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Climate Change Impact on the Duration of Great Vegetation Period and Vegetation Period of Beetroot and Watermelon in Slovakia

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Abstract: Climate change brings to the whole world numerous challenges such as an increase in the global temperature, weather fluctuations, periods of drought and heat alternating the local floods. While the majority of the effects are negative for agricultural production, some can be beneficial. Our work presents the evaluation of the changes in the duration of the great vegetation period (delineated with the beginning and end of days with an average temperature $T \geq 5.0$ °C) and the vegetation periods of watermelon (*Citrullus lanatus* Thumb.) and beetroot (*Beta vulgaris* L.). Data sets on the average monthly air temperatures for the period 1961–2020 from one hundred agroclimatic stations in Slovakia were selected for the estimation of the future average air temperatures using statistical methods (linear trendline). Based on the temperature requirements of the selected crops, the potential maximum duration of the vegetation period was estimated for several decades from 2041 up to 2100. The results clearly showed prolongation of the vegetation periods and changes of their zonation in Slovakia. In 2011–2020, the duration of the beetroot vegetation period in the southernmost part of Slovakia (Danubian Lowland) was 15–20 days longer than in decade 1971–1980. It is expected, that this value will rise by another 10–15 days in decade 2091–2100. Since 1971–1980, watermelon vegetation period duration increased by 5–10 days when compared to decade 2011–2020. It is expected that by 2091–2100, its duration will prolong by another 30–35 days.

Keywords: climate change; temperature; vegetation periods; agroclimatic analyses; GIS analyses; watermelon; beetroot

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1. Introduction

Agroclimatic analyses of recent decades have shown that the weather is currently one of the main limiting factors for agricultural production, and in the future this influence will multiply [1,2]. The climate changes are the result of anthropogenic activities. An increase in the concentration of greenhouse gases (CO_2, N_2O, methane, freons, etc.) in the air results in the significant changes of the energy and water regime in the atmosphere and causes various risks affecting agriculture [3,4]. General warming has been observed also in the conditions of Slovakia (located in Central Europe) and in its agricultural production areas. Furthermore, a decrease in atmospheric precipitation (followed by drought) is affecting especially the lowland areas of southern Slovakia [5]. These changes have been having various impacts on agriculture, sometimes positive, but mostly negative. It is necessary to determine and analyze them and based on these analyses, look for the possibilities of reducing the negative effects and increasing the positive effects [6,7].

The change in CO_2 concentration alone will lead to a change in the fertility of almost all field crops. It is known that, depending on the species, type of photosynthesis and the environmental conditions, increasing the concentration of CO_2 can lead to an increase in the growth and fertility of crops. In case of a group C–3 which includes the majority of field and horticultural crops (cereals, sugar beet, sunflower, etc.) and cultures of a group C–4 (corn, millet, sorghum, etc.) this change can be up to 10–50% [8]. Changes in the energy (radiation, temperature) and moisture security are also expected [9]. At same time, there will be changes in the wintering conditions, physical and chemical properties of the soil, occurrence of diseases and pests, etc. [10,11].

The predicted climate changes invoke incentives also among the agricultural scientists for the extensive discussions, considerations and especially for proposals of measures that should be used to respond to these changes [12]. The changes in agroclimatic regionalization and the structure of cultivated crops and varieties, changes in the cultivation technologies, breeding intentions, conservation, nutrition, water management and other intentions are expected [13,14].

Global warming has increased the average annual air temperature by about 1.1 °C over the last 100 years (1901–2000) in Slovakia. This is mainly based on observations from the observatory in Hurbanovo, which has been ongoing since 1871 [15]. Seven warmest years have been recorded during 2015–2021. Moreover, years 2016, 2019 and 2020 have been the warmest years since the systematic measurements began in 1850 [16]. Concurrently, atmospheric precipitation decreased in average by 5.6 % (1901–2000) [15]. In Slovakia, we will have to get used to the faster onset of warm and dry weather in the spring. Another expected manifestation of climate change in Slovakia will be an increase of the daily maximum and minimum air temperature [17]. Therefore, in our work, we focused on the analysis of the changes in the agroclimatic conditions (air temperature) and their impact on the development of the growing seasons of the selected agricultural crops including the prediction of the future development. The aim of this study was to evaluate the observed changes in the duration of the great vegetation period and vegetation period of selected crops—watermelon (*Citrullus lanatus* Thumb.) and beetroot (*Beta vulgaris* L. var. *vulgaris*) using the basic agroclimatic analyses for the observation period 1961–2020. The future predictions on the duration of the vegetation periods were estimated for the time horizons of decades 2041–2050, 2071–2080 and 2091–2100.

2. Materials and Methods

2.1. Climate Conditions

Temperature conditions are one of the basic factors of a complex assessment of the territory. In Slovakia, they are characterized by an extraordinary variety caused mainly by the orographic fragmentation of the territory [18] and changing elevation (Figure 1). The mountain ranges that form climatic valleys have a significant effect on the properties of Slovakia's climate and its temperature regime. The regime of overall wind conditions also has a significant influence on the distribution of temperatures in Slovakia [19].

Based on measurements in 1961–1990 in Slovakia, the average air temperature ranges from −1 to −2 °C in January, and from 18 to 21 °C in July. The average annual air temperature is within 9–11 °C. In the river basins and valleys, the average annual air temperature reaches 6–8 °C, in the highest located basins it is less than 6 °C. The total annual rainfall varies from less than 500 mm (the lowlands on the south of Slovakia) to approximately 2000 mm (in the High Tatras mountain range) [20].

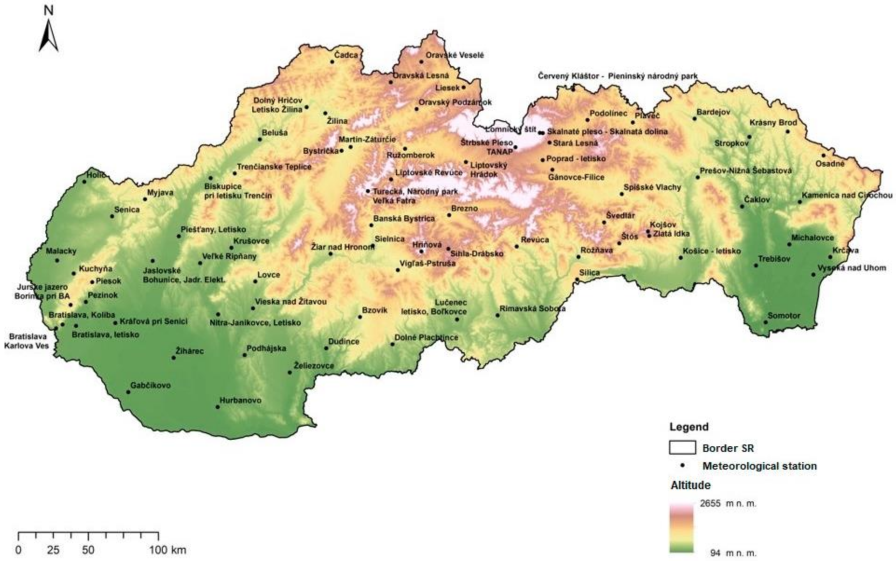

Figure 1. The elevation of Slovakia and position of the meteorological stations used for data input.

2.2. Data Analysis

The temporal course of plant growth stages—the phenophases is mainly influenced by the energy and water regime of the environment. The changes in temperature, total precipitation, and other environmental factors affect the dates of onset and termination of the phenophases, and thus also the length of phenophases intervals and the entire vegetation periods of crops [21–23]. For the basic analyzes of the temperature conditions and phenology of vegetables in Slovakia, 100 stations were selected throughout the territory of Slovakia (Figure 1).

We evaluated the meteorological data representing the average daily air temperatures for the reference time series of 1961–2020 that were provided by the Slovak Hydrometeorological Institute. From the data, we created a plot of temperature development for decades from 1961 to 2020 at altitudes up to 200 m, 200–400 m, 400–600 m, 600–800 m and above 800 m above sea level (Figure 2). The onset (in spring) and termination (in autumn) of the vegetation period were analyzed for great vegetation period, delimited by the beginning and end of days with an average daily temperature T $\geq$ 5.0 °C. This temperature activates physiological processes in plants [24,25].

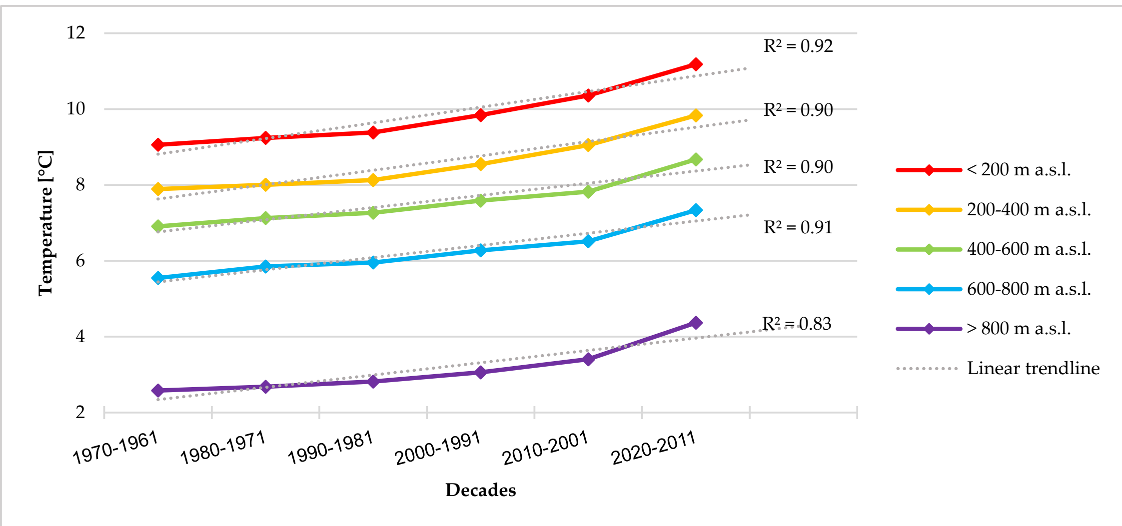

Figure 2. Average air temperature in decades 1961–1970, 1971–1980, 1981–1990, 1991–2000, 2001–2010 and 2011–2020 at meteorological stations located in altitudes <200 m, 200–400 m, 400–600 m, 600–800 m and >800 m above sea level.

For the purposes of the agroclimatic analyses in this study, we selected two vegetable species grown in the field conditions:

- watermelon (*Citrullus lanatus* Thunb.),
- beetroot (*Beta vulgaris* L. var. *vulgaris*).

Based on the phenological observations, air temperatures were determined for the onset and termination of the vegetation period of the analyzed types of vegetables (Table 1).

Table 1. The air temperature delineating the beginning and end of the vegetation period of watermelon and beetroot grown in field conditions from sowing.

Vegetable Species	Starting Temperature [°C]	Ending Temperature [°C]
Watermelon (*Citrullus lanatus* Thunb.)	13.0 °C	12.5 °C
Beetroot (*Beta vulgaris* L. var. *vulgaris*)	3.0 °C	7.5 °C

The duration of the vegetation period was calculated by determining the beginning and end of the vegetation period (according to Equations (1) and (2)) and was analyzed from the average daily temperatures for the years 1961–2020. The onset and termination of the defined temperatures was calculated according to the following equations:

Onset of vegetation period:

$$r_v = R\frac{T_n - T_2}{T_1 - T_2} \tag{1}$$

Termination of vegetation period:

$$r_p = R\frac{T_1 - T_u}{T_1 - T_2}, \tag{2}$$

where:

r_v—difference between middle of month with temperature T_2 and date when T_n was reached [days],
r_p—difference between middle of month with temperature T_1 and date when T_u was reached [days],
T_n—the starting temperature [°C],
T_u—the ending temperature [°C],
T_1—the nearest monthly average temperature above T_n or T_u [°C],
T_2—the nearest monthly average temperature below T_n or T_u [°C],
R—difference between midst of months with average temperature T_2 and average temperature T_1; it can be expressed as R = 30 [days].

Subsequently, the forecasts were made for the decades 2041–2050, 2071–2080 and 2091–2100. The future scenarios were based on the expected development of climate change and a linear trend of temperature increase which is predicted in Paris Agreement from 2015 [26,27]. For each meteorological station, the maximum duration of the vegetation period was calculated by a mathematical function. The used linear trendline equation uses the least squares methods to seek the slope and intercept coefficients and its general form is as follows [28]:

$$y = bx + a, \tag{3}$$

where:

b—slope of a trendline,
a—y-intercept, which is the expected mean value of y when all x variables are equal to 0.

2.3. Map Outputs Creation

The spatial data and map outputs were created and processed in geographic information system ArcGIS (ESRI, Redlands, CA, USA). It is a modular system which enables to create solutions that suit individual users [29]. The ArcGIS software consists of several groups of products. For the purposes of this study, we used ArcGIS Desktop which provides applications for collecting, processing, searching, and presenting geographic information [30]. To create the map outputs, firstly the input data layer was prepared. It included information on the calculated duration of the studied vegetation periods for the selected meteorological stations in Slovakia. The spatial position of the stations was defined by XYZ coordinates. This information was loaded into the ArcGIS Desktop environment and subsequently converted into a point vector model (*.shp) in the S-JTSK coordinate system. Subsequently, the interpolation and the creation of a GIS layers using data from weather stations was elaborated. Interpolation was needed to find out the values in the areas without data (between the meteorological stations) and to determine the spatial structure of the entire studied phenomenon. We tried to realize spatial estimates of values from more or less irregularly (or regularly) distributed available data. The result was a map of the spatial distribution of the vegetation period duration. Among the interpolation methods available in the ArcGIS environment, we used the Topo to Raster method, which is based on the ANUDEM version 4.6.3 program. The method combines the properties of Inverse Distance Weighting (IDW), Spline and Kriging interpolation techniques [31]. It is optimized for the computational efficiency of local interpolation methods such as IDW, but without losing the surface continuity of global interpolation methods such as Spline and Kriging.

In the final, we created the GIS layers which showed the models of the spatial structure obtained by interpolation, i.e., distribution of vegetation period duration for a total of 9 time periods. Furthermore, we calculated differences in the vegetation period duration using Raster Calculator tool in GIS. Depending on the histogram, we subsequently reclassified the values of the output layers and adjusted them into classes that are shown in the legends of the individual outputs [32] or as tabular data.

3. Results

Figure 2 presents the increasing trend of the observed average annual temperatures for decades 1961–1970, 1971–1980, 1981–1990, 1991–2000, 2001–2010 and 2011–2020 for meteorological stations located up to 200 m, 200–400 m, 400–600 m, 600–800 m and above 800 m above sea level. The data clearly confirms that the average air temperature in Slovakia has been increasing from 1961 up to the present. A significant increase in temperature can observed especially for the last 30 years, which further affects the beginning and end of the vegetation periods.

The vegetation period is defined by physiologically significant temperatures. The earlier onset and later termination result in its prolongation [33]. The great vegetation period is limited by the onset and termination of days with an average daily temperature T $\geq$5.0 °C. The map outputs (Figure 3a–d) showed significant change in the duration of the great vegetation period (GVP) during the period of years 1961–2000. In the decade 1961–1970, the great vegetation period in the Danube Lowland (southwest of Slovakia) lasted for 240–245 days. In the next two decades, GVP was prolonged by another 5 days. In the decade 1991–2000, GVP duration reached 250–255 days, which represents an increase by 10 days when compared to decade 1961–1970. The predicted GVP duration for the period 2041–2100 also shows significant changes (Figure 3g–i). It is expected, that the length of the GVP in the southwest Slovakia will reach 280–285 days by the horizon of 2100. It means a predicted increase of GVP in this most fertile part of Slovakia overall by 25–30 days and by 35–40 days when compared to when compared to the present and the decade 1961–1970, respectively.

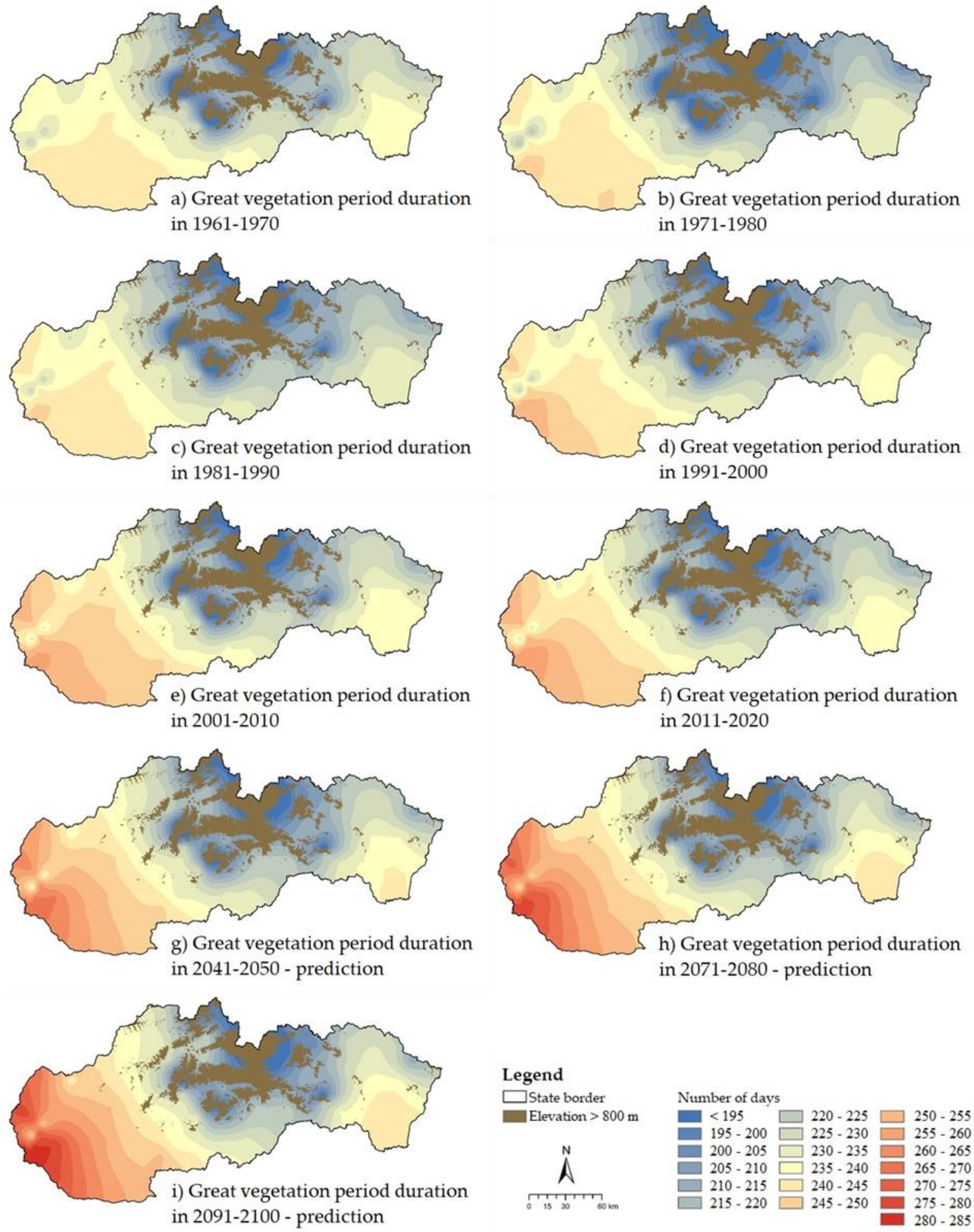

Figure 3. Great vegetation period (days) for: (**a**) 1961–1970; (**b**) 1971–1980; (**c**) 1981–1990; (**d**) 1991–2000; (**e**) 2001–2010; (**f**) 2011–2020; (**g**) 2041–2050—prediction; (**h**) 2071–2080—prediction; (**i**) 2091–2110—prediction.

The vegetation period of beetroot is limited by the onset and termination of days with an average daily temperature from 3.0 up to 7.5 °C. The maximum duration of the beetroot vegetation period in the decade 2011–2020 was 175–180 days. According to the map outputs for the period 1961–2020 (Figure 4a–f), there were no significant changes in the beetroot vegetation period. The exception was the cold decade 1971–1980, when the maximum length of the vegetation period was shorter by 15–20 days. The forecast for the decade 2041–2050 (Figure 4g) predicts a prolongation of the vegetation period by 5 days when compared to the period 1961–2020. The predictions estimate that by the 2050, the duration of the beetroot vegetation period will be 175–180 days in the most fertile parts of Slovakia. It is expected that the duration of beetroot vegetation period will further increase to 190 days in the southern parts of Slovakia by the decade 2091–2100 (Figure 4i) (an increase by 10–15 days). In comparison to the coldest decade (1971–1980), the maximum predicted beetroot vegetation period duration in the Danube Lowland will be 25–30 days longer.

The vegetation period of watermelon is limited by the onset and termination of days with an average daily temperature from 13.0 up to 12.5 °C. The maximum duration of the watermelon vegetation period in the decade 2011–2020 was 160–170 days. According to the map outputs for the period 1961–2000 (Figure 5a–d), there were no significant changes in the vegetation period duration except for the cold decade 1971–1980, when the length of the vegetation period in the Danube Lowland decreased by 5–10 days. In the period from 2000–2020, the duration of watermelon vegetation period increased by 10 days. The forecast for the period 2041–2050 (Figure 5g) shows a clear increase in the vegetation period duration by 15 days when compared to the years 1961–2000. The duration of the watermelon vegetation period is expected to rise up to 160–165 days in the most fertile parts of Slovakia by 2050 and further prolongation up to 205 days is expected by the decade 2091–2100 (Figure 5i). In comparison to the coldest decade (1971–1980), the maximum predicted watermelon vegetation period duration in the southern parts of Slovakia will be 35–40 days longer by 2100.

Our results show that as the air temperature increases, the duration of the studied vegetation periods is prolonging. While Figures 3–5 show the spatial representation of the individual vegetation period duration classes in Slovakia, Tables 2–4 enable the comparison of the quantitative representation of vegetation period duration classes for the selected decades. The comparison clearly shows the increasing trend of the maximum duration of the vegetation period with time. For example, while in 2011–2020 the watermelon vegetation period could reach maximum duration of 160–170 days on the 7039 km^2 of land, by 2091–2100 its expected to be more represented (area of 10,628 km^2 of land) (Table 4). Moreover, its expected that the categories with shortest vegetation period duration for watermelon (such as 100–110 days in 2011–2020) will not be occurring in the future. The graphical visualization of this anomaly is shown in Figure 6. The positive values in the plots represent the duration of the specific vegetation period that was not observed in the decade 2011–2020 but it is expected to occur in by 2091–2100.

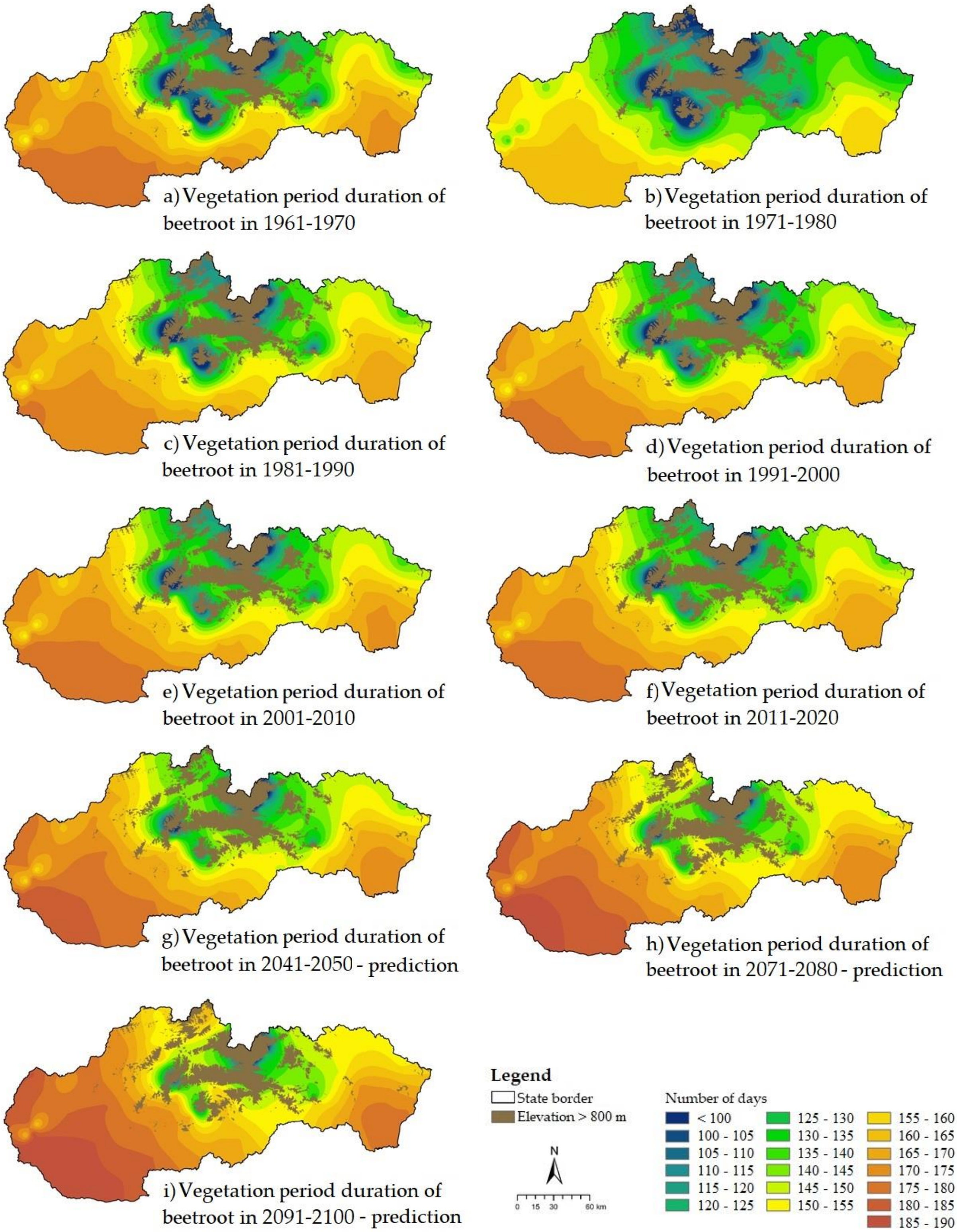

Figure 4. Beetroot vegetation period duration (days) for: (**a**) 1961–1970; (**b**) 1971–1980; (**c**) 1981–1990; (**d**) 1991–2000; (**e**) 2001–2010; (**f**) 2011–2020; (**g**) 2041–2050—prediction; (**h**) 2071–2080—prediction; (**i**) 2091–2110—prediction.

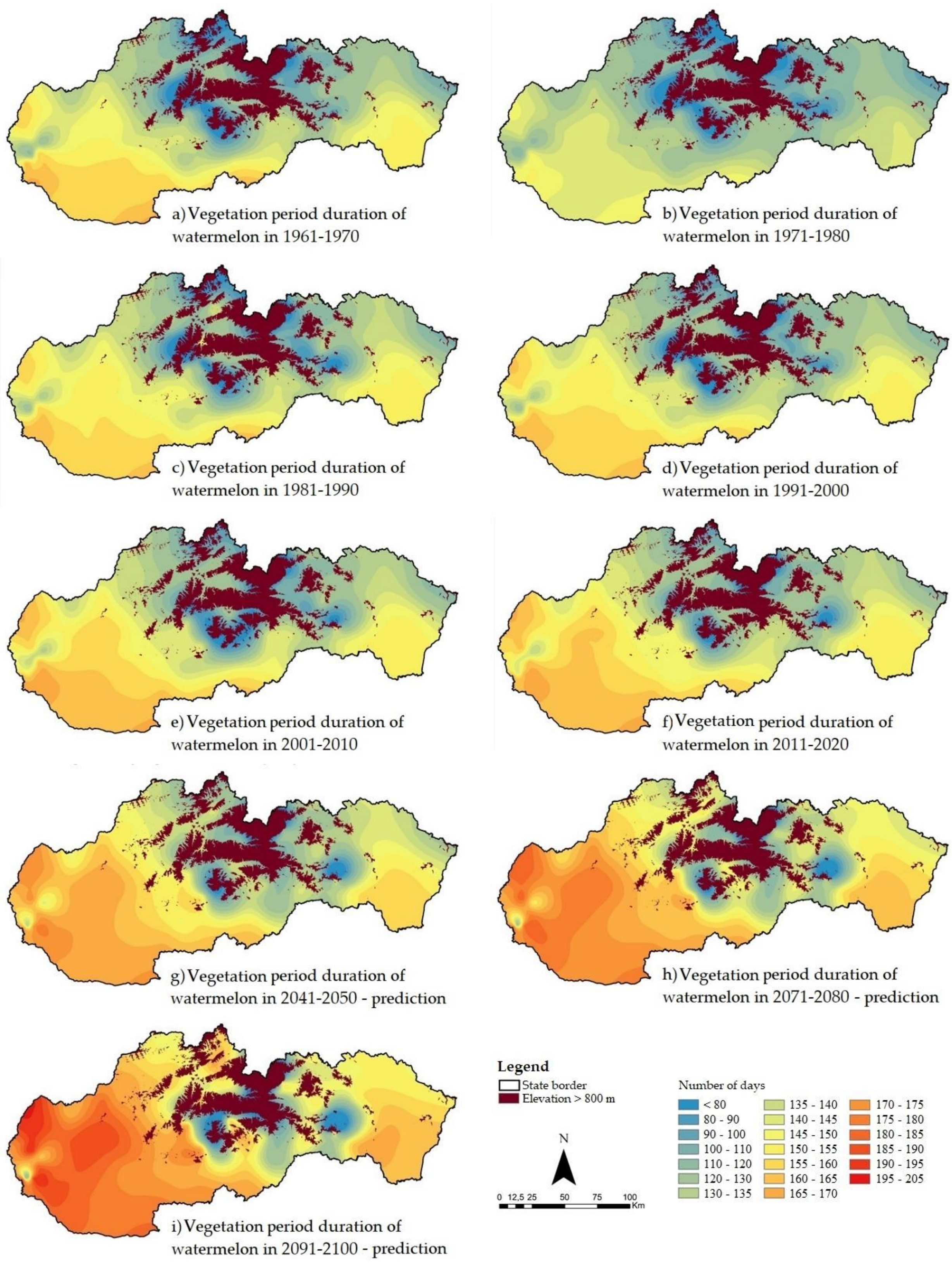

Figure 5. Watermelon vegetation period duration (days) for: (**a**) 1961–1970; (**b**) 1971–1980; (**c**) 1981–1990; (**d**) 1991–2000; (**e**) 2001–2010; (**f**) 2011–2020; (**g**) 2041–2050—prediction; (**h**) 2071–2080—prediction; (**i**) 2091–2110—prediction.

Table 2. The quantitative representation (area in km^2) of the great vegetation period duration.

Duration of the Vegetation Period [Days]	1971–1980 Area [km^2]	2011–2020 Area [km^2]	2041–2050 Area [km^2]	2071–2080 Area [km^2]	2091–2100 Area [km^2]
<190	1711	0	0	0	0
190–200	87,138	159,269	213,355	260,751	49,883
200–210	402,372	456,812	420,869	389,904	396,520
210–220	1,093,161	586,435	474,318	409,143	387,792
220–230	1,426,159	1,136,775	1,020,594	873,531	787,553
230–240	1,319,145	1,295,869	1,253,355	1,181,744	1,177,852
240–250	545,512	888,637	811,493	865,979	847,876
250–260	26,804	378,117	461,193	471,288	497,069
260–270	0	88	246,817	259,146	250,842
270–280	0	0	8	190,516	207,314
280–290	0	0	0	0	97,265

Table 3. The quantitative representation (area in km^2) of the vegetation period duration for beetroot.

Duration of the Vegetation Period [Days]	1971–1980 Area [km^2]	2011–2020 Area [km^2]	2041–2050 Area [km^2]	2071–2080 Area [km^2]	2091–2100 Area [km^2]
<100	2263	0	0	0	0
100–110	6063	6245	4654	3538	2590
110–120	10,454	9459	9501	8737	8680
120–130	12,839	11,552	11,215	11,138	10,274
130–140	14,645	8575	8557	8964	7075
140–150	2756	4808	4322	3706	3734
150–160	0	5986	3698	3368	3145
160–170	0	2216	4040	3547	2545
170–180	0	0	2388	2361	3176
180–190	0	0	645	3460	4800

Table 4. The quantitative representation (area in km^2) of the vegetation period duration for watermelon.

Duration of the Vegetation Period [Days]	1971–1980 Area [km^2]	2011–2020 Area [km^2]	2041–2050 Area [km^2]	2071–2080 Area [km^2]	2091–2100 Area [km^2]
<80	331	0	0	0	0
80–90	825	0	0	0	0
90–100	3476	0	0	0	0
100–110	6078	1632	0	0	0
110–120	7191	3772	2368	0	0
120–130	10,506	7276	4093	3531	0
130–140	10,613	9595	9316	4876	5848
140–150	10,001	10,549	11,014	10,390	8189
150–160	0	9156	10,042	11,963	10,466
160–170	0	7039	10,280	7346	10,628
170–180	0	0	1908	10,337	8526
180–190	0	0	0	579	5188
>190	0	0	0	0	174

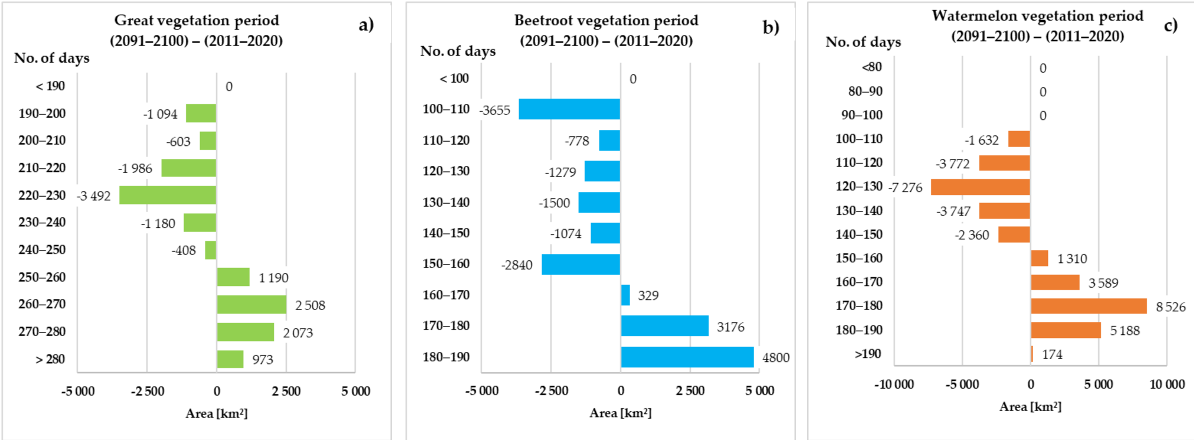

Figure 6. The difference between the predicted representation of vegetation period duration (decade 2091–2100) when compared to 2011–2020 as predicted for: (**a**) the great vegetation period; (**b**) beetroot vegetation period; (**c**) watermelon vegetation period.

4. Discussion

The presented results are consistent with the conclusions found in other works studying the influence of climate change on the beginning and end of the vegetation period. Based on the phenological, satellite and climate studies in the recent decades, a growing number of works reports a shift of about 10–20 days in the length of the growing season associated with global warming [34].

Study of Chervenkov and Slavov [35] presents evidence for the prolongation of the vegetation period as a consequence of ongoing global warming. Ruosteenoja et al. [36] projected the length of the growing season and growing degree day sum based on CMIP5 under the RCP4.5 and RCP8.5 scenarios. According to the modeled RCP8.5 simulations, the growing season will be extended by 1.5–2 months in most of Europe, while the growing degree day sum above 5 °C will increase by 60–100% by the end of the 21st century. The predictions for RCP4.5 scenario had similar trend but the predicted changes were smaller. In their other work, Ruosteenoja et al. [37] assessed the change according to the SREAS A2 and B1 scenarios. Their results showed that according to scenario A2, the thermal growing season will become 40–50 days longer by 2099 in inland Finland. They expect even bigger changes in the southwest of the country and that the conditions in Lapland will be like currently in southern Finland. Scenario B1 gave similar results on a smaller scale. According to evaluation of the representative concentration pathway scenarios RCP 4.5 and RCP 8.5 made by Sar et al. [22], the vegetation period in the Inner West Anatolia subregion can increase by 20 to 40 days. Weather data collected by the Swedish Meteorological and Hydrological Institute used to evaluate the changes in irrigation demand over the period 1981–2050 showed an increasing need for irrigation of cereal crop during May–June due to the shift to an earlier start of the harvest season, leading to earlier irrigation demand [38]. Mesterházy et al. [39] studied the effect of temperature on grape varieties. They expect earlier start of the ripening of the later varieties, and that the red varieties will start to predominate over the white ones. Nieróbca et al. [40] in their study predicted longer potato growing season in south-western Poland by about 11–17 days in 2030, and approximately 22–30 days in 2050. Olszewski and Żmudzka [23] analysed data in Poland and reported an increase in the length of vegetation period from 1 to 3 days per decade.

Several authors have dealt with this issue in Slovakia. According to Valšíková-Frey et al. [41], in comparison to present, the sowing of fruiting and leafy vegetables at the locality Hurbanovo will be happen earlier by approximately 26 days. Root and bulb vegetables are expected to be sown approximately 41 days earlier by 2075. The delay in the harvest of fruiting and bulb vegetables will be approximately 17 days, leafy vegetables 10 days and root vegetables 12 days. Špánik et al. [42] analyzed the change in the vegetation period duration of selected fruiting vegetables (tomato and pepper), leafy vegetable (white cabbage), root vegetables (carrot and beet) grown in field conditions from sowing, depending on climate change according to global model scenarios of the general circulation of the atmosphere from 2000 - Canadian Climate Center Model (CCCM 2000). The analysis showed an extension of the vegetation period by 21–26% by 2075 depending on the analyzed types of vegetables at the locations of Hurbanovo and Liptovský Hrádok. Similar predictions were done by Čimo et al. [21] for the growing seasons of tomato, white cabbage, and carrot, but also for bell pepper [43]. These authors also studied the changes in temperature development in Slovakia and its future predictions [7].

5. Conclusions

The results of the work show that due to climate change, the average air temperature has been increasing in Slovakia from 1961 to the present, with the exception of the colder period 1971–1980. The higher average air temperature has the effect of extending the length of the vegetation period of all crops in the entire territory of Slovakia. Our results showed that over the past 30 years, the vegetation period has started earlier in the spring and the end delayed in the autumn. For the great vegetation period, an increase is expected by an average of 25–30 days for the decade 2091–2100 when compared to the present. The forecasted duration of the vegetation period will be approximately 10–15 days and 30–35 days longer for beetroot and watermelon, respectively.

The results of the work can appear to be positive, especially in terms of the possibility of growing more crops. However, it will be important how farmers and especially agricultural crops can adapt not only to the extended length of the growing season, but also to the changes that will occur (and seem to be occurring already) in precipitation, periods of drought and the occurrence of ground frosts during the vegetation period.

It is very unlikely that the mankind will meet the commitments regarding the limitation of greenhouse gas emissions, which aim to stabilize an increase in the average global temperature below 2 °C and are agreed in the Paris Agreement. One of the possible solutions to partially deal with the consequences of climate change is the application of various adaptation measures. In agriculture, the main adaptation measures should include the restoration of outdated and the construction of new irrigation facilities, the construction of structures for water retention in the landscape, and, if necessary, changing the cultivated variety or crop. At the same time, all these measures should be supported by soil erosion control measures.

However, because climate change represents a complex problem affecting various sectors of life, it is necessary to achieve cooperation in the development of adaptation strategies, but especially in the application of these adaptation measures in practice, not only at the level of various professional institutions, departments, and ministries, but also at the international level.

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