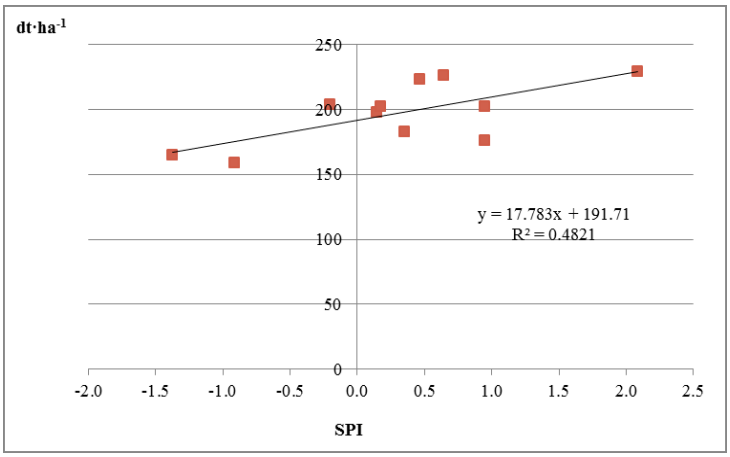
A strong drought in the period of intense water needs of medium-early potato occurred across the Kujawsko-Pomorskie region in the years 1983, 1989, 1992 and 1994. In 2005 a moderate drought was found in the entire region, while a weak drought in the years 1982, 1984 and 1999 (Fig. 1).Despite the lack

of a significant trend, points out the fact that the great majority of those droughts (6 of 8) occurred in a 15-year period 1981-1995, and only two were found in the years 1996-2010.



Source: own elaboration

Figure 1. Temporal variability of SPI values during July-August in the multiannual period 1981-2010 in the region of Kujawsko-Pomorskie

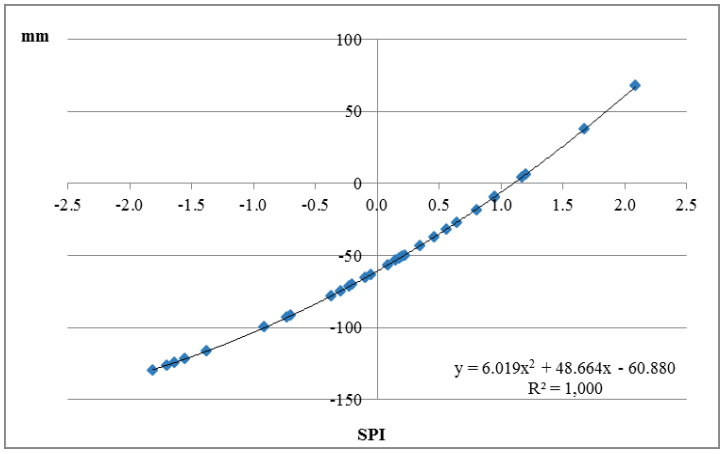


Source: own elaboration

Figure 2. The relationship between the tuber yield of potato (dt·ha^{-1}) in the period 1999-2010 in the region of Kujawsko-Pomorskie and the value of SPI during July-August

Drought results in decreased yielding of crops. The analysis of the dependence of potato yields in the Kujawsko-Pomorskie region of the value of SPI index in the period July-August shows that droughts in 1999 and 2005 resulted in a reduction in yields of tubers to the level of 160dt·ha^{-1}, i.e. by 20% as compared to the average yields in the years 1999-2010, excluding the year 2006 (Fig. 2). Currently, potatoes in the region are grown on the area of about 20 thousand ha, accounting for more than 2.2% in the crop structure. Thus occurrence of drought during the increased water demand has resulted in the regional losses of 80 thousand tons of tubers and deterioration of the yield quality.

A significant dependence of average yield of potato in the region, on SPI values (coefficient of determination at the level of 48.2%) indicates the ability to use it not only as a determinant of rainfall category, in particular the identification of dry conditions, but also as an indicator of productivity. Since this is an indicator computed just on the basis of the amount of precipitation, it correlated strictly with the needs of irrigation of potato calculated in the same way (Fig. 3).These needs have been defined as shortages of actual rainfall in July and August in the consecutive years 1981-2010in relation to the optimal total of rainfall equal 190 mm [2009 Żarski and Dudek, Żarski et al. 2011]. As is apparent from the relation described by the second degree polynomial (Fig. 3), when the SPI index values equal 0, the shortages of rainfall are approximately 60 mm, and thus are close to the multiannual averages in the region. Taking advantage of this relationship presented temporal variation of potato irrigation needs (shortages of rainfall during the increased water needs) and the expected production effects of this treatment, in relation with the SPI value and category of rainfall conditions (Table 3).



Source: own elaboration

Figure 3. Values of SPI during July-August and the shortages of rainfall [mm] in the cultivation of potato in the region of Kujawsko-Pomorskie

Table 3. Needs for irrigation in potato cultivated on light soils mostly the quality class IV in the region of Kujawsko-Pomorskie on the background of rainfall categories expressed by SPI

Category of rainfall conditions	Value of SPI	Water needs of potato				
		Category	Rainfall shortages (mm)	No. of single doses of water	Expected increase in grain yield ($t \cdot ha^{-1}$)	The number of occurrence in the period1981-2010
Extreme drought	≤ –2.00	Very high	> 135	5-6	> 20.2	0
Strong drought	(-2.00; -1.50]	High	105-135	4	15.7-20.2	5
Moderate drought	(-1.50; -1.00]					
Weak drought	(-1.00; -0.50]	Medium	60-105	3	9.0-15.6	9
Regular conditions	0; -0.50)					
Regular conditions	0	Minor	35-60	1-2	5.2-8.9	7
Regular conditions	(0.50; 0					
Humid	[0.50; 1.00)	None	< 35	0	< 5.2	9
Moderately wet	[1.00; 1.50)					
Very wet	[1.50; 2.00)					
Extremely wet	≥ 2.00					

Source: own elaboration

Irrigation needs of potato were found in 21 years of the 30 analyzed, but in 7 years, these needs were minor, equivalent to the normal conditions in the classification of rainfall and SPI values between 0 and 0.49. In the remaining 14 years (the frequency of 46.7%) were found sprinkler irrigation needs requiring the use of at least 3 single doses of irrigation. In 9 years, the needs weredefined as medium, equivalent to values of SPI for July and August in the range from 0 to -1.00. In 5 years, were found great needs equivalent to moderate or strong drought periods (SPI from -1.00 to -2.00) of increased water needs of potato. Developed in earlier studies formula [Żarski and Dudek 2009, Żarski et al. 2011] allowed associate the various categories of rainfall conditions and of sprinkler irrigation needs with the projected increase in tuber yield under the influence of the application of this treatment (Table 3).In the years with average sprinkler irrigation needs, these increases amount to at least 9.0$t \cdot ha^{-1}$, in the case of major needs they are greater: 15.7$t \cdot ha^{-1}$, and in years of extreme drought increases will exceed 20.2$t \cdot ha^{-1}$. The positive effects of sprinkler irrigation as a high-yield growth of tubers cannot be the sole basis for a decision on installing and running irrigations, but they are the basis for an assessment of their cost-effectiveness. This efficiency, in turn, determines the current state of irrigations and is the most important prerequisite for their possible development in agricultural crop cultivation, which is the primary of the national department of agriculture.

CONCLUSIONS

1. Precipitation conditions in the Kujawsko-Pomorskie region, in the period of increased water needs of medium-early potato, were characterized by small spatial diversity and very high temporal variability.

2. The frequency of drought conditions during the peak demand for water of potato was in the region on the frequency of 26.7-40.0%, depending on the locality. Severe droughts occurred in 1983, 1989, 1992 and 1994, moderate in 2005 and the poor in the years 1982, 1984 and 1999.

3. Standardized precipitation index, which defined the category of rainfall conditions in July and August, was a significant indicator of potato yielding in the Kujawsko-Pomorskie region.

4. High-level sprinkler irrigation requirements of medium-early potato, that correspond to periods of strong and moderate droughts (SPI $\leq$ -1.0), were identified in the 5 years of the 30 studied. An expected increase in the potato tuber yield grown on light soils under the influence of irrigation, was formed in recent years at the level higher than 15.7t·ha^{-1}.

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