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MULTI-YEAR VARIABILITY OF PHENOLOGICAL PHASES AND PERIODS OF OAT (*AVENA SATIVA* L.) IN POLAND

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ABSTRACT

The objective of the study was to determine the multi-year variability of the phenological phases and periods of oat (*Avena sativa* L.) in relation to the air temperature in Poland. The material for the study consisted of the results of experiments from 28 COBORU (Cultivar Testing) stations, from the period of 1971-2010, concerning the growth, development and yields collected for model oat. The mean monthly air temperatures in the March-August period were collected from 43 meteorological stations of IMGW, distributed uniformly over the territory of the whole country with the exception of the submontane regions. Analysis of regression was used for the estimation of variability and trend of the indices under consideration. Acceleration was demonstrated for 3 out of the 5 phases: start of heading (SH), wax maturity (WM) and harvest (H), by an average of from about 3 to 13 days/10 years, as well as extension, by an average of about 10 days/10 years, of the L_{SH}-$_{WM}$ (start of heading-wax maturity) period, and shortening, by an average of 2 and 13 days/10 years, respectively, of periods L_{SG}-$_{H}$ (sowing-harvest) and L_{E}-$_{SH}$ (emergence-start of heading). The year-to-year variation of phases SH and, to a lesser extent, emergence (E) and WM, depended in about 25-53% on the thermal conditions of the air, varying primarily in March, April and June. The duration of the L_{SG}-$_{H}$ phase of oat depended significantly on monthly air temperatures of April to July ($Ta_{4-7)}$, the effect of Ta_4 being positive, while that of Ta_{5-7} – negative. An increase of the mean air temperature was observed throughout the period of oat vegetation (March-August), by an average of 0.44°C/10 years. The yields of oat were positively correlated with the duration of period L_{SG}-$_{H}$ and negatively with the changes of Ta_{5-7}.

Key words: climate change, plant growth and development, spring cereals.

INTRODUCTION

At present, climate change affects various regions of the world, causing a lot of damage to the population and to the environment (Caldwell et al., 2003; Reidsma et al., 2010). The climate changes are becoming increasingly observable, e.g. in the plant world (García-Mozo et al., 2010; Rybski et al., 2011; Xiao et al., 2013). In Europe a significant increase is observed in the mean air temperature, as well as a decrease of the sum of precipitations in the southern regions with an increase in the north (IPCC, 2013). The last decade was the warmest noted in Europe. The air temperature over land was higher by about 1.3°C than the mean value from before the industrial era. The climate change scenarios indicate that in the later decades of the 21st century Europe may be warmer by as much as 2.5-4,0°C compared to the multi-year mean value in the years 1961-1990 (Iglesias et al., 2009; IPCC, 2013). Extreme weather phenomena are also more and more often noted, such as waves of heat, ground frosts, floods and droughts (Klein Tank and Können, 2003; Andrade et al., 2012). The intensifying climate changes may increase the susceptibility of agroecosystems to threats related with extreme meteorological phenomena, occurring not only more frequently but also with ever greater intensity (Falloon and Betts, 2010; Kalbarczyk, 2010; Olesen et al., 2011). Climate changes can be assessed not only on the basis of the particular meteorological elements, but also of the variation of plant phenology (Ahas et al., 2000; Menzel, 2002). Numerous studies confirmed significant changes in the growth, development and yielding of plants under the

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effect of increased air temperature (Sônego, 2000; Saiyed et al., 2009; Al-Karaki, 2012). The vegetation periods or individual development phases of certain cereal cultures changed (Olesen et al., 2012; Siebert and Ewert, 2012; Xiao et al., 2013). As an example, an acceleration of the phenological phases of spring triticale was observed in Poland, by from +1.8 day/10 years for the start of tillering to +10.2 days/10 years for wax maturity (Kalbarczyk, 2009). An acceleration of the growth and development of many wild-growing and cultivated plants was observed also in other countries of Europe and the world (Menzel et al., 2006; Estrella et al., 2007).

According to climate change scenarios prepared for Europe, the productivity of certain cereal crops will most probably decrease in the coming decades due to intensification of occurrence of not only waves of heat but also droughts, especially in the central and southern parts of the continent (Iglesias et al., 2009; Supit et al., 2010; Isidro et al., 2011).

One of the spring cereals cultivated in Poland is oat whose plantations cover the area of about 550 thousand ha (FAO, 2012). In recent years the area of cultivation of that cereal remained at a stable level. In the structure of sowings of cereals oat has a 7% share. The grain produced is used for fodder in as much as about 87%. Oat is also highly important in human nutrition. Oat grain is characterised by very good amino acid composition of proteins, and contains considerable amounts of valuable lipids (Biel et al., 2009; Litwinek et al., 2013). Oat products can regulate the level of cholesterol in the blood, and the lipids contained in them may prevent the formation intravascular clots (Webster, 2002). Oat is a cereal with low thermal requirements (Kołodziej and Kulig, 2007). It responds negatively to high temperatures during the vegetation season. For this reason it would appear to be a good indicator of the response of crop plants to climate warming.

The objective of the study was to estimate the variability of oat growth and development in relation to air temperatures in the years 1971-2010.

MATERIAL AND METHODS

The basis for the study was material characterising field cultivation of oat (*Avena sativa* L.) under experimental conditions, acquired from the reports of the Research Centre for Cultivar Testing (COBORU) for the consecutive years of the analysed multi-year period of 1971-2010. The experimental data, originating from 28 COBORU stations (Figure 1), represented the yields, the times of sowing (SG) and harvest (H), the times of the phenological phases of emergence (E), start of heading (SH) and wax maturity (WM), and the duration of the phenological periods of sowing-emergence ($L_{SG\text{-}E}$), emergence-start of heading ($L_{E\text{-}SH}$), start of heading-was maturity ($L_{SH\text{-}WM}$), wax maturity-harvest ($L_{WM\text{-}H}$), and also the duration of the period of sowing-harvest ($L_{SG\text{-}H}$). In addition, the development phases of oat were determined by means of the BBCH scale which has been adopted in the countries of the European Union (Meier, 2001). The initial material was collected for a model formed by oat cultivars the most common in field cultivation, studied in a given year. The application of a collective model in the study was based on the assumption that intra-species differences do not obscure the general regularities sought for the species.

The field experiments were conducted in accordance with the methodology used by the COBORU. The experiments were set up on soils typical for oat cultivation, classified among both sandy and loamy soils. The spring mineral fertilisation was, on average, 230 kg ha^{-1}, which included N and P_2O_5 at doses of 85 and 55 kg ha^{-1} respectively, and K_2O – at 90 kg ha^{-1}. The forecrops for oat were mainly root crops, legumes, and rapeseed.

The study included also the use of meteorological data, monthly air temperatures (Ta) during oat vegetation (March-August), acquired from 43 stations of the Institute of Meteorology and Water Management (IMGW). The IMGW stations were uniformly distributed throughout the territory of Poland (Figure 1). Due to the small number of the stations and to the high micro-regional variation of meteorological conditions, the study excluded the mountain regions situated on the south-western and south-eastern fringes of Poland.

Figure 1. Distribution of COBORU experimental station (o) and IMGW meteorological stations (•) in Poland

Statistical analyses were performed for three multi-year periods, *i.e.* two twenty-year periods of 1971-1990 and 1991-2010, and one forty-year period of 1971-2010. The estimation of variability of the cultivation operations (SG, H) and phenological phases (E, SH, WM), and of the duration of the development periods of oat ($L_{SG\text{-}E}$, $L_{E\text{-}SH}$, $L_{SH\text{-}WM}$, $L_{WM\text{-}H}$, $L_{SG\text{-}H}$) was made with the use of the basic statistical parameters: mean values ($\bar{x}$), standard deviation (*SD*), and the minimum (Min) and maximum (Max) values. The study involved also the calculations of deviations (Δ), in the consecutive years of the analysed multi-year period, from the mean relative to the assumed base period of 1971-2010.

The relations between the analysed cultivation operations, duration of development periods and thermal conditions of the air, and their linear trend in the years 1971-2010 were determined on the basis of regression function. In the case of analysis of the relations between the duration of the sowing-harvest period and the thermal conditions, and between the level of yields and the sowing-harvest period and air temperature, the dependent variables were expressed as deviations from the linear trend to eliminate the effect of the biological and technological progress (Estrella et al., 2007). The hypothesis on the significance of the regression function was tested by means of the Snedocor *F*-test, and the significance of the regression coefficient – with the *t*-Student test. The measure of fit of the regression function to the empirical data was the coefficient of determination (R^2). The occurrence of autocorrelation of the random components was verified by means of the Durbin-Watson test. Co-linearity was eliminated through the application of ridge regression analysis. The contribution of each of the selected independent variables in the prediction of the dependent variable was determined on the basis of partial correlation (r^2).

RESULTS

In the period of 1971-2010 the mean country-wide date of oat sowing was the 7th of April and it was nearly identical in both analysed twenty-year periods of 1971-1990 and 1991-2010 (Table 1).

In Poland the earliest date of oat sowing was 23rd of March in 1990, and the latest, 23rd of April – in 1975 (Figure 2). In the first half of the analysed base period the standard deviation of the date of sowing was approximately twice as high (*SD* = 7.8 days) as in the second (*SD* = 3.8 days), and during the whole study period it was 6.1 days. The time of oat emergence, like the time of sowing, did not differ significantly in both of the analysed periods; on average the plants emerged on 23rd April, the earliest – on 10th April in 1990, and the latest – on 5th May in 1980.

The variation in the time of emergence was twice as high in the first half of the analysed base period (*SD* = 6.6 days) than in the second (*SD* = 3.3 days), *i.e.* the same as in the case of the time of sowing. In the period of 1971-2010 there was no significant linear trend in the times of sowing and emergence. In the forty year period the mean dates of the start of heading (SH), wax maturity (WM) and harvest (H) were noted, respectively, as follows: 11th June, 1st August and 17th August. In the years 1971-1990 the average phenological phases of the second half of vegetation and the time of harvest were noted considerably later (SH by 27 days, WM by 7 days, H by 6 days) than in the next twenty-year period of 1991-2010. The time of SH was recorded the earliest, 2nd May, in 2007, and the latest – 8th July – in 1980. Decidedly the highest standard deviation was determined for SH in the years 1991-2010 (*SD* = 17.4 days), followed by that for H in the years 1971-1990 (*SD* = 8.3 days). For SH, WM and H a linear trend was statistically proven - R^2 varied from approximately 22% for H to as much as 70% for SH (Figure 2). The highest acceleration was recorded in the case of SH (-13.4 days/10 years), notably lower in the case of WM (-3.9 days/10 years) and H (-3.1 days/10 years).

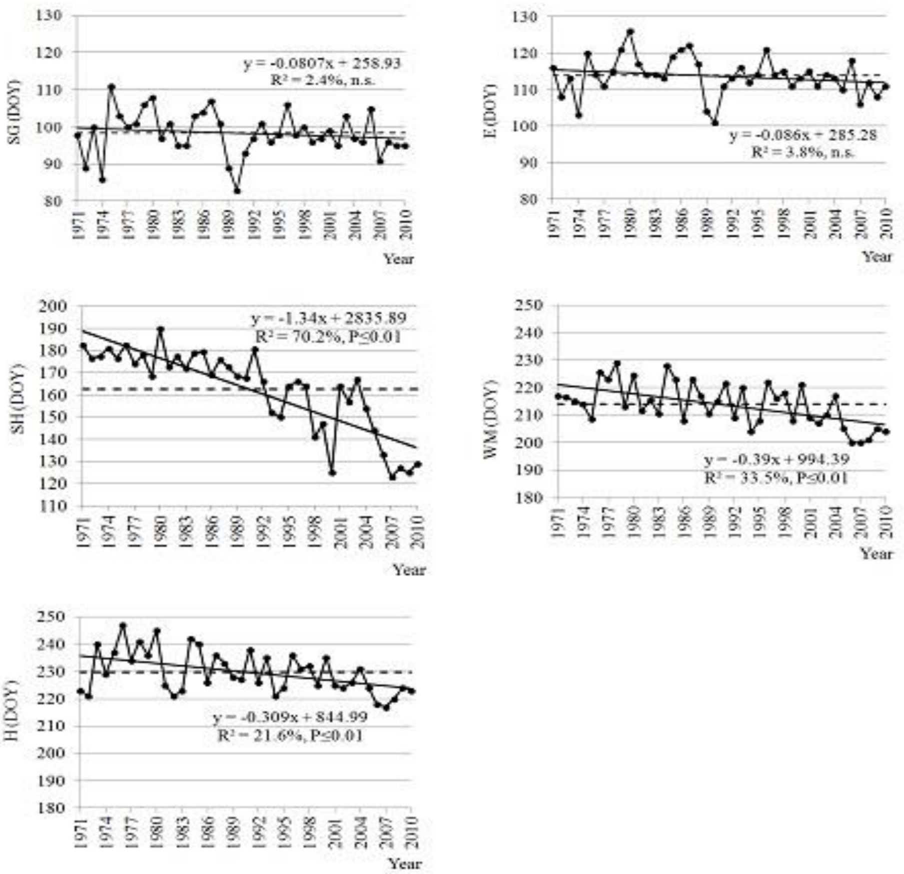

Figure 2. Temporal distribution of variation of cultivation opetations (SG,H) and phonological phases (E,SH, WM) of oat. R^2 – determination coefficient (%), P – level of significance. Other explanations as in Table 1.

Table 1. Statistical indices describing the cultivation operations[1] and phenological phases of oat

Agrophases	Symbol	BBCH - scale	Period	Statistical parameters			
				$\bar{x}$ ±*SD* / date (DOY)	Min/Year (DOY)	Max/Year (DOY)	Trend direction
Sowing [1]	SG		a	99.0±7.8 / 08-04	83 / 1990	114 / 1975	
			b	97.7±3.8 / 07-04	91 / 2007	106 / 1996	
			c	98.4±6.1 / 07-04	83 / 1990	114 / 1975	n.s.
Eemergence	E	09	a	114.5±6.6 / 24-04	101 / 1990	126 / 1980	
			b	112.9±3.3 / 22-04	106 / 2007	121 / 1996	
			c	113.7±5.2 / 23-04	101 / 1990	126 / 1980	n.s.
Start of heading	SH	51	a	176.1±5.7 / 24-06	168 / 1990	190 / 1980	
			b	148.9±17.4 / 28-05	123 / 2007	167 / 2003	
			c	162.5±18.7 / 11-06	123 / 2007	190 / 1980	-**
Wax maturity	WM	85	a	217.4±6.5 / 04-08	208 / 1986	229 / 1978	
			b	210.3±7.5 / 28-07	200 / 2007	222 / 1996	
			c	213.8±7.8 / 01-08	200 / 2007	229 / 1978	-**
Harvest[1]	H		a	232.7±8.3 / 20-08	221 / 1982	247 / 1976	
			b	226.8±6.1 / 14-08	217 / 2007	236 / 1987	
			c	229.7±7.8 / 17-08	217 / 2007	247 / 1976	-**

Period of study: a – 1971-1990, b – 1991-2010, c – 1971-2010, $\bar{x}$ – mean value, *SD* – standard deviation, Min – minimum value, Max – maximum value, -/ – negative trend, n.s. – statistically non-significant, ** – significant at P≤0.01, DOY – day of the year.

Among the three analysed relations between phenological phases (E, SH, WM) and air temperature during the period of oat vegetation (Ta_{3-8}), the strongest one was proved for the relation between Ta_4 and SH, R^2=53.3% (Figure 3). Increase of Ta in April by 1°C caused an acceleration of SH by 9.6 days. In the case of emergence and wax maturity, the acceleration was notably slower and amounted to, respectively, 1.4 days/1°C for Ta_3 and 3.4 days/1°C for Ta_6. The changes in the times of oat phenological phases in the successive years of the analysed multi-year period were caused by the diversified thermal conditions. From the beginning of the 1990's one can observe a distinct advantage of positive deviations of air temperature in the months that significantly determine the run of the phenological phases of oat, i.e. in March, April and June. In the final 20-year period under analysis positive deviations of air temperature relative to the average value were noted from 12 times in March to 14 times in April. In March the biggest positive deviations were recorded in 1982 (+4.4°C), 1990 (3.8°C) and 2007 (3.6°C); in April – in 2000 (+3.9°C), 2009 (3.1°C) and 1998 (2.0°C); and in June – in 1979 (+2.5°C), 1992 (2.2°C) and 2007 (2.0°C).

As an example, the greatest, by nearly 38 days, acceleration of the start of heading relative to the average in the years 1971-2010 occurred in 2000, when Ta_4 was higher than average by 3.9°C.

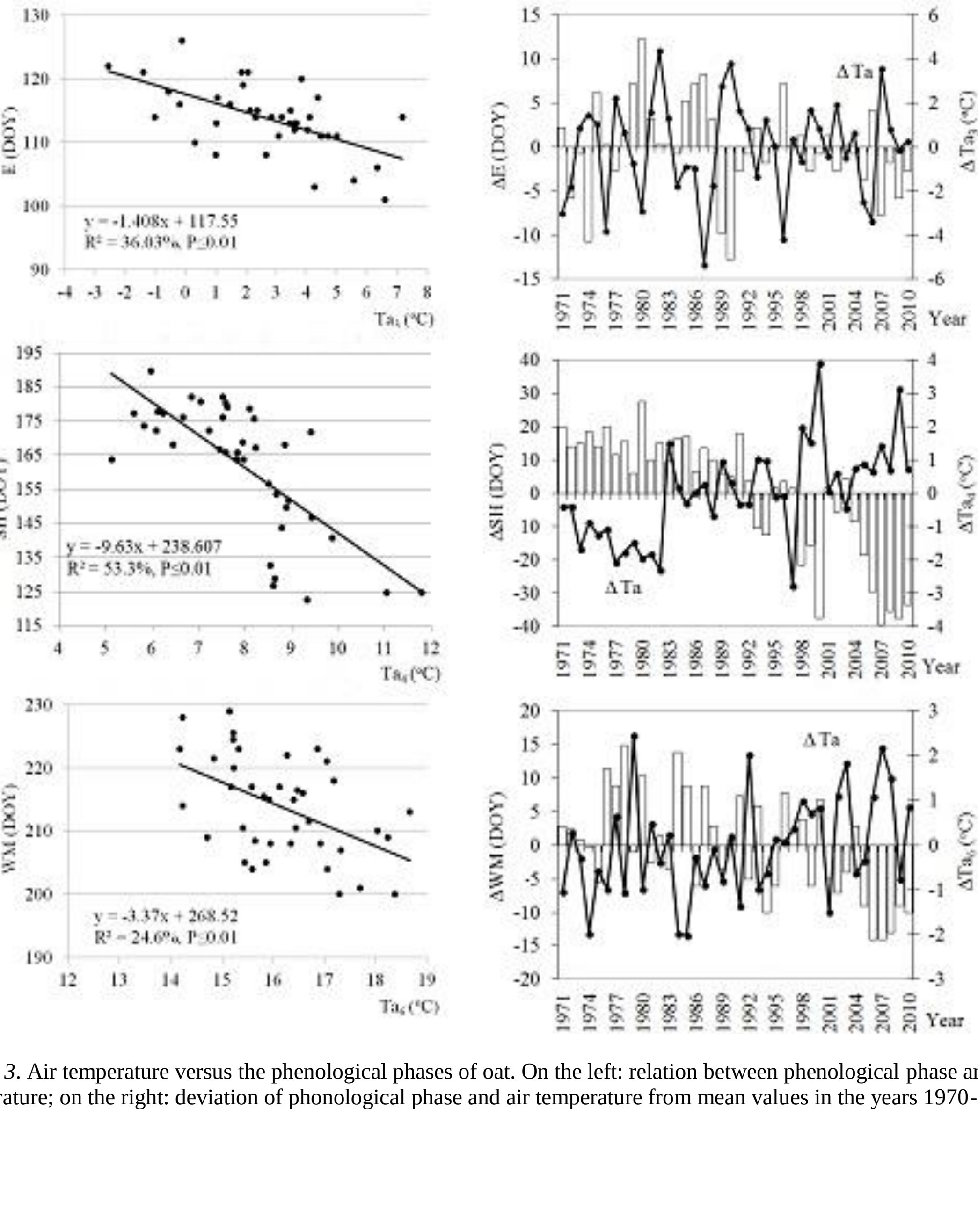

Figure 3. Air temperature versus the phenological phases of oat. On the left: relation between phenological phase and air temperature; on the right: deviation of phonological phase and air temperature from mean values in the years 1970-2010

In Poland the average duration of the period sowing-harvest (L_{SG-H}) of the cereal under analysis was 132 days, with only a small difference between the first and the second half of the base period – 5 days (Table 2, Figure 4). The shortest, 113 days, period of vegetation was noted in 2006, and the longest – of 147 days – in 1984. In the years 1971-2010 vegetation periods shorter than average occurred decidedly more frequently in the final 10-year period – as many as nine times. From year to year the duration of the L_{SG-H} period was shorter and shorter. The regression equation demonstrates that during the 40 years the period of oat vegetation decreased by 9.2 days.

Table 2. Statistical indices describing the duration of phenological phases and of the period from oat sowing to harvest

Agrophases	Symbol	Period	Statistical parameters			
			$\bar{x}$ ±*SD* (day)	Min/Year (day)	Max/Year (day)	Trend direction
Sowing - emergence	L_{SG-E}	a	15.6±3.0	9 / 1975	20 / 1981	n.s.
		b	15.2±1.5	11 / 2003	16 / 2010	
		c	15.4±2.4	9 / 1975	20 / 1981	
Emergence - start of heading	L_{E-SH}	a	61.6±7.3	48 / 1979	78 / 1974	-**
		b	36.0±16.4	12 / 2000	53 / 1992	
		c	48.8±18.0	12 / 2000	78 / 1974	
Start of heading - wax maturity	L_{SH-WM}	a	41.4±5.6	32 / 1975	51 / 1978	+**
		b	61.4±15.2	41 / 1991	96 / 2000	
		c	51.4±15.2	32 / 1975	96 / 2000	
Wax maturity - harvest	L_{WM-H}	a	15.3±6.4	5 / 1972	29 / 1975	n.s.
		b	16.5±1.8	14 / 2000	19 / 2009	
		c	15.9±4.6	5 / 1972	29 / 1975	
Sowing - harvest	L_{SG-H}	a	133.9±7.8	120 / 1982	147 / 1984	-*
		b	129.1±6.4	113 / 2006	138 / 2000	
		c	131.5±7.5	113 / 2006	147 / 1984	

-/+ – negative / positive trend, *– significant at P≤0.05. Other explanations as in Table 1.

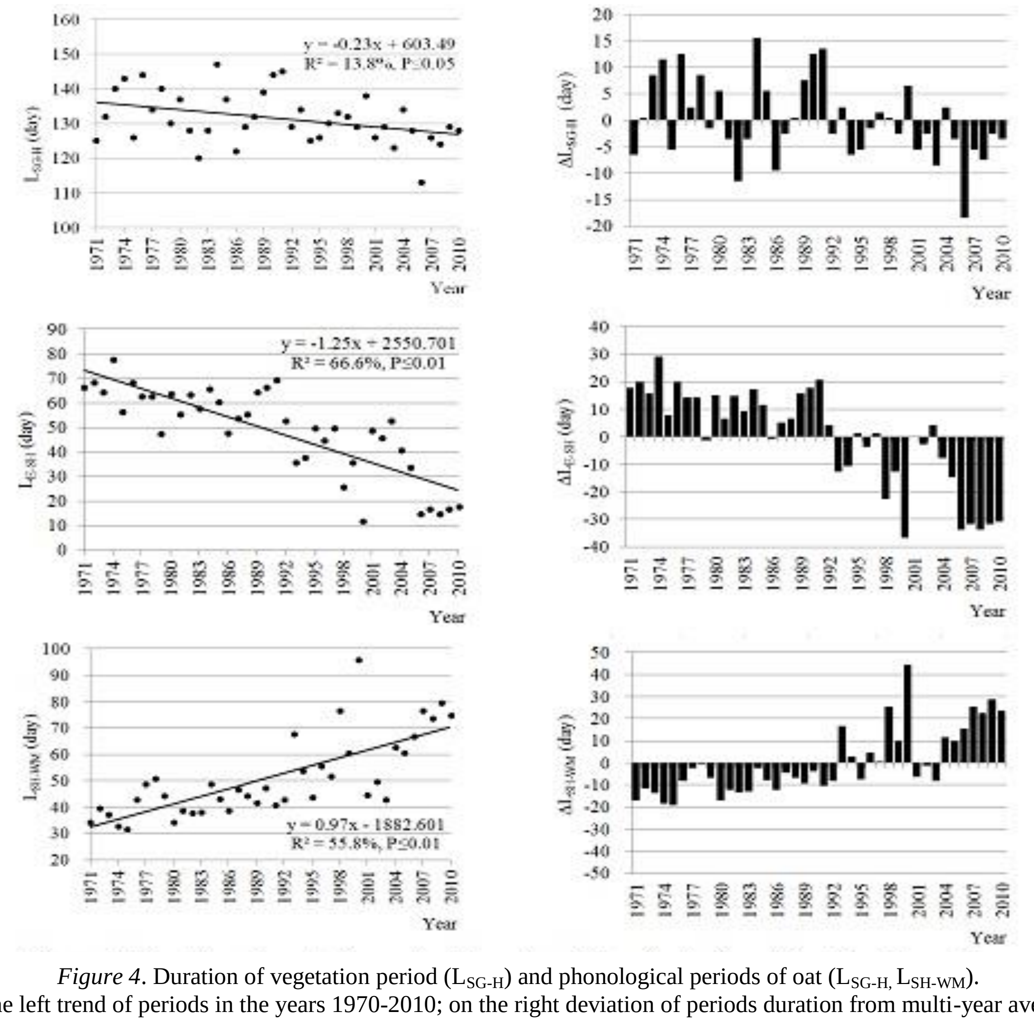

Figure 4. Duration of vegetation period (L_{SG-H}) and phonological periods of oat (L_{SG-H}, L_{SH-WM}).
On the left trend of periods in the years 1970-2010; on the right deviation of periods duration from multi-year average.

The duration of the shorter development periods varied, on average, from 15-16 days in the case of the periods of sowing-emergence and wax maturity-harvest to 49-51 days in the case of the periods of emergence-start of heading and start of heading-wax maturity. The first ($L_{SG\text{-}E}$) and the last ($L_{WM\text{-}H}$) of the analysed periods of oat development were characterised by a greater, even 2-3-fold, variation of duration in the first half of the base period under analysis – 1971-1990, and the periods $L_{E\text{-}SH}$ and $L_{SH\text{-}WM}$ – in the second half, i.e. in the years 1991-2010. In the years 1971-2010 there appeared a statistically significant, at P≤0.01, shortening of the period $L_{E\text{-}SH}$. The coefficient of determination calculated for the significant linear trend was 66.6%. During 10 years the duration of the period of emergence-start of heading decreased by 12.5 days. From the year 1993 the duration of $L_{E\text{-}SH}$ was as many as 14 times shorter than average for the period of 1971-2010; the shortest was noted in 2000, and then in the years 2006 and 2008. The next period of oat development, $L_{SH\text{-}WM}$, increased from year to year by 9.7 days/10 years (R^2 = 55.8%). In the final 15 years of the multi-year period under analysis positive deviations of the duration of the period $L_{SH\text{-}WM}$ relative to the average were noted as many as 12 times, the greatest – >25 days – in the years 1998, 2000, 2007 and 2009.

In the period of 1971-2010 the mean air temperature in the months March-August, i.e. the time between oat sowing and harvest, was 12.7°C (*SD* = 0.9°C) and varied from 10.5°C in 1980 to 14.6°C in 2002 (Figure 5). The increase of $Ta_{3\text{-}8}$ was at the level of 0.45°C/10 years. A similar increase of Ta, amounting to 0.42°C/10 years, was demonstrated for the period May - July (Table 3).

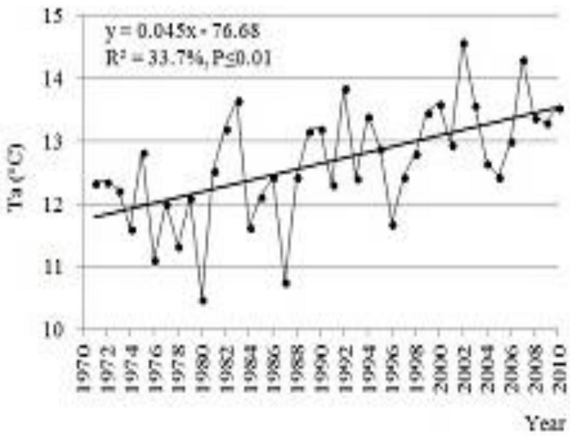

Figure 5. Linear trend of Ta in the period of oat vegetation (March-August) in the years 1970-2010

Table 3. Relation between deviation from linear trend of duration of oat sowing-harvest period and air temperature

Variable			Regression coefficient	*t*-Student	*F*-Snedocor	R^2, %	r^2, %	P
Symbol	$\bar{x}$ ±*SD*	°C/10 years						
Ta_4, °C	7.9±1.4	0.75	1.63	2.5	12.1	39.4	14.5	0.01
$Ta_{5\text{-}7}$, °C	15.9±0.9	0.42	-4.76	-4.7			38.2	0.01

Ta_4 – air temperature in April, $Ta_{5\text{-}7}$ – air temperature in the period May-July.
R^2 – coefficient of determination (%), r^2 – coefficient of partial correlation (%), P – level of significance.
Other explanations as in Table 1.

In April, Ta increased notably faster, by 0.75°C/10 years. The duration of the sowing-harvest period of the cereal under discussion depended significantly on air temperature in the period of April-July (Table 3). Ta_4 had a positive effect on the duration of $L_{SG\text{-}H}$, and $Ta_{5\text{-}7}$ – a negative one. Increase of Ta_4 by 1°C caused an extension of the duration of $L_{SG\text{-}H}$ by 1.6 day above the linear trend, while increase of $Ta_{5\text{-}7}$ by 1°C – a shortening by 4.7 days. The coefficient of regression determined for Ta_4 was about 3-fold lower than that for $Ta_{5\text{-}7}$, which indicates a greater effect of Ta in the second half of oat vegetation period. Also the coefficients of partial correlation support the decidedly closer correlation of $Ta_{5\text{-}7}$-$L_{SG\text{-}H}$ (r^2 = 38.2%) than Ta_4-$L_{SG\text{-}H}$ (r^2 = 14.5%). The independent variables of the regression equation, describing the above relation, were significant at the level of P≤0.01, and the values of *t*-Student's test were -4.7 for $Ta_{5\text{-}7}$ and 2.5 for Ta_4. The coefficient of determination for the equation was about 40%, and the value of Snedocor *F*-test – approximately 12.

In the years 1970-2010 the mean national yields of oat harvested from COBORU experiments were 54.9 dt ha^{-1}, and variation described with standard deviation was 12.1 dt ha^{-1} (Figure 6). The yields of oat displayed a significant increase year to year, which was confirmed by analysis of linear regression (R^2 = 81.9%). On the scale of Poland the mean annual yield increase was 0.94 dt ha^{-1}/year. The yield was significantly and positively correlated with the duration of L_{SG}-$_H$. The variation of yields was determined in about 27% by the duration of vegetation, an increase being noted only when the duration of L_{SG-H} was at least 131 days (Figure 7). The yield of oat was significantly negatively correlated with Ta_{5-7} (R^2 = 32.3%). Ta_{5-7} ≥ 15.9°C determined yield lower than the trend line. As an example, in 1974, when Ta_{5-7} was 13.5°C, a positive deviation of yields from the trend was noted, amounting to 5.3 dt ha^{-1}.

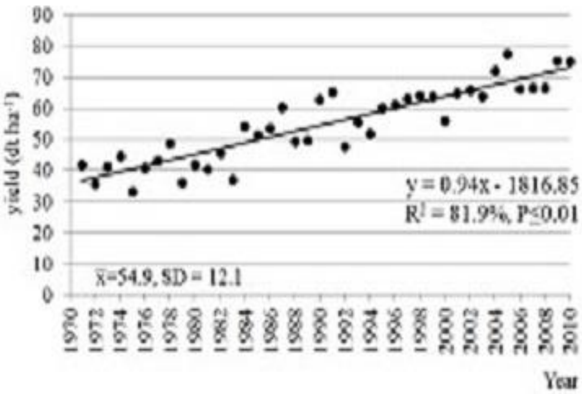

Figure 6. Linear trend of experimental yields of oat in the years 1970-2010

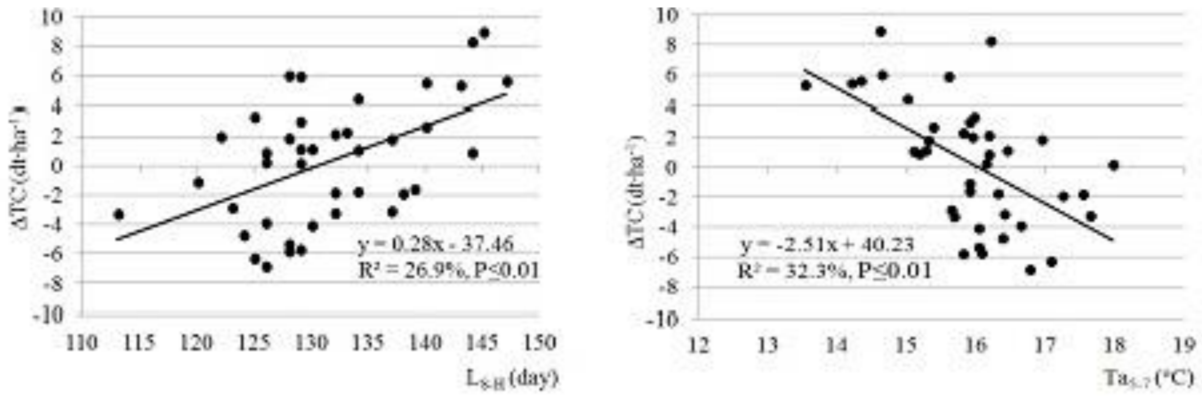

Figure 7. Correlation between deviation from linear trend of oat yields (ΔTC) and duration of sowing-harvest period (L_{SG-H}) and air temperature in the period May - July (Ta_{5-7})

DISCUSSION

The results of this study confirm the results obtained by other authors concerning the temporal structure of the development periods of crop plants (Menzel et al., 2006; Estrella et al., 2007; Kalbarczyk, 2009). In the years 1971-2010 a significant negative trend was demonstrated for 3 out of 5 of the analysed cultivation operations terms and phenological phases of oat. From year to year the start of heading (SH) and wax maturity (WM) appeared earlier, and the plants were harvested from the field earlier (H). The acceleration of those terms in Poland varied from 3.9 days/10 years (WM) to 13.4 days/10 years (SH). Similarly, an acceleration of those terms for not only cereals but also other plants, both cultivated and wild-growing, was demonstrated by e.g.: Sônego (2000), Menzel et al. (2006) and García-Mozo et al. (2010). Occasionally during the vegetation period both a delay and an acceleration of the particular phenological phases is recorded. For example, the sowing and emergence of winter wheat in the northern part of the Chinese Plain were delayed by about 1.5-1.7 days/10 years relative to the average multi-year dates, and the flowering and maturity – accelerated by 2.7 days and 1.4 day/10 years, respectively (Xiao et al., 2013). Studies by Olesen et al. (2012) indicate that the greatest changes in the cultivation periods and phenological phases, estimated on the basis of climate models for the year 2040, will concern spring cereals growing in Northern Europe.

This study also revealed changes in the duration of the development periods of oat, varying from 2 to 13 days/10 years. An extension was demonstrated in the case of one period - L_{SH-WM}, and a shortening – in the duration of two periods, L_{E-SH} and L_{SG-H}. Shortening or extension of development periods of cereals were also demonstrated by Saiyed et al. (2009), Siebert and Ewert (2012). Studies by Nieróbca et al. (2013) indicate that in the perspective till 2030 the vegetation period in central Poland will be longer by 10-14 days than in the years 1971-2000, and till 2050 – even by 18-27 days.

The growth, development and yields of the cereal under analysis were significantly determined by Ta. In the years 1971-2010 the variation of times of E, SH and WM was explained by the changes in Ta in about 25% to 53%. The duration of the vegetation period of oat depended significantly on Ta_4, which had a positive effect, and on Ta_{5-7} – with a negative effect. Both the duration of the period L_{SH-WM} and Ta_{5-7} significantly determined the final yields of oat, the extension of the duration of that period having a positive effect, and the increase of Ta – a negative one.

The effect of Ta on the phenological phases and yielding of cereals was demonstrated by e.g. Kołodziej and Kulig (2007), Saiyed et al. (2009) and Al-Karaki (2012). Research shows that the rate of plant growth depends mainly on genetically determined responses to temperature, and also on vernalisation, day duration or physiological stress (Limin et al., 2007; Olsen et al., 2012). In general it can be stated that the growth and development of plants is the fastest within a specific range of optimum temperatures and decreases with increasing deviation from that range (McMaster et al., 2008; Craufurd and Wheeler, 2009). As an example, in recent years an increase of Ta by 1^oC may cause an acceleration of the phenological phases of agricultural and horticultural plants in Germany by an average of 4 days (Estrella et al., 2007).

CONCLUSIONS

It can be stated that the dates of the phenological phases of oat, describing the annually recurring stages of plant development in nature, are of particular interest as they can be treated as an indicator of changes in air temperature. Shifts in the course of the phenological phases, and thus changes in the duration of vegetation, that take place e.g. under the effect of changes of air temperature, significantly determined the final yields of oat. Air temperature, depending on the season of the year, can shorten or extend the period of oat vegetation. Under the climatic conditions of Poland, extension of the sowing-harvest period of the cereal under analysis contributed to an increase of yields, and increase of temperature Ta_{5-7} to its reduction.

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