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REGULAR ARTICLE

Effect of weather conditions on early potato yields in east-central Poland

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ABSTRACT

This work is based on data on monthly air temperature and precipitation and early potato yields in 2000-2013 obtained from seven COBORU (Research Centre for Cultivar Testing) stations in east-central Poland. The relationships between potato yields and average monthly air temperatures and monthly precipitation of the growing season were studied with step-wise multiple regression followed by polynomial regression. Precipitation affected early potato yields more than temperature, particularly in June and July.

Key Words: *growing season; east-central Poland; yield; early potato; air temperature; precipitation.*

INTRODUCTION

Potato is one of the most widely cultivated crop plants (Ahmadizadeh and Felenji 2011). In Poland, like in other countries, cultivation of early maturing potatoes is gaining in popularity (Serio et al. 2004, Hamouz et al. 2006, Leyla and Halis 2009). Under the climatic conditions of Poland, potato yields depend on soil, cultivation practices, and weather, in particular temperature and precipitation. Water conditions are especially important for potato cultivation (Jun and JianPing 2010, Solomon et al. 2013). Because potatoes are grown mainly on light soils, their yielding depends on evenly distributed precipitation. However, in practice rainfall distribution cannot be controlled (Kalbarczyk 2003). A combined effect of temperature and precipitation is crucial (Borkowska and Grundas 2007, Hutorowicz et al. 2008). High temperature can decrease yield due to physiological and biochemical changes occurring in the plant, such as photosynthesis, respiration and water status. A negative impact of too high temperature can, however, be partially reduced by evenly distributed optimum precipitation. The optimum precipitation for early potato ranges from 250 mm to 350 mm Precipitation higher than this optimum leads to yield loss as it prolongs germination and sprouting, and increases disease incidence.

As climate is changing all the time, studying the effect of weather on potato yield is gaining more and more importance in terms of potato adaptation to environmental conditions (Rosenzweig et al. 2002, Hijmans 2003, Aasa 2004, Ziernicka-Wojtaszek 2009). According to various studies, potato responds to improved moisture conditions (Mazurczyk et al. 2009, Rolbiecki et al. 2009, Żaski 2011). Even though the effect of precipitation on early potato yields seems to be obvious, it has not always been confirmed by rigorous statistical analysis (Biniak et al. 2007, Solomon et al. 2013).

The objective of this work was thus to study the effect of precipitation and temperature on the tuber yield of early cultivars of edible potato in east-central Poland.

MATERIALS AND METHODS

Experiments with early potato cultivars were carried out in seven COBORU (Research Centre for Cultivar Testing) stations in east-central Poland in 2000-2013 (Table 1). The field experiments were conducted following the methodology drawn up by COBORU. The following cultivars were tested: Amora (NL), Augusta (DE), Altesse (FR), Anabelle (NL), Aruba (PL), Lady Florine (NL), Bellarosa (DE), Bila (PL), Carrera (NL), Cyprian (PL), Ewelina (DE), Gracja (PL), Gwiazda (PL), Michalina (PL), Oman (PL), Owacja (PL), Rossalind (DE) and Veronie (NL); the sets of cultivars studied differed over the years. To examine the cultivars, one-factor trials were arranged either as randomised complete blocks or 1-resolvable incomplete block design with 3 or 4 replicates. The former design was chosen when 15 or less cultivars were examined whereas the latter design was chosen otherwise. The harvested plot area was around 15 m² (60 plants per plot). The soils of the experiments were usually medium compact with slightly acid reaction (pH ranged from 5.5 to 6.0).

Table 1. Geographic coordinates of stations in central-eastern Poland

Station	Geographic coordinates		H_s
	φ°	λ°	
Cicibór Duży	51°19′	22°16′	206
Krzyżewo	53°01′	22°46′	135
Marianowo	53°13′	22°07′	140
Nowy Lubliniec	50°28′	23°10′	210
Przecław	50°20′	21°46′	183
Seroczyn	52°00′	21°56′	150
Uhnin	51°58′	23°03′	155

Explanations: φ – geographic latitude, λ – geographic longitude, H_s – elevation in meters above sea level.

The average air temperature for the growing season (April-July) ranged from 12.9°C (Krzyżewo) to 13.7°C (Uhnin) (Table 2), the warmest month in the study period being July. The highest monthly air temperature in July was from 19.2°C in Krzyżewo to 20.2°C in Uhnin. The lowest monthly air temperature in the study area was recorded in April, with the average of 8.5°C. The total precipitation over the growing season (April-July) varied and fell within the range 230 mm (Krzyżewo) to 311 mm (Nowy Lubliniec), the highest sums being recorded in July. Over 2000-2013, the sum in July was 119 and 114 mm in Nowy Lubiniec and Przecław, respectively. Average monthly air temperatures between individual stations were less variable (coefficients of variation from 1.6 to 3.6%) than monthly precipitation (coefficients of variation from 8.9 to 17.7%).

Table 2. Average monthly air temperatures and monthly precipitation sums during the 2000-2013 growing seasons in stations located in east-central Poland.

Station	Month				Average for the growing season
	April	May	June	July	
	long-term average temperature (°C)				
Cicibór Duży	8.6	14.2	11.4	19.8	13.5
Krzyżewo	8.0	13.6	10.8	19.2	12.9
Marianowo	8.2	13.7	10.9	19.3	13.0
Nowy Lubliniec	8.9	14.2	11.6	19.5	13.6
Przecław	8.6	14.6	11.6	19.6	13.5
Seroczyn	8.7	14.3	11.5	19.6	13.5
Uhnin	8.8	14.3	11.6	20.2	13.7
CV (%)	3.6	2.3	2.8	1.6	2.1
Station	long-term precipitation sum (mm)				Sum for the growing season
Cicibór Duży	34	70	52	89	245
Krzyżewo	29	65	47	89	230
Marianowo	31	66	48	86	231
Nowy Lubliniec	44	84	64	119	311
Przecław	47	78	63	114	302
Seroczyn	33	70	52	91	246
Uhnin	33	68	50	81	232
CV (%)	17.7	8.9	12.0	14.0	12.5

The set of tested cultivars differed across the years and in some years differed among the stations. Thus, the analysis based on mean yields of the cultivars recorded at each station in each year. Since genotype only slightly affects potato yield performance (Allen et al. 1979, Yildrim and Caliscan 1985, Firman et al. 1995, Sawicka and Pszczółkowski 2004), the genotype/environment interaction being more important, yield averaging should not lead to great loss of information.

Meteorological conditions at each station tested in each study year were described with average air temperatures and monthly precipitation sums during the growing season (April to July).

To analyse yield performance of potato representing the early cultivars group at 7 stations across 14 years, linear mixed models with continuous fixed effects of temperatures and precipitation were used. Year and station were random factors. Linear mixed models assume that the random effects of the years and stations are normally distributed with expected value 0 and different variances. F-tests were performed using the Satterthwaite method for calculation of degrees of freedom.

With the above model, potato yield was analysed according to years and stations. To make the analysis deeper, we divided the potato growing season into two parts: part one (April-May) and part two (June-July). Two analyses were performed for part one. The first analysis used mean monthly temperatures in April and May as continuous variables while the second analysis used precipitation in April and May . Two analyses were conducted for part two, with the following continuous variables: average monthly temperature in June and July, and precipitation in June and July.

To study the effect of temperature and precipitation at individual localities on potato yield, a general linear model (GLM) was used. Yield was a dependent variable and temperature and precipitation in April and May, and temperature and precipitation in July and August were continuous variables.

All calculations were performed in Statistica 10.0 with the significance level α=0.05.

RESULTS AND DISCUSSION

Over 2000-2013, early potato yields ranged from 17.6 to 65.4 t·ha^{-1} the mean yield being 42.6 t·ha^{-1} (Table 3). The lowest mean yield was obtained in Uhnin (32.6 t·ha^{-1}), with the highest coefficient of variation (CV=27.9%); thus this station offered poor and unstable conditions for potato cultivation. The highest mean yield was harvested in Krzyżewo (65.4 t·ha^{-1}) while the lowest variation in potato yield (CV=8.7%) was observed in Przecław.

Table 3. Mean, minimum and maximum early potato yields (t·ha^{-1}) at stations located in east-central Poland over 2000-2013.

Station	Average yield	Min.	Max.	Coefficient of variation (%)
Cicibór Duży	445.0	32.7	57.8	22.0
Krzyżewo	55.4	41.2	65.4	14.3
Marianowo	39.8	29.4	50.4	16.9
Nowy Lubliniec	49.5	40.4	59.6	12.3
Przecław	41.0	36.4	45.2	8.7
Seroczyn	34.6	20.0	48.6	22.3
Uhnin	32.6	17.6	53.0	27.9
Altogether	42.6	17.6	65.4	25.1

The analysis with station as a random factor demonstrated that stations played a key role in tuber yield variation, with the share of 51.5% (Tables 4 and 5). When the analysis was extended to include temperatures in April and May (describing thermal conditions during the first part of the growing season) as continuous variables, the share of the individual variation components changed. The effect of years increased from 4.4 to 11.4% and became significant (P = 0.007). The effect of stations remained significant (P < 0.001) but slightly declined from 51.4 to 45.4% (Table 4). A decrease in the global F-value indicates that the concomitant variables introduced to the model were not only correlated with the dependent variable, but also with the inter-group factor.

Table 4. Variance components for random effects relating to the yield of early cultivars of potato, as obtained from linear mixed models.

Sources of variation	Variance components and percentage of total variation					
	Without meteorological variables		With meteorological variables			
			temperature in April May		precipitation in April and May	
	value	%	value	%	value	%
Year	503.84	4.4	1,229.28	11.4	481.42	4.1
Station	5,950.74	51.4	4,911.18	45.4	6,139.74	52.4
Error	5,085.63	44.1	4,683.69	43.3	5,092.03	43.5

When precipitation in April and May was included in the model, the share of years and stations in potato yield variation was 4.1 and 52.4%, respectively. Only the effect of station was significant (P<0.001).

The small changes in the estimates of random effects following the inclusion of precipitation in April and May indicate that these continuous variables only slightly affected yield (Table 4).Station gave the highest effect on potato yield, regardless of the concomitant variable. Its contribution to the yield variation was 53.2% when temperature was included in the model and 52% when precipitation was included in the model. The Temperature in June and July did not affect yield. When precipitation in June and July was included in the model, the variance components for year, station and error were reduced Also, F values for both year and station were reduced, which means that the continuous meteorological variables had a relevant effect on yield (Table 5).

Table 5. Variance components for random effects relating to the yield of early cultivars of potato, as obtained from linear mixed models.

Sources of variation	Variance component and percentage of total variation					
	Without meteorological variables		With meteorological variables			
			temperature in June July		precipitation in June and July	
	value	%	value	%	value	%
Year	503.84	4.4	466.02	4.1	254.87	2.3
Station	5,950.74	51.6	6,108.12	53.2	5,671.98	52.0
Error	5,085.63	44.1	4,906.31	42.7	4,983.07	45.7

Inclusion of temperature in April and May as concomitant variables decreased the error component and increased the F-value for year, which indicates that these variables affected yield. Similar results were reported by Kalbarczyk (2004), who analysed the effect of agrometeorological factors (over 24 years) on potato yield in various regions of Poland (23 stations). He found that air temperature in May and precipitation in May-June were the most important factors affecting yield. The effect was most pronounced in Masovian, Lublin and Łódź Voivodeships. In the study by Sawicka and Pszczółkowski (2004), meteorological conditions accounted for over 95% of yield variation, varietal characteristics for over 3%, and interaction of these factors for less than 1% of the variation. Also Yildrim and Caliskan (1985) demonstrated a major effect of weather conditions and a much smaller effect of cultivar-related traits on potato yield.

The analysis also revealed that stations had a greater effect than years on yield. Żarski et al. (2011) reported poor yielding in regions affected by water shortages, which was associated with soil compactness and complexes of soil agricultural usefulness.

Regression analysis showed that early potato yields in Cicibór depended on precipitation in April and May (Table 6). A 1 mm increase in precipitation resulted in a mean yield decrease of 81 kg. According to Jakubowski (2007), at initial growth stages potato plants use winter-accumulated water supplies in the soil. As a result, much rain from March to May can negatively impact yield and its quality. If it is warm after planting, plants grow more quickly because plants need less water during this period.

The analysis yielded the model in which the average monthly temperature in April and May and monthly precipitation in June and July positive affected yield in Przecław and Nowy Lubliniec. Temperature and precipitation did not affect yield in Krzyżewo, Marianowo, Seroczyn and Uhnin (Table 6).

Table 6. F ratios, p-values and regression coefficients for meteorological variables (precipitation and temperature in the first and second part of the growing cycles) against tuber yield.

Variables in the model	F	p-value	Parameter estimate
Cicibór Duży			
Intercept	2.91	0.101	418.38
Temperature April and May	0.11	0.743	0.84
Temperature June and July	2.21	0.150	1.20
Precipitation April and May	517	0.032	-0.81
Precipitation June and July	2.26	0.146	0.14
Krzyżewo			
Intercept	3.84	0.062	567.23
Temperature April and May	2.12	0.158	-0.77
Temperature June and July	1.12	0.300	0.27
Precipitation April and May	1.17	0.290	-0.13
Precipitation June and July	2.21	0.151	0.02
Marianowo			
Intercept	7.73	0.010	638.98
Temperature April and May	2.43	0.132	-15.10
Temperature June and July	3.5	0.070	-2.22
Precipitation April and May	2.32	0.140	-0.06
Precipitation June and July	2.46	0.130	0.90
Nowy Lubliniec			
Intercept	0.32	0.577	10.918
Temperature April and May	4.31	0.049	15.587
Temperature June and July	3.31	0.082	8.713
Precipitation April and May	1.25	0.276	0.004
Precipitation June and July	9.16	0.006	0.462
Przecław			
Intercept	0.09	0.766	143.607
Temperature April and May	4.3	0.049	19.123
Temperature June and July	2.22	0.149	-1.846
Precipitation April and May	1.53	0.228	-0.521
Precipitation June and July	4.9	0.037	1.050
Seroczyn			
Intercept	8.51	0.008	1,000.918
Temperature April and May	2.61	0.112	-13.255
Temperature June and July	2.83	0.110	-21.859
Precipitation April and May	1.19	0.286	-0.393
Precipitation June and July	3.21	0.086	-0.027
Uhnin			
Intercept	1.21	0.282	-39.300
Temperature April and May	3.71	0.070	14.873
Temperature June and July	1.26	0.273	6.292
Precipitation April and May	1.53	0.223	-0.017
Precipitation June and July	2.29	0.143	0.184

According to literature, under appropriate agrotechnology, meteorological conditions account for about 40% of variation in potato yield (Trawczyński 2009), the value reaching 50% in years with particularly adverse conditions (Kalbarczyk 2004). In our study, variation in temperature was much lower than that in precipitation. Despite small differences in average temperatures among localities, stations had a major effect on potato yield variation. Such a response may have been due to varied precipitation as, according to Ziernicka (2004), a 1-2^{o}C increase in temperature results in increased water demand of crop plants, which in

Poland ranges from 6.3 to 14.5 mm per month. A slight increase in temperature accompanied by a lack of rainfall may negatively affect potato tuber yields. Such a response is especially important nowadays because the global air temperature is increasing. However, due to a short study period (less than 35 years), the analysis presented in this work cannot be related to climatic change.

CONCLUSIONS

1. Stations accounted for more variation in early potato yield (from 45 to 52%) than years (from 2 to 11%). Potato yield was positively influenced by temperature only in April and May as well as by precipitation only in June and July. The relations were confirmed only in Przecław and Nowy Lubiniec, both the localities being placed in the south-eastern part of the study area.
2. Only in Cicibór, potato yields declined when monthly precipitation in May and June increased.

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