Impacts of potential climate change on damaging frost during growing season of vegetable crops in Elbe River Lowland (Polabí)

Vera Potop[1], Pavel Zahraniček[2], Luboš Türkott[1], Petr Štěpánek[3]

[1] Czech University of Life Sciences Prague, Faculty of Agrobiology, Food and Natural Resources, Department of Agroecology and Biometeorology, Prague, Czech Republic; [2]Global Change Research Centre AS CR, Bědila 986/4a, 603 00 Brno, Czech Republic; [3]Czech Hydrometeorological Institute, Kroftova 43, Brno 616 00, Czech Republic

Abstract. The Elbe River Lowland has experienced a decrease in the number of frost days, while the length of the frost-free period between the last spring frost and the first fall frost has increased. A longer frost-free period can be particularly beneficial for thermophile vegetables (e.g., tomato, eggplant, pepper and melon) in lowlands. The daily minimum air temperature from 116 grid points throughout the studied area for the current (1961-2000) and two future climates under A1B SRES scenario (2021-2050 and 2071-2100) was used. As a result, for the current climate (1961-2000), the dates of the last spring frost have advanced by 2-day per decade on average. The respective fall dates are delayed up to 1.8 days per 10 years, whereas the frost-free period is lengthening by up to 3.7 days per 10 years on average. The average and earliest the first mild fall frosts in 1961−2000 were October 19 and September 26, respectively. The last mild spring frost occurred most frequently between April 23 and May 13 in the current climate. The average the length of frost-free period was 178 days. Under projected future climates, for the entire study region dominant dates of the last spring frost significantly advanced (i.e., occurred earlier) compared to the current climate. The first fall frost will be significantly delayed (i.e., occurred later) under the climate change scenario compared to the current climate (1961-2000).

Key words

Thermophile vegetables, climate change, spring and fall frosts

Introduction

The accelerated rates of change observed in the past three decades indicate that "in a near future we will see large changes in ecosystems; latitudinal/altitudinal extension of species' range boundaries by establishment of new local populations and, consequently, extinction of low latitude/altitude populations; increasing invasion of opportunistic, weedy and/or highly mobile species; progressive decoupling of species interaction (e.g. plants and pollinators) because of out-of-phase phenology" (Hughes, 2000).

The Elbe River lowland is the traditional name for a lowlands region located in Bohemian plateau (Česká tabule). The analysis was performed throughout Bohemian plateau with regard to a possible extension of growing vegetables outside the traditional area of the Elbe River lowland. Bohemian plateau are following landforms: tablelands, valley and hills. The vegetable growing areas are found in the all of these landforms with regard to the climatic requirements of vegetables. As an example can be mentioned areas with the widespread cultivation of cabbage (*Brassica oleracea* L) on the border of Jičínská pahorkatina and Východočeská tabule (Potop et al., 2013a). Thereby, a wide assortment of vegetables grown in the studied region has been divided into three basic types according to their sensitivity to low temperatures: *thermophilic vegetables* (heavy damage to plants in all development stages), *cold-resistant vegetables* (can tolerate a short period of decreasing temperature slightly below 0°C) and *frost-resistant vegetable* (can tolerate a frost less than -2.2°C depending on development stage) (Potop et al., 2013d). *Thermophilic vegetables* (e.g., tomato, pepper, pumpkins and cucumber) from an agronomic point of view should be planted before 15 May, considering risk (Potop et al., 2013c). During the sowing/planting of *cold-resistant vegetables* (e.g., early kohlrabi, summer savoy cabbage, late cauliflower, late cabbage, late carrots and celeriac), a severe last spring frost after April 15 has occurred every second year at higher altitudes. The date of planting/sowing of *frost-resistant vegetables* (e.g., onion, root parsley) in the Czech Republic corresponds with the end of March, and a gradual shift occurs from the hottest regions of South Moravia towards the Elbe region.

The objective of this study was to assess the potential changes in dates of spring and fall frosts for three frost severities and the length of frost-free period in the Elbe River Lowland based on the regional climate model ALADIN-Climate/CZ simulated data.

Material and methods

Frost-free period indicators were determined using the inclusive threshold of 0°C for daily minimum temperature from 116 grid points throughout the studied area for the current (1961-2000) and two future climates under A1B SRES scenario (2021-2050 and 2071-2100) (Figure 1).

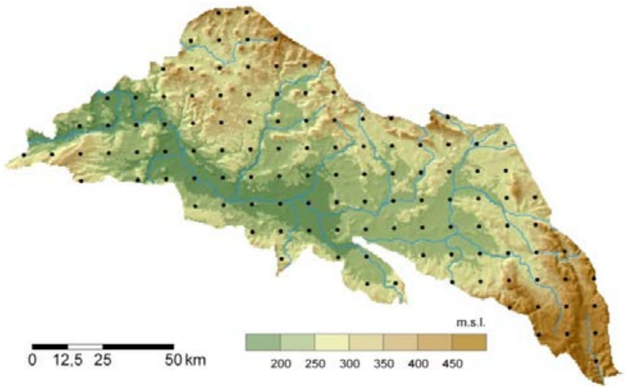

Figure 1. *Location of the 116 grid points and their elevation (m a.s.l.) situated in the Elbe River Lowland.*

In the present study, a regular gridded network (CZGRIDS, ALADIN-Climate/CZ) from the Czech Hydrometeorological Institute (CHMI) was applied. The daily values of minimum air temperature ranges of 0°C to −1.1°C, −1.2°C to −2.2°C, and below −2.2°C were considered to constitute mild, moderate, and severe frosts intensities, respectively. Using these definitions, the last three spring and first three fall frosts were specified for the spring and fall of each year.

The last spring frost day is defined as the last date in a year on or before 15 July on which the daily minimum temperature Tmin ≤ 0°C. The first fall frost day is defined as the first date in a year on or after 16 July on which Tmin ≤ 0°C. The frost free-period is the number of days between the last spring frost and the first fall frost.

For each grid-point and for each year, the first and the last frost day and the frost-free period were identified. The spatial interpolation of the frost temperature occurrences for 116 grid-points with a horizontal resolution of 10×10 km ranges between the longitudes 13.7°E and 16.5°E and the latitudes 49.6°N and 50.8°N. The lowest and highest altitudes of the gridded dataset were 169 m and 573 m above sea level, respectively.

The regional climate model (RCM) ALADIN-Climate/CZ was adopted to assess and project level risk of the last spring frost (first fall frost) and the length of the frost-free period during growing season of vegetable crops under future climates (2021-2050 and 2071-2100) in Bohemian plateau.

The ALADIN-Climate/CZ model is run in the CHMI and became of the basis RCM for impact studies in the Czech Republic. The SRES scenario A1B is used as a baseline scenario referred to in IPCC (2007). Moreover, the performance of the Czech regional climate model ALADIN-Climate/CZ in comparison to the other RCMs is satisfactory solution to use in impact studies (Huth et al., 2004; Farda et al., 2007; Štěpánek et al., 2008; Holtanová et al., 2012). They found that ALADIN-Climate/CZ performed very well in simulating temperature-related statistics over the Czech Republic. The model is well capable to capture the main features of the present climate in the Czech Republic (Farda et al., 2007) and is working well even over the smaller areas with a rather complex orography represented here by the territory Bohemian plateau. However, it should be always kept in mind that model simulations of future climate are affected with many uncertainties, and it is necessary to apply some kind of post-processing of model outputs the RCM simulation are used for further application.

First, the observed data of air minimum temperature was transferred into a regular grid of ALADIN-Climate/CZ model. The ALADIN-Climate/CZ simulations forced with the ARPEGE global circulation model (GCM) have been corrected against the systematic errors induced by the GCM. The bias correction was applied on the scenario runs. The bias correction method is based on variable correction using individual percentiles whose relationship is derived from observations and control RCM simulation (Dequé 2007). After the correction, the model outputs (2021-2050 and 2071-2100) are fully compatible with gridded observation dataset (1961-2000).

Air temperature is the most important agro-climatic characteristic, which determines the suitability of field vegetable crops due to its relationship with the length of the growing season. In Table 1 shows overview on the length of growing period of thermophilic vegetable crops. The growing periods are distinguished as being the time from sowing until harvest (S-H) or the time from planting until harvest (P-H). For example, 3 – 5 months means from sowing/planting to first harvest/last harvest.

Table 1. *Overview on the length of growing period of thermophilic vegetable crops.*

	Growth period	Planting or sowing period (month)
***Solanum lycopersicum* L.** (Tomato)	*S - H 4-5 months*	<u>*Bush tomatoes for industrial processing:*</u> (a) 10 – 25 April (direct sowing); (b) Sometimes pre-cultivation (like indeterminate tomatoes) for prolongation of harvest period;
	P – H 3-5 months*	<u>*Indeterminate Tomato and cultivars of bush tomatoes for fresh market:*</u> a) half of March – sowing in greenhouse than outplanting b) end of April – half of May (cowered with non-woven textile) c) second half of May (without cowering)
***Solanum melongena* L.** (Eggplant)	*P - H 2- 4 months*	Sowing end of January – beginning of February in greenhouse, than outplanting on field in second half of May
***Capsicum annuum* L.** (Pepper)	*P - H 2- 4 months*	Sowing till 20 February in greenhouse, than outplanting on field in second half of May
***Cucurbita pepo* L.** (Pumpkins)	*2-4 months*	Direct sowing – half of May Precultivation – sowing in greenhouse end of April, than outplanting after 3 weeks
***Cucumis sativus* L.** (Cucumber)	*2.5- 5 months*	<u>Pickling cucumber:</u> direct sowing – end of April – beginning of May (alternative till beginning of June)
***Cucumis melo* L.** (Melon)	*4-5 months*	Sowing in greenhouse (April), outplanting on field (May – June)

Results and discussion

The mean, latest and earliest occurrence of the last spring frost and the first fall frost, and length of the frost free-period for current climate (1961-2000) are given in Table 2. The mean date of occurrence of the last mild spring frosts in

Bohemian plateau is on day 113 (23 April). The mean dates of the last spring frost with moderate and severe intensity were April 14 and April 9, respectively. On regional average frost series, the earliest last mild, moderate and severe spring frosts occurred on day 91(1 Apr), 87 (28 Mar) and 76 (17 Mar), respectively. The latest mild frosts occurred on day 133 (13 May). According to these results, the highest risk for field vegetables is a late spring frost. The mean date of occurrence of the first mild, moderate and severe fall frosts occurred on day 292 (19 Oct), 301 (28 Oct) and 306 (2 Nov), respectively. The earliest first mild fall frosts occurred on 26 September and the latest onset was November 6.

Frosts with a higher intensity occurred later, and the earliest beginnings of the moderate and severe frosts were on 7 October and 9 October, respectively, whereas the latest onsets of moderate and severe frosts fell at the end of fall season on November 29 and 30, respectively.

In the studied region, there were years with a possible extension of the growing season for frost-resistant vegetables, allowing distribution of the harvest. According to Table 2, on average, the length of the frost free-period in the studied area ranges from 143 to 217 days. The average length of the frost-free period was 178 days, almost half of the year.

Table 2. *The date of the last spring frost and the first fall frosts for three frost severities (mild, moderate and severe) and the length of frost-free period for current climate (1961-2000).*

	Median	Earliest	Latest
spring			
Last mild frost	23 Apr	1 Apr	13 May
Last moderate frost	14 Apr	28 Mar	8 May
Last severe frost	9 Apr	17 Mar	1 May
fall			
First mild frost	19 Oct	26 Sep	6 Nov
First moderate frost	28 Oct	7 Oct	29 Nov
First severe frost	2 Nov	9 Oct	30 Nov
Frost-free period	178	143	217

The projects of the date of occurrences of the last spring frost and the first fall frosts for three frost severities (mild, moderate and severe) and the length of frost-free period for two future climates (2021-2050 and 2071-2100) over Bohemian plateau are presented in Table 3. Under projected future climates, for the entire study region dominant dates of the last spring frost significantly advanced (i.e., occurred earlier) compared to the current climate. The mean date of the last mild spring frosts will be projected on day 99 (9 April) for the A1B scenario (2021-2050) and on day 88 (29 March) for the period 2071-2100. The latest mild frosts could be occurred on day 111 (21 April) during 2021-2050 and on day 106 (16 Apr) during the period 2071-2100.

The first fall frost will be significantly delayed (i.e., occurred later) under the climate change scenario compared to the current climate. The earliest and mean dates of the first mild fall frost for the period 2021-2050 will be projected on day 283 (10 October) and on day 313 (9 November), respectively. The delay will be greatest during the period 2071-2100, when the earliest date of the first mild fall frosts occurring October 27, compared to September 26 in the current climate.

An early ending of spring, together with the late onset of fall frosts provides suitable conditions for sowing/planting of field vegetables, as well as their ripening and harvesting. The late onset of fall frosts extends the growing season of field vegetables. ALADIN-Climate/CZ simulation projected increases of the length of the frost-free period (Table 3). Under A1B scenario, the shortest and longest length of the frost-free period varies between 173 and 239 days for the period 2021-2050 and between 201 and 271 days for the period 2071-2100.

Table 3. *Projects of the date of the last spring frost and the first fall frosts for three frost severities (mild, moderate and severe) and the length of frost-free period for two future climates (2021-2050 and 2071-2100) over Bohemian plateau.*

	Median	Earliest	Latest
2021-2050 (A1B scenario run)			
Last mild frost	9 Apr	23 Mar	21 Apr
Last moderate frost	31 Mar	17 Mar	13 Apr
Last severe frost	28 Mar	13 Mar	10 Apr
First mild frost	9 Nov	10 Oct	28 Nov
First moderate frost	18 Nov	17 Oct	13 Dec
First severe frost	20 Nov	20 Oct	20 Dec
Frost-free period	213	173	239
2071-2100 (A1B scenario run)			
Last mild frost	29 Mar	6 Mar	16 Apr
Last moderate frost	17 Mar	17 Feb	12 Apr
Last severe frost	14 Mar	21 Jan	9 Apr
First mild frost	13 Nov	27 Oct	10 Dec
First moderate frost	22 Nov	4 Nov	18 Dec
First severe frost	23 Nov	5 Nov	19 Dec
Frost-free period	228	201	271

This study can be considered as an initial step towards assessment of the potential impacts of climate change on the assortment of vegetable crops growing in the Elbe River lowland. In our future work, we plan to compare the ALADIN-Climate/CZ simulation of growing season events to different sets of RCMs and to develop field vegetable crop growth model.

Increased temperatures advanced the last spring frosts and delayed the first fall frosts under A1B scenario. With earlier the last spring frosts, logically, sowing/planting dates of vegetable crops should be adjusted earlier, although soil temperature and moisture also need to be considered. Likewise, the predicted longer growing season (computed by using daily mean temperatures for three thresholds: Tmean≥5, 10 and 15°C) due to climate change would enable a production shift to cultivars and vegetable types that are not currently suitable under the current frost-free period. A more detailed results and discussing are provided in Potop et al. (2013 e).

There is no doubt that a complete prevention of frost damages to farms is impossible; however, it would be possible to minimize the frost damages with appropriate management of cropping pattern based on occurred frost events. In Polabí, late spring frosts cause considerable damage to early types of vegetables, and delay the start of harvesting. To achieve high production of thermophile vegetables (e.g., tomato, pepper, and cucumber), growers must sowing so that the crops is not at a sensitive stage when frost is most likely occur or planting after ending of a later spring frost (e.g. Petříková and Malý, 2003; Potop et al 2013 b, c, d). It is essential to closely monitor the occurrence of frosts in Polabí to minimise the risk of frost damage.

Conclusions

In this study a temporal evolution of frost events for the current climatic conditions (1961-2000) and possible changes in the near future (2021-2050) and at the end of the century (2071-2100) have been undertaken using both the observed gridded data and ALADIN-Climate/CZ simulation data over Polabí.

Damaging frosts are an important constraint to vegetable production in this region and the rising temperatures are predicted to have significant effects of the last spring frost, first fall frost and frost free-period. The last spring frost is expected to occur earlier while the first fall frost is expected to be later over the entire region. As a result, frost free-period is anticipated to become longer. ALADIN-Climate/CZ simulation projected to increase the the frost free-period; however, a high inter-annual variability is preserved as well as in current climate.

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References

Dequé, M., 2007: Frequency of precipitation and temperature extremes over France in an anthropogenic scenario: Model results and statistical corrections according to observed values. *Global and Planetary Change*, 57, 16–26.

Farda, A., Štěpánek, P., Halenka, T., Skalák, P., Belda, M. 2007: Model ALADIN in climate model forced with ERA40 reanalysis (coarse resolution experiment). *Meteorological journal*, 19, 123-130.

Holtanová, E., Mikšovský, J., Kalvová, J., Pišoft, P., Motl, M., 2012: Performance of ENSEMBLES regional climate models over Central Europe using various metrics. *Theor Appl Climatol*,108, 463-470.

Huth, R., Kyselý, J., Pokorná, L., Farda, A., Mládek, R., Kliegrová, S., Metelka, L., 2004: One month-long integrations of the Aladin model in the climate mode: effect of selected parameters. *Meteorological Bulletin* **57**: 41-46. (in Czech)

Hughes, L., 2000: Biological consequences of global warming: is the signal already apparent? *Trend Ecol Evol*, 15, 56–61.

Petříková, K., Malý, I., 2003: Fundamentals of growing fruit vegetables. Institute of Agricultural and Food Information. Prague. 50 p.

Potop, V., Türkott, L., Zahradníček, P., Štěpánek, P., 2013 a: Evaluation of agro-climatic potential of Bohemian plateau (České tabule) for growing vegetables. Meteorological Bulletin, 66 (2), 42–48.

Potop, V., Türkott, L., Zahradníček, P., Štěpánek, P., 2013 b: Temporal variability of late spring and early autumn frosts during growing season of vegetable crops in Elbe River lowland (Polabí). *Meteorological Bulletin*, (in printing).

Potop, V., Zahradníček, P., Türkott, L., Štěpánek, P., 2013 c: Spatial variability of late spring and early autumn frosts for different severity during growing season of vegetable crops in Elbe River lowland (Polabí). *Meteorological Bulletin*, (in printing).

Potop, V., Zahraniček, P., Türkott, L., Štěpánek, P., Soukup, J., 2013 d: Risk analysis of the first and last frost occurrences during growing season of vegetables in the Elbe River lowland. *Jdojaras*. (in printing).

Potop, V., Zahraniček, P., Türkott, L., Štěpánek, P., Soukup, J., 2013 e: Potential impacts of climate change on damaging frost during growing season of vegetables. *Scientia Agriculturae Bohemica*.(under review)

Štěpánek, P., Skalák, P., Farda, A., 2008: RCM ALADIN-Climate/CZ simulation of 2020-2050 climate over the Czech Republic. In: Rožnovský, J., Litschmann, T. (eds): Bioclimatology aspects of the evaluation process in the landscapes (Mikulov 9. – 11.9.2008). CD-ROM. ISBN 978-80-86690-55-1.