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Risk to Onion (*Allium cepa* L.) Field Cultivation in Poland from Precipitation Deficiency

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Abstract

The onion is the most common vegetable cultivated in Poland and yield is marked by high year to year variability. The yield quantity is predominantly affected by variable meteorological conditions, especially by precipitation deficiency. Data were collected from the Research Centre for Cultivar Testing and the Institute of Meteorology and Water Management for the period 1966-2005 to evaluate the effect of precipitation conditions on the yield of onions (*Allium cepa* L.) cultivated in Poland using multiple regression analysis. Verification of the curvilinear regression equation was conducted on the basis of relative forecast error and average relative forecast error. For this equation the *ARFE* amounted to 9.6%. The threshold precipitation value, i.e. the value at which reduction by at least 5% of the total yield occurs, was determined by curvilinear regression. Reduction of potential yield caused by precipitation deficiency and the frequency of precipitation deficiency were determined. Reductions of at least 5% in the average domestic onion yield in Poland occurred when atmospheric precipitation was ≤ 183 mm. This level of precipitation constituted 87% of the norm and took place in the period between the end of emergence to the beginning of leaf bending. Potential reduction in onion yield in Poland caused by precipitation deficiency in this period varied between 9 and 18%. In Poland, the frequency of atmospheric precipitation deficiency between 1966 to 2005 varied from 10% in the south-east to 50% in the central west and north west. The average frequency of atmospheric precipitation deficiency amounted to about 37%.

Keywords: regression analysis, vegetable, weather conditions, yield reduction

Introduction

The onion is the most common vegetable cultivated in Poland and its share of the domestic structure of vegetables fluctuates between 15-17% (FAO, 2009). Poland is one of the largest onion producers in the EU; however, onion yield in Poland is lower than 21 t ha^{-1} (FAO, 2009). The differences in yield between Poland and other EU countries is due to different production technologies as well as a lack of irrigation equipment (Chudzik, 2007).

Onion yield in Poland varies yearly. Yield quantities depend on total atmospheric precipitation during the whole growth and development period, as well as air temperature (Kalbarczyk, 2008). The onion is very sensitive to water deficiency in the soil at every stage of growth, but especially in the periods of emergence, formation, and intensive bulb increase. Water shortage in the soil causes a reduction in yield and deterioration in the quality of the onion (Tendaj, 2000). Drought in the periods of germination and emergence cause a decrease in the number of plants per unit of surface area, and is also a cause of retarded, weak and uneven emergence. Drought in the period of bulb formation causes a decrease in individual bulb weight (Pelter *et al*., 2004; Shock *et al*., 2000). According to Sarkar *et al*. (2008), water requirements of the onion mainly depend on the region of the world in which this plant is cultivated. In Poland, water requirements of the onion amount to about 350-400 mm in the growing season (Dzieżyc and Dzieżycowa, 1986).

Irrigation of onion crops results in high production potential (Al-Jamal *et al*., 2000; Patel and Rajput, 2008; Pelter *et al*., 2004). The positive effects of irrigation mainly depend on the stage of plant growth, soil type, and the course of meteorological conditions (Enciso *et al*., 2007; Meranzova and Babrikov, 2002; Rumpel *et al*., 2003).

The first goal of this study was to determine the potential reduction in onion yield caused by insufficient precipitation in Poland. The second goal was to determine the frequency of precipitation deficiency during the critical periods.

Materials and methods

This work used data concerning the total yield quantity and dates taken from the period between the end of emergence and beginning of leaf bending of medium-late cultivars of onion *(Allium cepa* L.*)* between 1966 to 2005. The data came from experimental stations located all over Poland, run by the Research Centre for Cultivar Testing (COBORU) in Słupia Wielka (Fig. 1).

Fig. 1. The COBORU experimental stations (□) and the IMGW meteorological stations (•) which provided data used in this work

Onion materials were collected for a standard, i.e. medium-late cultivars of onion most common in cultivation in a given year (about 40 cultivars). This collective standard was used with the premise that intra-species differences do not interfere with general regularities (Kalbarczyk, 2008). Onions collected were grown in soils of: a very good wet complex, a good wet complex, and a very good dry complex. Field water capacity was determined using the tensiometric and gravimetric methods. Cultivars of onion are usually cultivated after cereal plants and also after peas, beans and early brassica vegetables. The full organic manuring dose most often used was from 30 to 50 t ha^{-1}. The manure was ploughed into the ground in autumn. Mineral fertilisation depended on the present soil richness, ranged from 150 to 510 kg per 1 ha of cultivation, and usually amounted to 370 kg per 1 hectare of crops. N and P_2O_5 were sown respectively at doses of 120 and 80 kg, and K_2O-at 170 kg.

Daily and decade agrometeorological precipitation totals for the period 1966-2005 were determined for 18 COBORU experimental meteorological stations. Moreover, the study used databases made accessible by the Institute of Meteorology and Water Management (IMGW) in Warsaw, which meant data was also available from a total of 53 IMGW meteorological stations.

Multiple regression analysis was used to determine the effect of atmospheric precipitation on the total yield of onion crops in the examined period. In the regression equation, the total onion yield was a dependent variable. The sum of precipitation in the period between the end of emergence to beginning of leaf bending, and a linear trend, i.e. successive years of the examined multiannual period 1966-2005, were independent variables. Parameters of linear regression functions were determined using the least squares method. The hypothesis of the significance of the regression function, i.e. the multiple correlation coefficient, was assessed with the *F*-Snedecor test. The significance of regression coefficients was assessed with the *t*-Student test. The occurrence of autocorrelation of random components was checked with the Durbin-Watson test.

Moreover, regression equations were verified using the relative forecast error calculated according to the formula:

$$RFE = \frac{y - y_p}{y} \cdot 100\% \qquad (1)$$

and the average relative forecast error for all analysed COBORU stations and all considered years of the 1966-2005 period, was calculated according to the formula:

$$ARFE = \frac{1}{n}\sum_{i=1}^{n}|RFE| \qquad (2)$$

where y-actual yield (t ha^{-1}); y_p-yield calculated according to the formula (t ha^{-1}); n-number of years in a time series (number of stations x number of years).

Additionally, the amount of times the relative forecast error in the analysed period 1966-2005 amounted to $|RFE| \leq 5\%$ (a very good forecast), and $5\% < |RFE| \leq 10\%$ (a good forecast) was determined (Dobosz, 2001). The equation was verified using independent material with cross-validation (Picard and Cook, 1984).

Risk to onion cultivation in Poland posed by unfavourable precipitation conditions was determined using a curvilinear regression equation. This equation was able to determine the threshold value of precipitation deficiency, i.e. that causing a 5% reduction in the total yield. Next, an average sum of precipitation was substituted into the formed regression equation describing the effect of precipitation for the period between the end of emergence to beginning of leaf bending. This average sum of precipitation was calculated only for those years it exceeded earlier specified threshold values. Yield was calculated for each of the COBORU and IMGW stations included in the research. The difference between the multiannual actual onion yield determined for all of Poland (the arithmetic mean of yield from all stations of COBORU) and the yield calculated according to the equation, enabled the determination of potential yield reduction caused by a lack of precipitation.

The frequency of precipitation deficiency (over the determined threshold) in the period between the end of emergence to beginning of leaf bending for the period 1966-2005 was determined using the following formula:

$$P = \frac{n_1}{N} \cdot 100\% \qquad (3)$$

where n_1-number of periods with precipitation deficiency; N-number of all examined periods.

All statistical calculations were carried out using STATISTICA 7.1 software.

Results and discussion

Water inflow in the form of atmospheric precipitation in the period between the end of emergence to beginning of leaf bending of medium-late onion cultivars in Poland

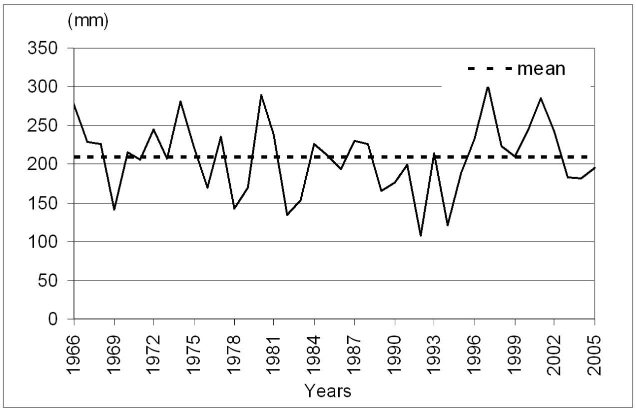

Fig. 2. Course of atmospheric precipitation totals (mm) in the period between the end of emergence to beginning of leaf bending, in Poland, 1966-2005

on average amounted to 210 mm (Fig. 2). The end of emergence of medium-late onions to beginning of leaf bending typically takes place between 10th May and 4th August in Poland (Kalbarczyk, 2008). The amount of precipitation varied from 52% of the multiannual average in 1992 to 145% in 1997.

In Poland, onion crops receive a varied amount of precipitation. In the considered development stage, plants cultivated in the north-western part of the country usually receive the lowest amount; on average below 180 mm. In the whole northern half of the country precipitation is below 220 mm (Fig. 3). The highest precipitation, above 300 mm, occurs in the south-eastern part of Poland. In the years 1992 and 1997, when extremely different precipitation totals were recorded, the spatial distribution was similar to the multiannual one. For the period 1966-2005, the onion in Poland yielded on average about 32 t ha^{-1}. In the period between the end of emergence to beginning of leaf bending, precipitation variability caused significant onion yield variability statistically confirmed at $P \leq 0.01$. The reaction of onion to the precipitation deficiencies was yield reductions, both below and above the norm.

The regression equation took into account total atmospheric precipitation from the period between the end of emergence to beginning of leaf bending and the yield trend for the period 1966-2005. The regression equation also explained the 53% variability of the yield (Tab. 1). For this equation the *ARFE* amounted to 9.6%. The regression equation produced about 45% very good forecasts, i.e. such forecasts with an error not exceeding 5%, and about 40% good forecasts, i.e. with an error between 5 and 10%.

The onion has a shallow and weakly developed root system. For this reason, the onion is sensitive to water shortage in the soil in each growth and development period, particularly between emergence and intensive growth of bulbs (Kalbarczyk, 2010; Ramalan, 2003). The results of the study confirm the onion's high vulnerability to precipitation conditions prevalent during its growing season, mainly in the period between the end of emergence to beginning of leaf bending. In Poland, during this period, the

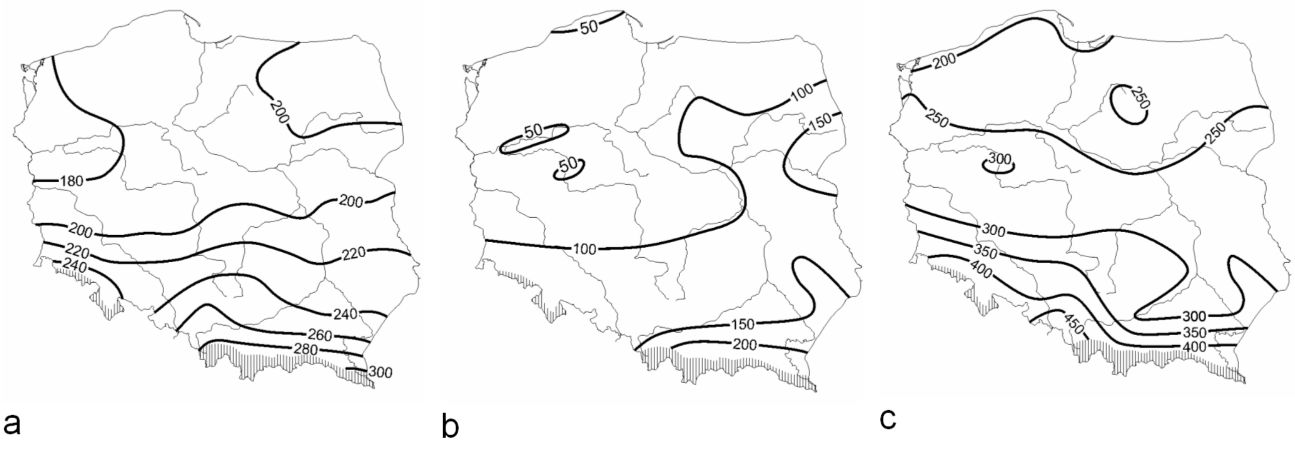

Fig. 3. Spatial distribution of atmospheric precipitation totals (mm) in Poland, in the period between the end of emergence to beginning of leaf bending: a-average (1966-2005), b-in 1992, c-in 1997

Tab. 1. Multiple regression equation for the relationship between the total onion yield and atmospheric precipitation total in the period between the end of emergence to beginning of leaf bending, based on the linear trend in Poland for the period 1966-2005

Regression equations	Variable			Characteristics			
	y (t ha^{-1})	Pr (mm)	R^2 (%)	*Sd-Sy* (t ha^{-1})	*ARFE* (%)	frequency of the occurrence of |*RFE*| in range 0-5 (%)	5-10 (%)
$y = -541.244^{***} + 0.284Yl^{***} - 0.000229Pr^{2***}$	31.9	201.4	52.8	1.8	9.6	45.3	40.4

y-average multiannual yield (t ha^{-1}), *Yl*-linear trend of the yield, i.e., the successive years 1966-2005 multiannual period, ***-significant at $P \leq 0.01$, *Pr*-atmospheric precipitation total, R^2-determination coefficient (%), *Sd-Sy*-difference between a standard deviation of a dependent variable and a standard error of equation estimation (t ha^{-1}), *ARFE*-average relative forecast error (%), *RFE*-relative forecast error (%)

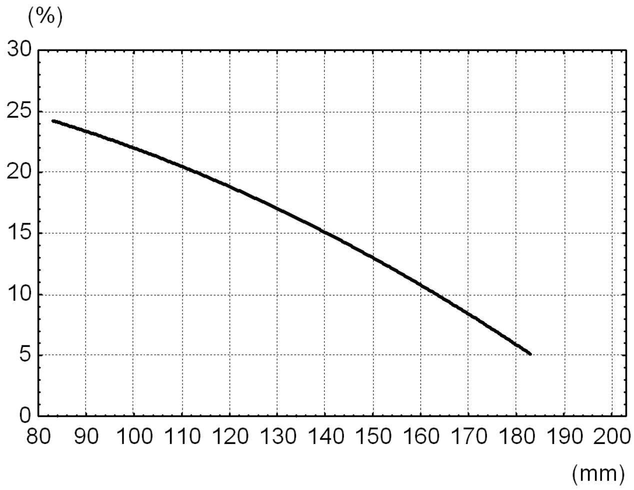

Fig. 4. Potential reduction in the total onion yield caused by atmospheric precipitation deficiency in Poland in the period between the end of emergence to beginning of leaf bending (reduction calculated using the equation given in Tab. 1)

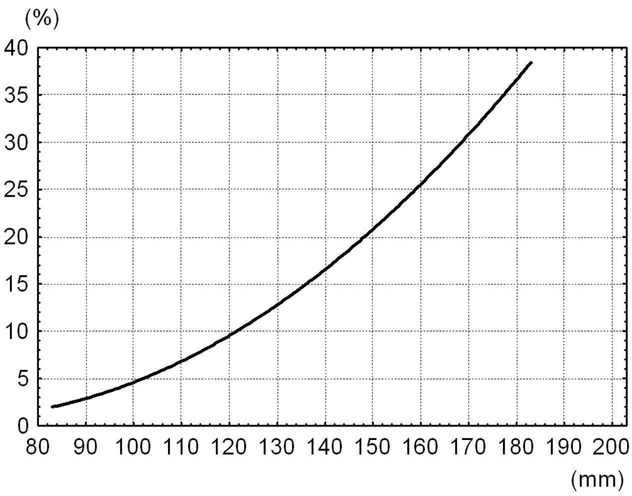

Fig. 6. Occurrence frequency of atmospheric precipitation deficiency in Poland in the period between the end of emergence to beginning of leaf bending (frequency calculated at 53 meteorological stations), 1966-2005

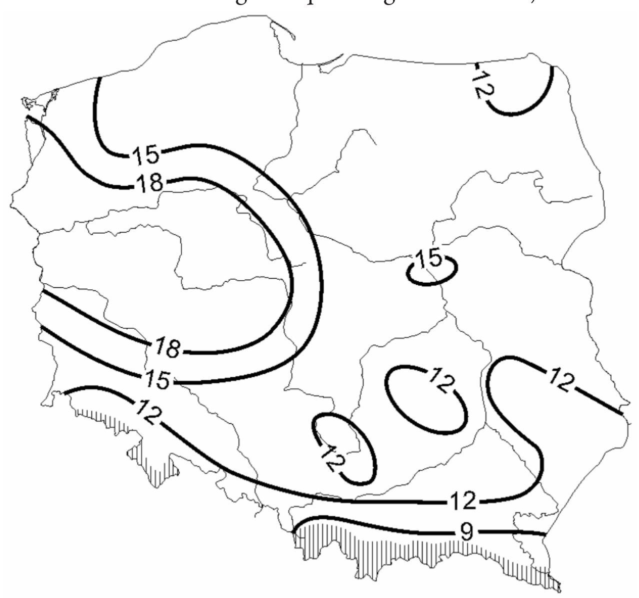

Fig. 5. Spatial distribution of potential reduction in the total onion yield caused by atmospheric precipitation deficiency in Poland, in the period between the end of emergence to beginning of leaf bending (reduction calculated using the equation given in Tab. 1)

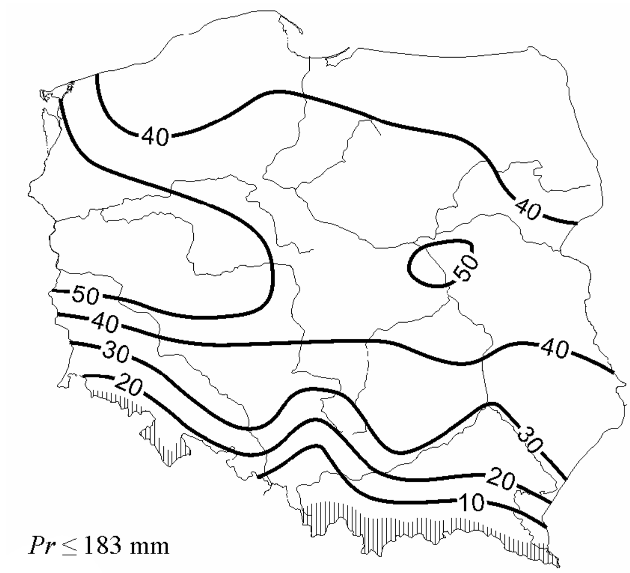

Fig. 7. Occurrence frequency of atmospheric precipitation deficiency in the period between the end of emergence to beginning of leaf bending causing reduction by at least 5% in the total onion yield, 1966-2005

occurrence of precipitation deficiencies over 13% of the norm caused a 5% reduction in onion yield, in comparison with the multiannual average (Fig. 4). The determined threshold value of precipitation in the period between the end of emergence to beginning of leaf bending amounted to 183 mm; which is below the value of optimal precipitation. According to Kalbarczyk (2008), in central Poland, optimal precipitation in the period between the end of onion emergence to beginning of leaf bending amounts to 204 mm. In Poland, the optimal precipitation in the whole sowing-to-onion-harvesting period significantly exceeds the threshold value determined in this study (Dzieżyc and Dzieżycowa, 1986).

The yield losses vary in different regions of Poland depending on the atmospheric precipitation deficiency (Fig. 5). The onion reacted most strongly to precipitation deficiency ($Pr \leq 183$ mm) in central-western and north-western Poland. In these areas, potential yield reduction amounted to more than 18% of the average multiannual yield. The lowest potential yield reduction, below 9%, was caused by precipitation deficiency in the south-east part of the country. In most parts of Poland, mainly in the centre, the north and the east, potential yield reduction caused by precipitation deficiency was within the range 12 and 15%.

Dzieżyc and Dzieżycowa (1986) compared years with a precipitation up to 200 mm against years of optimal precipitation. For the years with precipitation up to 200 mm, they found onion yield in Poland was lower by even 43% in medium-heavy soils and by 24% in heavy soils. Precipitation deficiency in the periods between germination, emergence, and bulb formation leads both to a decrease in yield and deterioration of yield quality (Tendaj, 2000). The average frequency of atmospheric precipitation deficiency in Poland between 1966-2005 which caused at least a 5% reduction in the total onion yield, amounted to about 37%. Average precipitation in Poland in 11 out of the 40 examined years did not reach 183 mm. In most parts of the country, the frequency of precipitation deficiency fluctuated between 10% and 50% (Fig. 6, 7). Precipitation deficiency occurred least often in the south-east part of the country where the frequency of atmospheric precipitation deficiency factor was below 10%. Precipitation deficiency was recorded most often, with a frequency of above 50%, in the central-west part of Poland, in the vicinity of Warsaw, and in the Szczecin Lowland.

In Poland, onion production potential is limited by recurrent periods of precipitation deficiency. With the predicted climate change in mind (Knight and Staneva, 2002; Ventura *et al*., 2002), Poland faces a shortening of onion development stages and further deterioration of conditions for onion cultivation (Kalbarczyk, 2009).

Conclusions

The obtained results confirm the onion's high vulnerability to precipitation conditions prevalent during its growing season, mainly in the period between the end of emergence to beginning of leaf bending. Average potential reduction in onion yield caused by precipitation deficiency in Poland was assessed to be from 9% in the south-east to 18% in the central west and north-west parts. In Poland, precipitation deficiency in the period between the end of onion emergence to beginning of leaf bending on average occurs least frequently in the south-east (on the average, every 10 years), and most often (on the average, every two years) in the central west and the north west parts.

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