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DEVELOPMENT AND PREDICTION OF SELECTED TEMPERATURE AND PRECIPITATION CHARACTERISTICS IN SOUTHERN MORAVIA

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Abstract

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In recent years, rising temperatures and changes in precipitation patterns have a significant impact on agriculture. This paper presents analyses of selected climatic characteristics of the South Moravian region. The evaluation was based on the data from the Czech Hydrometeorological Institute. Climatic data for future periods were gained using the A1B emission scenario. With regard to the agricultural activity of this region, climatic characteristics (average air temperature, heat waves, average precipitation and periods without precipitation) were selected and compared in the following three periods 1961–1990, 2021–2050 and 2071–2100. The results showed an increase of the average air temperature, increase in the number of tropical days and days in heat waves. It was also found that as a result of rising air temperatures and different distribution of precipitation, the period of drought will significantly prolong in the future. Very unfavourable climate situation is expected in the particular period of 2071–2100 in this region. Increasing drought, predicted by climate models, presents major problem for the agriculture of South Moravia. It is necessary to adapt to these anticipated changes not only in the agricultural activities but also in the landscape management in general.

Keywords: emission scenario, agriculture, precipitation, temperature, drought, South Moravia

INTRODUCTION

The issue of climate change fully touches the whole country and hence the agriculture. Therefore, it is necessary to study the dynamics of the current climate and climate predicted by climate models and to focus on the adaptation measures. Climate models are based on scenarios of greenhouse gas emissions development. The Intergovernmental Panel on Climate Change (IPCC) established four main groups of emission scenarios concerning the future development until the end of the 21st century. A1 scenario describes a world of very rapid economic growth and development of new technologies. The population grows until 2050. This scenario is divided into three subgroups according to the predominant energy source (A1F1 – fossil fuels, A1T – without fossil fuels and A1B – balance in the use of all fuels). In the A2 scenario, the population grows until 2100. All measures are taken at the regional level. The economy is growing more slowly compared to the A1 scenario. Scenario B1 describes a worldwide collaboration, rapid development of information, services and new technologies and moderately rapid economic growth. The population grows until 2050 and subsequently decreases. Scenario B2 – the future with a focus on regional solutions and sustainable development. Population growth is lower than in A2 and economic progress slower than in A1 and B1. The response of the climate system to a certain volume of emissions is then calculated using a climate model. Use of numerical and mathematical procedures enables incorporation of physical, chemical and biological properties of the climate system into the model

(Carter *et al.*, 1994). The climate cannot be predicted with certainty because it depends on factors that we cannot be aware of in advance. Scenarios describe predictable climate conditions likely to occur in given circumstances (UNEP, 2008).

In recent years, rising temperatures and changes in rainfall have a significant impact on the agriculture. The occurrence of droughts is one of the adverse effects of climate extremes and often corresponds with the period of lack of rain and hot weather. Pongrácz *et al.* (2006) analyzed a sample of agricultural temperature and precipitation indices and changes in the second half of the 20th century. The results showed that regional intensity and frequency of extreme precipitation has increased, while the total precipitation has decreased and the climate became drier. Although the lack of rain is the leading cause of droughts, rapidly rising temperature increases the severity of these dry episodes due to loss of water in the process of evapotranspiration (Dai, 2011).

The Czech Republic (CR) will also see higher air temperatures associated with increased evaporation and greater fluctuations in precipitation which is likely to bring more frequent problems with lack of moisture. Due to the topography of CR, the major part of the area depends on saturation of the soil profile only by rainfall. The typical characteristic of precipitation in CZ is a large local and temporal variability depending on altitude and exposure. Lack of soil moisture is anticipated in the main growing season (approximately 200 days) when rainfall does not exceed 340 mm. This figure results from consumptive water usage of the main crops defined by the transpiration coefficient. The impact of drought on yield depends on the timing, duration of stress and other factors (Středová *et al.*, 2011). The occurrence of drought is a crucial parameter of wind erosion risk. The comparison of potential and actual erodibility of soil by wind was analyzed by Dufková (2007).

Study of variability development of temperature and precipitation anomalies during the 20th century allows assessment of their impact on the frequency and magnitude of droughts in lowland areas of CR. To describe drought combined with the lack of precipitation and warmer conditions in the context of global climate change, Breshears *et al.* (2005) and Adams *et al.* (2009) introduced a new term “global-change-type drought”.

Definition of drought by precipitation was reported by Cablík (1951) who considers annual rainfall of 550 mm to be the rough boundary of drought. Lack of soil moisture will become evident in vegetation period (VP) if rainfall does not exceed 340 mm and if it does not reach 50 mm in the individual months. Climatography relates drought to a part of the year when almost regularly very little precipitation or rainfall occurs. After this period, the rainy season usually starts. Climatological literature often defines this dry period as precipitationless (usually 5 consecutive days when there was no or very low precipitation measured at a station (0.0 mm, rarely up to 1 mm) as shown by Nosek (1972). From this perspective, it is necessary to pay close attention to the variability of precipitation and its trends.

The heat waves have become an increasingly frequent extreme temperature phenomenon in the Central Europe. Heat wave is defined as variable-length episode of extremely hot weather. Meteorological Dictionary (Sobíšek *et al.*, 1993) defines the heat wave as a multi-day summer heat during which the maximum daily air temperature reaches 30 °C and more. The occurrence of heat waves in CZ was analyzed in the Southern Moravia by Kyselý and Kalvová (1998).

This paper analyzes the precipitation and temperature conditions in selected areas of Southern Moravia and evaluates anticipated changes in moisture conditions in particular with regard to agricultural activity.

MATERIALS AND METHODS

Area of interest:

Land register of Žabčice village is located in Southern Moravia at a distance less than 25 km south from Brno and its area is 817 ha. There is a University agricultural enterprise (UAE) of Mendel University in Brno located in this area.

The territory of this land is flat and the altitude ranges from 180–185 m a.s.l. The soils are of different compositions, ranging from sandy soils being the most frequent type to clayey soils. The most frequent are genetic soil types of chernozem, slightly podzolic turf soil and alluvial gley soil. The area falls within the catchment of Svratka. While the agricultural production in this area plays a major role, its climate is not particularly favourable to agricultural production. The territory is located in the South Moravian region with typical dry continental climate. Dryness of the climate is increased by winds that cause large evaporation of soil moisture. The area is also influenced by rain shadow. Precipitation in the VP is distributed very unevenly. According to The Agro-climatic conditions of Czechoslovakia (Kurpelová *et al.*, 1975) Žabčice belongs to the agro-climatic makroregions of warm, mostly warm, mostly dry and sub-district of relatively mild winters. According to Quitt’s climatic classification type Cfb, according to Koppen (CFB – climate type of temperate deciduous forests) Žabčice falls into the warm area (units T4) which is characterized by very long, very hot and very dry summers, warm and very short transitional period, short, moderately warm and dry winter with very short duration of snow cover (Quitt, 1971).

Database used:

For the purposes of the analysis of climatic conditions, data from a series of technical climatic elements was used. These were based on measured data from a station network of the Czech

Hydrometeorological Institute (CHMI). Scenario data was gained by integration of a regional climate model ALADIN-Climate/CZ. Using the regional climate model, weather conditions were simulated for Central Europe with a resolution of 10 km. The simulation was carried out for two 30-year periods (2021–2050 and 2071–2100) using the emission scenario A1B according to IPPC (Štěpánek *et al.*, 2011; Štěpánek *et al.*, 2013).

Two points lying closest to the cadastral territory of interest were chosen for the evaluation of selected climatic characteristics. Since Žabčice lies between two selected points where the altitude is comparable, the climatic data for the area were calculated as an average of these two points.

Evaluated characteristics:

Based on the "screenplay" data for a grid network of the CZ created by the CHMI Institute, characteristics of temperature and precipitation for the period 2021–2050 and 2071–2100 were evaluated. These two future periods were compared with a previous norm of 1961–1990. The following selected climatic characteristics were evaluated:

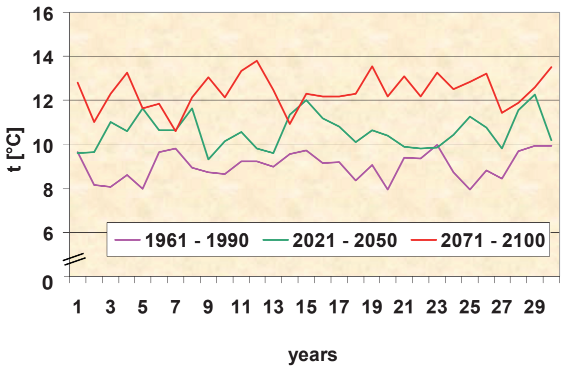
- average air temperature in each period (monthly, yearly),
- occurrence of heat waves: multiple (at least three days long) summer heat with maximum daily temperature of 30 °C and more,
- average precipitation (annual, monthly, for VP – from April 1 to October 30),
- number of precipitationless periods in VP and during the year: at least five consecutive days, when there was no or low precipitation measured.

RESULTS

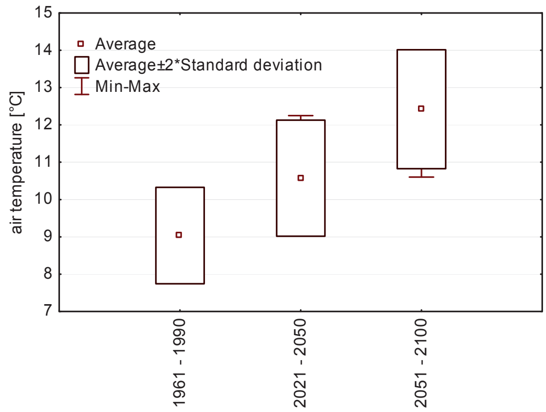
Air temperature

Fig. 1 and 2 present a comparison of the average annual air temperatures of three ranked thirty-year periods in Žabčice. The normal period of 1961–1990 shows an average temperature of 9 °C. The model calculated and predicted a temperature increase to an average air temperature of 10.6 °C for the future normal period of 2021–2050, and even a greater increase for the second future period of 2071–2100 showing 12.4 °C. The average temperature during the VP shows 15 °C in 1961–1990, and should increase to 16.1 °C in the first future period and to 18.0 °C in the second future period.

The comparison of results of the "screenplay" temperatures with the normal period of 1961–1990 shows that the period of 2021–2050 will see an increase in temperature by 1.5 °C in average and the period 2071–2100 will be warmer by 3.4 °C. The maximum deviation from the past norm is 3.7 °C over the period of 2021–2050 and 4.9 °C in the period of 2071–2100.



1: *Comparison of the average annual air temperature in °C in three periods (1961–1990, 2021–2050, 2071–2100)*



2: *Boxplot of average annual air temperature in °C in three periods (1961–1990, 2021–2050, 2071–2100)*

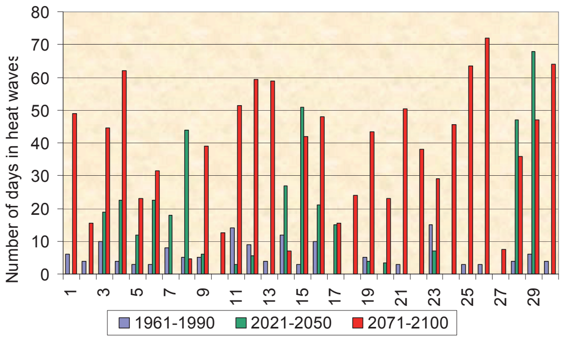
Heat waves

The total number of days in heat waves occurring in the period of 1961–1990 is 143, heat waves occurred mainly from June to August and sporadically in May and September. The total number of heat waves during the period of 1961–1990 is 39. In the first future reporting period of 2021–2050 there should be a total of 396 days in heat waves, the total number of heat waves being 72, while the maximum number of waves per year is 11. The absolutely longest heat wave should last 25 days (Fig. 3).

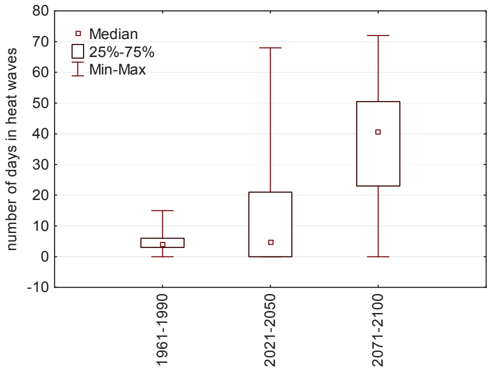
In the period of 2071–2100 there should be 1108 days in heat waves. The total number of heat waves should be 132 and the maximum number of waves per year is expected to be eight. The absolutely longest heat wave should last 54 days (Fig. 5).

Precipitation

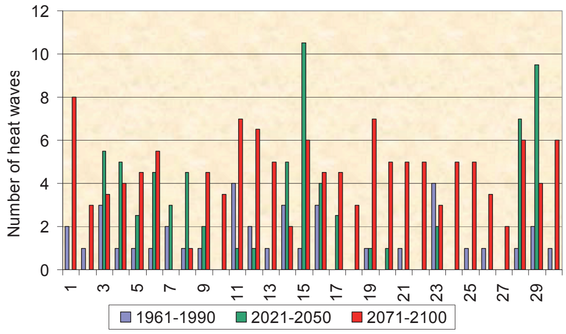
The average annual rainfall for the period of 1961–1990 is 484.8 mm, the VP being 313.0 mm. The maximum annual total was reached in 1985 (630 mm) and a minimum in 1983 (354 mm), see Fig. 7. In regards to the VP, the maximum 30-year monthly mean of precipitation was measured in June (68.4 mm) and the minimum in October (31.1 mm). Annual precipitation for the period of



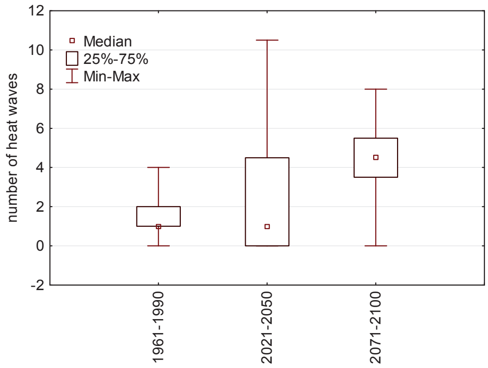
3: *Number of days in heat waves (1961–1990, 2021–2050, 2071–2100)*



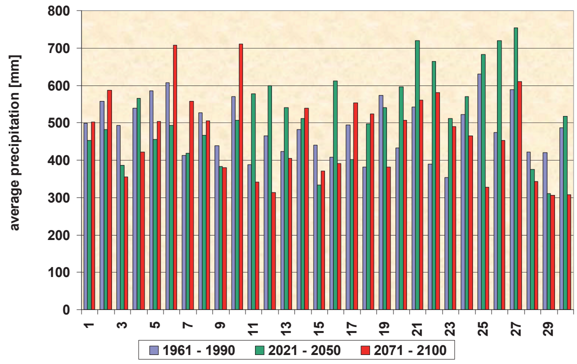
4: *Boxplot of days in heat waves (1961–1990, 2021–2050, 2071–2100)*



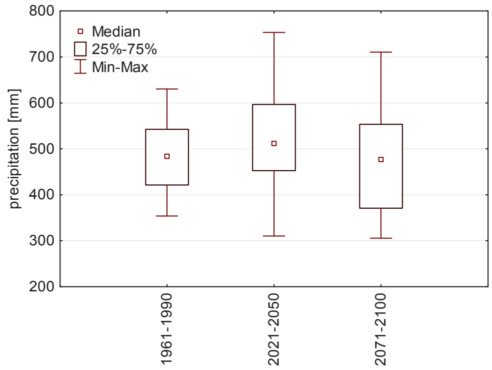
5: *Number of heat waves (1961–1990, 2021–2050, 2071–2100)*



6: *Boxplot of heat waves (1961–1990, 2021–2050, 2071–2100)*



7: *Comparison of running total precipitation (mm) of three periods (1961–1990, 2021–2050, 2071–2100)*



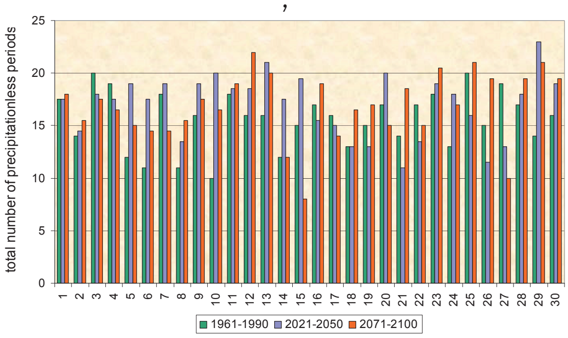
8: *Boxplot of running total precipitation (mm) of three periods (1961–1990, 2021–2050, 2071–2100)*

2021–2050 amounts to an average of 521.4 mm and 392 mm in the VP. The VP should be richest in precipitation in July (30-year monthly mean: 85.2 mm) and the minimum should be measured in April (25.6 mm). The average annual rainfall for the period of 2071–2100 is expected to be 466.4 mm (329.9 mm in the VP). The VP should be richest in precipitation in May (30-year monthly mean: 72.2 mm), and the minimum should be measured in April (23.9 mm).

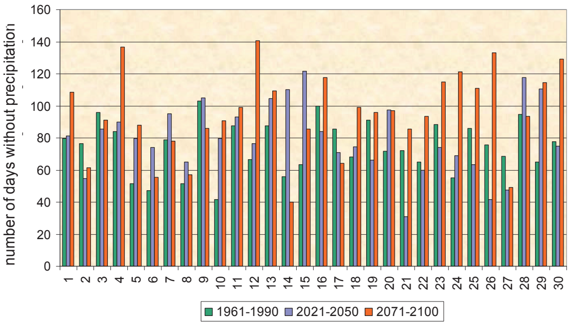
Due to the previous normal values, the maximum and minimum total annual precipitation will increase. Very unfavourable rainfall situation is expected in the particular period of 2071–2100.

Precipitationless period

Most days without precipitation for the period of 1961–1990 were measured in 1983 (161). According to Pokladníková *et al.* (2008) this year was evaluated as strongly subnormal in rainfall. The least days without precipitation for this period were seen in 1970 (66 days), which was evaluated as abnormal precipitation. The largest number of days without precipitation in the VP for the period of 1961–1990 was measured in 1969 (103 days), the total minimum being in 1970 (42 days), see Fig. 10. Fig. 9 shows the number of precipitationless periods in a year. The highest number of precipitationless periods



9: *Comparison of the total number of precipitationless periods a year for three seasons 1961–1990, 2021–2050 and 2071–2100*



10: *Comparison of the number of days without precipitation in VP for three seasons 1961–1990, 2021–2050 and 2071–2100*

in a year is 20 (1963, 1985), the minimum being 10 (1970).

In the period of 2021–2050, the maximum number of days without precipitation in a year is expected to be 195 and minimum 76. The maximum of precipitationless periods should be 22, the minimum 11 (Fig. 9). The maximum length of one precipitationless period is expected to be 30 days.

The period of 2071–2100 should see the most days without precipitation a year to be 227, the minimum is expected to be 79. The maximum of precipitationless periods should be 22 and the minimum 8 (Fig. 9). The maximum length of one precipitationless period is expected to be *40* days.

For VP, the average number of days without precipitation for the period of 1961–1990 is 74 days, for the period of 2021–2050 it should be 80 days and for the period of 2071–2100 it is expected to be 95 days.

DISCUSSION

Fukalová *et al.* (2012) elaborated climadiagrams for the selected area to judge an annual dynamics of monthly mean air temperature and total precipitation and estimate drought period. While in 1961–1990 the drought lasted from mid-August to early October, during the years of 2021–2050 it should occur in mid-April and then should take from August to early September. In the years of 2071–2100 it should be dry from mid-March to the end of April and then from late June to early October. It is obvious that there will be drought in spring (especially April – already visible). The results showed that in the future rainfall during the year should have a different distribution than it had previously and in regards to agricultural production this distribution will be less favourable. Doleželová (2013) evaluated precipitation from 10 meteorological stations of the CHMI network in Southern Moravia in 2010–2012 and compared the results with the long-term average from 1961–2012. The occurrence of dry periods shows a marked tendency especially in the spring which from the mid-70's shows a positive and further amplifying trend of the average and maximum lengths. The amount of precipitation in recent years shows a growing trend which is evident especially in the summer. On the other hand, there are also lengthening periods of drought, which however occur especially in the spring and are weaker than in case of the effect of extreme rainfall events.

Agroclimatic characteristics of Žabčice executed on the basis of data obtained at the climatological station located in the experimental area of MENDELU for the period of 1961–1990 was elaborated by Rožnovský and Svoboda (1995). Although the dry season in the period of 1961–1990 did not occur in the spring as shown by the climadiagram, the authors pointed out that in some years the spring is typical by a drought, especially in April and May.

High temperatures will increase evapotranspiration and thus soil drought. Kohut (2008) conducted a time trend analysis of development of moisture conditions in CZ for the period of 1961–2000. The results of this analysis showed that during the period there was a worsening moisture situation, and in addition the last decade 1991–2000 generally appeared to be the least favourable in terms of moisture conditions. At the same time, he identified the key areas of scarce precipitation and significant values of evapotranspiration (South Moravia, Poohří region and Labe Lowlands).

The fact is that the temperature increase is documented by long-term trends, therefore we have to count with it in the perspective. The vast majority of scenarios do not report significant change in total annual precipitation. However, the increase in temperature clearly changes the moisture ratios (Rožnovský *et al.*, 2010).

Frequent droughts can be expected in areas with lower altitudes, i.e. in intensively cultivated landscapes such as Žabčice. It may not be possible to finance the irrigation systems in such areas and, therefore, it is necessary to adapt to the increased incidence of drought. The negative impact of drought can be reduced by some agronomical interventions. Adaptation measures should primarily dwell in the selection of varieties of crops and the introduction of saving measures of soil moisture. In regards to the first measure it is important to not only choose suitable crop varieties for the region but also breed new drought-resistant varieties. The area of Žabčice widely cultivates wheat. The total water consumption for a high yield of wheat is between 450–650 mm, depending on the climate and the length of VP. Moisture requirements change during vegetation (Stehno *et al.*, 2011). Due to the changing climate, fluctuations in rainfall patterns have occurred recently. These often accumulate into short periods of time and are followed by the emergence of long periods without precipitation. The aforementioned facts supported by the results of this paper stress the need to breed varieties of wheat not only for resistance to drought but also for a certain flexibility and adaptation to uneven distribution of rainfall during the VP. With this aim, attempts are made to determine the tolerance of wheat to drought during the growing season. The Department of gene bank under Crop research institute (CRI) Prague also evaluated the genetic resources of wheat as potential donors of resistance to drought during the growing season. Standard evaluation of genetic resources of winter wheat indicated the possibility to use earliness as a character, which allows avoidance of adverse drought which may come in the production stage of a VP (Stehno *et al.*, 2011).

Technologies using the principle of minimization in soil cultivation are more suitable for dry areas especially in regards to cultivation of grains. Temperature increase at approximately the same precipitation is generally preferable when considering the development of diseases and pests with possible increase in the number of generations of mature individuals causing the need for increased chemical protection and may lead to increased costs. Another considerable hazard can be seen in weed infestation by perennial weeds many of which are more resistant to drought than crops.

CONCLUSION

Based on the "screenplay" of CHMI data, selected climatic characteristics were analyzed. These are important in terms of agricultural production for two thirty-year periods of the 21st century (2021–2050 and 2071–2100). Results from these two periods were compared with the previous period (1961–1990).

The results of temperature analysis showed that the future period of 2021–2050 will be warmer by an average of 1.5 °C and the period of 2071–2100 will be even warmer by 3.4 °C than 1961–1990. Also, the average monthly temperature will rise. The increasing trend was also observed in the number and duration of heat waves. In the future, there will be an increased incidence of precipitationless periods which will also be longer. Precipitation during the year should have a different distribution than it was seen previously. There will be less rainfall especially in August and April. The distribution of rainfall will therefore be rather less favourable with regards to agricultural production. Less precipitation in connection with high temperatures in the spring will negatively affect the development of crops. High temperatures will also increase evapotranspiration and thus soil drought.

Temperature increase is documented in long-term trends and therefore it is necessary to calculate with it in the perspective. The vast majority of scenarios of totals for our country does not report significant change in total annual precipitation. However, the increase in temperature clearly changes the moisture conditions. Therefore, it is necessary to continue to monitor the dynamics of rainfall and temperature conditions and gradually develop new adaptation mechanisms to prevent agricultural losses.

Utilization of the land in Žabčice should not notice significant changes in the context of climate change in the first future period when assuming described implementation of adaptation measures. If UAE is able to adapt to the increased incidence of drought, it would not have to change the structure of the crops grown on arable land. Predicted weather conditions for the second future period may already cause existential problems to agriculture.

SUMMARY

This paper presents an analysis of selected temperature and precipitation characteristics for the agricultural region of South Moravia. The evaluation was based on data measured by the CHMI and data for the future periods created by the integration of the regional climate model ALADIN-Climate/CZ using the emission scenario A1B. With regard to the agricultural activity of this region the following climatic characteristics were selected: average air temperatures, heat waves, rainfall and precipitationless periods. These characteristics were evaluated for two future periods 2021–2050 and 2071–2100 and compared with the period 1961–1990. The results showed the expected increase in average air temperature in the period of 2021–2050 by 1.5 °C and in the period of 2071–2100 by 3.4 °C as compared to the period 1961–1990. The increase in the number of days of heat waves was considered to be another prerequisite. Heat waves should not only increase in frequency but also in terms of length, i.e. number of days. As for the average total precipitation during the growing season, the normal period of 1961–1990 saw the richest precipitation in the month of June while the lowest amounts were measured in October. The period of 2021–2050 should see the richest rainfall in July and the minimum should be reached in April. As for the period of 2071–2100, it is expected

that the most precipitation will be seen in April and May. The maximum and minimum total annual precipitation will increase. Very unfavourable rainfall situation is expected in particular in 2071–2100. In the future, there is an increased incidence of precipitationless periods which will also be longer. While the longest precipitationless period in 1961–1990 took 20 days, the future period 2071–2100 could see the longest precipitationless period take up to 40 days. Low spring rainfall coupled with high temperatures will also increase evapotranspiration and thus the soil drought occurrence and negatively affect crops development. Increasing drought predicted by climate models is a major problem for the agricultural region of South Moravia and the region needs to adapt to these anticipated changes not only in farming but also in landscape management in general. It is certainly necessary to continue to monitor the dynamics of precipitation and temperature conditions as well as gradually develop new adaptation mechanisms to prevent agricultural losses. This paper points out possible adaptation measures for agriculture in the analyzed area.

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