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TECHNOLOGICAL SOLUTIONS FOR COMMON SUNFLOWER (*Heliantus annuus*) GROWING IN A CHANGING CLIMATE CONDITION

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Abstract

Climatic changes in recent years have adversely affected the development of a number of crops. Especially the spring ones suffer, since the development phases in which the yield is formed take place during the periods most strongly influenced by climate change. In the present study, the different climate components during the period 1991-2020 that most strongly influence sunflower development are characterized. It was established that the unfavorable trends of changes in agrometeorological conditions in the studied area are related to a decrease in summer precipitation and an increase in temperatures during the same period. As a result, the last two months of the sunflower growing season are in a moisture deficit. Temperatures in the region during the studied period have increased, with positive deviations in all months, except for December. No differences were recorded in the dates of the transition of the air temperature through 5ºC. During the researched period, they increased by 167ºC compared to the previous one. During the studied period, precipitation in summer decreased at the expense of its increase in autumn, compared to the previous one.

Key words: *climate change, climate conditions, sunflower.*

INTRODUCTION

In recent years, sunflower yields in Bulgaria have been increasing, but to be profitable, they must exceed 250 kg (Mikova, 2020). Environmental conditions determine 65-80% of plant productivity (Hogenboom, 2000), but the analysis of the agroclimatic potential of the region and the adaptation of the cultivation technology to the peculiarities of the agrometeorological conditions is the basis of good crop yields.

In recent years, we have witnessed unfavorable trends in changes in the main meteorological elements, as well as an increase in extreme weather events. This puts sunflower growing in some traditional areas of crop production at risk.

Since the beginning of the 21st century, we have witnessed annual weather and climate records - globally and nationally. The frequency of extreme weather events increases every year. The World Meteorological Organization (WMO) marks the fifth warmest year since the beginning of the 21st century.

The climate in Bulgaria changed not only to warmer but also to drier at the end of the 20^{s} of our century. In the last decade, however, total rainfall has increased, but heavy rainfall is more damaging than irrigating. An example of this is the rainiest year for the entire period 1988-2016 - 2014 when the average annual amount of rainfall was 1013 mm for the areas up to 800 m above sea level, which is more than previously reached a maximum of 924 mm in 2005 (Marinova et al., 2017). The rainiest months are September and October. In 2014, were measured extreme amounts of rainfall in 24 hours between April and October. The largest value of 245 mm (Burgas region) ranks 2014 among the seven years in the 1988-2014 period with extreme daily rainfall above 220 mm.

The assessment of agrometeorological conditions in Bulgaria during the period 1986-2015 in Bulgaria based on 55 meteorological stations shows an average monthly air temperature increase in the months from January to September for all stations of 0.5º-1.5ºC. The biggest deviations are observed in January, July and August.

The significant increase of the yearly rainfall sums is observed in Northeastern part of the country - Razgrad, Shumen and Varna in about 10-18%. Insignificant decrease is detected in

part of stations in Central and Western Bulgaria (Georgieva et al., 2022).
The indicated trends of changes in temperature and humidity conditions are unfavorable for cultivating sunflowers, especially in Central South Bulgaria. Therefore, the present study aims to investigate the agro-climatic potential and the changing trends of the main agro-climatic indicators in this area and to indicate technological solutions to increase the profitability of sunflower cultivation.

MATERIALS AND METHODS

Study area

The study area covers Central South Bulgaria. According to the climatic division of Bulgaria, it falls into two climatic regions and sub-regions and 3 climatic regions (Table 1.). Most of the territory of the studied region falls into the transitional-continental climate subregion of the European-continental climate region and the regions south of Haskovo in the South Bulgarian climate subregion of the Continental-Mediterranean climate region (Sabev et al., 1959).

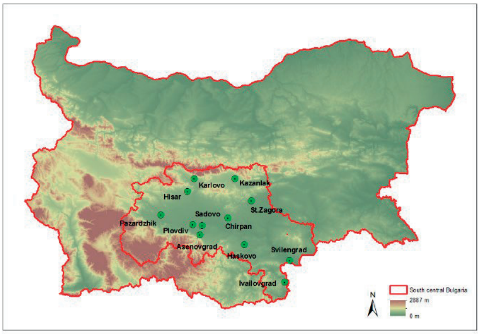

Figure 1. Location of the stations

The climatic region of Eastern Central Bulgaria is characterized by relatively mild winters. The average air temperature in January is around and above 0°C, with relatively frequent warming under the influence of Mediterranean cyclones. Rainfall in winter is between 100-150 mm. Due to the milder winter, spring starts early, and the temperature remains above 5°C at the end of February beginning of March. Summer in the area is hot. Rainfall conditions in the area are continental. In the Northern part of the region, summer rainfall exceeds winter rainfall by 10% of the annual amount. In the eastern and southern parts of the region, the seasonal amounts level off and even the maximum passes into autumn or spring.

Table 1. Distribution of the studied stations by climatic regions

Climatic region	Stations
1. Climatic region of Eastern Central Bulgaria	St. Zagora, Chirpan, Plovdiv, Sadovo, Asenovgrad, Pazardzhik, Hisar
2. Climatic region of the Eastern Sub-Balkan fields	Karlovo and Kazanlak
3. Climatic region of the Eastern Rhodope river valleys	Haskovo, Svilengrad, Ivaylovgrad

Winter in the climatic region of the Eastern Sub-Balkan Fields is mild, but due to the hollow character of the terrain, the absolute minimum temperatures reach lower values. The basin-like nature of the terrain also affects the frost regime. Summer is moderately warm. The seasonal distribution of rainfall has a continental character. Summer rainfall amounts are the largest, and winter rainfall amounts are the smallest. The difference reaches 10-15% of the annual amount. In the second half of summer, prolonged droughts often occur.
In the climate of the Eastern Rhodope river valleys, some of the largest rainfalls were reported from the lowland part of the country during the autumn-winter period. Winter in the area is mild. Everywhere in the region, the average January temperature is positive. The spring here is one of the warmest in the country. Summer is hot and dry, with the most rainfall in June. Then a long period with no rainfall begins, well expressed in late summer and early autumn. Autumn is warmer than spring. Due to the high-temperature sums that accumulate during the period with temperatures higher than 5 and 10°C, the region has some of the largest thermal resources in the country. The seasonal distribution of rainfall in the region with an autumn-winter maximum and a summer minimum.

Agrometeorological conditions for growing sunflowers in Bulgaria

The biological minimum of the culture is 5°C, but optimal conditions for germination are obtained at temperatures of 10-12°C. Young plants tolerate short-term colds up to - 5°C. The optimal temperature for culture development during critical phases is 20-25°C. Temperatures above 30°C already have a stagnant effect. The temperature sum for ripening the seeds under our conditions is 2500°C. The sunflower is relatively drought-resistant, as it satisfies its needs for moisture from the deeper soil layers. A critical period of moisture is the period from budding to flowering. From the inflorescence formation to the flowering phase, plants use about 45% of the water they need, and the maximum water consumption per day reaches 5-6 m^3/ha. From flowering to full maturity, plants use an average of 35% of all required water.

Data and methods

The study period is 1991-2020, and the reference period is 1961-1990. Daily temperature and rainfall data were used at 11 stations, Figure 1. To estimate the moisture conditions, we use the Balance of atmospheric humidity:

$$BAH = \frac{ETo}{\sum r}.,$$

ETo is the potential evapotranspiration calculated by the Penman-Monteith equation using CROPWAT8, $\sum r$ is the sum of rainfall.

In order to detect and estimate trends in the 30-year time series of the meteorological factors air temperature, rainfall totals, VPD totals, as well as of AI_{DM} and ETo, Mann-Kendall test was applied. Theoretically, the data values x_i of the 40-year time series were assumed to obey the model

$$x_i = f(t_i) + \varepsilon_i$$

where $f(t_i)$ is a continuous monotonic increasing (or decreasing) function of time, and the residuals ε_i can be assumed to be with zero mean, i.e. the variance of the distribution is constant in time.

By Mann-Kendall test we tested the null hypothesis of no trend, H_o, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. S-statistics and the normal approximation (Z statistics) were exploited.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k)$$

where x_j and x_k are the annual values in years j and k, $j>k$, respectively and:

$$sgn(x_j - x_k) = \begin{cases} 1 & if\ (x_j - x_{k)} > 0 \\ 0 & if\ (x_j - x_{k)} = 0 \\ -1 & if\ (x_j - x_{k)} < 0 \end{cases}$$

The variance of S was computed by the following equation which took into account that ties may be present:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right]$$

where t_p - number of data values in the p^{th} group; q - number of tied groups; n – number of the consequent data in the time series.

The presence of a statistically significant trend was evaluated using the Z value, which was calculated by using S and $VAR(S)$:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases}$$

The condition for upward trend is if Z>0 and vice versa. To test for either an upward or downward monotone trend (a two-tailed test) at a level of significance, H_0 was rejected if $|Z| > Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ was obtained from the standard normal cumulative distribution tables. The tested significance levels were α = 0.001, α = 0.01, α = 0.05 and α = 0.1.

RESULTS AND DISCUSSIONS

The average monthly air temperature during the studied period 1991-2020 is positive in all months (Figure 2). In the coldest month - January, the average monthly air temperatures exceed 2°C in the southernmost regions. Temperatures in central and western regions of the studied area - Pazardzhik, Sadovo and Kazanlak from the Sub-Balkan fields - are below 1°C. The lowest January temperature was recorded in Chirpan. In the warmest month of July, the average monthly values are equal to those in August (St. Zagora, Haskovo, Hisar and Ivaylovgrad), and in some stations, even August temperatures are higher than those in July (Asenovgrad, Karlovo and Chirpan).

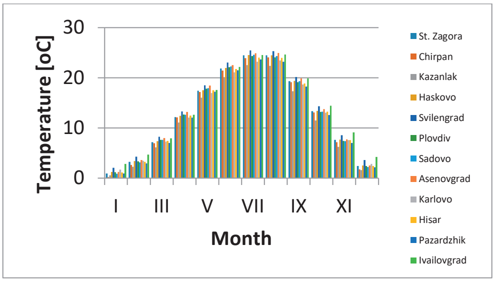

Figure 2. Average multi-annual monthly air temperatures during the period 1991-2020

The deviations of average monthly temperatures during the studied period compared to the reference (1961-1990) show an increase from January to November and a decrease in most stations in December, reaching 0.6°C (Figure 3). Exceptions are Asenovgrad and Ivaylovgrad stations. In January and February, the increase fluctuates between 0.2°C and 0.7°C, and in March, it exceeds 1°C in Svilengrad, Sadovo and Hisar. An increase of 1 or more than 1°C was also reported in May in Svilengrad and Hisar. The increase in average monthly air temperatures is greatest in July and August. In July, only in Karlovo and Ivaylovgrad it is less than 1°C. In August, the increase exceeded 2°C in almost all stations except Sadovo, Pazardzhik and Ivaylovgrad.

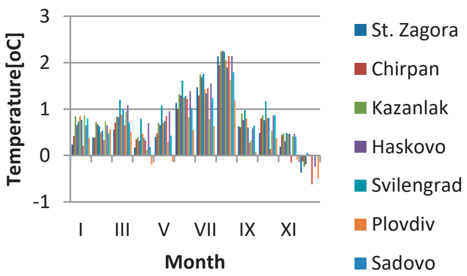

Figure 3. Deviation of the average monthly temperature for the period 1991-2020 compared to 1961-1990

The rainfall regime very clearly distinguishes the two climatic regions. Ivaylovgrad, Svilengrad and Haskovo stations have an autumn-winter maximum and a summer minimum, with the highest rainfall values in autumn and winter in Ivailovgrad. In the summer, the lowest rainfall amounts were recorded there - in July - 28.4 mm, and in August - 19.6 mm. In the remaining stations, the rainfall regime is summer, with maximum values exceeding 80 mm in Karlovo (Figure 4).

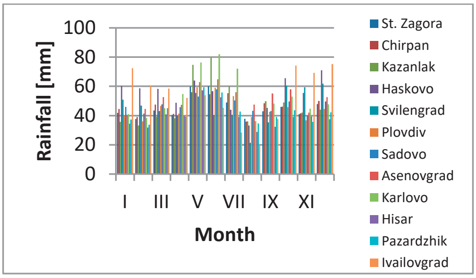

Figure 4. Average multi-annual monthly rainfall during the period 1991-2020

The most significant deviations of rainfall during the studied period compared to the reference period, exceeding 10%, were noted in February, March, September and October - an increase, and in April, June, August, November and December - a decrease. In July, a decrease was reported only at the Hisar station, and in Asenovgrad and Svilengrad, the rainfall increased significantly by 13 and 33%, respectively (Figure 5).

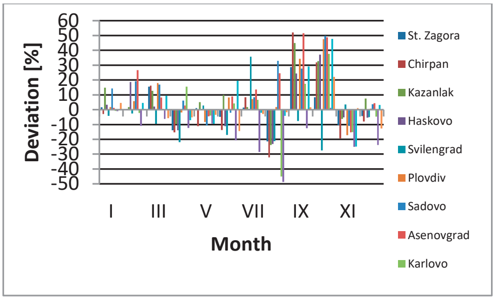

Figure 5. Deviations of monthly rainfall totals for 1991-2020 compared to the reference period 1961-1990

Temperature conditions for the growth and development of sunflowers in Central South Bulgaria

Under these weather conditions during the period 1991-2020, the permanent transition of the daily air temperature above 5°C in the Central South Bulgaria region is observed in the second decade of February, except for the Chirpan and Karlovo regions, where this happens later (Figure 6).

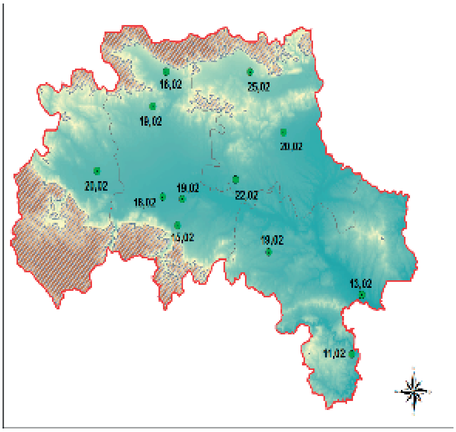

Figure 6. The average date of permanent transition of air temperature above 5°

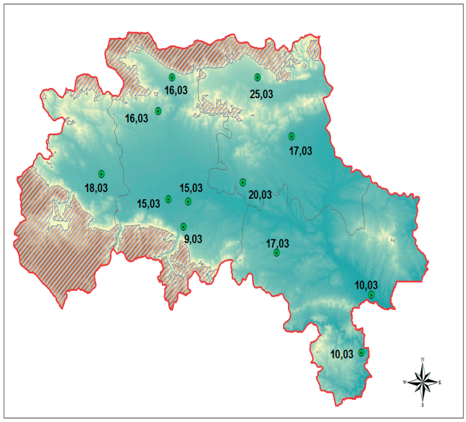

Figure 8. The average date of permanent transition of air temperature above 10° with a probability of 75%

The increase in average daily temperatures above 10°C with a probability of 50% takes place during the last ten days of March for most of the region and during the second for the southern parts (Figure 7). With a probability of 75% or once every 4 years, the date of the transition through 10ºC is observed in the southernmost regions at the end of the first decade of March, in the second decade in the rest, except for Kazanlak, where it happens on March 25 (Figure 8).

During the period with temperatures higher than 10°C in the central and southern regions of Central South Bulgaria, temperatures sum between 4200°C and 4430°C accumulate (Figure 9), while in the northern regions, they are close to 4000°C.

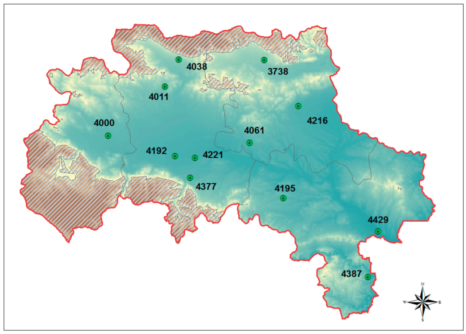

Figure 9. A sum of active temperatures during the period with temperatures higher than 10°C

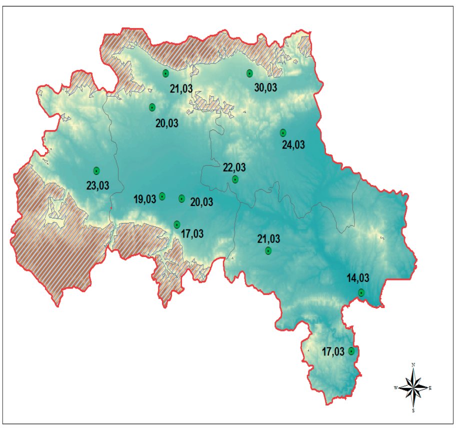

Figure 7. The average date of permanent transition of air temperature above 10ºC with a probability of 50%

Humidification conditions in Central South Bulgaria for sunflower cultivation

The amount of rainfall during the sunflower growing season - April-July exceeds 200 mm, except for the Svilengrad, Ivaylovgrad, Hisar and Pazardzhik stations (Figure 10). At the same time, potential evapotranspiration exceeds twice the amount of rainfall and reaches values of 480-600 mm/ºC (Figure 11). The amount of rainfall during the April-July sunflower growing season is between 33 and 53% of the amount of potential evapotranspiration. In the conditions of Central South Bulgaria, the growing season of the sunflower takes place in conditions of moisture deficiency. This ratio is unfavorable in Svilengrad, Ivaylovgrad and Pazardzhik 33-35%.

The study of the changing trends of the average multi-annual amount of rainfall for the studied stations during the period 1991-2020 shows that in most stations, there are no proven changing trends, except for the Plovdiv region, where all three stations show an increase in 90 and 95% confidence interval (Table 2).

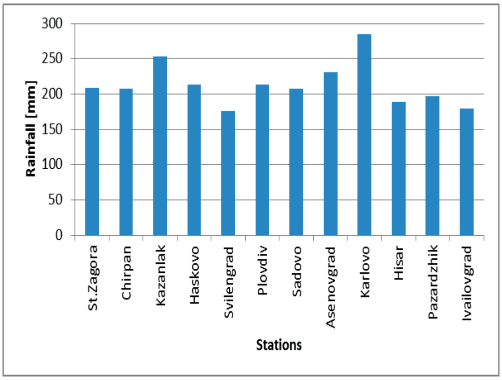

Figure 10. Average multi-annual amount of rainfall in [mm] April-July

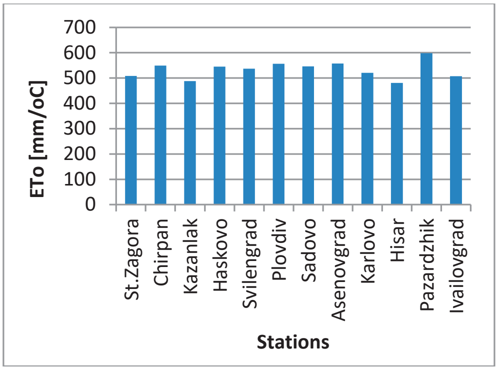

Figure 11. Average multi-annual sum of ETo [mm/°C] during April-July period

Table 2. Evaluation of the significance of the changing trend in rainfall [mm] VI-VII during the studied period. The tested significance levels were α = 0.001, α = 0.01, α = 0.05 and α = 0.1

Time series	First year	Last Year	n	Test S	Test Z	Signific.
St. Zagora	*1991*	*2020*	*30*		0.79	
Chirpan	*1991*	*2020*	*30*		0.09	
Kazanlak	*1991*	*2020*	*30*		0.82	
Haskovo	*1991*	*2020*	*30*		0.82	
Svilengrad	*1991*	*2020*	*30*		0.57	
Plovdiv	*1991*	*2020*	*30*		2.03	*
Sadovo	*1991*	*2020*	*30*		1.93	+
Asenovgrad	*1991*	*2020*	*30*		1.96	*
Karlovo	*1991*	*2020*	*30*		1.61	
Hisar	*1991*	*2020*	*30*		0.50	
Pazardzhik	*1991*	*2020*	*30*		1.07	
Ivailovgrad	*1991*	*2020*	*30*		1.43	

The same study at ETo shows an increase in the 90 and 95% confidence interval in Kazanlak and Chirpan and a significant increase in Ivaylovgrad in the 99.9% interval in Ivaylovgrad (Table 3).

Table 3. Evaluation of the significance of the trend of the change in the amount of ETo [mm/°C] VI-VII during the studied period

Time series	First year	Last Year	n	Test S	Test Z	Signific.
St. Zagora	*1991*	*2020*	*30*		0.20	
Chirpan	*1991*	*2020*	*30*		2.03	*
kazanlak	*1991*	*2020*	*30*		1.89	+
Haskovo	*1991*	*2020*	*30*		-0.25	
Svilengrad	*1991*	*2020*	*30*		-0.98	
Plovdiv	*1991*	*2020*	*30*		-1.03	
Sadovo	*1991*	*2020*	*30*		-0.82	
Asenovgrad	*1991*	*2020*	*30*		0.00	
Karlovo	*1991*	*2020*	*30*		-0.64	
Hisar	*1991*	*2020*	*30*		0.45	
Pazardzhik	*1991*	*2020*	*30*		-0.86	
Ivailovgrad	*1991*	*2020*	*30*		3.66	***

The critical period for the formation of the sunflower yield is the formation of an inflorescence - flowering. The amount of rainfall during this period did not exceed 100 mm, except for Karlovo and Asenovgrad (Figure 13). During the period of vegetation , potential evapotranspiration exceeds three times the rainfall and fluctuates between 280 and 350 mm/°C.

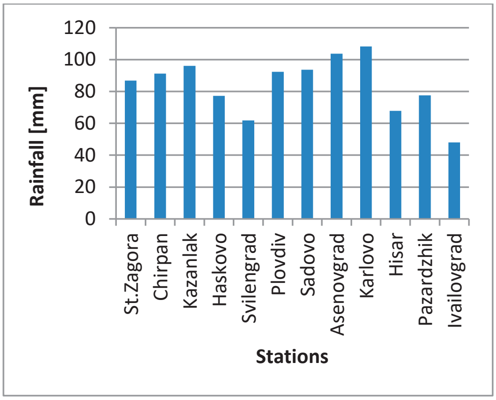

Figure 12. Average multi-annual rainfall totals [mm] in June-July

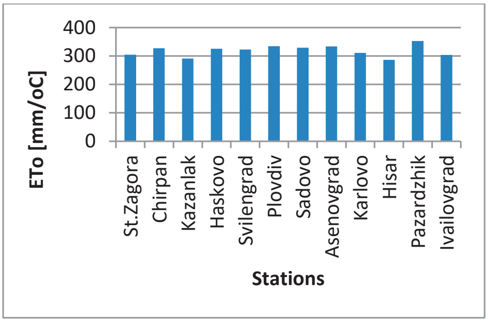

Figure 13. Average multi-annual sum of ETo [mm/°C] during the period June-July

During the period 1991-2020, the values of the Balance atmospheric moisture during the critical period June - July varied between 160 and 200 mm/°C in the northern parts of the region and 200-240 mm/°C in the rest (Figure 14).

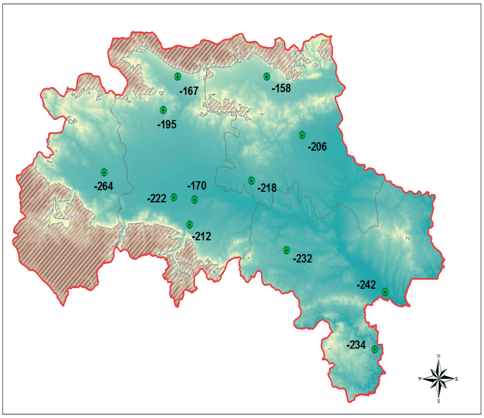

Figure 14. Sum of atmospheric moisture deficit [mm] for the months of June and July

Discussions

Central South Bulgaria region is defined as slightly favorable for growing sunflowers due to the climatic features of the region and, more specifically, the large deficit of atmospheric humidification in June and July (Soil-climatic zoning of the main field crops, 1969). The study of the agro-climatic conditions for growing sunflowers in Central South Bulgaria shows that during the last thirty-year period, there has been no statistically significant change in the amounts of rainfall and ETo during the growing season. There is no significant change in the two parameters during the critical period of inflorescence formation - flowering. The risk of drought at this time remains.

The possibilities for technological response are related to the earliest possible sowing. Because the biological minimum of the culture is 5°C, we have presented the average dates of air temperature increase above 5°C, which is in the second decade of February. Theoretically, this is the term that can be used to start sowing. In the regions with a winter maximum of rainfall, even though they have higher temperatures, this is difficult to implement due to the impossibility of preparing the areas and carrying out the sowing. When sowing at the end of February, due to the still low temperatures, germination occurs more slowly, and some of them lose their germination (Stoyanova at all., 1977). If early sowing is applied, the seeding rate should be increased. The recommended sowing dates for the region are March 25-30, but if possible, sowing can be done after the permanent retention of temperatures above 10°C. During the analysis of temperature conditions, it was found that the earliest dates with temperatures above 10°C, with a probability of once in four years, are in the southernmost regions at the end of the first decade of March, in the second decade in the rest, except for Kazanlak, where this happens on 25.03. The average dates of the increase in average daily temperatures above 10°C are in the last decade of March for most of the region and in the second decade for the southern parts. Such conditions suggest withdrawing the sowing dates as early as possible. As an alternative to increasingly severe droughts in the critical periods of crop development, the zoning of varieties with a shorter vegetation period can be recommended, which, combined with the earliest possible sowing date, will result in more guaranteed crop yields. Otherwise, the trend of droughts resulting in a large deficit of atmospheric moisture in the period of flowering-fruiting will make growing the crop riskier, and years with zero yields will be more and more common.

CONCLUSIONS

The assessment of agrometeorlogcal conditions shows that the average date of the permanent transition in 5°C and 10°C are, respectively, in the second decade of February and the last decade of March for the greater part of the region and in the second for the southern parts. The rainfall totals during the sunflower vegetation period April-July is between 33 and 53% of the amount of potential evapotranspiration, and for the critical period June-July between 16 and 35%.

There are no statistical differences in the trends of changes in rainfall amounts and potential evapotranspiration for both periods - April-July and June-July. An exception is increased rainfall in the three stations near Plovdiv and the potential evapotranspiration in Ivaylovgrad, Chirpan and Kazanlak.

Although in the northern points of the study area (Karlovo, Kazanlak), the conditions for growing sunflowers are similar to the average value for a long period. For the rest, it can be concluded that the sowing of the crop should be done as early as possible depending on the conditions in the particular year (the first or second decade of March), and it should be combined with the cultivation of varieties with -short vegetation, in which the flowering-fruiting phases are earlier when the atmospheric moisture deficit is the smallest.

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