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THERMAL CONDITIONS OF SOYBEAN CULTIVATION IN SIEDLCE REGION

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A b s t r a c t. We observe an increase of air temperature in the world which, apart from negative effects, gives opportunities for growing new plant species. A good example of this phenomenon is soybean (*Glycine max* L.). Not only soybean reveals valuable nutritional properties but also the plant is an excellent element of a balanced crop rotation and is a good forecrop for follow-up plants, especially cereals. Soybean shows phytomelioration and phytosanitary properties. This plant has a well-developed root system which allows penetration of deeper soil layers. As a consequence, the soil is well aerated. In addition, soya cleans the field position off the stalk base diseases. The purpose of this thesis is to display the characteristic thermal conditions of soybean cultivation in Siedlce region from 1971 to 2015. The analysis of thermal conditions was based on daily, monthly and annual average air temperatures in Siedlce during the vegetation season (April-October). The sum of effective temperatures was also defined as the sum of daytime temperatures above 6, 10 and 15°C during the growing season. Basic distribution characteristics are specified in the article: arithmetic mean, minimum and maximum. The direction and significance of the trend of changes in analysed parameters were determined on the basis of linear trend equations. The significance of the directional coefficient of the trend was assessed with Student's t-test at the significance level of $\alpha = 0.05$.
K e y w o r d s: soybean, sum of effective temperatures, thermal resources, air temperature

INTRODUCTION

The progressive global warming of the climate may lead to significant changes in the phenology of plants and, consequently, changes in agricultural production on the European continent, including Poland (Sulikowska *et al*. 2016). It has been proven that for every 1°C increase in mean annual air temperature the growing season extends by about 5 days (Chmielewski and Rötzer 2001) and up to 12 days for every 1°C increase in average air temperature in spring (Chmielewski and Rötzer 2001, Scheifinger *et al*. 2003, Menzel *et al*. 2006). In addition to extending the vegetation season, the increase in temperature during the growing season is extremely important for the development of plants. It results in an increase in heat resources which may accelerate or delay the occurrence of subsequent phenological phases of the plant (germination, leaf development, flowering, fruit ripening, leaf fall) (Chmielewski and Rötzer 2001). Studies show that an increase in temperature by 1°C will reduce global wheat production by 6% (Lobell and Field 2007, Asseng *et al*. 2015). A warmer climate significantly increases the risk of drought (Sulewski and Czekaj 2015). Researchers participating in the American AgMIP project (Agricultural Model Intercomparison and Improvement Project), in which coordinated global and regional analyses of the impact of global warming at +1.5 and +2.0°C (Coordinated Global and Regional Assessments) are carried out, predict drought risks for southern Europe and North-Western and South America in the time perspective until 2050 (Ruane *et al*. 2018).

However, for agriculture climate warming may be beneficial – it opens up opportunities for cultivating new varieties not previously used in given latitudes (Gendron St-Marseille 2019). Under CGRA it is predicted that tropical maize (*Zea mays* L.) will experience the highest crop losses, while soybean (*Glycine max* L.) will bring the most benefits (Ruane *et al*. 2018). This is one of the factors that makes interest in soybean in the feed industry in the world increase (Kulkarni *et al*. 2018). Soybean, as a cultivated plant, has several very significant advantages, mainly its seeds are characterized by a high content of easily digestible protein and fat its cultivation effectively contributes to the reduction of soil erosion. Moreover, *Glycine max* L. has a wide adaptability to various climate zones (Asekova *et al* 2014, 2016). Soybean is a plant that binds nitrogen in the soil. It is estimated that it may leave an average of 79 kg N ha^{-1} for succeeding plants (Salvagiotti *et al*. 2008). Soybeans harvested at the growth stages from R5 (seed development) to R7 (initial maturity) (Fehr *et al*. 1971) were considered a highly suitable animal feed due to the combination of high protein content, low fiber content and high energy digestible (Asekova *et al*. 2014). All this makes *Glycine max* L. the fourth plant in the world in terms of growing area, and it is estimated that its area will grow in subsequent years to satisfy the demand for valuable vegetable protein (Jumrani 2018). The area of leguminous crops covers only 1.5% of arable land in Europe (compared to 14.5% in the world) (Watson *et al*. 2017).

In Poland, the area of soybean cultivation is still small, although it is systematically growing. In 2017 *Glicyne max* L. cultivation area amounted to 9333 ha, in comparison to 7514 ha in 2016 (GUS 2017, GUS 2018). The greater interest in the cultivation of this plant was contributed to by an increase in soybean meal prices in recent years, changing climatic conditions, as well as the availability of new varieties. High nutritional values, as well as the beneficial effect of soybean on the soil, make it more and more widely grown, especially in the southern regions of our country (Jaskulska *et al*. 2017).

The following research hypothesis has been formulated: progressive global warming causes an increase of soybean cultivation possibilities in the region of Siedlce.

The aim of the work is to assess the variability of thermal resources and the possibilities of growing soybeans in Siedlce region.

MATERIAL AND METHOD

The work assessed the variability of thermal resources and its impact on the possibility of growing soybeans in the Siedlce area. Meteorological data (average daily air temperature) from the meteorological station in Siedlce were used (φ°=52°10′03″N; λ°=22°17′24″E; H_sm a.s.l. = 150 m). The analysis covered the years 1971-2015. The monthly averages and the minimum and maximum values were determined. Thermal resources were determined on the basis of sums of effective temperatures (STE), i.e. a surplus of mean daily values of air temperature above 6°C (vegetation period), above 10°C (period of active plant growth), and above 15°C (plant ripening period). In Poland the recommended date for soybean sowing is the day when the air temperature reaches 11°C. An algorithm for calculating the sum of effective temperatures (above 6, 10 and 15°C) was established from the day after, after April 15, when the air temperature reached 11°C, to the day when in October it dropped below 10°C.

$$STE1 = \sum ti > 6 \quad STE2 = \sum ti > 10 \quad STE2 = \sum ti > 15 \qquad (1)$$

STE – sums of effective temperatures, ti – average daily air temperature.

The number of days with the temperature in each analysed range was determined. The direction and significance of the trend of changes in the sum of effective temperatures and the number of days with the sum of air temperatures in a particular range were determined on the basis of linear trend equations for the years 1971-2015 and for the decades 1976-1985, 1986-1995, 1996-2005, 2006-2015. To determine the variability of thermal resources during the growing season of soybean, the trend of STE changes in each month (April-October) for each temperature value was calculated. The direction and significance of the trend of changes in the parameters analysed was determined on the basis of linear trend equations. The significance of the directional coefficient of the trend was assessed by Student's t-test at the significance level of $\alpha = 0.05$.

RESULTS

The highest variability in the period from April to October was characteristic of sums of effective temperatures in the period of plant ripening (Tab. 1). The coefficient of variation in this period was 80.57%. The highest variability of the analyzed parameter of all studied ranges was recorded in October. The variability

(April-October) of the sum of temperatures above 6 and 10°C was at a similar level. The coefficient of variation was 36.02 and 40.58%, respectively. The lowest values of monthly coefficients of variation for sums of temperatures >6 and >10°C were noted in June and August, and for >15°C in July and August. The largest sums of effective temperatures in all analyzed periods (above 6, 10 and 15°C) in the years 1971-2015 in Siedlce were recorded in July and August, and the lowest in October.

Table 1. Arithmetic mean, minimum, maximum and coefficients of variation sums of effective temperatures in Siedlce from 1971 to 2015

Parameter	IV	V	VI	VII	VIII	IX	X
			>6° C				
Min	0.00	258.60	417.90	448.30	461.80	289.10	0.00
Max	253.80	516.90	574.00	672.00	644.20	454.70	197.50
Art. mean	93.60	409.15	485.38	565.24	546.11	383.69	34.72
Coefficient of var.	61.17	12.59	7.25	9.42	7.31	11.60	142.77
			>10° C				
Min	0.00	157.30	390.10	448.30	461.80	149.20	0.00
Max	253.80	516.90	574.00	672.00	644.20	454.70	187.50
Art. mean	73.96	366.63	478.57	565.24	545.48	337.28	33.83
Coefficient of var.	72.73	20.44	8.41	9.42	7.48	22.74	142.88
			>15° C				
Min	0.00	15.50	193.00	178.2	202.50	15.20	0.00
Max	189.20	396.60	559.70	672.00	644.20	300.80	51.20
Art. mean	23.58	186.53	334.30	494.82	448.77	132.00	6.16
Coefficient of var.	175.87	51.67	27.93	23.79	21.66	57.43	205.64

The average of annual sums of effective temperatures of over 6°C in the years 1971-2015 in Siedlce was 2518°C (Fig. 1). On average, 161 days were recorded with such a temperature. It was found that in the analyzed multi-year period an increase of both the sum of temperatures and the number of days with the temperature above 6°C occurs. However, this trend was not statistically significant.

Statistically, the largest significant trend of the increase in the sum of effective temperatures above 6°C was noted in the first analyzed decade (1976-1985) (Fig. 2). In that decade, the number of days with temperature above 6°C also significantly increased. The sum of temperatures increased then by about 35°C year^{-1}, and the number of days by about 1/year. In the next two decades, both parameters showed an upward trend, but it was not statistically significant. In contrast, in 2006-2015 a slight downward trend was recorded.

It is true, that the average annual total of temperatures above 10°C in the analyzed multi-year period in Siedlce was 2400°C, and the number of days with such a temperature was around 148 during the year (Fig. 3). Both the sums of temperatures and the number of days showed an upward trend, but it was not statistically significant.

The analysis of the trend of STE changes and the number of days with the temperature above 10°C in particular decades showed a statistically significant increase in these parameters only in the first decade (1976-1985) (Fig. 4). The sum of temperatures increased in those years by about 35°C per year, and the number of days with this temperature range increased by 1 day per year. In the following decades there were no statistically significant trends in changes in both parameters.

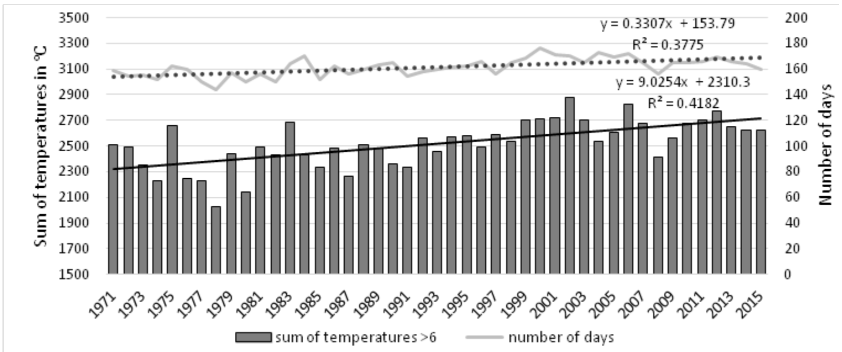

Fig. 1. The sum and number of days of effective temperatures above 6 °C in Siedlce from 1971 to 2015

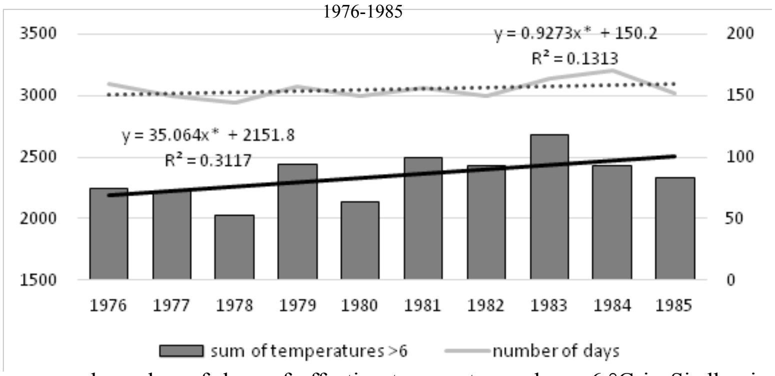

Fig. 2. The sum and number of days of effective temperatures above 6 °C in Siedlce in decades. Explanations: * significant at α = 0.05

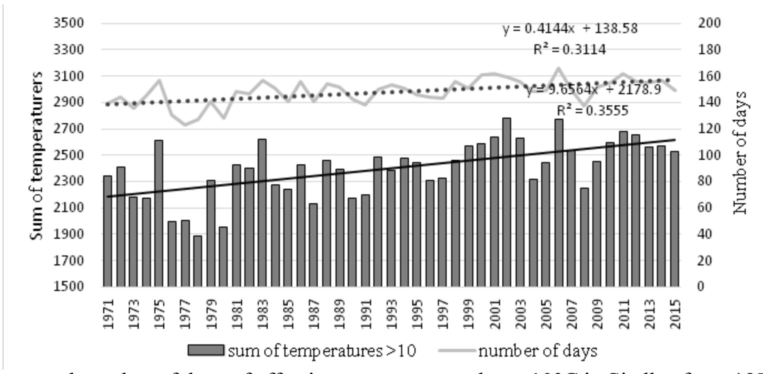

Fig. 3. The sum and number of days of effective temperatures above 10°C in Siedlce from 1971 to 2015

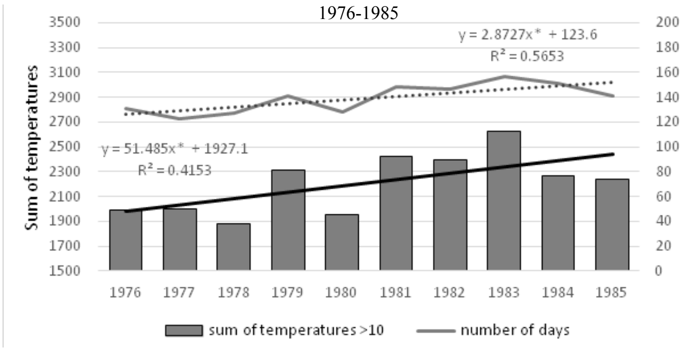

Fig. 4. The sum and number of days of effective temperatures above 10°C in Siedlce in decades. Explanations: * significant at α = 0.05

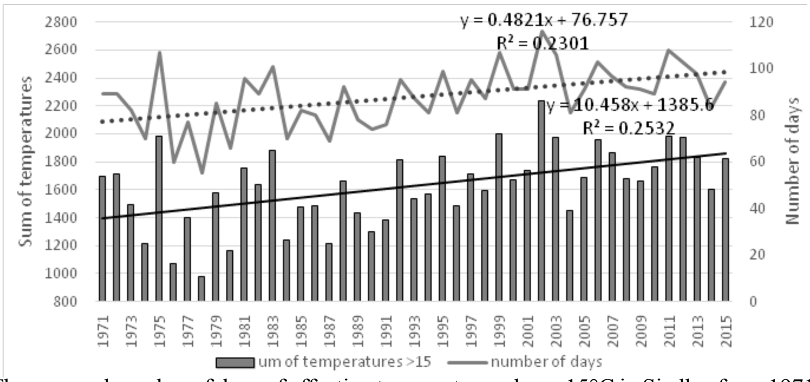

Fig. 5. The sum and number of days of effective temperatures above 15°C in Siedlce from 1971 to 2015

The sum of STE determined above 15°C in the analyzed multi-year period was on average 1626°C, and the number of such days in the year was 88 (Fig. 5). The trend analysis showed a significant increase in both STE and the number of days with temperatures above 15°C in 1971-2015.

A significant upward trend was maintained in the first two decades of the analyzed multi-year period (Fig. 6). In the years 1976-1985, STE increased by about 47°C year^{-1}, and the number of days with temperature of this range by 2.5 days year^{-1}. In the years 1986-1995. this increase was already smaller (STE increased by 38°C year^{-1}, and the number of days by 1.7 days year^{-1}). In the following decades, the trend of changes was not significant, and in 2006-2015 there was even a downward trend in both STE and the number of days with the analyzed temperature.

It was found that in all the analyzed months of the soybea growing season of STE soybeans increased year by year (Tab. 2). Only the sum of air temperature in April, above 6 and 10°C, increased significantly. However, in the period of plant maturation (>15°C), this sum was significantly increased in July and August, by 4.6 and 3.3°C, respectively.

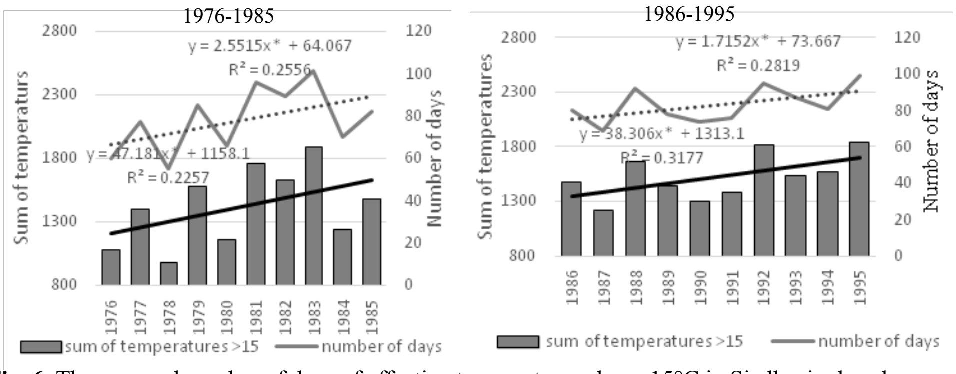

Fig. 6. The sum and number of days of effective temperatures above 15°C in Siedlce in decades

Table 2. Equations of the trend of changes in the sum of effective temperatures in Siedlce from 1971 to 2015

Month	>6°C	>10°C	>15°C
IV	y=**2.419*x**+37.95	y=**2.0521*x**+26.76	y=0.6335x+9.00
V	y=0.792x+392.38	y=0.8751x+346.50	y=0.0194x+186.08
VI	y=0.6073x+47.12	y=0.8399+459.25	y=1.037x+310.45
VII	y=1.9808x+52.54	y= 1.9088x+521.34	y=**4.5997*x**+310.45
VIII	y=1.395x+51.36	y=1.4228x+512.76	**y=3.3096*x+372.65**
IX	y=1.044x+359.67	y=1.629x+299.80	y=0.6352x+117.39
X	y=0.9215x+13.22	y=0.9281x+12.48	y=0.224x+1.01

Explanations: * significant at $\alpha = 0.05$

DISCUSSION

Usicka-Kowalkowska and Kejna (2009) analysed the variability of thermal and rainfall conditions in Koniczynki in the period 1994-2007, and they found that the number of anomalously and extremely warm months was three times higher than the number of anomalously and extremely cold months. It should be emphasised that the results of work on forecasting the future climate situation show significant differences. Sulikowska *et al.* (2016) analyzed the variability of the sum of effective temperatures determined on the basis of minimum and maximum temperatures by GDD. They argue that the trends they describe result in an increase in heat resources in Poland by an average of 60°C for 10 years for the 0°C threshold, and a slightly less intense but significant increase in temperature sums for the remaining thresholds: 46°C 10 years^{-1} for 5°C, 28°C for 10 years for 10°C. The smallest and statistically insignificant changes were observed by the authors in the eastern voivodships and in the mid-west of Poland. The given values of changes in thermal resources differ from those obtained in this work for the Siedlce region. These differences may also result from differences in the way STE is determined.

In Poland's climatic conditions, early varieties of "000" and "00" soybeans are suitable for cultivation (sum of effective temperatures in the growing season >1500°C, physiological 6°C, 120-130 days of vegetation), ripening at the turn of August and September (Boros and Wawer 2016). According to Stuczyński *et al*. (2000), the area of soy and pea cultivation will increase significantly, while the area of cereals and potato yield will be reduced (by 20 to 30%).

CONCLUSIONS

1. The average of annual effective temperature over 6, 10 and 15°C during the soybean vegetation period in the area of Siedlce in the years 1971-2015 amounted to 2518, 2401 and 1626°C, respectively. Most days were with STE above 6 and 10°C (161 and 148 respectively), and the least with STE above 15°C (87days).

2. Statistically significant trend of STE increase and number of days with air temperature above 6 and 10°C was noted in the first analyzed decade (1976-1985). The sum of temperatures increased then by about 35°C year^{-1} and by 51°C year^{-1}, respectively, and the number of days by about 1 day/year and 3 days year^{-1}. However during the ripening period, STE significantly increased in the first two decades (1976-1985 and 1986-1995), by 47 and 38°C, respectively. On the other hand, the number of days at that time significantly increased by 2.5 days year^{-1} and by 1.7 days year^{-1}, respectively.

3. It was found that in particular months of the growing season of soybean a significant increase in STE occurred only in April (for temperatures >6 and 10°C) and in July and August (for temperatures >15°C).

4. Taking into account the increase in the sum of effective temperatures it can be assumed that it will accelerate the development of plants and extend the growing season. Therefore, it is possible to develop the cultivation of new thermophilic plant species, including soybean, in the studied area.

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