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REACTION OF FIELD CUCUMBER (*Cucumis sativus* L.) TO THE DELAY OF AGROTECHNICAL DATES AND PHENOLOGICAL PHASES IN POLAND

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Abstract

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The aim of the work was to determine a potential decrease in yields and a risk of cultivation of field cucumber of pickling varieties in Poland caused by the delay of the dates: flowering, fruit setting and harvesting. In order to carry out this task the following phenological dates from whole Poland were used: emergence, flowering and fruit setting and also the agrotechnical dates: sowing and harvesting from 28 experimental stations of the Research Centre for Cultivar Testing (COBORU) through 1966–2005. On the basis of linear regression analysis the relation between the yield of field cucumber and the analysed agrotechnical and phenological dates was determined, taking into account the trend of the yield from 1966–2005. Moreover, a potential decrease in the yield caused by the delay of phenophases was calculated for both the whole country and for its particular regions. The measure of matching of the regression function to empirical data was the determination coefficient and the regression equation error. Moreover, to determine the share of each of the selected factors in the prediction of cucumber yield partial correlation analysis was used. The obtained results may be used, among other things, in the meteorological protection of agriculture and improvement of new technologies of cucumber field cultivation.

cucumber, potential decrease in yield, phenological phase, agrotechnical date

Out of agrotechnical factors the decisive influence on the final yield of field-cultivated plants, including cucumber, is exerted by the date of sowing or planting and mineral fertilization (Gronowicz et al., 1992; Śnieg and Ludko, 1995; Schittenhelm, 2001; Kalbarczyk, 2003; Jadczak and Żurawik, 2004; Caliskan et al., 2008). The delay, in comparison to the optimal date of sowing or planting of field-cultivated plants, causes that the plants develop in different light, thermal and moisture conditions, which in consequence leads to the movement of successive development stages in time and shortening of the vegetation season (Koźmiński et al., 1993; Chmielewski and Rötzer, 2001; Tao et al., 2006).

According to Babik (2004), cucumbers should be sown when average daily temperature amounts to approximately 16.0 ^{0}C. In Poland the optimal air temperature for sowing occurs, on average, in the second half of May, but in particular years may occur in the period between the third decade of April and the second decade of June (Koźmiński and Michalska, 2001; Kalbarczyk, 2006b). Too late sowing of field cucumber denotes a bigger risk of shortening of the vegetation season and, thus, a decrease in the final yield of the plant and a higher probability of the occurrence of autumn ground frost in the period of its fructification. On the other hand, too early sowing of field cucumber, into not warmed soil, exposes the seeds to diseases and decay in the period of lengthened emergence. Earlier sowing often means also earlier emergence of cucumber and a danger of the occurrence of spring frost at the time, which causes damage to young seedlings (Babik, 2004).

According to Koźmiński and Trzeciak (1971), an average duration of the period with no frost (between average dates of the last spring and the first autumn frost) in Poland oscillates between below 130 days and over 200 days, in the south of the country it lasts shortest. The amount of risk of field cucumber cultivation is affected not only by average but also by extreme dates of the occurrence of the last spring and the first autumn frost. According to Koźmiński and Trzeciak (1971) and Koźmiński and Michalska (2001), the last spring frost can occur even at the end of May, especially in the North (the Pomorskie Lakeland) and the Central West of Poland; the first autumn frost, on the other hand, as early as at the end of the first decade and the beginning of the second decade of September, especially in the North (the Pomorskie Lakeland, the Olsztyńskie Lakeland) and the South of the country (the Carpathian Foothills, the Sudetic Foreland).

Plants react to the delay of sowing and planting, depending on a species and the region of Poland, with a diverse decrease in yields. For instance, the delay of the date of sowing by 10 days, in comparison with the optimal one, may cause a decrease in the yield of sugar beet from below 10% in the south-eastern part of Poland up to slightly above 15% in the north-eastern part (Koźmiński et al., 1993), and a decrease in the yield of late cultivars of potato plant from below 10% in South-East Poland up to even slightly above 20% in the North-East (Kalbarczyk, 2003). In the whole country spring crops react with a lower decrease of yields caused by a 10-day delay of the date of sowing: barley – 5%, triticale – 6%, and oats – 8% (Koźmiński and Michalska, 2001; Kalbarczyk, 2006a). According to the research by Toro (2005), a delay by 1 day of the date of sowing or harvesting, depending on a species of cultivated plants, may result in yield losses from 0.2 to 1.2%.

There are no studies dedicated to the reaction of field cucumber to the influence of both agrotechnical dates and phenophases. Therefore, this work made an effort to assess the relation between the yield of field cucumber of pickling cultivars, the agrotechnical dates and the dates of phenophases, and to determine a potential decrease in the yield of this plant due to the delay of the following dates: flowering, fruit setting and harvesting and also a risk of their occurrence.

MATERIALS

Field experimentation was represented by data concerning the yield volume of field cucumber fruits (total and marketable yield), agrotechnical dates (sowing, beginning of harvesting, end of harvesting) and phenological phases (end of emergence, beginning of flowering, beginning of fruit setting), coming from 28 experimental stations of the Research Centre for Cultivar Testing (COBORU) through 1966–2005, excluding two years: 2003 and 2004, in which the experiments were not conducted (Fig. 1). The marketable yield of cucumber comprised a part of fruits for pickling from 6–10 cm long, of the diameter from 2.5–4.0 cm, however not smaller than the half of the fruit length. Data concerning the level of crop productivity and the course of agrophenology were collected for all pickling varieties, the commonest in cultivation, examined in a given year, which after averaging were accepted as a collective model of the described plant. Employing the collective model in the research was based on a supposition that intraspecific differences do not obscure the searched general regularities for the species.

Experiments from 1966–2005 were conducted in accordance with the methodology of COBORU used in the 1960s and updated many times in the following years. Cucumber was cultivated in soils of wheat complexes: a very good one and a good one. Mostly, full organic manuring was used, at a dose from 30 to 40 t.ha^{-1}, which was ploughed in the autumn. Depending on soil richness of the time, mineral fertilization, on average, amounted to 400 kg of a pure component per 1 hectare of the crop, including N and P_2O_5, which were embedded respectively at doses of 115 and 90 kg, and K_2O – 195 kg.

METHODS

In order to determine the dependence of the yield of field cucumber on agrotechnical dates and phenological phases multiple regression analysis was used. It took into consideration, one after the other, the analysed dates in the period from sowing to the end of harvesting and a linear trend of the yield, i.e., successive years of the analysed period from 1966–2005. No statistically significant influence of soil conditions and fertilization on the yield volume of cucumber was found (own calculations). Therefore, the information was not included in the regression equation. These results confirm that the COBORU stations conducted correct agrotechnology of cucumber cultivation and, therefore, it was mainly unfavourable agrometeorological conditions, causing the delay or acceleration of agrotechnical dates and phenological phases, that determined the final yield. Parameters of the multiple

1: *Distribution of the stations of COBORU (■) with the experiments on field cucumber of pickling cultivars, conducted through 1966–2005 against a background of selected towns in Poland (●)*

regression function were defined with 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, and the significance of regression coefficients with the t-Student test. The measure of matching of the regression function to empirical data was the determination coefficient R^2 (%) and the regression equation error Sy ($t.ha^{-1}$). Moreover, to determine the share of each of the selected factors in the prediction of cucumber yield (agrotechnical and phenological dates, temporal trend) partial correlation analysis was used (Sobczyk, 1998; Stanisz, 2007).

In order to assess multiple regression equations, which describe the dependence of the yield of field cucumber on the dates of phenophases and harvesting, taking into account the linear trend of the yield from 1966–2005, two indexes were used – the so-called relative forecast error, calculated based on the formula:

$$RFE = \frac{y - y_p}{y} \cdot 100\,\%$$

and the average relative forecast error, for all the examined years of 1966–2005, which was calculated based on the formula:

$$ARFE = \frac{|y - y_p|}{y} \cdot 100\,\%,$$

where:
y..... actual yield ($t.ha^{-1}$),
y_p ... potential yield ($t.ha^{-1}$).

A decrease in the yield of field cucumber caused by the delay of the beginning of the following dates: flowering, fruit setting and harvesting, was calculated on the basis of the multiple regression equation which took into account, apart from successive dates of phenophases, the linear trend of the yield through 1966–2005. In each of the three created equations describing the influence of each date on the yield, a delayed by 10 days, average multi-year date of a given agrophase was placed, successively for each considered station. Next, the yield calculated for a given station was compared with the multi-year actual yield of field cucumber determined for the whole country, and the differences were expressed in %.

RESULTS AND DISCUSSION

The results of the partial correlation analysis obtained for the relation between total and marketable yield and successive agrotechnical dates and phenophases, considering the yield trend from 1966–2005, placed in Tab. I, indicate that there was statistically significant relation of all the analysed dates, except for the date of sowing. The lack of significant influence of the date of sowing on the yield volume of cucumber is a result of sowing of the plant in accordance with agrotechnical recommendations and not the lack of cucumber sensitivity to this factor, as it is confirmed by experiments with initially assumed 3 or 4 dates of sowing, oriented at investigating this relation (Babik, 2004). A stronger influence of agrotechnical dates and phenological phases was proved for the volume of the total yield than the marketable yield, except for the end of harvesting. The total yield of field cucumber was significantly affected by the dates from the end of emergence to the beginning of harvesting; the marketable yield, on the other hand, from the beginning of fruit setting to the end of harvesting. The delay of the following dates: the end of emergence, the beginning of flowering, the beginning of fruit setting and the beginning of harvesting significantly decreased the yield of cucumber and the delay of the end of harvesting positively affected the yield volume. The total yield was definitely determined in a strongest way by the date of the beginning of harvesting ($r_p = -0.54$, $P \leq 0.01$), and next by the dates of the beginning of fruit setting ($r_p = -0.49$, $P \leq 0.01$) and flowering ($r_p = -0.46$, $P \leq 0.01$); the marketable yield, on the other hand, by the date of the beginning of harvesting ($r_p = -0.37$, $P \leq 0.05$), and next the date of the end of harvesting ($r_p = +0.35$, $P \leq 0.05$). The causes of the delay of the dates of cucumber phenophases and the date of the beginning of harvesting in the conditions of proper agrotechnology were most probably unfavourable agrometeorological conditions; especially light and thermal conditions of air, which determine the rate of plant growth and development (Walczak and Sławiński, 2000; Chmielewski et al., 2004; Tao et al., 2006).

Another step of the work was the evaluation of a potential decrease in the cucumber total yield in field cultivation, but only through the dates which influenced the yield of the plant most ($r_p < -0.45$, $P \leq 0.01$), i.e., at the beginning of: flowering, fruit setting and harvesting (Tab. II). In order to carry out the task multiple regression equations were developed, in

I: *Partial correlation coefficients (rp) for the relation between the total and marketable yield of field cucumber and agrotechnical dates (s, bh, eh) and phenological phases (ee, bf, bfs) in Poland, taking into account the linear trend through 1966–2005*

Kind of yield	Date (day)					
	s	ee	bf	bfs	bh	eh
Total	–0.11	–0.35**	–0.46***	–0.49***	–0.54***	0.11
Marketable	–0.092	–0.097	–0.18	–0.34**	–0.37**	0.35**

s – sowing, ee – end of emergence, bf – beginning of flowering, bfs – beginning of fruit setting, bh – beginning of harvesting, eh – end of harvesting, *** significant at $P \leq 0.01$, ** significant at $P \leq 0.05$

which, apart from phenological dates or harvesting date, also the linear trend of the total yield of cucumber through 1966–2005 was included. The determination coefficient oscillated between 0.63 for the equation taking into account the date of the beginning of flowering and 0.67 for the equation taking into account the date of the beginning of harvesting. In all the three formed equations natural variability of the yield of field cucumber expressed by a standard deviation (S) was lower than the standard error of equation estimation (Sy); the lowest for the equation taking into account the date of the beginning of harvesting. The lowest, amounting to 6.8%, average relative forecast error was found in the equation taking into account the date of the beginning of harvesting, and the highest, amounting to 9.9% – the date of the beginning of flowering, which means that in all forecasts average differences between actual and predicted cucumber yield were lower than 10%, which supports the possibility of their practical use. Very good forecasts (within the range from 0 to 5%) constituted from about 45 up to slightly over 53% of all forecasts, and good ones (from 5 to 10%) – from about 27 to 33%.

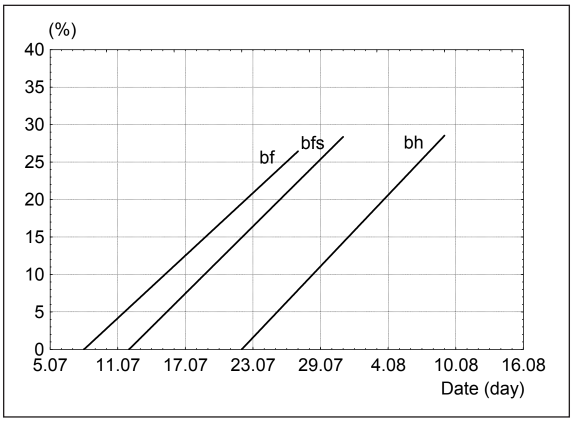
On the basis of these equations (Tab. II) a diagram was formed, which enabled the determination of a decrease in the country's total yield of field cucumber, expressed in percentage of multi-year yield, with the assumed size of the delay of the following dates: the beginning of flowering, the beginning of fruit setting and the beginning of harvesting, separately for each of them. A potential decrease of the total yield of cucumber for the whole country caused, e.g., by a 10-day delay, in comparison with the average multi-year yield of the period from 1966–2005, of the dates of the beginning of flowering may amount to 12.5%, the beginning of fruit setting – 13.5%, and the beginning of harvesting – even 14.3% (Fig. 2). Hence, it results that moving of successive phenophases and the date of the beginning of cucumber harvesting in the conditions of proper agrotechnology is affected not only by the date of sowing but also by the course of meteorological conditions in the vegetation season of the plant, especially by air temperature which may accelerate or delay successive phenophases, like in the case of other field-cultivated plants (Koźmiński et al., 1993; Dalezios et al., 2002; Kalbarczyk, 2003; Tao et al., 2006). Therefore, despite the insignificant influence of the date of sowing on the final yield of cucumber, a decrease in the yield may be caused by the delay of successive phenophases and by the date of harvesting. Frequency of the occurrence of the delay of: the beginning of flowering, the beginning of fruit setting and the beginning of field cucumber harvesting by, e.g., 10 days, in comparison with the average date, for the whole country amounted to about 16, 14 and 18% respectively, and, e.g., by 15 days only as little as about 4, 3, and 10% respectively (Fig. 3). Below 1% of all the dates of the beginning of: flowering, fruit setting and harvesting occurred with the delay of 17, 18 and 22 days, respectively, in comparison with average dates.

Diagrams presented in Fig. 2 enable the evaluation of the influence of the delay of phenophases and harvesting dates for the whole country. An identical delay may be, however, the cause of yield losses of different size depending on the region of the country (Koźmiński et al., 1993; Koźmiński and Michalska, 2001; Kalbarczyk, 2006b). Due to these reasons, another stage of the work was the determination of a potential decrease of cucumber yield caused by an assumed 10-day delay of the three analysed dates. As a result of the delay of the beginning of flowering by 10 days (in comparison with the average date) a potential decrease of the yield of field cucumber in Poland may run from below 3% in Central-West Poland (the Wielkopolska Lowland, the Silesian Lowland), in the Mazovian Lowland (the vicinity of Warsaw) and in the Sandomierz Basin (the vicinity of Rzeszów) up to over 15% in the northern, north-western and southern part of the country and in Roztocze (the vicinity of Zamość), the Kraków-Częstochowa Upland (the region between Częstochowa and Cracow) and in the vicinity of Kielce (Fig. 4). Similar spatial diversification of a potential decrease of the yield of field cucumber in Poland may be caused by a 10-day delay of the date of the beginning of fruit setting, which in Poland occurs in the second decade of July (Kalbarczyk, 2006b). A potential decrease of the yield in this case can also oscillate, most often, between 3 and 15%, when compared to the average multi-year yield; the highest decrease will occur in the northern, south-western and

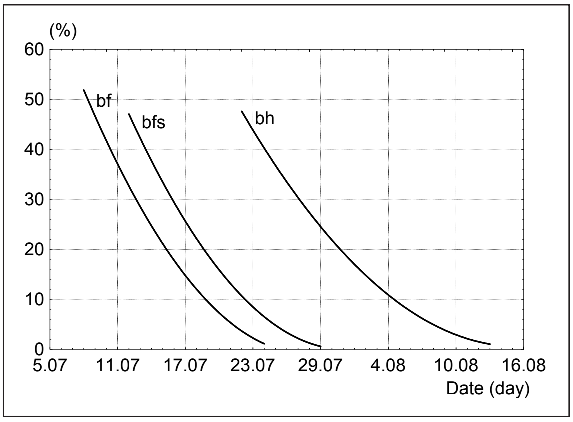
II: *Regression equations for the relation of the total yield of field cucumber and the dates of the beginning of: flowering (bf), fruit setting (bfs) and harvesting (bh), taking into account the linear trend through 1966–2005*

Regression equations	R2 (%)	Sy-S ($t \cdot ha^{-1}$)	ARFE (%)	Frequency of the occurrence of RFE in range	
				0–5 (%)	5–10 (%)
y = –489.736* + 0.3077R*** – 0.463bf*** **	0.63	3.0	9.9	45.3	32.9
y = –442.725* + 0.289R*** – 0.496bfs*** **	0.64	3.2	9.7	49.0	30.7
y = –307.782* + 0.223R*** – 0.527bh*** **	0.67	3.7	6.8	53.4	26.8

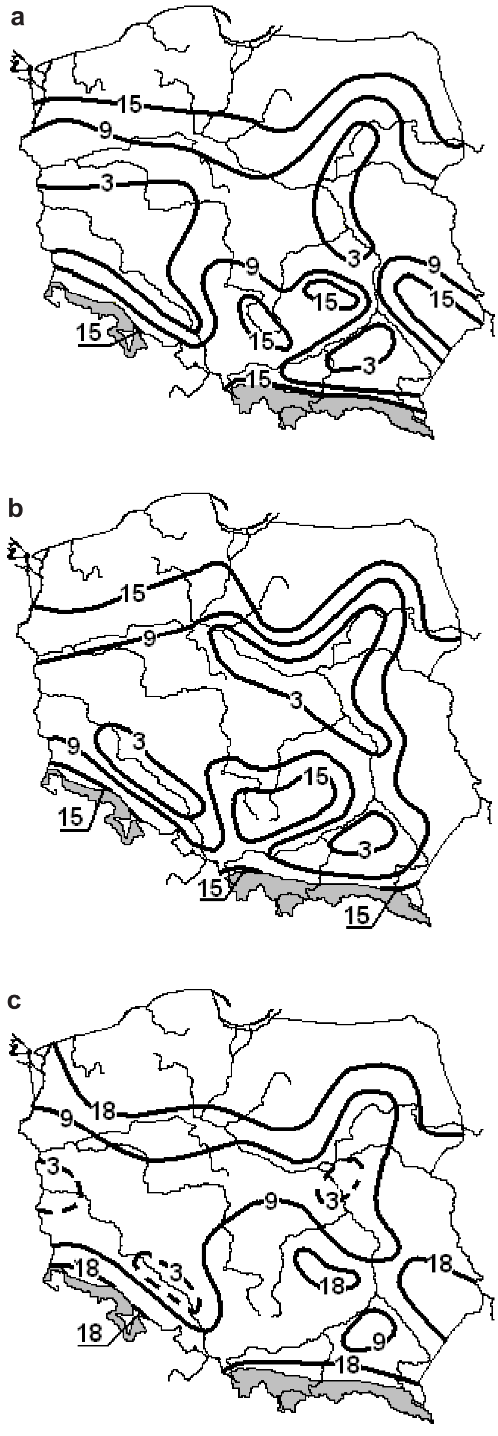
R2 – determination coefficient (%), Sy-S – difference between the standard error of equation estimation and a standard deviation (t·ha-1), R – the linear trend of the yield, i.e., successive years of the 1966–2005 period, *** significant at $P \le 0.01$, ARFE – average relative forecast error (%), RFE – relative forecast error (%), y – total yield of cucumber.
Other explanations, see table I.



2: *A potential decrease in the total yield of field cucumber (%) caused by the delay of the date of the beginning of: flowering (bf), fruit setting (bfs) and harvesting (bh) for the whole country*



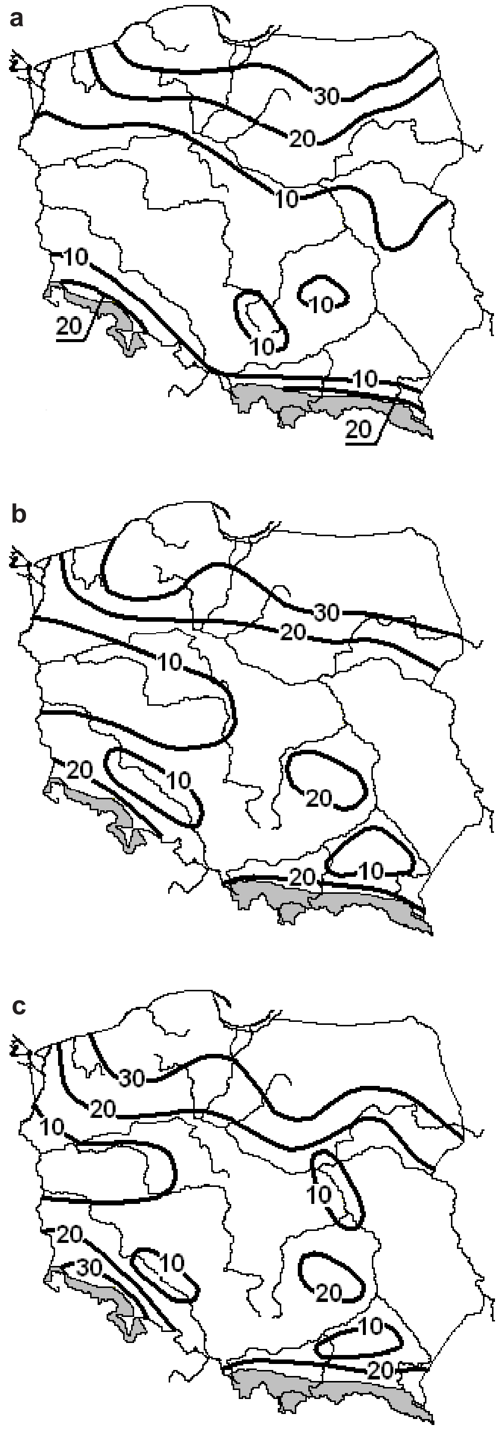
3: *Frequency of the occurrence (%) of the date of the beginning of: flowering (bf), fruit setting (bfs) and harvesting (bh) of field cucumber for the whole country*



4: *Spatial distribution of a potential decrease in the total yield of field cucumber (%) caused by the 10-day delay of the date of the beginning of: flowering (a), fruit setting (b) and harvesting (c)*

southern part of the country and in the Małopolska Upland (the regions of Częstochowa and Kielce). However, the highest danger to cucumber yields is connected with a 10-day delay of the date of the beginning of harvesting. At this development stage, the plant has no time to compensate for the loss caused by the course of unfavourable meteorological conditions earlier in the vegetation season (Koźmiński et al., 1993). In Central and Central-West Poland and in the Sandomierz Basin (the vicinity of Rzeszów) a potential decrease in the yield caused by the 10-day delay of the date of the beginning of harvesting may not exceed 9%, like in the case of the delay of the dates of the beginning of flowering and fruit setting, and in the regions of Warsaw, Wrocław and Zielona Góra – 3%. An over two-fold decrease of the yield, amounting to even above 18%, may occur in the North, South-West and South of the country and in the Lublin Upland (the vicinity of Zamość) and in the Kielce region.

The 10-day delays of each of the analysed dates occur in Poland with a similar frequency, oscillating, in general, between 10 and 30%, and can also be characterised by a similar, close to the latitudinal one, spatial distribution (Fig. 5). The area of the country in which the frequency of the delay of the dates by 10 days (compared to the average) did not exceed 10%, gradually decreased, from the biggest one covering the whole central part of the country – for the date of the beginning of flowering, to the smallest one, occurring only in Central-West Poland and



5: *Spatial distribution of the frequency of years (%) with the date of the beginning of: flowering (a), fruit setting (b) and harvesting (c) of field cucumber delayed by 10 days, 1966–2005*

in the vicinity of Wrocław, Rzeszów and Warsaw – for the date of the beginning of harvesting. Most often, over 30%, the delays of the analysed dates occurred in the North (the Pomeranian Lake District) and the North-East of the country, and in the case of harvesting also in the South-West; the biggest area of Poland with this threat pertained to the date of harvesting, the smallest area to flowering.

Comparing the frequency of the delay of the analysed dates of field cucumber with other agricultural plants in Poland one can point to a higher risk of the cultivation of the described plant caused by the delay than in the case of other plant species. For example, the frequency of a 10-day delay of the date of emergence and flowering of late cultivars of potato plant oscillates in Poland from below 8% to above 12%, and in the case of flowering up to above 18%; most often it occurs in the North-East of the country (Kalbarczyk, 2003). The date of emergence and tillering of spring triticale oscillates only between 5% and slightly above 10% (Kalbarczyk, 2006a). In the case of sugar beet and cereal plants the frequency of the delay in Poland is determined only for the date of sowing. Probability of the occurrence of the assumed 10-day delay of the date of sowing may oscillate between 5% – in the case of sugar beet, oats and spring barley and over 20% – in the case of spring wheat; most often it occurs in the North-East and South of the country (Koźmiński and Michalska, 2001).

CONCLUSIONS

The total yield and marketable yield of field cucumber fruits (pickling cultivars) was significantly correlated, at the level of $P \leq 0.01$, with all the examined agrotechnical and phenological dates in the vegetation season, except for the date of sowing. The strongest influence on the yield was exerted by the dates of the beginning of: flowering, fruit setting and harvesting. As early as possible dates of: the end of emergence, the beginning of flowering, the beginning of fruit setting and the beginning of harvesting and a late date of the end of harvesting were conducive to big total and marketable yields of cucumber. A delay by 10 days, in relation to average dates of the beginning of flowering, the beginning of fruit setting and the beginning of harvesting may, on average, lead to a decrease in the total yield of cucumber in Poland respectively by 12.5, 13.5 and 14.3%; the highest delay in the northern and south-northern and southern part of the country. The 10-day delay of the dates which determined the yield of field cucumber in the strongest way most frequently, over 30%, occurred in the North of the country, and most seldom, below 10%, in the central strip of Poland in the case of flowering, and in the central-western part of the country, in the Silesian Lowland and in the Sandomierz Basin in the case of fruit setting and harvesting.

SOUHRN

Reakce polních okurek (*Cucumis sativus* L.) na opoždění agrotechnických termínů a fenologických fází v Polsku

U polních okurek nakladaček byla zjištěna průkazná korelace na hladině P ≤ 0,01 mezi celkovým a tržním výnosem a všemi zkoumanými agrotechnickými a fenologickými daty v průběhu vegetace, mimo doby výsevu. Největší vliv na výnos měl začátek kvetení, začátek násady plodů a sklizně. Včasné ukončení klíčení, včasný začátek kvetení, začátek tvorby plodů a začátek sklizně a pozdní datum ukončení sklizně umožnily vysoký celkový a tržní výnos okurek. Zpoždění 10 dnů oproti průměrnému termínu začátku kvetení, začátku tvorby plodů a začátku sklizně může vést k poklesu celkového výnosu okurek v Polsku, a to v průměru o 12,5; 13,5 a 14,3 %; největší zpoždění je v severní, jižně severní a jižní části krajiny. Desetidenní zpoždění v termínech, které určují výnos polních okurek nejvýrazněji, vedou na severu k poklesu výnosu nejčastěji nad 30 %, a zcela ojediněle pod 10 % ve středním Polsku v případě kvetení, ve středozápadní části země, ve Slezské nížině a v Sandomierzském povodí v případě tvorby plodů a sklizně.

okurky, potenciální pokles výnosu, fenologické fáze, agrotechnické termíny

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