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ADAPTATION OF SPRING FIELD CROP TECHNOLOGY TO CHANGING CLIMATE CONDITIONS

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Abstract

Trends of changing climatic conditions in recent years have created serious challenges for the cultivation of the region`s traditional spring crops. Analysis of agro-climatic conditions shows a shift towards prolonged rainless periods combined with extremely high temperatures leading to heat and water stress. This worsens the hydrothermal conditions during the vegetative and generative stages. The succession of warm winters and the resulting unhardened plants are stressed, and the significant temperature amplitudes after the resumption of vegetation further deteriorate the phytopathological environment. Conditions of permanent soil and atmospheric drought are observed during all phenological phases. All this creates unfavourable conditions for the development of spring crops. They are particularly dangerous at the generative stage of plant development, which, combined with water deficit conditions, results in the impossibility of growing high-yielding mid- to late-season hybrids under non-flooded conditions. The analysis of conditions in recent years shows that optimisation and balance of the standard technological regimes of crop cultivation should be sought on the one hand and a differentiated approach applied to the different soil types, rainfall and temperature zones on the other.

Key words*: climate change, agrometeorological conditions, spring crops, abiotic stress, drought.*

INTRODUCTION

Agriculture is among the most vulnerable sectors of the economy to climate change. In recent years, fluctuations in agrometeorological conditions have posed challenges for Bulgarian farmers, necessitating adjustments in agronomic practices. The increasing trend in air temperatures, changes in precipitation distribution, and the heightened frequency and intensity of extreme weather events - such as floods, droughts, and thermal and hydric stress - have led to variability and reductions in yields of major agricultural crops.

The Plovdiv region is one of the most favorable areas for agriculture in Bulgaria, with a long-standing tradition of cultivating cereal crops, which occupy up to 50% of the arable land in the region (Agrostatistics, No. 418 - November 2022). Over the past three decades, there has been a deterioration in climatic conditions, consistent with the overall trend of rising air temperatures and seasonal shifts in precipitation distribution, albeit without a clear pattern for Bulgaria (WMO, 2021, 2022). The country's mean annual temperature increased by 0.8°C during the period 1991-2020 compared to 1961-1990 (Marinova, 2023). Positive annual and seasonal anomalies are most pronounced in Northern Bulgaria. Although the total annual precipitation amount has not changed significantly in the period 1991–2020 relative to the previous period, substantial reductions (up to 30%) have been observed in mountainous areas, whereas in Northeastern Bulgaria, local increases of up to 40% have been recorded. The same study (Marinova, 2023) identifies shifts in precipitation patterns post-1990, with an increasing contribution of heavy rainfall events (≥30 mm/24 h) to total annual precipitation, while the contribution of light (≤5 mm/24 h) and moderate (5–15 mm/24 h) rainfall events has declined, following the general regional trend (Alpert et al., 2002).

In a separate study, Malcheva and Bocheva (2023) demonstrated that during the period 1991-2020, significant changes occurred in the distribution of the main climate subtypes according to the Köppen classification. The transition from colder to warmer and/or drier climatic conditions has affected approximately 36% of Bulgaria's territory.

As a result, agrometeorological conditions have also undergone transformations. Between 1986 and 2015, an extension of the potential growing season but a shortening of the actual growing season has been observed, along with an increase in potential evapotranspiration, a decline in precipitation totals over certain periods (particularly in Southern Bulgaria), a decrease in soil moisture reserves, and an increase in soil water deficit during the growing season (Georgieva et al., 2022).

Given the pressure of climatic factors on the economic viability of agricultural production and food security, the global scientific community has been developing strategies and measures to facilitate the adaptation of agriculture to the changing environmental conditions (Olesen et al., 2011; Grigorieva et al., 2023). These measures are formulated at national, regional, and local levels based on risk and vulnerability assessments for specific regions.

Advancements in agricultural technologies in recent years offer opportunities for transforming agri-food systems towards climate-resilient and environmentally sustainable practices.

With the objective of selecting suitable adaptation measures for agriculture under changing environmental conditions, the present study aims to assess the agroclimatic resources of the Plovdiv region for the cultivation of spring crops.

MATERIALS AND METHODS

Study area

The studied area is part of Central Southern Bulgaria. It falls within the climatic region of Central Eastern Bulgaria, classified under the transitional-continental climatic subregion and the European-continental climatic zone (Sabev et al., 1959).

The climatic region of Central Eastern Bulgaria is characterized by relatively mild winters. The mean annual temperatures in the area range between 12-13°C, and precipitation is relatively evenly distributed throughout the year, with the majority occurring in spring and autumn. These conditions are particularly favorable for the cultivation of wheat and barley, which are among the primary cereal crops in the region.

Winter temperatures in Plovdiv are moderate, with a low risk of prolonged frost and freezing events. The average winter temperatures range from -1 to 5°C, which is suitable for winter wheat and barley varieties that are tolerant to lower temperatures. Summer temperatures frequently reach 35-40°C, creating favorable conditions for the growth of spring cereal crops such as maize. The accumulation of heat during the grain ripening period is crucial for the formation of dry matter in the kernels.

The average annual precipitation is approximately 500-600 mm, which is a moderate amount but often insufficient for certain crops without irrigation. Due to the relatively mild winter, spring arrives early, with temperatures consistently exceeding 5°C by late February to early March.

Data

The study utilizes data on key meteorological variables, including air temperature (minimum, maximum, and daily mean [°C]), daily precipitation sum [mm], relative air humidity [%], wind speed [m/s], and wind duration [h]. The study period covers 1991–2020, with data sourced from two stations: the Plovdiv synoptic station and the Sadovo climate station, both part of the meteorological network of the National Institute of Meteorology and Hydrology (NIMH).

Indices

Key agrometeorological indices were analyzed, including:

- Dates of permanent air temperature transitions through 5°C (early) and 10°C (mid-early);
- Potential vegetation season duration;
- Accumulated active temperature sums;
- Rainfall sums during main periods – IV-X; X-III; IV-VI; VII-VIII;
- Potential evapotranspiration (ETp) during the periods – year, IV-X; IV-VI; VII-VIII ;
- Temperature stress was assessed by consecutive days with air temperature above 28ºC and 35ºC;
- Water stress was assessed by consecutive days without rain >1 mm.

Data on the minimum and maximum temperature, relative air humidity, wind speed, and duration of solar radiation were used to calculate the values of potential evapotranspiration (PET) using the Penman–Monteith equation.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{C_n}{(T+273.16)}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)} \quad (1)$$

where ET_o is the reference crop evapotranspiration for short (ETos) or tall (ETrs) reference crops ($mm \cdot d^{-1}$ for daily time step or $mm \cdot h^{-1}$ for hourly time step), R_n is the net radiation at the crop surface ($MJ \cdot m^{-2} \cdot d^{-1}$ for daily time step or $MJ \cdot m^{-2} \cdot h^{-1}$ for hourly time step), u_2 is the mean daily or hourly wind speed at 2 m height ($m \cdot s^{-1}$), T is the mean daily or hourly air temperature at 2 m height (°C), G is the soil heat flux density at the soil surface ($MJ \cdot m^{-2} \cdot d^{-1}$ for daily time step or $MJ \cdot m^{-2} \cdot h^{-1}$ for hourly time step), e_s is the daily or hourly saturation vapor pressure (kPa), e_a is the daily or hourly mean actual vapor pressure (kPa), Δ is the slope of the saturation vapor pressure-temperature curve ($kPa \cdot °C^{-1}$), γ is the psychrometric constant ($kPa \cdot °C^{-1}$), C_n and C_d are constants, which vary according to the time step, the reference crop type (bulk surface resistance, and aerodynamic roughness of the surface) and daytime/nighttime ratio.

The annual sums of precipitation and potential evapotranspiration were calculated. By their ratio, we calculated the values of the aridity index (AI) (2) and Balance atmospheric humidification (BAH) [mm] (3).

$$AI = \sum r / \sum PET \quad (2)$$

$$BAH = \sum r - \sum PET \quad (3)$$

All data, used in the study are from the meteorological and agrometeorological archive of the National Institute of Meteorology and hydrology (NIMH).

RESULTS AND DISCUSSIONS

The long-term mean monthly air temperatures in the Plovdiv region, based on data from two stations—the Plovdiv synoptic station and the Sadovo climate station—are consistently positive (Figure 1).

During the winter months (December, January, and February), temperatures range between 0.9°C (January, Sadovo) and 3.3°C (March, Plovdiv). In Sadovo, temperatures tend to be lower than in Plovdiv from November through February, with differences varying from 0.1°C (November) to -0.3°C (January).

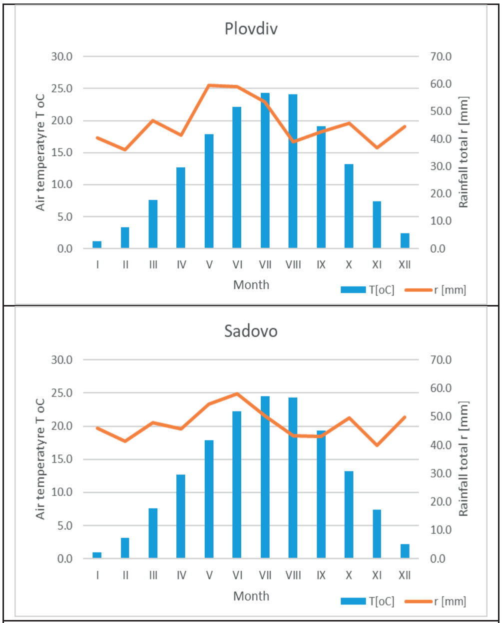

Figure 1. Long-term mean monthly air temperatures and total precipitation sums for the period 1991-2020

During the spring months, the average monthly air temperatures range from 7.6°C in March to 17.9°C in May. The temperatures in March and April are similar across both stations, while in May, Sadovo is 0.1°C warmer than Plovdiv.

In the summer months (June, July, and August), temperatures fluctuate between 22.1°C in June and 24.4°C in July (Plovdiv) and August (Sadovo). During this period, Sadovo is slightly warmer, with differences of 0.1°C in June and 0.3°C in August.

During autumn (September, October, and November), air temperatures vary between 19.1°C in September and 7.4°C in November. In the first two months of autumn, Sadovo recorded higher temperatures than Plovdiv by 0.2°C and 0.1°C, respectively.

The mean annual air temperature in the period 1991-2020 increased by approximately 0.9°C compared to 1961-1990, aligning with global warming trends. Compared to the reference period (1961-1990), long-term monthly mean air temperatures have increased at both stations, except in December (Figure 2). The most significant positive deviations were recorded during the summer months. In August, temperatures increased by 2.1°C in Plovdiv and 1.9°C in Sadovo, while in June and July, the rise was 1.3°C at both stations.

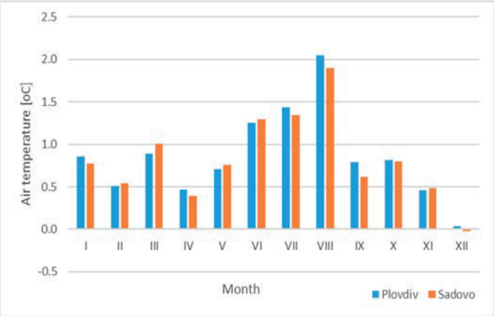

Figure 2. Deviations of average multiannual monthly air temperature values during 1991-2020 period compare with 1961-1990

For the remaining months, positive temperature anomalies ranged between 0.5°C and 1.0°C, with significant increases observed in January, March, September, and October.

During the summer, temperatures frequently exceed 35°C, posing a risk to cereal crop cultivation, particularly during critical growth stages such as flowering and grain filling.

The observed temperature increase in the study area is consistent with the global warming trend (FAO, 2001; Shirley et al., 2001) and the regional warming pattern in the Eastern Mediterranean, where a general warming trend has been evident since the 1980s, primarily driven by rising summer temperatures.

Under these thermal conditions, agrometeorological indicators such as transition dates through 5°C and 10°C, the duration of the potential growing season, and cumulative temperature sums suggest favorable conditions for cereal crop cultivation (Table 1).

The spring transition through 5°C occurs relatively early, in the second half of February, while the autumn decline below 5°C is recorded in late November. This results in a prolonged period with air temperatures above 5°C - 285 days - during which accumulated temperature sums range between 4286°C and 4213°C.

The spring transition through 10°C occurs in the last third of March, while the autumn decrease below 10°C happens in mid-November. This defines a relatively long potential growing season of 238 days, with accumulated temperature sums ranging between 3971°C and 4009°C.

Table 1. Mean multiannual dates of permanent transition of air temperature above and below 5 and 10°C during spring and autumn

Stations	T > 5°C	T < 5°C	Duration/ days/
Plovdiv	18.II	29.XI	285
Sadovo	18.II	30.XI	285
	T > 10°C	T < 10°C	
Plovdiv	19.III	12.XI	238
Sadovo	20.III	13.XI	238

Despite the increased potential vegetation period, the established trends of rising air temperatures, especially during the summer months in the Plovdiv region, and the significant decrease in summer precipitation deteriorate the agrometeorological conditions in the area. Critical risks for the region include extremely low soil moisture reserves and low atmospheric humidity. These factors create conditions for heat stress, particularly for spring crops. The reduction or absence of rainfall during the summer months, combined with extreme high temperatures, hampers pollination in crops with a spring sowing period, such as maize and sunflower, and subsequently affects grain filling.

The high values of accumulated temperature sums during the potential vegetation season indicate that the thermal resources of the region are suitable for cultivating heat-loving crops. Due to the increasing trend of heat waves in recent years (Bocheva et al., 2024) and the fact that these sums do not account for temperatures exceeding the upper optimum threshold for plant growth and development, the values of air temperatures above the optimum have been calculated using the Heat Stress Unit (HSU) for both locations - Plovdiv and Sadovo. The upper limit of the optimum was set at T>28°C and T>35°C (Figure 3, 4). The average sum of maximum air temperature values exceeding 28°C is 350°C in Plovdiv and 370°C in Sadovo, while in the years 2000, 2007, 2012, and 2017, temperatures above 35°C reached 60-80°C. These results indicate that agricultural crops in the studied area are exposed to heat stress.

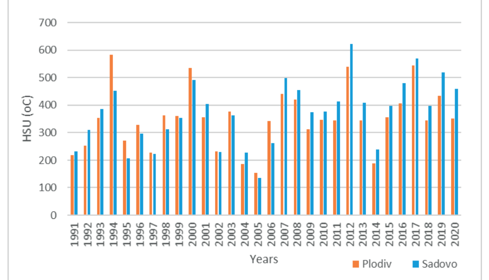

Figure 3. HSU >28°C during 1991-2020

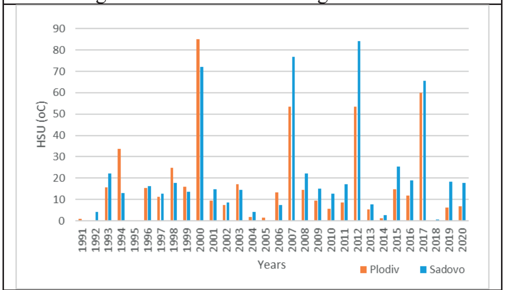

Figure 4. HSU >35°C during 1991-2020

The moisture conditions are directly related to the amount of precipitation in the region. The annual sum is 590 mm in Plovdiv and 618 mm in Sadovo. The annual precipitation distribution has a continental character, with a maximum in April-May, as shown in Figure 1. The distribution of precipitation during the vegetation period of the main crop types and outside the vegetation period is shown in Figure 5.

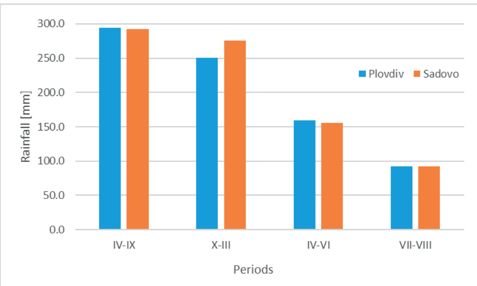

Figure 5. Distribution of multiannual rainfall totals during the periods

During the actual vegetation period from April to October, the average multi-year total precipitation in the Plovdiv region is 340 mm. There are no significant differences in precipitation totals between the two analyzed stations across the periods. An exception is observed during the autumn-winter moisture accumulation period when the total precipitation in Sadovo exceeds that in Plovdiv by 28 mm. It varies between 250 and 275 mm, ensuring good soil moisture availability at the start of the spring vegetation season.

During the spring vegetation period of winter cereal crops (April-June), the multi-year precipitation totals are 160 mm in Plovdiv and 158 mm in Sadovo, close to 150 mm, which is sufficient for achieving good yields of winter cereals.

In July-August, during the generative phase of maize development, the average multi-year precipitation total is around 100 mm-94 mm in Sadovo and 90 mm in Plovdiv. Probability assessments indicate that in a moderately dry year (i.e., once every four years), the precipitation total is 35-40 mm, which is insufficient to compensate for water loss from soil and plants due to evapotranspiration.

The comparison of precipitation totals during the vegetation and non-vegetation periods across the two periods 1961-1990 and the reference period 1991-2020 shows no significant change, except for the total in Plovdiv during the entire vegetation period, which has increased by 40 mm in the current period.

Given the established trends of increasing heavy, potentially hazardous precipitation events (≥ 30 mm/24 h) contributing to the total annual precipitation (Marinova et al., 2023), precipitation totals alone are not sufficient to characterize moisture conditions. Therefore, for both locations, the duration of dry periods from June to October was determined over a twenty-year period. A total of 52 and 54 cases were recorded in Plovdiv and Sadovo, respectively, with an average duration of 27 days (Figure 9). At the Plovdiv station, the maximum duration of this period reached 79 days, while in Sadovo, it was 69 days. A dry period of 22 days occurs with a probability of once every two years at both stations.

The annual total of potential evapotranspiration (ETp) and the totals for different periods are presented in Table 2. The annual total in the Plovdiv region is close to 1000 mm. During the vegetation period (April-October), it varies between 826 and 861 mm. Water consumption during the spring vegetation period is close to 50 mm, while in July-August, it ranges between 317 and 329 mm.

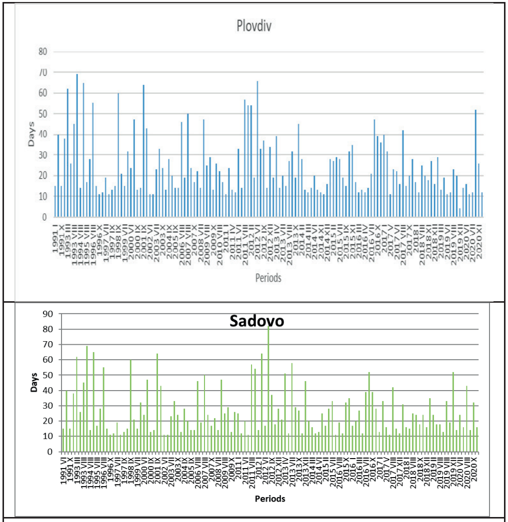

Figure 6. Number of consecutive days wyth rainfall <1 mm

The totals for these periods have increased in both stations compared to the previous period (1961–1990), as shown in Figure 7. The annual total in Sadovo has increased significantly by 160 mm, while in Plovdiv, the increase is 53 mm. All three subperiods also show an upward trend. For the entire vegetation period, the increase in Sadovo is again significant, reaching 125 mm, whereas in Plovdiv, it is 40 mm.

To assess water availability in the Plovdiv region, the atmospheric moisture deficit index and the drought index have been used.

The absolute values of the water deficit (Table 2) indicate that throughout the entire vegetation period, ETp exceeds precipitation by 483 mm in Sadovo and 520 mm in Plovdiv. By subperiods, the deficit is 201 mm and 211 mm for April-June, and 223 mm and 237 mm for July-August, respectively.

Table 2. Balance of atmospheric humidification and Aridity index

Station	Balance of atmospheric humidification, mm		
	IV-X	IV-VI	VII-VIII
Plovdiv	-520	-211	-237
Sadovo	-483	-201	-223
	Aridity index		
Plovdiv	0.4	0.4	0.3
Sadovo	0.4	0.4	0.3

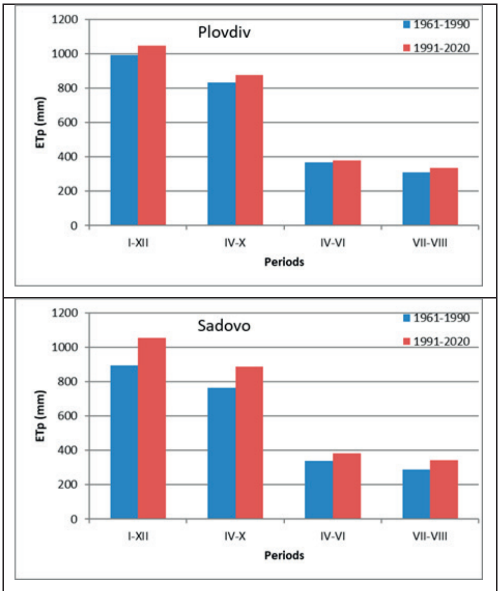

Figure 7. ETp sums during different periods for 1961-1990 г. and 1991-2020 г

A drought index value below 0.5 is considered to classify a region as dry. During both subperiods of the vegetation period, the Plovdiv region is classified as dry (Table 2). In April-June, precipitation compensates for only one-fourth of the losses (ETp), while in July-August, it covers just one-third.

The analysis of agro-meteorological conditions in the Plovdiv region indicates that the generative stage of spring crops occurs under heat and water stress. However, the overall conditions in Central Southern Bulgaria are still considered potentially suitable for growing spring crops. The observed trends of rising temperatures, decreasing precipitation, and the fact that ETp exceeds precipitation at both studied locations (Plovdiv and Sadovo), combined with the early onset of temperatures meeting the biological requirements of spring crops, suggest that sowing dates should be moved as early as possible potentially by 10-15 days, depending on the specific year.

Although some maize hybrids from the new Bulgarian selection in the FAO 500 group exhibit a generative stage around June 20, we recommend earlier FAO hybrids as more suitable for the region. Early spring sowing of sunflower would also ensure development during a more moisture-secured period with lower temperatures, reducing heat stress in the hottest summer months. However, late spring frosts significantly limit these possibilities in some years. The average date of the last spring frost in Plovdiv is April 1. With a probability of once every 10 years, frost can occur on April 22 in Plovdiv and April 23 in Sadovo. The latest recorded frost dates are May 8 in Plovdiv and May 9 in Sadovo. This indicates that early sowing is not always feasible.

These trends in agro-meteorological changes over recent years highlight the relative unsuitability of growing spring crops under rainfed conditions.

CONCLUSIONS

The analysis of agro-meteorological conditions and their changes compared to the previous period shows rising temperatures and worsening moisture conditions.

The increase in temperatures and the earlier stable transition through biological thresholds for different crop types in spring allow for earlier sowing, utilizing the soil moisture reserves available in spring.

The unfavorable temperature regime, combined with prolonged droughts typical for the region, creates adverse conditions for spring crop development, especially during the generative stage. Heat and water stress make it practically impossible to grow high-yielding mid-late and late hybrids under rainfed conditions.

The primary risk factor in the Plovdiv region is summer droughts, which shorten the actual vegetation period, especially for rainfed spring crops.

Successful adaptation to changing agro-climatic conditions requires a comprehensive approach, including the implementation of new technologies and a differentiated approach based on soil types, precipitation, and temperature zones.

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