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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

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Abstract

This study uses 40 years valuable of data (1966-2005) obtained by the Polish Research Centre for Cultivar Testing and the Polish Institute of Meteorology and Water Management to recognize weather conditions conducive to large and small crops of onion *(Allium cepa* L.*)*, more specifically its mid-late cultivars growth in Poland. We found three clusters of agrometeorological conditions, determining different sizes of onion crops. Cluster no. 1 included observations which were characterized by large onion crops (45.9 t ha^{-1} for the total crop and 44.7 t ha^{-1} for the commercial crop) and cluster no. 3 was characterized by a small crop (respectively 26.2 and 24.8 t ha^{-1}). Large crops were favored by the following weather patterns: during sowing-end of emergence, above-average sunshine duration (8.1 h) and above-average air temperature (13.0°C); in the end of emergence-beginning of leaf bending-average sunshine duration (7.4 h), average soil temperature (18.7°C) and air temperature (16.8°C) and above-average rainfall, described by the coefficient of rainfall (2.8 mm); in the beginning of leaf bending-harvest-soil temperature (17.3°C) and air temperature (16.0°C) lower than a long-term average. Temperatures of soil and air that are higher than a long-term average, especially in the period sowing-end of emergence, with a parallel stable level of rainfall, may cause a reduction in onion crops in Poland.

Keywords: onion, factors agrometeorological, cluster analysis

Introduction

Field plants are an important part of vegetable production in Poland. In 2006 it was the onion that had the greatest share of total vegetable production (15.5% acreage), slightly higher than cabbage (Kulikowski, 2007). The acreage of onion cultivation is one of the greatest in the European Union: in 2006 it was above 35.000 ha and the average between 1996 and 2005 was almost 34.000 ha, while in Romania (the country with the greatest acreage of onion cultivation in the EU)-the mean was almost 37.000 ha. (Juszczak, 2005; Chudzik, 2007; FAO, 2007). The greatest acreage of onion cultivation in Poland was observed in 1995 -38.600 ha, and in the following years it gradually decreased. Among the countries of the European Union, the greatest producers of onion are Spain and Holland, the greatest exporter is Holland, and the largest importer is Germany, which annually imports about 300.000 tons (Behr, 2003).

Field onion cultivation in Poland is characterized by a great year-to-year variability of the crop volume, resulting both from the variability in the acreage and weather conditions (Cieślak-Wojtaszek, 2000; Koźmiński and Michalska, 2001; Kalbarczyk, 2006; Kalbarczyk and Kalbarczyk, 2006). In Poland, commercial onion production does not exceed 20 t ha^{-1} and in this regard, it is smaller by about 50% than the average crop in European Union countries in which onion cultivation is of great importance (Juszczak, 2005). In the four decades between 1966 and 2005, the highest (23.7 t ha^{-1}) national onion crop in commercial production was achieved in 2004 and the lowest (11.5 t ha^{-1}) in 1969 and 1980, whereas in experimental conditions the yields of this plant ranged from 10 to even 80 t ha^{-1}.

Onion crops obtained both in commercial production and in experimental conditions show a significant increase which in 1966-2005 was 100% -from 12 to almost 24 t ha^{-1} and from 20 to almost 40 t ha^{-1} (Jarocka, 1970; Górka, 1989; Koźmiński and Michalska, 2001; Kalbarczyk, 2006; Kalbarczyk 2009). According to Malepszy (2004), an increase in plant production in Poland at the end of the 20th century was caused mostly by biological progress and only in second by fertilization and plant protection.

The aim of this study was to find clusters of weather conditions that are conducive to large and small crops of mid-late onion cultivars in Poland.

Materials and methods

In this paper we used results of experiments with mid-late onion cultivars conducted at 17 stations of the Research Center for Cultivar Testing (COBORU) across the whole of Poland between 1966 and 2005, except 2003 when no experiments were conducted (Fig. 1). As Fig. 1

Fig. 1. Distribution of meteorological- ▲ and experimental-■ stations conducting experiments on mid-late onion cultivars in years 1966-2005

shows, the quantity and location of experimental stations generally fulfilled conditions of representativeness, especially for regions with a large acreage of onion cultivation. A certain scarcity of experimental stations appears to exist in the north-eastern part of Poland (Machnik, 1973).

The subject matter of the study were 261 observations (quantity of stations x quantity of years) conducted at 4 to 9 experimental stations. The conditions included in the analysis were: sunshine duration, soil and air temperatures, and rainfall in the plant's consecutive agrophenological stages: from sowing to the end of emergence (on average from 9.04 to 11.05), from the end of emergence to the beginning of leaf bending (on average from 12.05 to 5.08) and from the beginning of leaf bending to harvest (on average from 6.08 to 2.09) and data concerning the total and commercial onion crops.

In order to standardize the definition of onion development, each phase of development defined according to the Research Center for Cultivar Testing was additionally described by means of BBCH scale being in force in European Union countries, using the key for defining growth stages of mono-and dicotyledonous plants (Meier, 2001): end of emergence (code 09 009) and beginning of leaf bending (code 48 408).

Data was collected for a standard that is the most common to mid-late onion cultivars 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). Experiments conducted in 1966-2005 were carried out according to COBORU methodology applied in the 1960s and modernized several times in later years (Litka, 1966; 2002; Domański, 1998). Mid-late cultivars of onion were usually cultivated after cereal plants and also after peas, bean and early brassica vegetables. Usually full fertilization with manure was used and plowed in autumn, from 30 to 50 t ha^{-1}. Depending on current soil richness, mineral fertilization ranged from 150 to 510 kg per 1 ha of cultivation, on average 370 kg per 1 ha of cultivation including N and P_2O_5 -respectively 115 and 75 kg, and K_2O -180 kg (Litka, 1966; 2002; Domański, 1998).

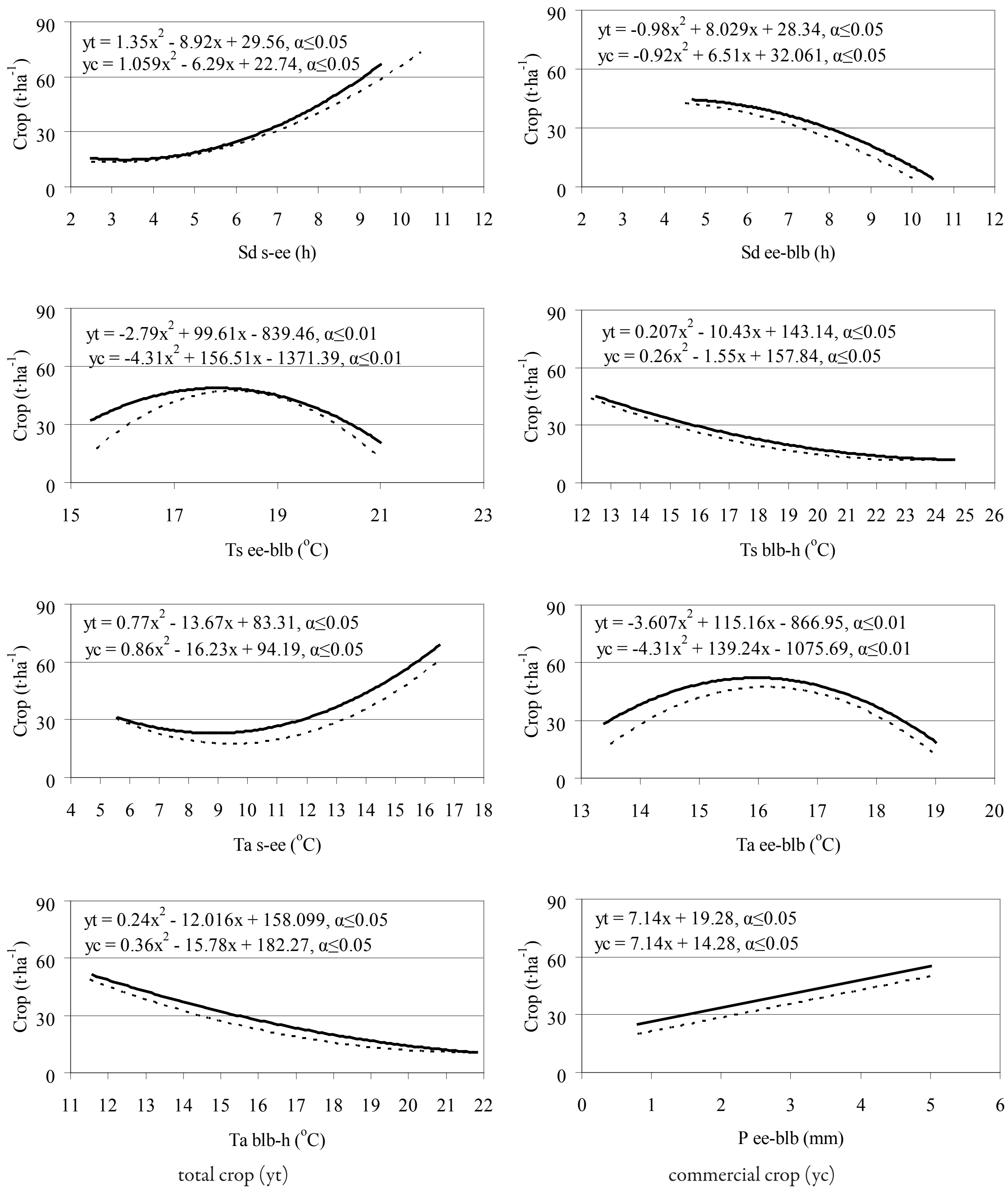
Agrometeorological data in agrophenological stages of the onion for the assumed period 1966-2005 were collected from all the COBORU meteorological measuring stations -presented in the Review of Agrometeorological Conditions (Rybarczyk, 1966-2002) or, in the case of a lack of data, from stations of the Institute of Meteorology and Water Management (IMGW) using the nearest and also the best reflecting meteorological conditions of the conducted experiments presented in the "Annual Precipitation" (Zieliński, 1966-1981) and Agrometeorological Bulletins (Zieliński, 1966-2002) and partly from databases made available by IMGW in Warsaw (Fig. 1). Analysis used the following data in the assumed periods of time: an average daily sunshine duration (h), average soil temperature at a depth of 5 cm (°C), average air temperature at a height of 2 m amsl (°C) and the coefficient of rainfall (mm), i.e. the quotient of total rainfall and the number of days in an examined agrophenological period.

Before clustering weather patterns that are conducive to large and small onion crops, an initial quantitative estimation was made to find dependences between onion crops and the studied agrometeorological factors (4 factors x 3 agrophenological periods) using a linear and square regression analysis (Sobczyk, 1998). As a result of this procedure, out of 12 considered agrometeorological factors only 8 factors were significantly used for further analysis; these 8 factors correlated with the total and commercial onion crop at the level of significance of at least $\alpha \leq 0.05$ (Fig. 2). A significant influence on the size of the crop was exerted by average daily sunshine duration in stages sowing-end of emergence and end of emergence-beginning of leaf bending, average soil temperature in the stages: end of emergence-beginning of leaf bending and beginning of leaf bending-harvest, average air temperature: sowing-end of emergence, end of emergence-beginning of leaf bending, and beginning of leaf bending-harvest and the coefficient of rainfall in end of emergence-beginning of leaf bending.

The actual stage of recognizing weather patterns conducive to large and small crops of mid-late onion cultivars was based on the generalized cluster analysis. Before the analysis, 8 agrometeorological factors were subjected to normalization according to the formula:

$$Z_j = \frac{X_j - Min(X_j)}{Max(X_j) - Min(X_j)}$$

where: $Max(X_j)$ and $Min(X_j)$ are respectively the greatest and smallest value of the j^{th} factor. After such normalization, all the agrometeorological factors assumed values from the same interval (0.1) (Dobosz, 2001).



Sd-sunshine duration, Ts-soil temperature, Ta-air temperature, P-coefficient of rainfall, s-ee-sowing-end of emergence, ee-blb-end of emergence-beginning of leaf bending, blb-h-beginning of leaf bending-harvest

Fig. 2. Relationship of onion crop in Poland to agrometeorological factors in years 1966-2005

Tab. 1. Statistical estimation (variance analysis) of recognized clusters on the basisof agrometeorological factors in agrophenological stages of onion

Factor	SS	DfSS	SSE	DfSSE	F	α
Sd s-ee	9830.5	2	415.5	258	3052.3	0.000
Sd ee-blb	13382.2	2	220.3	258	7835.0	0.000
Ts ee-blb	88963.2	2	184.9	258	62061.8	0.000
Ts blb-h	89749.5	2	911.3	258	12704.9	0.000
Ta s-ee	26214.8	2	610.3	258	5541.4	0.000
Ta ee-blb	70185.2	2	128.7	258	70329.3	0.000
Ta blb-h	75560.8	2	726.7	258	13413.3	0.000
P ee-blb	1573.2	2	142.1	258	1428.3	0.000

SS-sum square error of between-group variation, Df_{SS}-number of degrees of freedom for sum square error SS, SSE-sum square error of within-group variation, Df_{SSE}-number of degrees of freedom for sum square error SSE, F-Fisher's test, α-level of probability; other explanations, see Fig. 3

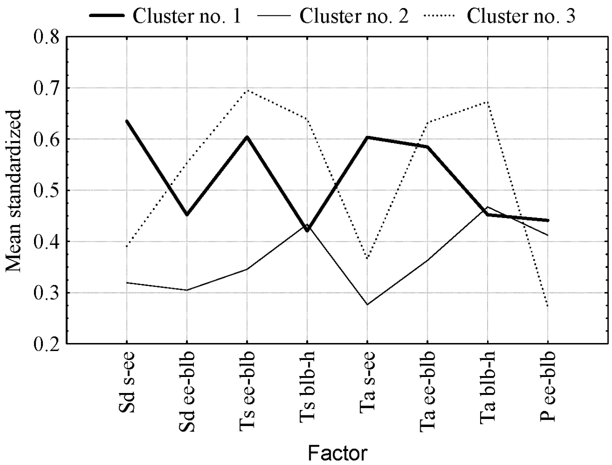
The partition of all observations of the analyzed agrometeorological factors into clusters was carried out using non-hierarchical *k*-means clustering in which a Euclidean distance was used, i.e. a geometrical distance in a multidimensional space (Jain *et al.*, 1999; Everitt *et al.*, 2001; Holden and Brereton, 2004).

K-means clustering involved moving an observation from a cluster to another cluster in order to maximize variance between clusters, and minimize variance within the examined clusters. In order to determine the best number of clusters, *v*-fold cross validation was used. The significance of differences between the clusters was estimated using a variance analysis by means of Fisher's test at a level of $\alpha \leq 0.05$ (Dobosz, 2001).

A linear trend of agrometeorological factors in agrophenological stages of onion development in the years 1966-2005 was determined on the basis of linear regression analysis. Parameters of the regression function were determined using the method of least squares. A hypothesis about the significance of the regression function, i.e. a coefficient of multiple correlation, was examined using an *F*-Snedecor's test and the significance of coefficients of regression -using a Student's *t*-test. The occurrence of autocorrelation of random data was examined using a Durbin-Watson's test (Sobczyk, 1998).

Results and discussion

Using a cluster analysis, three groups of agrometeorological observations were recognized, each reflecting a different weather pattern in the period of growth and the development of mid-late onion cultivars in the climatic conditions of Poland (Fig. 3). Cluster no. 1 had the highest (among the recognized clusters) daily sunshine duration and the highest average air temperature in sowing-end of emergence and the highest coefficient of rainfall in the end of emergence-beginning of leaf bending, cluster no. 2 -the lowest values of all the investigated agrometeorological factors, with the exception of average soil and air temperatures in the beginning of leaf bending-harvest, and except the coefficient of rainfall in the end of emergence-beginning of leaf bending, cluster no. 3 -the highest average soil and air temperature in stages: end of emergence-beginning of leaf bending and beginning of leaf bending-harvest.



Sd s-ee-mean daily sunshine duration in sowing-end of emergence (h), Sd ee-blb-mean daily sunshine duration in end of emergence-beginning of leaf bending (h), Ts ee-blb-mean soil temperature in end of emergence-beginning of leaf bending (°C), Ts blb-h-mean soil temperature in beginning of leaf bending-harvest (°C), Ta s-ee-mean air temperature in sowing-end of emergence (°C), Ta ee-blb-mean air temperature in end of emergence-beginning of leaf bending (°C), Ta blb-h-mean air temperature in beginning of leaf bending-harvest (°C), P ee-blb-coefficient of rainfall in end of emergence-beginning of leaf bending (mm)

Fig. 3. Mean standardized values of agrometeorological factors in agrophenological stages of onion for each recognized cluster

The variance analysis shows that all the analyzed agrometeorological factors (sunshine duration, soil temperature, air temperature, rainfall expressed with a coefficient) are statistically significant, at a level $\alpha \leq 0.01$ and differentiate the recognized clusters, i.e. significantly determine the size of onion crops (Tab. 1). The greatest values of Fisher's test were obtained for the average air temperature in the end of emergence-beginning of leaf bending, smaller values of the test for the average soil temperature in the same stage of development and the lowest for the coefficient of rainfall in the end of emergence-beginning of leaf bending (Tab. 1).

Greatest differences between the average values of the analyzed agrometeorological factors within the recognized clusters were observed between cluster no. 1 and cluster no. 2 for air temperature (4.4°C) and then for sunshine duration (2.9 h), both factors in the stage: sowing-end of emergence; the smallest differences were observed between cluster no. 1 and cluster no. 3-for the coefficient of rainfall (0.7 mm) in the end of emergence-beginning of leaf bending (Fig. 4).

Tab. 2 shows that cluster no. 1 included 46 observations, cluster no. 2 -99 observations and no. 3 -116 observations. In order to estimate the influence of agrometeorological clusters on the size of onion crop, for all the observations

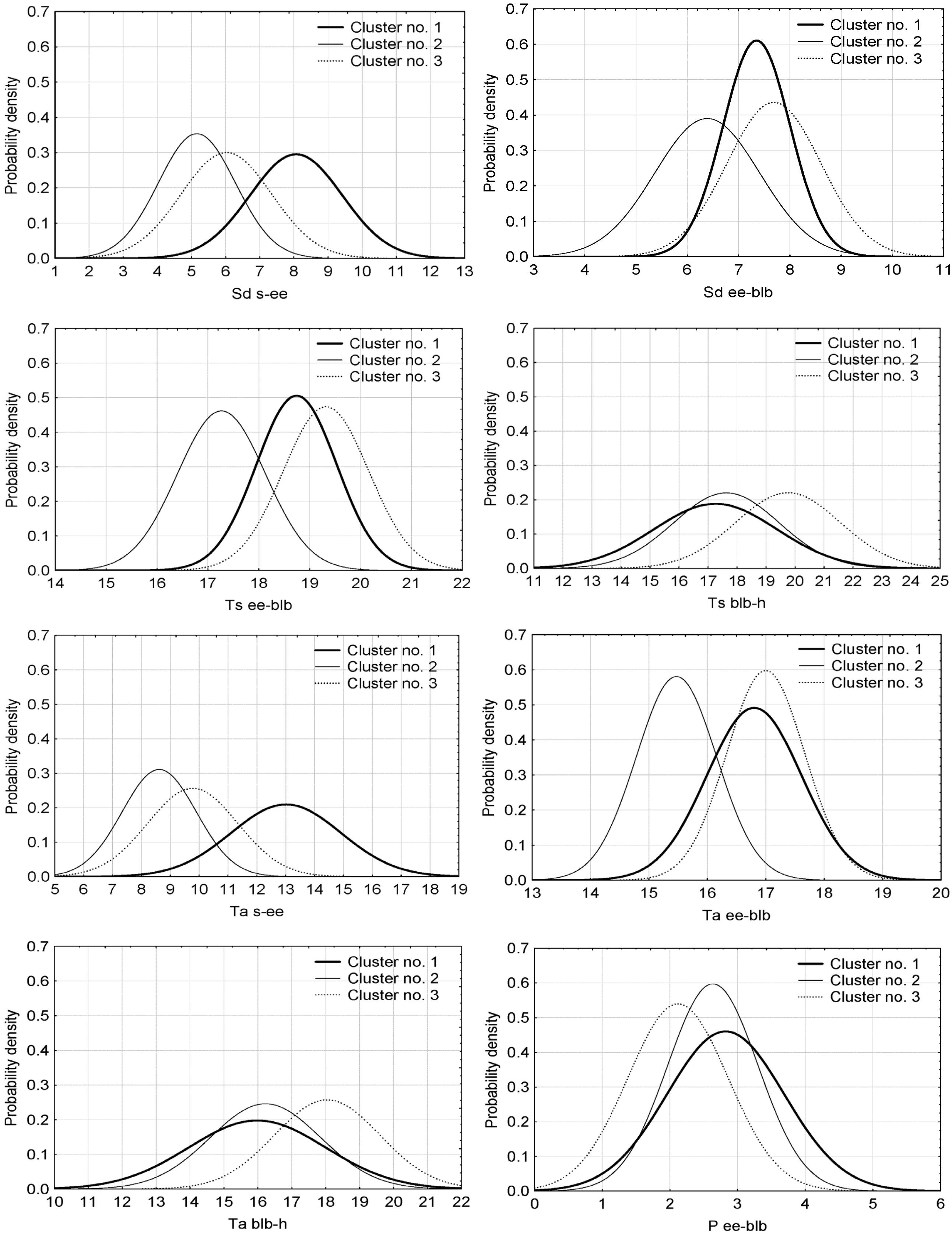


Fig. 4. Probability distribution of agrometeorological factors in agrophenological stages of onion for each cluster (the cluster no. 1, 2, 3), explanations, see Fig. 3

Tab. 2. Statistical characterization of agrometeorological factors in the following agrophenological stages of onion for each cluster (clusters no. 1. 2. 3 and 1-3)

Cluster number	Number of observations	Crop ($t \cdot ha^{-1}$)		Characteristics	Factor							
		total	commercial		Sd (h)		Ts (°C)		Ta (°C)			P (mm)
		mean±SD*	mean±SD		s-ee	ee-blb	ee-blb	blb-h	s-ee	ee-blb	blb-h	ee-blb
				minimum	5.6	6.0	16.9	12.5	8.9	14.8	11.7	1.6
1	46	45.9±15.4	44.7±15.6	maximum	10.7	9.6	20.8	21.0	16.3	19.1	20.3	5.1
				mean	8.1	7.4	18.7	17.3	13.0	16.8	16.0	2.8
				SD*	1.4	0.8	0.7	2.1	1.9	0.8	2.0	0.9
				minimum	2.5	4.6	15.2	13.2	5.6	13.4	11.4	1.3
2	99	32.1±12.3	30.3±12.4	maximum	8.0	8.5	19.4	21.2	11.8	17.4	18.9	4.5
				mean	5.2	6.4	17.3	17.6	8.6	15.5	16.2	2.6
				SD	1.1	1.0	0.9	1.8	1.3	0.7	1.6	0.8
				minimum	3.4	5.5	17.4	15.7	6.2	15.4	14.8	0.8
3	116	26.2±10.3	24.8±10.2	maximum	9.6	10.4	21.2	24.6	14.8	18.7	21.9	4.5
				mean	6.0	7.7	19.3	19.8	9.8	17.0	18.0	2.1
				SD	1.3	0.9	0.8	1.8	1.6	0.6	1.6	0.7
				minimum	2.5	4.6	15.2	12.5	5.6	13.4	11.4	0.8
1-3	261	31.9±14.7	30.4±14.9	maximum	10.7	10.4	21.2	24.6	16.3	19.1	21.9	5.1
				mean	6.1	7.1	18.4	18.5	9.9	16.4	17.0	2.4
				SD	2.6	1.2	1.6	4.8	4.7	1.0	3.7	0.6

*Standard deviation. Other explanations, see Fig. 2

present in each cluster an average total and commercial crop was determined, along with the average value of the investigated agrometeorological factors. Additionally, crop characteristics were augmented with the standard deviation value, and the agrometeorological factors were additionally characterized by extreme values (minimum and maximum) and the standard deviation. The greatest average onion crop, both total and commercial, was found for cluster no. 1 and was respectively 45.9 and 44.7 t ha^{-1}, the smallest for cluster no. 3 -respectively 26.2 and 24.8 t ha^{-1}. Cluster no. 1 (large crops) was characterized by a greater standard deviation of onion crop size than cluster no. 2 (average crops) and no. 3 (small crops), 15.4 and 15.6 t ha^{-1} respectively for the total and commercial crops. The average total onion crop in the years 1965-2005 (clusters 1-3) was on a similar level to cluster no. 2 (average crops); 31.9 t ha^{-1} and was about 1.5 t ha^{-1} greater than the average commercial crop.

Large crops of onion, 45.9 t ha^{-1} for the total crop and 44.7 t ha^{-1} for the commercial crop (cluster no. 1) crop, were favored by the following weather pattern: in sowing-end of emergence -above-average sunshine duration (8.1 h) and above-average air temperature (13.0°C); in the end of emergence-beginning of leaf bending -above-average rainfall (2.8 mm) expressed with the coefficient, average sunshine duration (7.4 h) and average soil and air temperatures (18.7 and 16.8°C, respectively); at the end of vegetation cycle (blb-h) -soil and air temperatures below average, respectively 17.3 and 16.0°C (Tab. 2). Cluster no. 3 (small crops) can contribute to a decrease of total and commercial onion crop by even 20 t ha^{-1}. More precisely, it refers to an increase in sunshine duration by about 2.1 h and air temperature by about 3.2°C in the first stage of vegetation, the coefficient of rainfall by about 0.7 mm in the end of emergence-beginning of leaf bending, and a decrease in the remaining agrometeorological factors: by about 0.3 h, 0.6°C, 2.5°C, 0.2°C and about 2.0°C, respectively for sunshine duration in the end of emergence-beginning of leaf bending, soil temperature in stages: end of emergence-beginning of leaf bending and beginning of leaf bending-harvest, air temperature in stages end of emergence-beginning of leaf bending and beginning of leaf bending-harvest.

As Tab. 2 shows for all the recognized clusters, the greatest standard deviation was observed for average soil temperature at the end of the vegetation cycle (blb-h) and then the average air temperature and sunshine duration in sowing-end of emergence and the smallest standard deviation -average air temperature (clusters no. 2 and 3) or average soil temperature (cluster no. 1), both temperatures in the end of emergence-beginning of leaf bending. Absolute maximum values of agrometeorological factors were observed equally often both in cluster no. 1 (large crops) and cluster no. 3 (small crops). However, in cluster no. 1 they occurred for the sunshine duration and air temperature in the first stage of onion development (s-ee) and for the air temperature and coefficient of rainfall in the end of emergence-beginning of leaf bending. In cluster no. 3 maxima were observed for the remaining agrometeorological factors. In turn, absolute minima were observed mostly for cluster no. 2 (average crops), except the soil temperature at the end of the vegetation cycle (blb-h) and the coefficient of rainfall in emergence-beginning of leaf bending.

In the final stage of this study we determined the linear trends of the agrometeorological factors in all the agro-

Tab. 3. Regression equations for a linear trend of agrometeorological factors in agrophenological stages of onion in years 1966-2005

Factor	Period	Regression equation	$100R^2$	α
	s-ee	y = -126.603 + 0.067x	20.6	0.00
Sd (h)	ee-blb	y = -30.27 + 0.019x	3.9	0.01
	blb-h	y = -16.55 + 0.011x	0.7	0.16
	s-ee	y = -140.49 + 0.057x	14.7	0.00
Ts (°C)	ee-blb	y = -13.63 + 0.016x	1.9	0.02
	blb-h	y = -8.14 + 0.013x	0.4	0.27
	s-ee	y = -162.67 + 0.087x	19.5	0.00
Ta (°C)	ee-blb	y = -32.85 + 0.024x	7.3	0.00
	blb-h	y = -32.82 + 0.025x	2.0	0.02
	s-ee	y = 15.079 - 0.0068x	0.9	0.13
P (mm)	ee-blb	y = 3.34 - 0.00045x	0.3	0.91
	blb-h	y = -11.55 + 0.0069x	0.4	0.29

$100R^2$ -determination coefficient (%); α-level of significance, y-factor (Sd, Ts, Ta, P), x-subsequent year over 1966-2005; other explanations, see Fig. 2

phenological stages, even for the stages in which no statistically significant influence of the analyzed factors on the size of total and commercial onion crop was found, but which were initially taken into account (Tab. 3). A significant linear trend was observed for sunshine duration and soil and air temperatures in the first two stages of growth and development of onions (s-ee, ee-blb) and for the air temperature also in the third stage -from the beginning of leaf bending to harvest. Only rainfall described with a coefficient had no significant trend in any of the investigated agrophenological stages. The coefficient of determination for significant dependences ranged from about 2% to almost 21%, and the highest values were observed in sowing-end of emergence both for sunshine duration, as for soil and air temperatures. The greatest growth was observed for air temperature -0.9°C per 10 years, and then sunshine duration -0.7 h per 10 years and soil temperature -0.6°C per 10 years, all of the three factors at the beginning stage of the vegetation cycle. An increase of these factors, but only by 0.2°C, 0.2 h and 0.2°C per 10 years respectively, was also observed in the longest vegetation stage-end of emergence-beginning of leaf bending. Higher temperatures of soil and air, especially in sowing-end of emergence, with non-changing rainfall, can contribute to a decrease in the size of onion crops in Poland.

There are no publications on the agrometeorological requirements of onion for the entire area of Poland. The existing reports about this subject matter most often refer only to regions or even experimental fields and are given as the background data in agrotechnical, irrigation or storage studies. As the cluster analysis shows, requirements of onion concerning sunshine duration, temperature and rainfall, depend on its stage of development. Results of this study partly confirm an opinion that the onion is a plant of a temperate climate which favors warm and sunny spring and moderately sunny and warm summer, with a suitable total rainfall (Steer, 1980a,b; Bertaud, 1990; Lancaster *et al.*, 1996; Brewster, 1983; Bachie and McGiffen, 2007; Kalbarczyk, 2009).

According to Tendaj (2000) and Babik (2004), the minimum temperature of onion germination is about 5-6°C, and the optimum even up to 18°C. In sowing-emergence, longer sunshine duration and a higher air temperature with the sufficiently humid soil, accelerate and level the emergences, which favorably influence the final quantity of onion crops. Different results, obtained only on the basis of three years research in one small region of Pyrzyce and Gryfino situated in the NW of Poland and conducted on other cultivars, concerning thermal conditions in the first stage of growth, were obtained by Jarocka (1970), according to which onion favors cool spring which creates good circumstances for the development of a strong root bundle and an above-structure part, and thus a large crop.

Results concerning thermal conditions in the end of emergence-beginning of leaf bending, lasting 85 days on average, are consistent with the report by Tendaj (2000) and Babik (2004), according to which the fastest and best growth of the vegetative onion parts takes place in temperatures of 13-24°C and for bulb formation within 16-20°C, which in combination with a long day decides on a correct onion formation. Also Wojtaszek *et al.* (1993), in research on the influence of planting density and age of seedlings of the onion crop, confirmed higher crops in a year with a lower air temperature compared with many years' average in August, hence in the period similar to the examined agrophase: beginning of leaf bending-harvest.

Onion, due to a shallow root bundle is sensitive to water deficiency in soil at each stage of growth and development and especially in emergence and intensive growth, which has also been confirmed by the cluster analysis. Drought occuring during emergence often causes a decrease in the number of plants per unit of surface, and during bulb formation a decrease in their individual mass. Deficiency of rainfall occurring at both these stages contributes both to a decrease in size and the quality of onion crops (Kaniszewski and Perłowska, 1988; Tendaj, 2000; Babik, 2004; Kaniszewski, 2005). According to Górka (1989), losses in a long-term average onion crop caused by atmospherical droughts lasting ≥18 days in emergence-leaf bending can range from 1 t ha^{-1} in the south-east of Poland to even 4-5 t ha^{-1} -in the middle of the country. Kaniszewski and Perłowska (1988) show that watering onions in Poland is especially advantageous from the middle of June to the end of July, especially in years in with shortages of rainfall, causing improvement in the shape and leveling of onions, and therefore a rise in crops, especially commercial. On the other hand, excess rainfall and consequently sunshine duration deficiency during the final vegetation stage can inhibit the maturation of onion and worsens its quality and storageability (Jarocka, 1970; Babik, 2004). In the period from sowing to harvest, the optimum rainfall for the onion in Poland ranges from 300 to 350 mm on heavy soils, and from 351 to 400 mm-on average soils (Dzieżyc and Dzieżycowa, 1986; Kalbarczyk, 2006).

Conclusions

The cluster analysis helped recognize three statistically significantly different groups of observation with respect to the plot of agrometeorological conditions determining different sizes of crops of mid-late onion cultivars in Poland.

The large crops were correlated with the following weather pattern: above-average sunshine duration (8.1 h) and above-average air temperature (13.0°C) -in sowing-end of emergence; average sunshine duration (7.4 h), average soil temperature (18.7°C) and air temperature (16.8°C) and above-average rainfall described with a coefficient (2.8 mm) -in emergence-beginning of leaf bending; soil temperature (17.3°C) and air temperature (16.0°C) lower from the long-term average -in beginning of leaf bending-harvest.

In the light of proven positive trends in sunshine duration and soil and air temperatures at stages: sowing-end of emergence and end of emergence-beginning of leaf bending, with stable rainfall, onion crop size in Poland can systematically decrease, especially in the case of a lack of suitable irrigation.

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