The adverse effect of the long-term trend of the air temperature in Poland on the yield of onion

Niekorzystny przebieg wieloletniej temperatury powietrza w Polsce ograniczającej plon ogólny cebuli (*Allium cepa* L)

Robert KALBARCZYK[1] and Eliza KALBARCZYK[2]*

[1]Wroclaw University of Environmental and Life Sciences, Institute of Landscape Architecture, 24a Grunwaldzki Square, 50-363 Wrocław, Poland

[2]Adam Mickiewicz University, Department of Spatial Econometrics, 27 Dzięgielowa Street, 61-680 Poznań, Poland, *correspondence: ekalb@amu.edu.pl

Abstract

The yield of onion in Poland is highly variable. The year-on-year variability depends mainly weather conditions, including the air temperature conditions. This research aimed to determine the effect of air temperature on the total yield of onion grown in arable farmland. Using multiple curvilinear regression analysis, the variability of yield was explained in 56% by the air temperature in the period ‘end of emergence - beginning of leaf bending’ and the linear trend (consecutive years in the 1966-2005 period). Based on this equation, the critical average temperature during the end of emergence-beginning of leaf bending (Ee-Blb) period was determined at 16.7^{o}C, i.e. temperature followed by a reduction in the yield of onion by 5% compared to the long-term average. This decrease in the yield of onion caused by the occurrence of excessive air temperature also demonstrated spatial variability. In addition to high temperatures, the inclusion of the incidence of critical temperatures increased the diversity in the reduction in the yield of onions in Poland to < 3% and > 15%.

Keywords: arable farming, climate risk, phenology, vegetable

Abstrakt

Badania, prowadzone na podstawie wyników doświadczeń z lat 1966-2005 na terenie całej Polski, miały na celu określenie wpływu temperatury powietrza na plon ogólny cebuli w uprawie polowej. Przy zastosowaniu metody analizy regresji wielokrotnej krzywoliniowej, zmienność plonu cebuli wyjaśniono w 56%. W równaniu regresji zmiennymi objaśniającymi były: trend liniowy (kolejne lata wielolecia 1966-2005) oraz temperatura powietrza z okresu koniec wschodów-początek załamywania szczypioru (ee-blb). Na podstawie tego równania wyznaczono wartość krytyczną średniej temperatury powietrza w okresie ee-blb. Temperatura krytyczna, przy której następuje potencjalne zmniejszenie plonu cebuli o 5% wartości średniej wieloletniej, wyniosła 16,7^{o}C. Potencjalne zmniejszenie plonu cebuli powodowane wystąpieniem zbyt wysokiej temperatury powietrza, było zróżnicowane przestrzennie. Uwzględnienie, oprócz wysokości temperatury, również częstości występowania temperatury krytycznej, spowodowało zwiększenie zróżnicowania potencjalnego zmniejszenia plonu cebuli na obszarze Polski. Wyznaczone w ten sposób zmniejszenie plonu wyniosło od <3% do >15%.

Słowa kluczowe: fenologia, ryzyko klimatyczne, uprawa polowa, warzywo

Detailed abstract

Temperatura powietrza stanowi, wraz z opadem atmosferycznym, główny czynnik meteorologiczny kształtujący zmienność plonów roślin uprawnych. Cebula należy do najpopularniejszych w Polsce warzyw uprawianych w polu. Jej plony podlegają dużym wahaniom z roku na rok, do czego przyczynia się stosunkowo duża wrażliwość tej rośliny na zmienne warunki atmosferyczne, w tym termiczne. Wymagania cieplne cebuli są wyraźnie zróżnicowane w poszczególnych okresach jej rozwoju. Prognozowane w wielu doniesieniach zmiany warunków termicznych Polski, skłoniły autorów do podjęcia szczegółowych badań nad wpływem temperatury powietrza na plon tej rośliny w ujęciu wieloletnim.

Badania, prowadzone na podstawie 40.letnich wyników doświadczeń na terenie całej Polski (ryc. 1), miały na celu określenie wpływu temperatury powietrza w okresie krytycznym na plon ogólny cebuli w uprawie polowej. Po uśrednieniu danych dotyczących ponad 40, najbardziej rozpowszechnionych w uprawie, odmian średnio późnych cebuli (każdego roku przeciętnie 4-6 odmian), utworzono wzorzec zbiorowy analizowanej rośliny. Zastosowanie w dalszym etapie badań wzorca zbiorowego oparto na założeniu, iż różnice wewnątrzgatunkowe nie zaciemniają poszukiwanych dla gatunku, ogólnych prawidłowości.

W latach 1966-2005 średnia krajowa wielkość plonu cebuli podlegała dużym wahaniom, od około 11 $t \cdot ha^{-1}$ do prawie 70 $t \cdot ha^{-1}$ (tab. 1). Spośród zbadanych zależności pomiędzy zmiennością plonu cebuli a średnią temperaturą powietrza w jej okresach rozwoju, najsilniejszy związek stwierdzono pomiędzy plonem i temperaturą z okresu koniec wschodów-początek załamywania szczypioru (ee-blb).

Przeciętna temperatura powietrza w Polsce w okresie ee-blb cebuli wynosiła średnio 16,3^{o}C (tab. 1). W poszczególnych latach wielkość odchylenia od średniej sięgała prawie 2^{o}C (ryc. 2). Najzimniejsze okresy ee-blb wystąpiły w latach 1974-1987, z minimum w roku 1974. Od roku 1992 włącznie średnia temperatura powietrza w okresie ee-blb z reguły była wyższa od średniej wieloletniej (ryc. 3). W Polsce rozkłady przestrzenne temperatury w stosunkowo długim okresie ee-blb w poszczególnych latach wielolecia były zazwyczaj do siebie podobne (ryc. 4).

W opracowanym równaniu regresji (tab. 2) zmienność plonu cebuli w 56% objaśniły: trend liniowy, będący odpowiednikiem postępu technologicznego, jaki nastąpił w latach 1966-2005 oraz temperatura powietrza z okresu koniec wschodów – początek załamywania szczypioru (ee-blb). O tym, że równanie wystarczająco dobrze opisało badaną zależność, świadczy obliczony średni względny błąd prognozy ARFE <10% oraz duża częstość niskich wartości względnych błędów prognozy (tab. 2).

Na podstawie tego równania wyznaczono wartość krytyczną średniej temperatury powietrza w okresie ee-blb. Temperatura krytyczna, przy której następuje potencjalne zmniejszenie plonu cebuli o 5% wartości średniej wieloletniej, wyniosła 16,7^{o}C. Przy wzroście temperatury powietrza z okresu ee-blb do ok. 18^{o}C, potencjalne zmniejszenie plonu cebuli zwiększa się do ok. 14% (ryc. 5). Największe potencjalne zmniejszenie plonu, >12%, powodowane wystąpieniem zbyt wysokiej temperatury wystąpiło w Polsce środkowej, w dolinie Wisły od Krakowa do Torunia i na niewielkim obszarze w środkowowschodniej części kraju (ryc. 6). Najmniejsze zmniejszenie plonu, <9%, wystąpiło na północy oraz na południu Polski, na obszarach podgórskich. Niekorzystna dla cebuli temperatura powietrza (16,7^{o}C) występuje w Polsce stosunkowo często, bo średnio prawie raz na 2,5 roku (ryc. 7). Największa częstość występowania temperatury 16,7^{o}C charakteryzuje środkową i środkowozachodnią część Polski, Kotlinę Sandomierską położoną w południowo-wschodniej części kraju oraz niewielki obszar na środkowym wschodzie (ryc. 8).

Uwzględnienie, oprócz wysokości temperatury, również częstości występowania temperatury krytycznej, spowodowało zwiększenie zróżnicowania potencjalnego zmniejszenia plonu cebuli na obszarze Polski (ryc. 9). Wyznaczone w ten sposób zmniejszenie plonu wyniosło od <3% we wschodniej części wybrzeża oraz w rejonach podgórskich do >15% w Kotlinie Sandomierskiej.

Przeprowadzone analizy pozwoliły na stwierdzenie, że utrzymanie się obserwowanych w Polsce tendencji zmian temperatury powietrza może spowodować pogorszenie klimatycznych warunków uprawy cebuli.
Wskazane jest więc kontynuowanie badań nad czasową i przestrzenną zmiennością krytycznych wartości temperatury powietrza, przy uwzględnieniu zmian zachodzących w przebiegu terminów agrofenologicznych cebuli w uprawie polowej.

Introduction

The onion is one of the most common vegetables in the world, with recognized nutritional, health and taste values. Among the countries of the European Union, Poland has one of the largest total areas on which onion is grown; in individual years from 2000-2011, onions were grown on 24 to 37 thousand hectares (FAO, 2013). It is also one of the few common vegetables (the others being: cabbage, carrots, beets, tomatoes and cucumbers) in Polish arable farming. Onion yields in Poland, however, are among the lowest in the European Union, with the average national yield at about 21 t·ha^{-1} in the period 2000-2011, compared to the EU average at 29.1 t·ha^{-1} (Juszczak, 2005; FAO, 2013). The reasons for the differences in yield between Poland and the EU include lower quality of agricultural production, lower spending on means of production, deficiency of irrigation and less effective production technologies (Chudzik, 2007).

In the years 2000-2011 the total onion harvest in Poland ranged from 580 to 720 thousand tonnes. A significant year-on-year variation resulted from great changes in the acreage of cultivation and also in yield. In the years 1965-2004 the maximum yield of onions in Poland was higher than the minimum six times (i.e. six years), and higher than the average twice (Kalbarczyk, 2010). Air temperature and atmospheric precipitation are the main meteorological factors that decide harvest variation. Expected changes in the thermal conditions in Poland against the established thermal requirements of the onion, different in its individual stages of development, were the main reasons behind our research on the effect of air temperature on onion yield. The findings of this paper are supplemented by our other publications on how onion yield in Poland is influenced by precipitation (Kalbarczyk et al., 2011) and by meteorological conditions (temperature, radiation and precipitation) taken as a whole (Kalbarczyk, 2010).

As the year-on-year variation depends mainly on weather conditions (variable in time and space), including the air temperature conditions (Mierwinski, 1985; Cieślak-Wojtaszek, 2000; Kalbarczyk et al., 2011), the aim of this study was to determine the effect of the air temperature in the critical period on the volatility of the total yield of onions in Poland.

Materials and Methods

The study analyzed the size of the total yield and agronomic and phenological dates for medium-late varieties of onions (*Allium cepa* L.) in the years 1966-2005. These data included the results of experiments conducted in 17 experimental stations of the Research Centre for Cultivar Testing in Słupia Wielka (COBORU) (Fig. 1).

Figure 1. Locations of experimental (■) and meteorological stations (●) in Poland

Agrophenological dates in the study included: sowing (Sg), the end of emergence (Ee), the beginning of leaf bending (Blb), and harvest (H). After averaging the data for over 40 of the most widely cultivated medium-late cultivars of onion (each year, an average of 4-6 cultivars), a collective pattern for the analyzed plants was created. The use of the collective pattern was based on the assumption that intraspecies differences do not obscure the overall regularities.

Onions were grown in fertile soils with a high water content, permeable, easily heated in spring and not creating crust on the surface. Mineral fertilizers were used at an average rate of 370 kg per hectare, including N (120 kg), P_2O_5 (80 kg) and K_2O (170 kg). Cereals and legumes were usually used as a forecrop.

The study also used daily and ten-day average data regarding air temperatures from all the weather stations operating at the COBORU experimental sites and 51 stations of the Institute of Meteorology and Water Management (IMGW) (Fig. 1). Based on data collected from the stations, the mean air temperature was calculated for times corresponding to average Polish agrophenological periods for onions: sowing - end of emergence (Sg-Ee, 09 April – 10 May), end of emergence - beginning of leaf bending (Ee-Blb, 11 May – 04 August) and beginning of leaf bending - harvest (Blb-H, 05 August – 02 September). The study did not take into account regions located in the south-western and south-eastern Poland, because of the very high diversity of physiographic conditions and altitudes often above 500 m above mean sea level, considerably limiting the possibility of arable farming.

The effect of air temperature on the yield of onion (y_p, t·ha^{-1}) was determined by multiple curvilinear regression analysis. The relationship is expressed by an equation in which the parameters of the regression function were determined by least squares. The fit of the regression function to empirical data was measured by correlation coefficient (r), coefficient of determination (R^2, %) and an indicator describing the difference between the standard deviation of the dependent variable and the standard error of estimation for the SD-Sy equation (t·ha^{-1}) (Dobosz, 2001). All statistical analyses were carried out using Statistica (Version 10.0, StatSoft Inc., Tulsa, USA). Relevance of quantitative forecasts determined for the equation was determined by the relative forecast error:

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

and the average relative forecast error:

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

which was determined for all analyzed COBORU stations and all years in the 1966-2005 period. In formulas (1) and (2) the applied symbols denote the following:

y_p – projected yield according to the regression equation, t·ha^{-1},

y_o – actual yield, t·ha^{-1},

n – number of years adopted for a time series (number of stations x number of years).

The study also identified the number of times the relative forecast error for 1966-2005 was $|RFE| \le 5\%$ (very good forecast) and $5\% < |RFE| \le 10\%$ (good forecast).

Based on the regression equation the threshold value of air temperature was determined, i.e. the temperature which would result in an at least a 5% reduction in the total yield of onion below the long-term average for the period 1966-2005. Then the equation describing the effect of air temperature during the Ee-Blb period on the size of the total yield of onion was supplemented with the average air temperature for each IMGW and COBORU station separately. The average was calculated only on the basis of the years in which the temperature exceeded a designated threshold. The differences between the long-term real yield of onion determined for the whole country and the yields calculated according to the procedure described above allowed determination of the reduction in the total yield of onion caused by unfavorable air temperatures.

The incidence of excessive air temperature (above the determined threshold) during Ee-Blb in the period from 1966 to 2005 was calculated by the formula (P_1, %):

$$P_1 = \frac{n_1}{N} \cdot 100\% \qquad (3)$$

where:

n_1 - number of periods with excessive air temperature,

N - the number of all the periods under consideration.

The risk to onion cultivation in arable farming in Poland was determined by a *Kw* indicator (4), taking into account onion yield losses caused by excessive air temperatures and the frequency of occurrence (Kalbarczyk, 2007):

$$Kw = \frac{P_2}{n_2} \cdot (-\beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_2^{\,2}) + (1 - \frac{P_2}{n_2}) \cdot yk \qquad (4)$$

where:

P - number of years with unfavorable air temperature in the period 1966-2005,
n_2 - number of years in the period 1966-2005,
x_1 - linear trend, which is further analyzed in the multi-year period 1966-2005,
x_2 - air temperature, °C,
β_o - intercept,
$\beta_1, \beta_2, \beta_3$ - regression coefficients,
yk - average yield in years with favorable air temperatures.

Results and Discussion

In the years 1966-2005 the national average yield of onion was subject to large fluctuations from about 11 $t \cdot ha^{-1}$ to almost 70 $t \cdot ha^{-1}$ (Table 1). There were also significant variations in weather conditions, including air temperature. The role of temperature as an important climate factor shaping crop yields is often described in literature (Lancaster et al., 1996; Baker and Reddy, 2001; Goldblum, 2009; Krishnan et al., 2011; Hasanuzzaman et al., 2013).

Table 1. Statistical characteristics of the total yield of onion and air temperature during the period 'end of emergence - beginning of leaf bending' in Poland in the years 1966-2005

Variable	Characteristics					Vs, %
	$\bar{x}$±SD	Min	Max	Q_1	Q_3	
y_o, $t \cdot ha^{-1}$	32.0±11.3	10.8	67.2	23.2	38.8	35.5
x_2, ^oC	16.3±1.1	14.4	18.2	15.5	17.2	6.7

y_o – total yield of onion ($t \cdot ha^{-1}$), x_2 – air temperature in the period 'end of emergence - beginning of leaf bending' (^oC), $\bar{x}$ – average, SD – standard deviation, Min – the minimum value, Max – the maximum value, Q_1 – lower quartile, Q_3 – upper quartile, Vs – variability coefficient (%)

Thermal requirements of onions are often reported to be higher during the periods of seed germination, formation of bulbs, as well as leaf bending and maturation. Among the examined relationship between the volatility of the yield of onion and average air temperature during the periods sowing-end of emergence (Sg-Ee), end of emergence-beginning of leaf bending (Ee-Blb), beginning of leaf bending–harvest (Blb-H), and sowing-harvest (Sg-H), the most significant relationship between yield and air temperature was found in the Ee-Blb period.

The optimal temperature for seed germination, depending on the cultivar, ranges from 10 to 20^{o}C, although the seeds begin to germinate at temperatures as low as 5-6^{o}C (Miedema, 1992; Parmar et al., 2001; Adamicki and Nawrocka, 2005). According to Miedema (1992), the optimal temperature for the rooting of onion is between 10 and 15^{o}C. Minimum air temperature for the growth of onion leaves is 6^{o}C (Brewster, 1997). After the emergence and in the period of rapid leaf growth, the thermal requirements of onion are relatively low. Development of the root system during this period is enhanced by an air temperature of 12-15^{o}C and a relatively short day (Adamicki and Nawrocka, 2005). After this period, thermal requirements of onion start to increase. During the growth of bulbs, optimum temperature ranges from 16 to 20^{o}C. An even higher air temperature, 20°C or more, is optimal during leaf bending and maturation (Steer, 1980ab).

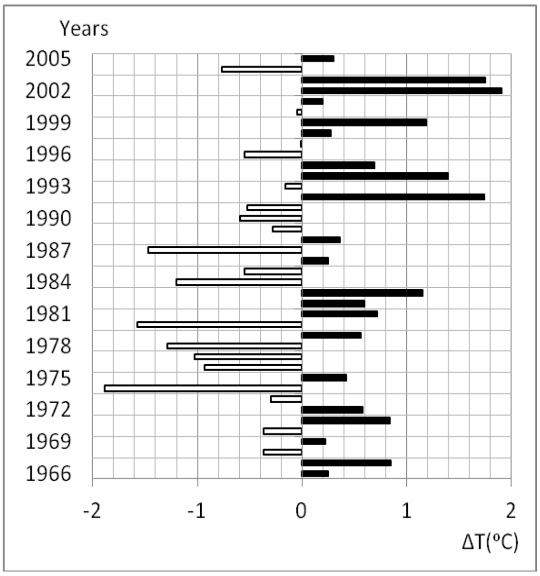


Figure 2. Deviations of air temperature during the period ‘end of emergence - beginning of leaf bending’ from the long-term average in the years 1966-2005 in Poland

The average air temperature in Poland in the Ee-Blb period of onions was 16.3^{o}C (Table 1). In some years the deviation from the average reached almost 2^{o}C (Fig. 2). The coldest Ee-Blb periods occurred in the years 1974-1987, with the minimum in 1974 (Fig. 3). Since 1992, the average air temperature during the Ee-Blb period was generally higher than the long-term average. The warmest Ee-Blb period appeared in 2002.

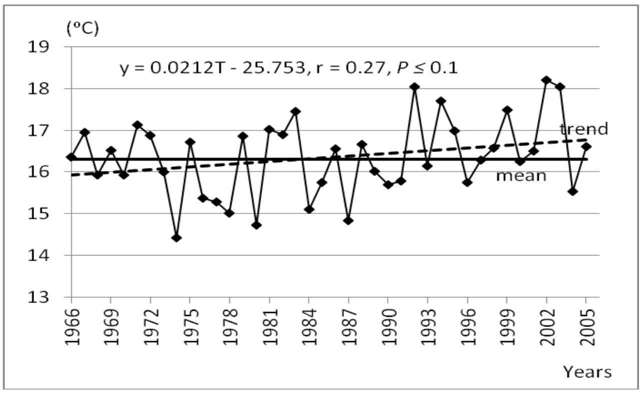
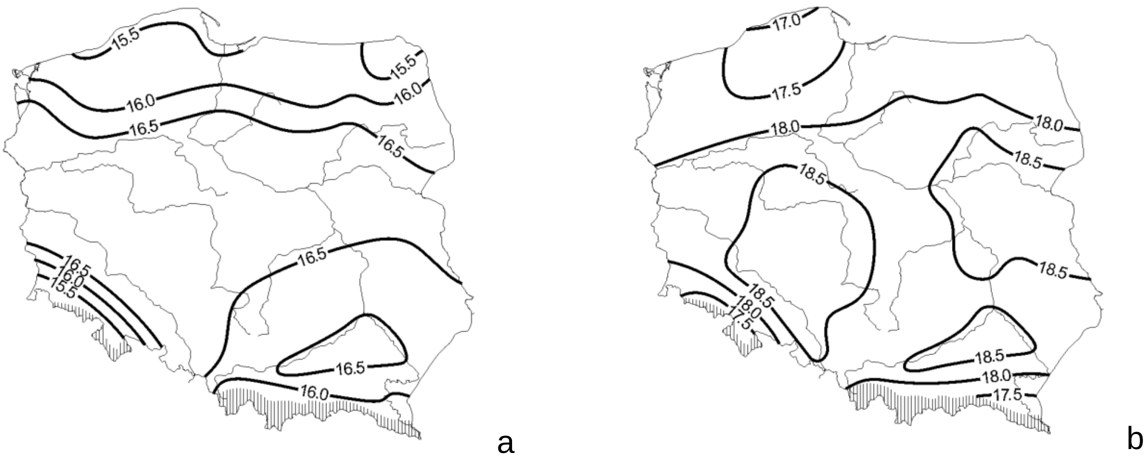


Figure 3. The average air temperature during the period ‘end of emergence - beginning of leaf bending’ in the years 1966-2005 in Poland

In Poland, the spatial distribution for air temperature during the relatively long Ee-Blb period was usually similar between years (Fig. 4). The coldest were the northern Baltic coast, and the foothills and mountain areas in the south. The warmest were the lowlands in the center of the country and in the Sandomierz Basin between the Vistula and San rivers. These spatial regularities were maintained also in the hottest and coldest years (2002 and 1974).



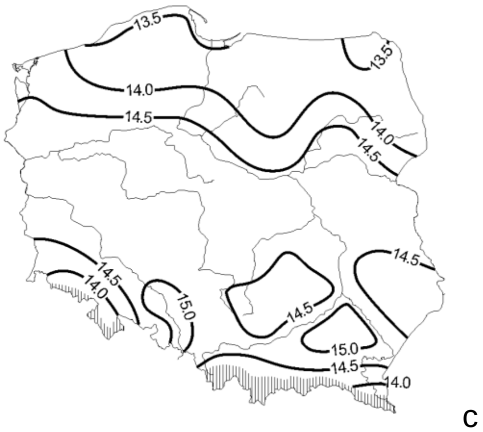


Figure 4. The spatial distribution of air temperature during the period ‘end of emergence - beginning of leaf bending’ in Poland; a - average in the period 1966-2005, b - in 2002, c - in 1974

Table 2. The regression equation and its characteristics describing the relationship between the overall yield of onion and the air temperature during the period ‘end of emergence - beginning of leaf bending’ in Poland in the years 1966-2005

Variable and intercept of the equation				Characteristics				Frequency of the occurrence of |RFE | in range	
Symbol	Value	t	P	r	R^2 (%)	SD-Sy ($t\cdot ha^{-1}$)	ARFE (%)	0-5 (%)	5-10 (%)
β_o	-88.899	3.242	0.01						
$\beta_1 x_1$	0.331	6.125	0.01						
$\beta_2 x_2$	-60.1035	-4.684	0.01	0.751	56.4	1.7	9.1	49.1	43.3
$\beta_3 x_2^2$	1.675	4.243	0.01						

x_1 – linear trend, which is further analyzed across the multi-year period 1966-2005, x_2 – air temperature in the period 'end of emergence - beginning of leaf bending' (^oC), β_o – intercept of the equation, $\beta_1, \beta_2, \beta_3$ – regression coefficients, t - Student’s *t*-test, P – level of significant, r – correlation coefficient, R^2 – determination coefficient (%), SD-Sy – indicator describing the difference between the standard deviation of the dependent variable and the standard error of estimation of the regression equation ($t\cdot ha^{-1}$), ARFE – average relative forecast error (%), RFE – relative forecast error (%)

In the regression equation (Table 2) the variability of yield of onions was 56% explained by the linear trend, equivalent to the technological progress made in the years 1966-2005, and the air temperature in the Ee-Blb period. The fact that the equation sufficiently described the relationship is shown by the average relative forecast error *ARFE* < 10% and a high frequency of low relative forecast errors. The equation (Table 2) was used to calculate the threshold average air temperature during Ee-Blb at 16.7^{o}C. With an increase in average air temperature in the Ee-Blb period to about 18°C, the decrease in the yield of onion was approximately 14% (Fig. 5). The negative effects of excessive air temperatures during Ee-Blb on yield, observed in this study, are consistent with the aforementioned thermal requirements of onions during its development. The results confirm the lower thermal requirements of onions grown in Poland in the period preceding leaf bending.

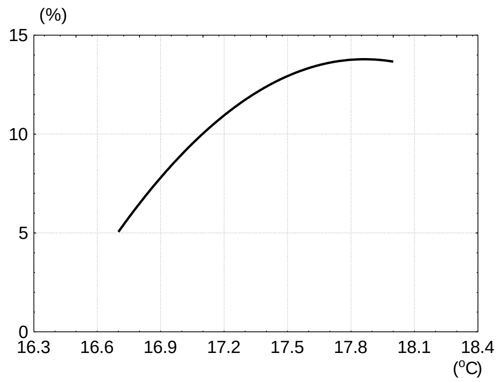


Figure 5. Average decline in the total yield of onion (%) caused by excessive air temperature during the period ‘end of emergence - beginning of leaf bending’ in Poland

A decrease in the yield of onion caused by the occurrence of excessive air temperatures varied spatially. The largest temperature-related decrease in the yield, > 12%, occurred in central Poland, in the Vistula river valley from Kraków to Toruń and a small area in the central eastern part of the country (Fig. 6).

Figure 6. The spatial distribution of the potential to reduce the total yield of onion (%) caused by excessive air temperature during the period ‘end of emergence - beginning of leaf bending’ in Poland

The smallest decrease in the yield, < 9%, occurred in the north and the south of Poland in foothill areas. Excessive air temperature may also cause crop losses of other plants grown in Poland, e.g. potato, wheat and spring triticale (Nowicka, 1993; Kalbarczyk E., 2010). In addition, it is also important how often this reduction in yield may occur. In the case of onions, this risk can be assessed as relatively high. Unfavorable air temperatures for onions occur relatively commonly in Poland, on average nearly every 2.5 years (Fig. 7). Temperatures resulting in the largest reduction in the yield of onion, i.e. 18.0°C, occur only once every 20 years.

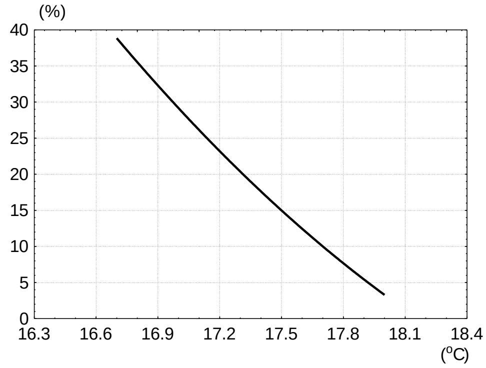


Figure 7. The mean frequency (%) of air temperature ≥16.7°C during the period ‘end of emergence - beginning of leaf bending’ in Poland

The highest incidence of temperature of 16.7°C can be found in the central and west-central part of Poland, Sandomierz Basin located in the southeastern part of the country, and a small area in the central-eastern part (Fig. 8). There, temperatures causing a 5% reduction in yield may occur more frequently than each other year. The incidence of adverse air temperature decreases south- and northwards. The lowest frequency, less than 10%, is found along the Baltic coast and in the mountainous areas.

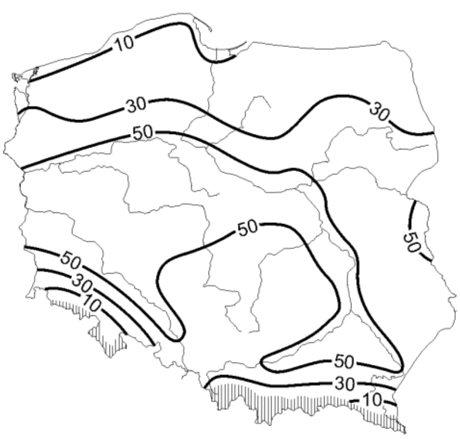


Figure 8. The spatial distribution of frequency (%) of air temperature ≥16.7°C during the period ‘end of emergence - beginning of leaf bending’ in Poland

Figure 9. The spatial distribution of the reduction in the total yield of onion (%) caused by excessive air temperature and frequency during the period ‘end of emergence - beginning of leaf bending’ in Poland

The spatial distribution of the potential to reduce the yield of onion, taking into account the combined effects of excessive temperature and the frequency of its occurrence, was much more diverse (Fig. 9). The largest reduction in onion yield, > 15%, is possible in the Sandomierz Basin. A significant reduction, >12%, may occur in the central-western and central Poland, as well as in the central valley of the Vistula river. The smallest potential reduction in yield, <3%, was found for the eastern part of the coast and in the mountainous areas.

Observations of long-term temperature changes in the months corresponding Ee-Blb period were conducted both by region and for the entire Poland (Żmudzka, 2004; Kożuchowski and Degirmendzic, 2005; Michalska and Kalbarczyk, 2005; Zawora, 2005; Żarski et al., 2007; Kalbarczyk et al., 2010). Analyses of air temperature changes in Poland showed that the most frequent trends included an increase in air temperature in both the cold and warm half of the year. It seems likely that if the trends are maintained, natural conditions for the cultivation of onion and other plants may considerably deteriorate in central Poland.

Conclusion

Onion yield variability is most correlated with air temperature variability in the Ee-Blb period. An air temperature of 16.7^{o}C-18^{o}C during the Ee-Blb period would result in a decrease in the yield by 5%-14%. A decrease in the yield of onion caused by the occurrence of excessive air temperature is spatially differentiated in Poland. It is therefore advisable to continue the study of temporal and spatial variability of the threshold temperatures, taking into account changes in agrophenological periods of onions cultivated in arable farming.

References

Adamicki, F., Nawrocka B., (ed.) (2005) Metodyka integrowanej uprawy cebuli. PIORIN Warszawa. Available at: http://piorin.gov.pl [Accessed 25 November 2013].

Baker J.T., Reddy V.R., (2001) Temperature effects on phenological development and yield of muskmelon. Annals of Botany, 87, 605–613. DOI:10.1006/anbo.2001.1381

Brewster J.L., (1997) Onions and garlic. In: Wien H.C. (ed.), The physiology of vegetable crops. CAB International, Wallingford, UK, 581–619.

Cieślak-Wojtaszek W., (2000) Zmiany w produkcji i rozmieszczeniu warzyw polowych w Polsce w latach 1975-1998. Skierniewice, Instytut Warzywnictwa Press. 126 pp.

Chudzik A., (2007) Produkcja wybranych gatunków warzyw gruntowych w Polsce w latach 1996-2005. Annales UMCS, sectio EEE, 17(1), 73–80.

Dobosz M., (2001) Wspomagana komputerowo statystyczna analiza wyników badań. Warszawa, EXIT Press. 452 pp.

FAO 2013. http//www.faostat.fao.org

Goldblum D., (2009) Sensitivity of corn and soybean yield in Illinois to air temperature and precipitation: the potential impact of future climate change. Physical Geography, 30 (1): 27–42. DOI: 10.2747/0272-3646.30.1.27

Hasanuzzaman M., Nahar K., Fujita M., (2013) Extreme temperature responses, oxidative stress and antioxidant defense in plants. In: Vahdati K., Lesli C. (eds). Abiotic Stress - Plant Responses and Applications in Agriculture, InTech, 169–205. DOI: 10.5772/54833

Juszczak K., (2005) Zmiany w produkcji warzyw gruntowych w Unii Europejskiej ze szczególnym uwzględnieniem cebuli. Stow. Ekon. Roln. i Agrobiz. Rocz. Nauk., 7(1), 114–119.

Kalbarczyk E., (2010) Klimatyczne ryzyko uprawy pszenżyta jarego (Triticosecale Wittmack) w Polsce. Szczecin, Zachodniopomorski Uniwersytet Technologiczny Press.136 pp.

Kalbarczyk R., (2007) Potencjalne zmniejszenie plonu ogórka w uprawie polowej na terenie Polski powodowane niedoborami opadów atmosferycznych. Annales UMCS, sectio EEE., 17(2), 83–95.

Kalbarczyk R., (2010) The application of the cluster analysis in recognizing weather patterns conducive to large and small crops of mid-late onion cultivars (*Allium cepa* L.) in Poland. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 38(1), 100–108.

Kalbarczyk R., Kalbarczyk E., Raszka B., (2011) Risk to onion (*Allium cepa L.*) field cultivation in Poland from precipitation deficiency. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 39(2), 214–218.

Kalbarczyk R., Raszka B., Kalbarczyk E., (2010) Variability of the course of tomato growth and development in Poland as an effect of climate change. In: Blanco J., Kheradmand H. (eds.). Climate Change – Socioeconomic Effects. InTech, 279–306. DOI: 10.5772/24235

Kożuchowski K., Degirmendzic J., (2005) Contemporary changes of climate in Poland: trends and variation in thermal and solar conditions related to plant vegetation**.** Polish Journal of Ecology, 53(3), 283–297.

Krishnan, P., Ramakrishnan B., Raja Reddy K. and Reddy V., (2011) High temperature effects on rice growth, yield, and grain quality. Advances in Agronomy, 111, 87–206. DOI: 10.1016/B978-0-12-387689-8.00004-7

Lancaster J.E., Triggs C.M., de Ruitter J.M., Gandar P.W., (1996) Bulbing in onions: photoperiod and temperature requirements and prediction of bulb size and maturity**.** Annals of Botany, 78, 423–430.

Michalska B., Kalbarczyk E., (2005) Longterm changes in air temperature and precipitation on Szczecińska Lowland. EJPAU Ser. Environmental Development, 8(1) Available at: www.media.ejpau.pl [Accessed 25 November 2013].

Miedema P., (1992) The effects of temperature on sprouting of onion bulbs. Onion Newsletter for the Tropics, 4, 52–54.

Mierwinski J., (1985) Scale and localization of cucumber production under covers in Poland. Acta Horticulturae, 156, 281–286.

Nowicka A., (1993) Temperatura In: Dzieżyc J. (ed.). Czynniki Plonotwórcze – Plonowanie Roślin. PWN, Warszawa, 99–147.

Parmar, J.N., Zode N.G., Sable N.H., Rathod T.H., Mohod V.K., (2001) Evaluation of substrata and temperature for testing germination of onion (*Allium cepa*) seed in laboratory. Annals of Plant Physiology, 15, 126–129.

Steer B.T., (1980a) The bulbing response to day length and temperature of some Australasian cultivars of onion (*Allium cepa* L.). Australian Journal of Agricultural Research, 31(3), 511–518.

Steer B.T., (1980b) The role of night temperature in the bulbing of onion (*Allium cepa* L.). Australian Journal of Agricultural Research, 31(3), 519–523.

Zawora T., (2005) Temperatura powietrza w Polsce w latach 1991-2000 na tle okresu normalnego 1961-1990. Acta Agrophisica, 6(1), 281–287.

Żarski J., Dudek S., Kuśmierek R., (2007) Zmienność ekstremalnej temperatury powietrza w rejonie Bydgoszczy w latach 1971-2005. Acta Agrophisica, 9(2), 542–547.

Żmudzka E., (2004) The climatic background of agricultural production in Poland (1951-2000). Miscellanea Geographica, 11, 127–137.