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Impact of climate change on vegetation period of basic species of vegetables in Slovakia

Ján ČIMO [1) ✉], Karol ŠINKA [2)], Andrej TÁRNÍK [1)], Elena AYDIN [1)], Vladimír KIŠŠ [1)], Lucia TOKOVÁ [1)]

1) Slovak University of Agriculture, Faculty of Horticulture and Landscape Engineering, Department of Biometeorology and Hydrology, Hospodárska 7, 949 76 Nitra, Slovakia
2) Slovak University of Agriculture, Faculty of Horticulture and Landscape Engineering, Department of Landscape Planning and Land Consolidation, Nitra, Slovakia

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Abstract

The aim of the paper is to provide climatic data from the basic elements and characteristics of the energy balance in terms of the current state and in terms of trends and assumptions of their future changes in Slovakia. Climate change affect agriculture and its procedures. Changes in vegetation period in Slovakia of selected vegetables are presented in this study. We used for agro-climatic analysis one hundred climatological stations, which were selected to cover all agricultural regions up to 800 m a.s.l. Actual data and predictions were compared with time period 1961–2010. Due to homogeneity in data measurements, was chosen this period. We obtained climate trends and assumed map outputs of future climate changes by mathematical-statistical methods for horizons of years 2011–2020, 2041–2050, 2071–2080 and 2091–2100. We analysed vegetation period changes of selected fruit vegetables, *Brassica* vegetables and root vegetable in field conditions with prediction to year 2100. In our results is shown the earlier beginning of vegetation period in a spring and later end in an autumn in last 30 years. The vegetation period is getting longer about 15–20 days for *Capsicum annuum*; 15–20 days for *Brassica oleracea var. capitate*; 10–15 days for *Beta vulgaris subsp. vulgaris* with comparation of nowadays situation and period 2091–2100.

Key words: *average temperature, basic species of vegetables, climate change, temperature changes, vegetation period*

INTRODUCTION

Europe's climate is characterized by significant regional variability, due to the continent's location in the Northern Hemisphere and the impact of the surrounding seas and oceans and the adjacent Asian continent and the Arctic. The main influence on the European climate is the atmospheric circulation and its temporal and spatial changes. As there is a sufficiently dense network of long-term measuring stations in the region, supplemented by a series of distance measurements, the analyses of trend changes are significantly more accurate than similar global analyses [BAKKENES *et al*. 2002].

The temperature of the European continent has risen by an average of 1.2°C over the last century, and by 0.45°C over the last three decades [BRÁZDIL, TRNKA 2015]. While the average rise trend over the last century has been around 0.1°C per 10 years across Europe, it has more than doubled in the last thirty years.

The Central European region has general features of climate change. Warming manifests itself in it in all locations and climatic areas. Trends in atmospheric precipitation are not so definite, but this fact is due to their greater variability, as well as the modification of total precipitation by windy and leeward influences.

According to LAPIN [2009] for the period 1881–2017 in Slovakia was observed:

– an increase in the average annual air temperature by about 1.73°C,
– decrease in annual totals of atmospheric precipitation on average by about 0.5% (in the south of the Slovak Republic the decrease was in some places even more than

10%, in the north and north-east the total precipitation rarely increased to 3%),
- decrease in relative humidity (in the south of Slovakia since 1900 by 5%, in other areas less),
- a decrease in all characteristics of the snow cover up to a height of 1000 m in almost the entire territory of the Slovak Republic (an increase was recorded at a higher altitude).

In the period 1989–2017, local or widespread drought occurred much more frequently than before, which was caused mainly by long periods of relatively warm weather with small total precipitation in some part of the vegetation period. The drought was particularly significant in the years 1990–1994, 2000, 2002, 2003 and 2007, in some regions in the west of the Slovak Republic also in 2015 and 2017, 2018, 2019.

The trend of an increase in the average temperature until the period 2030, regardless of the choice of the Special Report on Emissions Scenarios (SRES), is assumed to be slightly higher than the global estimate, i.e. slightly above 0.2°C per 10 years. The projection for the 2100 period for the SRES scenarios shows an increase in the range of the lower and upper estimate of 1.0–5.5°C compared to the period 1961–1990 [DETRAZ, BETSILL 2009].

Higher air and soil temperature bring a whole complex of effects on agroclimatological conditions. The course of both temperatures determines the development of crops and thus the timing of most agrotechnical operations. With a higher temperature, the beginning of a great vegetation period will shift. The length of vegetation periods and their geographical distribution are an indicator for delimitations of crops and various agricultural activities in the Slovak Republic. The zoning of crops, varieties and agrotechnics (e.g. tillage systems) is based on production areas and climate regions and will need to be updated more frequently. From the length of the vegetation period, together with other indicators, it is possible to determine which species of more heat-intensive crops will be possible to grow in the future. The longer vegetation period suggests the possibility of growing two crops per year, but this potential will be fundamentally limited by the amount of water available [PRETEL *et al*. 2011].

Temperature as a basic characteristic of the energy component impact the environment conditions such life processes of plants as photosynthesis, respiration, nutrient intake, transpiration and others. These are the processes that determine the production of organic matter – the yield. Thus, the temperature ranks among the agroclimatic sources of agricultural production and vegetable production, respectively. Plant requirements for agroclimatic environmental factors are expressed numerically as "agroclimatic indicators". Based on them, the agroclimatic conditions of the landscape are evaluated in synthetic form in agroclimatic zoning. From the complex of agroclimatic factors, it is mainly the sum of average daily air temperatures for the vegetation period of the crop.

The study analyses the impact of climate change on the change in the vegetation period of basic vegetable species grown in field conditions from sowing.

A similar issue was solved in Slovakia within the project E03 ČU 01 UŠP VV "Regionalization of vegetable production from the aspect of climate change" in the years 2003–2005. They dealt with this issue in our country (ANTAL *et al*. [2018], ŠEMELÁKOVÁ [2001], VALŠÍKOVA *et al*. [2011] and others).

MATERIAL AND METHODS

STUDY AREA

Slovakia is located between 49°36'48" and 47°44'21" northern latitude and 16°50'56" and 22°33'53" eastern longitude. Temperature conditions are one of the basic factors of any complex assessment of locality. MUCHOVÁ and TÁRNÍKOVÁ [2018] also said that climate change plays important role in landscape changes, biological diversity and ecological stability. In the country, air temperature is most affected by geographical location – latitude (determines the insolation conditions), altitude, orographic conditions, continentality or maritimity indicating the distance from the sea, etc. [KOVALENKO *et al*. 2019; MAGUGU *et al*. 2018]. Temperature conditions of Slovakia are characterized by extreme variety which is caused by orography of landscape. Climatic barriers from mountains like Carpathians, Beskids, High and Low Tatras and others have impact on climate and temperature regime in Slovakia. Further, regime of wind condition has significant impact on temporal and spatial character of temperatures in Slovakia.

The average annual vertical temperature gradient is 0.61°C per 100 m of high in Slovakia. This value grows up to 0.76°C in summertime and decrease to 0.33°C in winter period. Extreme temperatures could be limiting factor for production of agricultural and horticultural crops. Maximum absolute temperature in Slovakia was measured in Hurbanovo (20.07.2017; 40.3°C) and absolute minimum in Vígľaš – Pstruša (11.02.1929; –41.0°C).

Meteorological data for this study (monthly average of temperature) for reference time period 1961–2010 was provided by Slovak Hydrometeorological Institute (Sl. Slovenský hydrometeorologický ústav) in Bratislava. The beginnings (at spring) and endings (in autumn) of vegetation periods were analysed.

These species of vegetables which are sowed in field conditions were chosen for agro-climatic analysis:
- fruit vegetables (*Capiscum annuum*),
- *Brassica* vegetables (*Brassica oleracea var. capitate*),
- root vegetables (*Beta vulgaris subsp. vulgaris*).

On basis of phenological observations were determined air temperatures for beginnings and endings of vegetation period (Tab. 1). For basic analyses of phenological conditions of vegetables in Slovakia, 100 stations were selected throughout Slovakia (Fig. 1). It was based on the values of average monthly temperatures for the period 1961–2010, which are among the most homogeneous in terms of measurements and observations.

The predictions were created for each solved site separately in the form of a linear function. This means that in the first step, the onset and end of the vegetation period of individual vegetables (acc. to Tab. 1) for the years 1961–

Table 1. The air temperature for beginning and end of selected vegetable species vegetation period

Vegetable species	The beginning temperature (°C)	The ending temperature (°C)
Fruit vegetables (*Capiscum annuum*)	10.5	12.0
Brassica vegetables (*Brassica oleracea var. capitata*)	9.5	6.5
Root vegetables (*Beta vulgaris subsp. vulgaris*)	3.0	7.5

Source: own elaboration.

2010 were evaluated for each locality separately (acc. to Eqs. (1), (2)) based on daily average temperature data. This evaluation was carried out by software "Meteo Calculator" version 1_0_3, which we created. The software output data formed the basis for determining the number of days of the vegetation period for individual vegetables and localities. Based on the development of the number of days for each evaluated year (1961–2010), the mathematical function (linear trend equation) calculated the probable course of the number of days of the vegetation period up to the horizon of 2041–2050, 2071–2080 and 2091–2100 in conditions of changing climate for each crop and location separately. These data formed the input database for the final processing of map outputs.

Beginnings and endings of defined temperatures were calculated by equations:

Beginning: $$r_v = R\frac{T_n - T_2}{T_1 - T_2} \qquad (1)$$

Ending: $$r_p = R\frac{T_1 - T_u}{T_1 - T_2} \qquad (2)$$

Where: T_n = the beginning temperature (°C), T_u = the ending temperature (°C), T_1 = the nearest monthly average temperature above the beginning temperature or the ending temperature (°C), T_2 = the nearest monthly average temperature below the beginning temperature or the ending temperature (°C), R = difference (days) between the middle of months with average temperature T_2 and average temperature T_1; it could be expressed as R = 30, r_v = difference (days) between midst of month with temperature T_2 and date of temperature T_n beginning, r_p = difference (days) between midst of month with temperature T_1 and date of temp. T_u end.

CREATION OF MAP OUTPUTS IN GIS

Software package ArcGIS was used for processing and creating of map outputs for this study. It is modular system which is able to provide solutions for all types of users by their individual needs, working groups and complex company information systems also. ArcGIS is used in many spheres: state sphere, municipality, academic sphere, education, science and research, industrial and energetic companies, forestry and agriculture, transportation or telecommunications, etc. ArcGIS system consists of some product groups. ArcGIS desktop was used for this study. It allows collect, processing, searching and output of geographic information [ROZPONDEK *et al*. 2016, LEITMANOVÁ *et al*. 2013].

Input data preparation. Selected meteorological stations were defined by XYZ coordinates. These stations were load to ArcGIS Desktop environment and transformed to point vector model (*.shp) in S-JTSK coordinate system. Meteorological data (frost days, ice days, air temperature, etc.) from meteorological stations was processed in table format for easy import and processing in GIS. The aim of our study was spatial scale of meteorological elements at agricultural soils. Only areas below 800 m of altitude were selected from this reason and due to worse spatial layout of stations in mountains areas. Higher situated areas were excluded from processing.

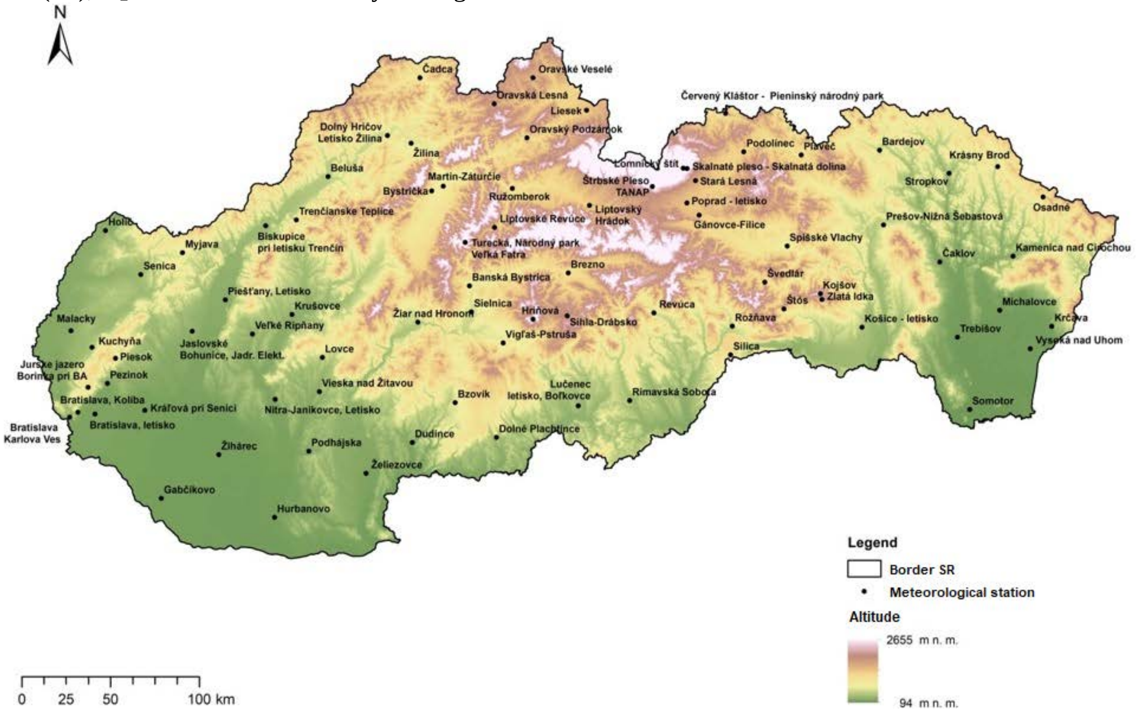

Fig. 1. Meteorological stations in Slovakia used in this study; source: own elaboration

Interpolation. Method Topo to Raster was chosen from interpolation methods available in ArcGIS software. This method has basis in software ANUDEM version 4.6.3. Topo to Raster combines options of interpolation methods IDW, Spline and Kriging. It is optimised for calculation effectiveness of local interpolation method like IDW but without losing of surface connection like is with method Spline or Kriging. It is discrete method Spline by type of interpolation.

Meteorological stations (like points vector shapefile) with attributes (meteorological data) and vector shapefile of boundaries of Slovak republic due to limitation of interpolation were input data to process of interpolation. The resolution of output raster was selected to 250 m with consideration of spatial layout of stations and range of interpolation.

Creation of map compositions. Outputs from interpolation show spatial structure of selected meteorological element. Outputs for 9 time periods were reclassified into classes depended by histogram of values. Legend, north arrow and scale were added in output module of ArcGIS version 10.52 for export maps.

RESULTS AND DISCUSSION

Impact of climate change to vegetation period length was analysed in this study. Reference period 1961–2010 and possible changes in periods 2011–2020, 2041–2050, 2071–2080, 2091–2100 were compared.

Timetable of plants life – phenophases are influenced by temperature and availability of soil water. Change of energetic and water balance character in Slovakia also change beginning of phenophases, their length and whole vegetation period of agricultural plants. For the vegetation period bounded by physiologically significant temperatures in connection with climate change, an earlier onset, delayed end and thus its extension apply.

This fact is based on the changing average temperature (warming), as evidenced by the analyses of the average temperature, which formed the basis for calculating the beginning and end of the vegetation period of individual analysed crops for the years 1961–2010.

The map outputs of *Capsicum annuum* (Fig. 2a–i) and analyses of the average monthly temperatures of individual weather stations for the years 1961–2015, indicate no substantial change in this period.

The *Capsicum annuum* vegetation period, depending on the altitude, did not change significantly in individual localities of Slovakia for the years 1961–2020. The only exception was the cold decade of 1971–1980, when the vegetation period in the warmest parts of Slovakia reached the level of 160–165 days. Compared to other decades over the period 1961–2010, it was less than 15–20 days. In period 2001–2020, the length of the vegetation period did not change compared to the years 1961–2000, but in the southern parts of Slovakia the boundary of vegetation period zone 175–180 days increased. Nevertheless, it means an increase by 5 days.

In the prognosis from the map outputs (Fig. 2g–i) is seen the extension of the vegetation period of *Capsicum annuum*. In comparison with periods 1961–2000 the prognosis for period 2041–2050 show longer vegetation period extended by 5 days (up to 185 days). For the period 2071–2080, the vegetation period is expected to increase by another 5 days (up to 190 days), and by the year 2100 it will be extended to 195 days. This value represents a difference of 15–20 days in comparison with 1961–2000, in the southern parts of Slovakia. In comparison with the coldest decade (1971–1980), the vegetation period of *Capsicum annuum* in the Danubian Lowland will rise in average 30–35 days in the horizon of 2091–2100.

The long vegetation period of *Brassica oleracea var. capitata* is bounded by days with average temperature (6.5–9.5°C). The *Brassica oleracea var. capitata* vegetation period length was not changed significantly in depends of various altitudes in years 1961–2000 says analysis of map outputs (Fig. 3a–i). Exception was cold decade 1971–1980, when vegetation period in the warmest areas of Slovakia was at level 195–200 days. In comparison with other decades in 1961–2000 it was about 10–15 days less in average. Period 1961–1970 and period 2001–2010 have the same length of vegetation period (215–220 days). The difference is in boundary of long vegetation period zone. The boundary was in south-east part of Danubian Lowland in 1961–1970, but it moved to south-west part of Slovakia in 2001–2010. Significant change of *Brassica oleracea var. capitata* vegetation period could be observed in map (Fig. 3g), where predicted vegetation period length is 220–225 days in 2041–2050. Our predictions for years 2071–2080 and 2091–2100 (Fig. 3h–i) clearly show trend of warming and growth of long vegetation period (about 15–20 days) compared to period 1961–2000. In comparison with the coldest decade it means growth about 35–40 days.

The long vegetation period of *Beta vulgaris subsp. vulgaris* is bounded by days with average temperature (3.0–7.5°C). Our analysis (Fig. 4a–f) shows the length of vegetation period of *Beta vulgaris subsp. vulgaris* is the same in period 1961–2020. The only exception was cold decade 1971–1980, when *Beta vulgaris subsp. vulgaris* vegetation period was about 15–20 days shorter. The prognose for 2041–2050 (Fig. 4g) shows 5 days increase of vegetation period (175–180 days vegetation period in the best fertile localities of Slovakia) in comparison of period 1961–2010. Even the prognose for 2091–2100 (Fig. 4i) shows increase to 190 days vegetation period (rise 10–15 days) for southern Slovakia. We can predict that vegetation period of *Beta vulgaris subsp. vulgaris* will be about 25–30 days longer in comparison with the coldest decades (1971–1980) in Danubian Lowland.

The presented results are in line with the conclusions in other studies focused on the impact of climate change on the change of the vegetation period. VALŠÍKOVÁ *et al.* [2011] reported that there is prediction of earlier seeding for year 2075 in Hurbanovo locality. It will be about 25 days for fruit and *Brassica* vegetable, about 30 days for root vegetable. Time of harvest will be also changed. Harvest of fruit vegetable will be about 15 days, harvest of *Brassica* vegetable about 10 days and harvest of root vegetable about 12 days later.

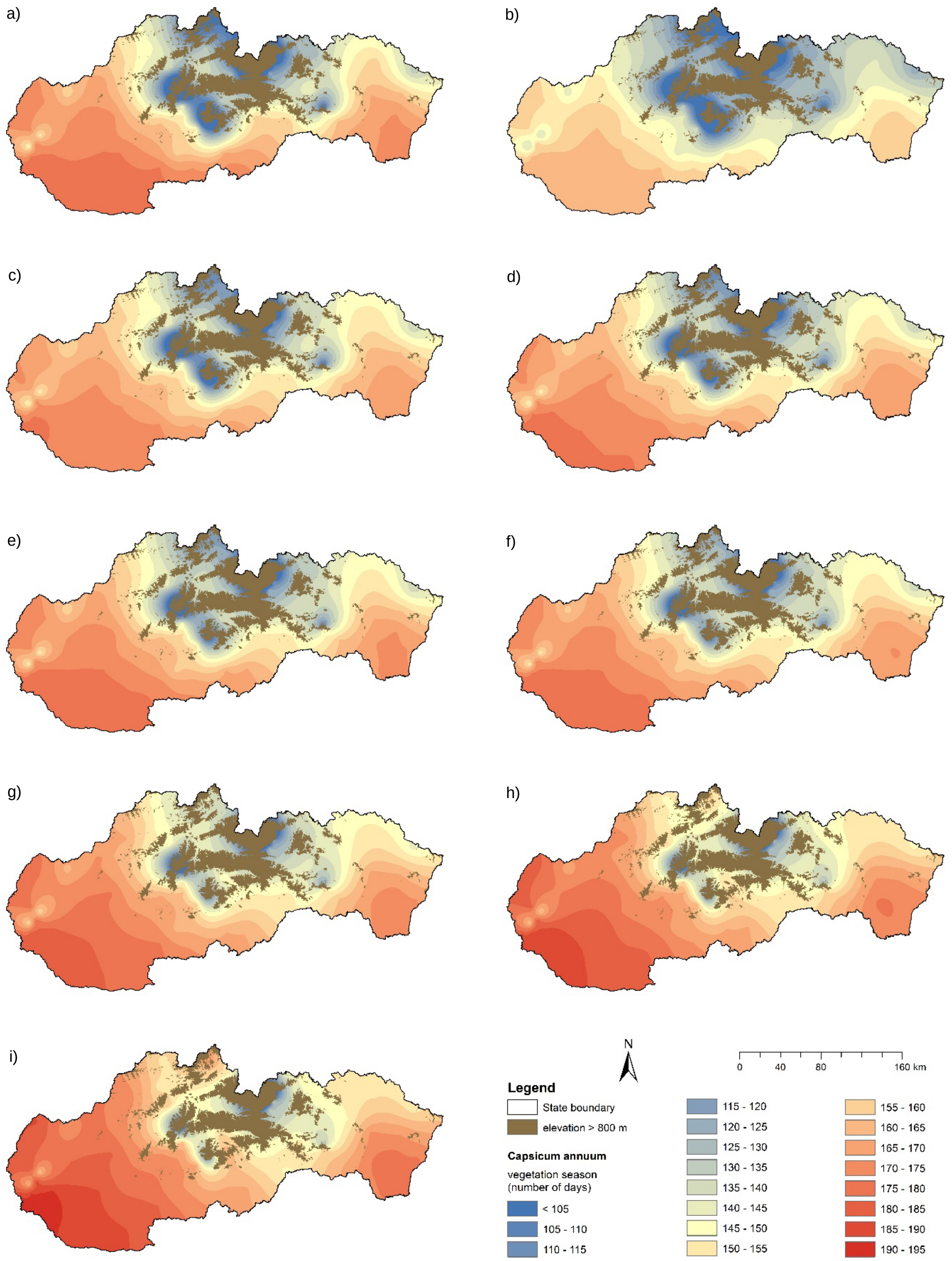

Fig. 2. Vegetation period (number of days) of *Capsicum annuum* in decades 1961–2100: a) 1961–1970, b) 1971–1080, c) 1981–1990, d) 1991–2000, e) 2001–2010, f) 2011–2020, g) 2041–2050, h) 2071–2080, i) 20191–2100; source: own study

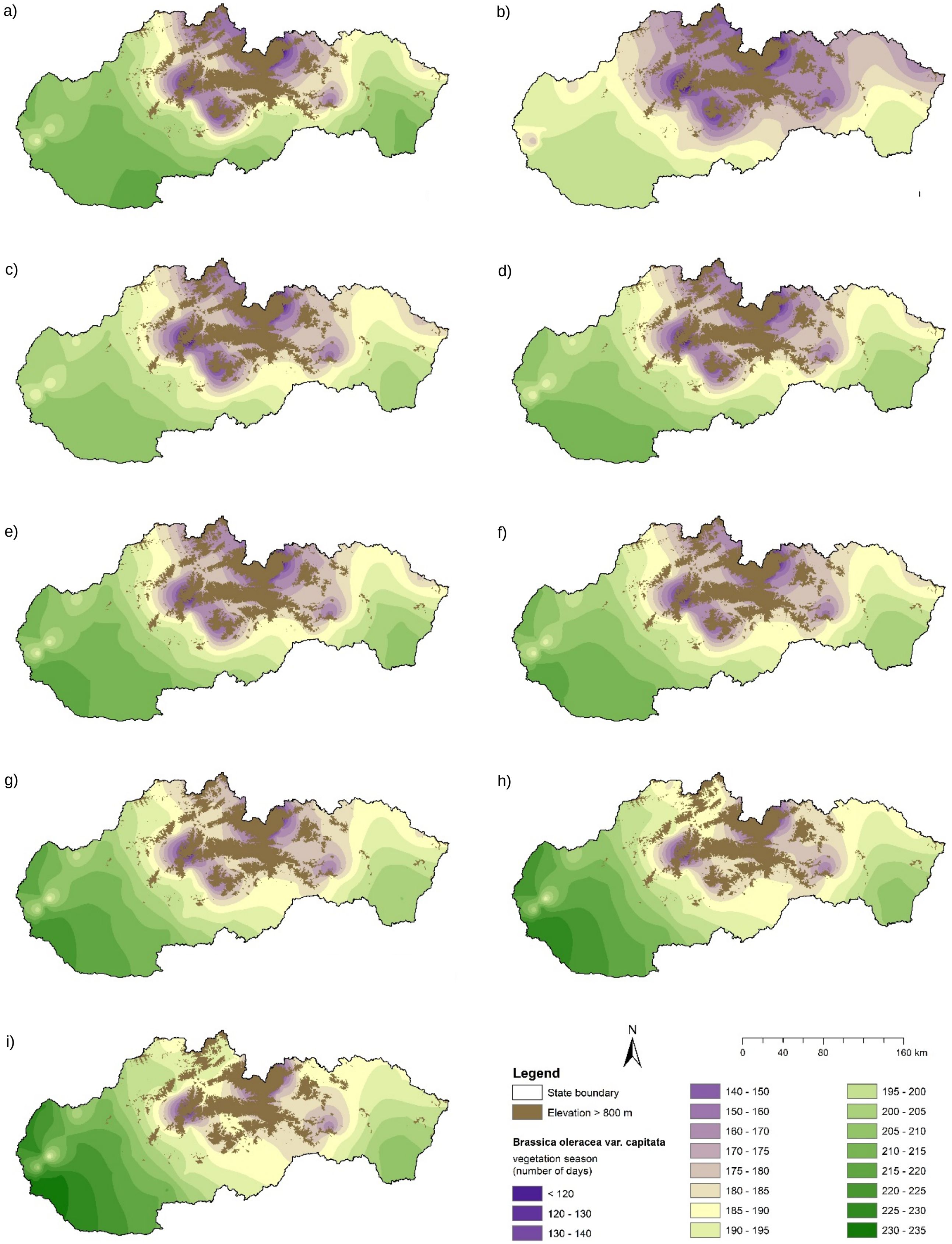

Fig. 3. Vegetation period (number of days) of *Brassica oleracea var. capitata* in decades 1961–2100: a) 1961–1970, b) 1971–1080, c) 1981–1990, d) 1991–2000, e) 2001–2010, f) 2011–2020, g) 2041–2050, h) 2071–2080, i) 20191–2100; source: own study

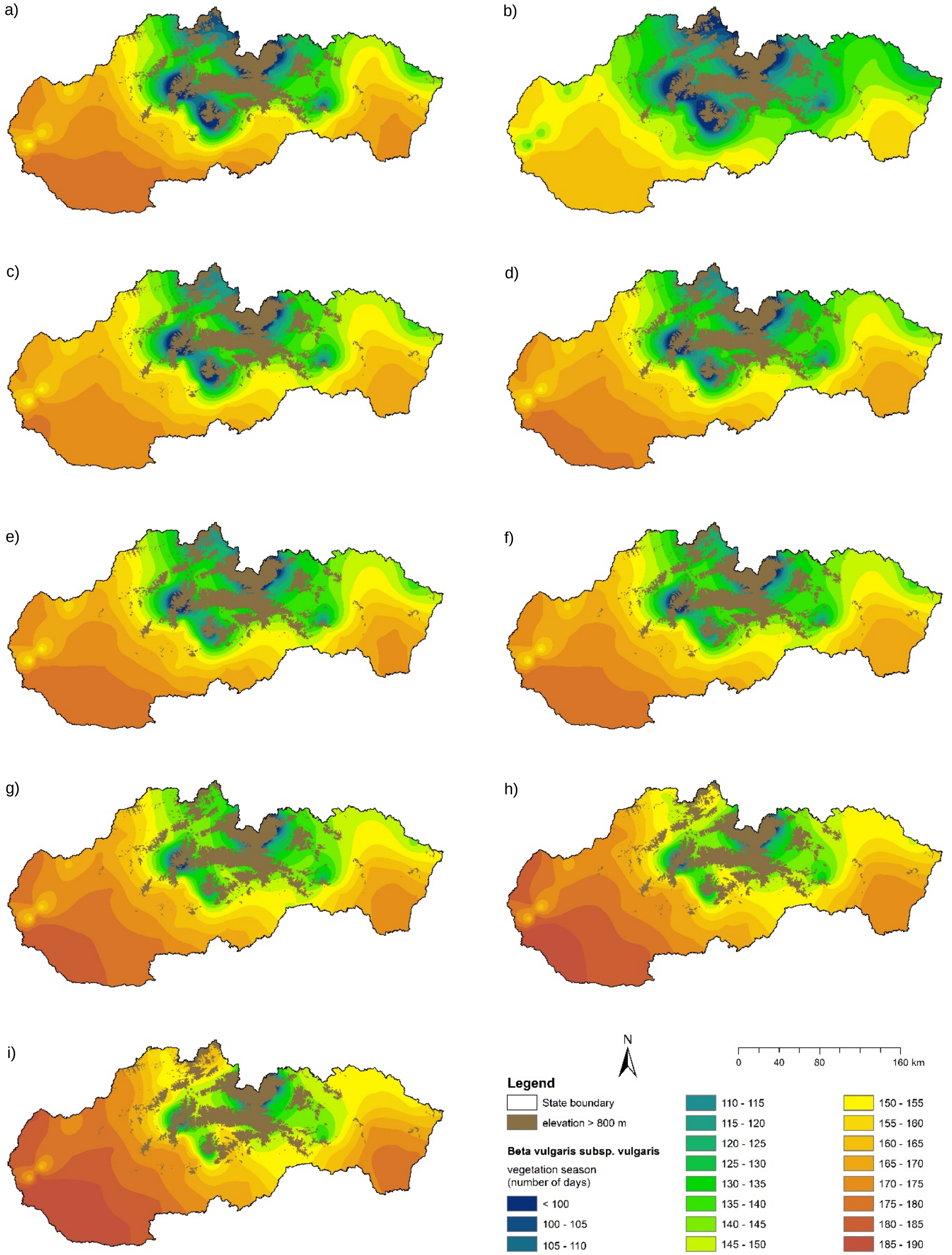

Fig. 4. Vegetation period (number of days) of *Beta vulgaris subsp. vulgaris* in decades 1961–2100: a) 1961–1970, b) 1971–1080, c) 1981–1990, d) 1991–2000, e) 2001–2010, f) 2011–2020, g) 2041–2050, h) 2071–2080, i) 20191–2100; source: own study

Change of vegetation period for fruit, *Brassica* and root vegetable in field conditions was also analysed by ŠPÁNIK *et al*. [2007]. They used global model of general circulation of atmosphere CCCM 2000 (Canadian Climate Centre Model). Their analysis predicts about 21–26% extension of vegetation period of analysed species of vegetables in 2075 in localities Hurbanovo and Liptovský Hrádok.

SAR *et al*. [2019] evaluated the vegetation period according to climate change scenarios (RCP 4.5 and RCP 8.5) in the Inner West Anatolia Subregion. Vegetation period in this locality may increase by 15–20 days and 40 days, respectively. According to OLSZEWSKI and ŻMUDZKA [2000], the length of the vegetative period increases at the rate of 1 to 3 days per decade. This is most probably connected with the acceleration of the beginning of vegetation by approximately 0.5 to 1.5 days per decade, coupled with the delay of its termination by approximately 0.5 to 1.5 days per decade.

According to WALTHALL *et al*. [2012] changes in temperature have varied by season as well as by region. During the most recent decades, the cooling of the south-east has slowed and then reversed, particularly in the cold seasons. Summer has warmed in most areas, but not as pronounced as winter. Spring is also warmer in most regions, likely related to more rapid melting of snow. In much of the United States, the century-long linear trend for autumn is still largely dominated by the warming in the 1930s and 1940s, and therefore the long-term trends remain small, with the south-west a notable exception. This overall warming is reflected in a lengthening of the vegetation period in the Northern Hemisphere by about 4 to 16 days since 1970 (i.e., 1 to 4 days per decade).

Based on the presented results, climate change must be understood comprehensively and in the sense of the "United Nations Framework Convention on Climate Change". Measures need to be sought to exploit the positive effects on the one hand and to reduce the negative effects of climate change on the other.

In the field of horticultural production, the recommendations are directed mainly at reworking of vegetable growing technologies, reworking of agro-climatic zoning of special horticultural plants, reworking of breeding plans, water regime regulation, focus on biological plant protection and reworking of integrated protection, reworking of management of the horticultural production and dissemination of knowledge on climate change.

CONCLUSIONS

The paper analyses the changes of vegetation period of selected vegetable (*Capiscum annuum*, *Brassica oleracea var. capitata* and *Beta vulgaris subsp. vulgaris*) grown under sowing conditions caused by climate change.

Agroclimatic analyses have shown an earlier onset of the vegetation period in spring, but also its delay in the last 30 years. *Capiscum annuum* vegetation period in the horizon 2091–2100 is expected to increase compared to the present by an average of 15–20 days, for *Brassica oleracea var. capitata* by 15–20 days, for *Beta vulgaris subsp. vulgaris* by 10–15 days.

The results and map outputs can be used as a base material for adaptation measures, in agronomic practice, breeding intentions, constructing irrigation systems, crop protection and nutrition and similar analysed vegetables.

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