# CLIMATE CHANGE AND ITS IMPACT ON THE CONDITIONS OF LATE BLIGHT OCCURRENCE*

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The paper is focused on the evaluation of trends in weather indicators influencing conditions for late blight occurrence, and subsequently on trends in the first treatment forecasts, number of infections, and number of infection days. The processing covering the period 1975–2016 was done with a higher density of points for the Czech and Slovak Republics and a lower density for European regions with more important distribution of potato growing on arable land. The obtained results show an unambiguous statistically significant trend in the increase of minimum temperature by around 0.5°C per 10 years; contrarily, no more significant trends were recorded for air humidity. For precipitation no statistically significant decreases were found at any of the processed localities, increases were rarely detected. Considering the number of days with precipitation, for the western part of the studied territory rather increases, while for the eastern part stagnation, and for Ukraine decrease in days with precipitation were recorded. Trends in the processed characteristics using the index method of late blight indicate a statistically more significant earlier onset of the first treatment especially at Czech localities; however, at most localities a slight increase in the number of infection periods and in the number of days with infection pressure was found.

potato, *Phytophthora infestans,* weather, Europe

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## INTRODUCTION

In recent decades, climate changes have been a matter of concern not only for climatologists, but also for farmers, water managers, politicians, and many other disciplines. We can expect that the changes have already affected and will virtually probably more affect all fields of human activity in the future. Climatology, previously rather a statistical and descriptive science, has recently become a dynamically developing scientific discipline that provides background materials and outputs from climate models for many other scientific branches. At present, a whole series of specific studies arises, focused on the changing distribution or frequency of occurrence of various plant pathogenic organisms. To model the development for poikilotherms, whose life processes are largely influenced especially by environment temperature, data on air temperatures are mostly sufficient (Gautam et al., 2013). In fungal diseases it is more complicated; the life cycle of fungi in various phases is not only affected by temperature, but also by air humidity and/or the presence of free water on the host plant surface (Hijmans et al., 2000). Potato late blight caused by *Phytophthora infestans* (Mont.) de Bary belongs to pathogens with a relatively strong dependence of pathogen development on weather conditions. Infections only occur, when water film is present on the surface of plant organs or plant parts and under suitable temperature conditions. Further progress of the disease also takes place under favourable moisture (high relative air humidity, surface wetness caused by precipitation, dew, fog or artificial irrigation) and temperature conditions. Therefore many mathemati-

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Table 1. Overview of used points

| Point No. in AGRI4CAST database | Latitude (°N) | Longitude (°E) | Altitude (m a.s.l.) | Country |
|---|---|---|---|---|
| 118156 | 53.35345 | 27.72079 | 163 | BE |
| 116146 | 53.40295 | 23.87648 | 150 | BE |
| 108147 | 51.6005 | 23.68081 | 167 | BE |
| 100123 | 50.49861 | 14.81687 | 296 | CZ |
| 96123 | 49.60166 | 14.72719 | 487 | CZ |
| 96125 | 49.57065 | 15.4172 | 499 | CZ |
| 98133 | 49.85103 | 18.24357 | 257 | CZ |
| 98123 | 50.05018 | 14.7715 | 256 | CZ |
| 93129 | 48.82472 | 16.70206 | 188 | CZ |
| 121149 | 54.3642 | 25.38424 | 191 | LT |
| 125139 | 55.66658 | 21.83844 | 107 | LT |
| 108094 | 52.23336 | 4.48718 | 1 | NL |
| 111139 | 52.56669 | 20.98341 | 103 | PL |
| 117134 | 54.05694 | 19.4434 | 28 | PL |
| 104132 | 51.21493 | 18.12684 | 181 | PL |
| 113125 | 53.37761 | 15.88971 | 127 | PL |
| 101146 | 50.09785 | 22.88415 | 202 | PL |
| 95140 | 48.98247 | 20.50961 | 553 | SK |
| 97136 | 49.54795 | 19.23643 | 503 | SK |
| 89134 | 47.81652 | 18.24688 | 117 | SK |
| 109118 | 52.57917 | 13.19488 | 40 | DE |
| 112106 | 53.28941 | 8.74793 | 16 | DE |
| 93149 | 48.21191 | 23.41949 | 194 | UK |
| 103160 | 49.88092 | 27.82054 | 261 | UK |
| 99154 | 49.31201 | 25.48272 | 336 | UK |

cal models were constructed, putting into dependence temperature and moisture conditions in relation to late blight progress (Forbes, Simon, 2007). Since it is a relatively complex event, influenced by factors in which the ongoing climate change is expressed in different ways, the resulting trends in the development of late blight importance in European conditions could not be a priori derived.

The aim of the paper is to evaluate, at first, climatic trends in critical weather indicators influencing late blight occurrence and then, after the assessment of those factors using the index method for late blight, to assess also the trends in changes of the first treatment forecast and intensity of infection conditions during growing season. The processing covers the broader territory of Europe with dominant distribution of potato growing on arable land, i.e. especially the belt stretching from the North Sea through the Baltics to Ukraine. Higher attention is paid to relations in the Czech (CR) and Slovak Republics (SR), although at most localities of these countries potato growing is not so largely distributed as in the above mentioned belt. The processing involves a 42-year period since 1975 to 2016 during which the climatic events were most pronounced.

## MATERIAL AND METHODS

In most late blight forecasting models values of basic weather indicators, including air temperature, relative air humidity, and precipitation serve as input data. A more detailed overview of these so far used models gave e.g. Litschmann et al. (2014a). For this paper a newly constructed and validated index was used, described e.g. by Litschmann et al. (2015). Input data of this index involve values of minimum air temperature, relative air humidity, and daily precipitation total. Compared to other systems, the advantage of the index consists in providing more reliable forecasts of the first fungicide application against late blight. In addition, it is relatively unassuming as regards input data and usually measured weather indicators have been sufficient not only at present, at a time of automated stations, but also in the past, when majority of meteorological measure-

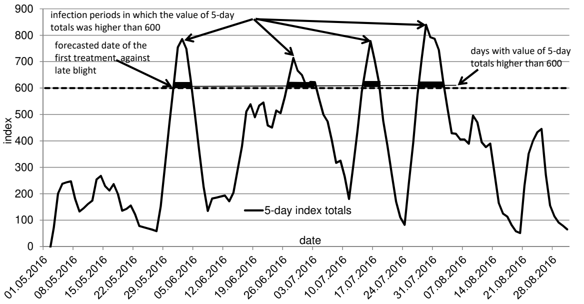


Fig. 1. Demonstration of late blight index calculation for point No. 104132

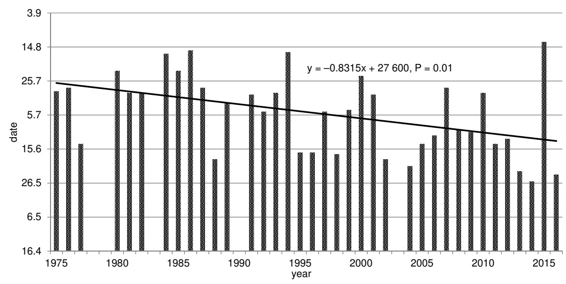


Fig. 2. Change in the date of the first treatment forecast (point No. 96123)

ments were manually done. Since the aim of the study is the processing of trends in used weather parameters essentially influencing emergence, development, and distribution of potato late blight and their subsequent assessment using the index method on a wider European scale, required data were derived from the database developed within the project AGRI4CAST by the Joint Research Centre (JRC), a Directorate-General of the European Commission under the responsibility of Commissioner for Education, Culture, Youth and Sport. This database provided daily values of all measures necessary for the construction of late blight index for individual points in a 25 × 25 km grid for the period 1975–2016. Being official, the source data may be taken as correct and fully reliable.

Although potatoes are a crop virtually grown in almost all climatic regions with conditions favourable for agriculture, the main potato distribution is in colder regions, where they are able to provide higher economic returns than other crops. For this study in total 25 points were processed, especially situated in the regions with more significant share of potato growing on total area of arable land. These points are a representative selection covering major production regions of the Netherlands, Germany, Poland, Ukraine, and Belarus. In the case of the CR and SR, regions were selected with lower share of potato area on the whole acreage of arable land. The points are listed in Table 1.

For each point linear trends of the following characteristics were calculated from May to August (main period of late blight occurrence) 1975–2016:

(1) basic weather indicators: minimum air temperature, mean air humidity, precipitation total, number of days with precipitation; (2) derived indicators using the index method for late blight: forecasted date of the first treatment against late blight when the total index value in the last 5 days exceeded 600 for the first time in the season, infection periods in which the value of 5-day totals was higher than 600, days with the value of 5-day totals higher than 600.

Fig. 1 illustrates the course of 5-day index totals combined with marked individual characteristics used for the trends evaluating. Fig. 2 illustrates the assessment of the trend in forecast of the first treatment against late blight for point No. 96123 including the value of trend and significance level.

All trends determined by the least squares method were subsequently evaluated by Mann-Kendall test (Mishra et al., 2014) and $P = 0.001$, $P = 0.01$ or $P = 0.05$ significance level was assigned to the result. In the rest cases the trend was considered insignificant. All statistical operations were done in R statistical environment (Venables, Smith, 2016). For graphical processing MS Excel program was used.

Fig. 3 demonstrates significant trend in minimum temperatures at the $P = 0.001$ significance level for the point No. 96125.

## RESULTS

Results from the trend processing for individual indicators and points are presented in individual maps of the given territory (Figs. 4–10).

### Trends in weather indicators entering index calculation

**Mean minimum air temperature**. The air temperature is an indicator showing increasing values in last decades. Ceppi et al. (2012) analyzed 1959–2008 seasonal air temperatures in Sweden and found the high-

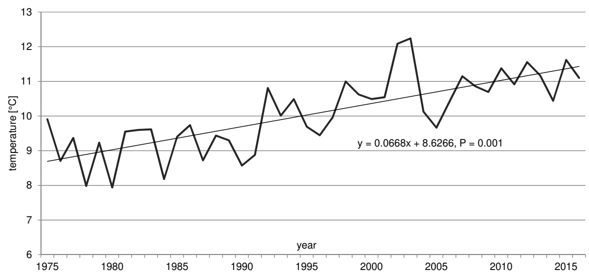


Fig. 3. Mean minimum air temperatures for V–VIII and overlaying with linear trend (point No. 96125 near Lípa near Havlíčkův Brod)

est values of trend for summer period (0.34–0.62°C per 10 years) and the lowest values for autumn (0.02–0.38°C per 10 years). For the territory of the CR Strestik et al. (2014b) mention the mean air temperature increase 1.5–2.25°C in summer for the period of 1961–2010. This corresponds to the mean increase of 0.3–0.45°C per 10 years. In winter the changes are smaller, the smallest changes are recorded for autumn. From the CR northwards the annual air temperature change is bigger than that in global temperatures for extratropical latitudes of the Northern Hemisphere.

Fig. 4 illustrates the trend in minimum air temperatures for the processed points from May to August.

**Precipitation totals**. Precipitation is related to potato late blight especially as a source of free water on leaf surface, enabling sporangium germination. In this case precipitation volume is not so critical, but rather the precipitation duration and duration of leaf wetness are important. However, higher precipitation totals result in increased soil moisture and as a consequence of this an increase in air humidity in canopy could occur. Compared to air temperatures, changes in precipitation totals during a longer period are characterized by higher spatial variability, indicating higher dependence on local agents. As referred by Strestik et al. (2014a), despite of the frequently repeated statement that global warming will bring less water and more drought to our regions, the course of precipitation totals in the last 50 years does not suggest this. On the contrary, annual precipitation

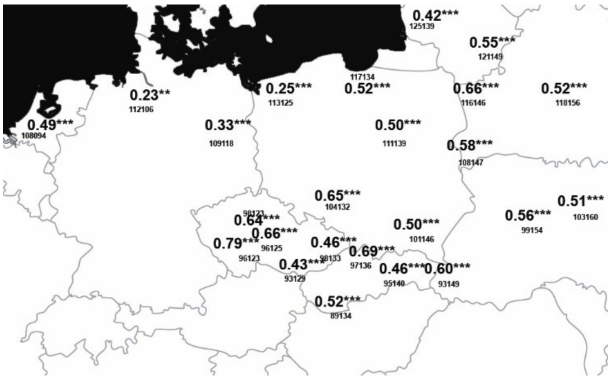


Fig. 4. Change in minimum air temperatures (°C per 10 years). The map illustrates numbers of individual points and trend range. The significance level is marked – insignificant trend, *P = 0.05, **P = 0.01, ***P = 0.001

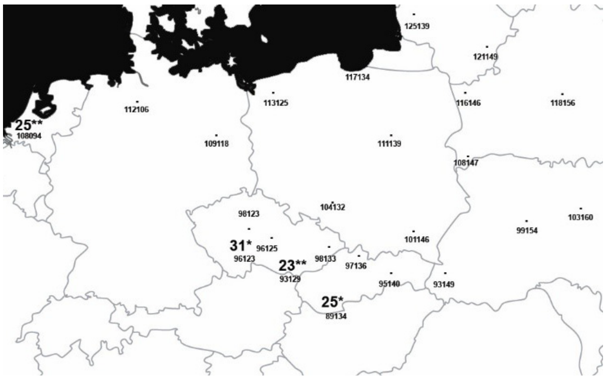


Fig. 5. Change in precipitation totals (mm per 10 years). For description see Fig. 4

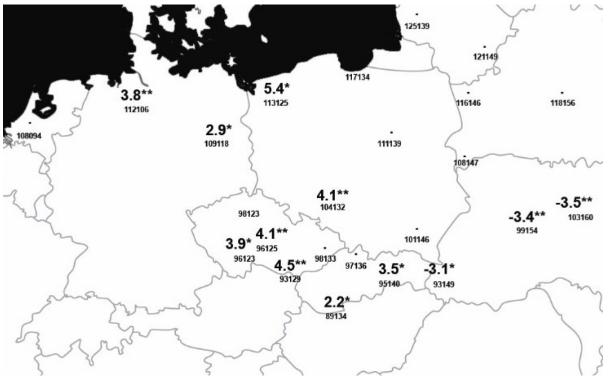


Fig. 6. Change in days with precipitation (days per 10 years). For description see Fig. 4

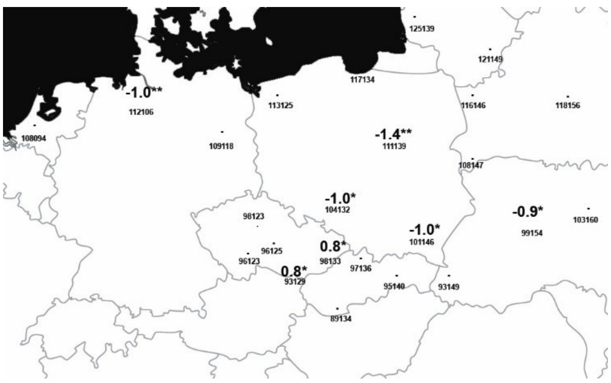


Fig. 7. Change in relative air humidity (% per 10 years). For description see Fig. 4

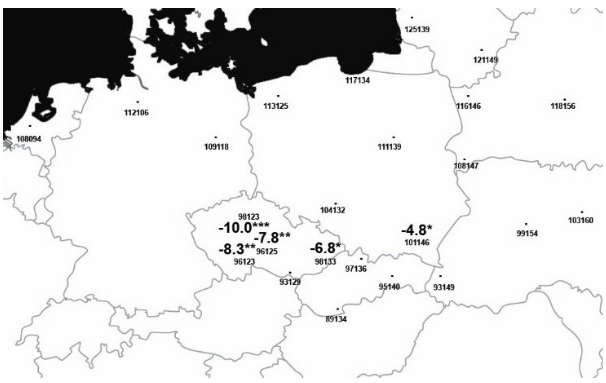


Fig. 8. Shift in the date of the first infection period occurrence (days per 10 years). For description see Fig. 4

totals for the whole CR have been slightly rising and nothing indicates any substantial changes in this trend for several following decades. This rising, mild and statistically insignificant, is not detected on the whole CR territory. In general, precipitation increase in the western part is more pronounced than the national mean, in the eastern part precipitation grows less and for several localities precipitation dropping has been recorded. For the European territory S t r e s t i k (2013) mentions that annual precipitation totals increased in Northern and Western Europe during the last century, whereas they dropped in Eastern and Southern Europe. Summer precipitation totals do not show any significant changes; a change in annual precipitation totals is induced by a change in winter precipitation totals. B r a z d i l et al. (2008) stated that changes of ± 5 mm per 10 years prevailed for month, seasonal, and annual linear trends in precipitation totals during 1961–2005. An insignificant trend toward precipitation increase is apparent for winter and autumn season and partly for spring.

Fig. 5 illustrates important changes in precipitation totals from May to August.

In addition to precipitation totals, for the development of suitable conditions for late blight the number of days with precipitation is important, since it increases the frequency of days with the presence of free water on leaves and simultaneously increases air humidity in canopy. When the other conditions are fulfilled, infection pressure is increased. Based on data presented in Fig. 6 it can be concluded that the changes in days with precipitation occur at more localities and they are statistically more significant compared to precipitation totals.

**Air humidity**. Air humidity combined with air temperature is highly significant in the life cycle of fungal diseases. Higher air humidity and higher temperatures are especially favourable for disease development (L i t s c h m a n n et al., 2014b). Changes in relative air humidity reflect air temperature changes and the content of water vapours in the atmosphere (B r a z d i l et al., 2008). They show a statistically significant trend to decreased air humidity in the half of processed stations in February, May, and August and in spring, while between October and December there is an apparent trend to higher air humidity. Trends in relative air humidity change are illustrated in Fig. 7.

#### Trends in derived characteristics using the index method for late blight

By processing the trends of several outputs derived by index calculation for late blight in individual years of the 42-year period considered we tried to find out to what extent the trends in the above mentioned input meteorological variables are reflected in the change of conditions for late blight development.

**Change in the date of the first infection period**. Based on L i t s c h m a n n et al. (2015), the first infection period, beginning on the date, when the total index in the last 5 days exceeds the value 600, indicates a suitable moment for the first fungicide treatment against late blight. This is similar to achieving values 18–20 in NoBlight system or 130–150 in 'negative prognosis' by U l l r i c h , S c h r o d t e r (1966). A shift in this date could result in prolonging or shortening the period of fungicidal protection and thus to cost saving or increase. Based on the model application of 'negative prognosis' and climate change scenarios Z a l u d et al. (2008) stated that by the year 2025 the date of the first fungicide treatment could have come by 4–6 days earlier for very early varieties and by 6–8 days earlier for medium-late varieties at four CR localities.

Fig. 8 illustrates a shift in the date of the first fungicide treatment for all 25 processed localities.

**Change in the number of infection periods**. The suitability of weather conditions for late blight development can also be expressed by the total number of infection periods from May to August. The infection period means a coherent time interval with values of five-day index totals above 600. An increasing number of infection periods could signalize higher frequency

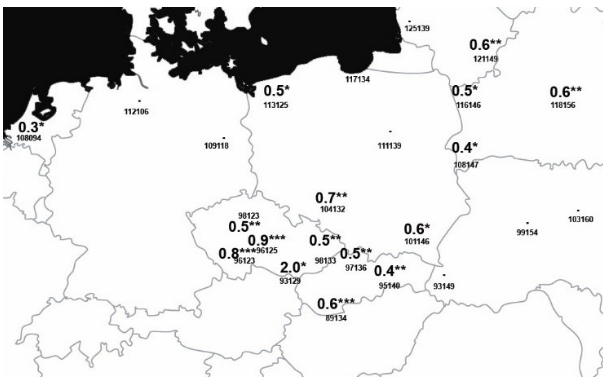


Fig. 9. Change in the number of infections (infections number per 10 years). For description see Fig. 4

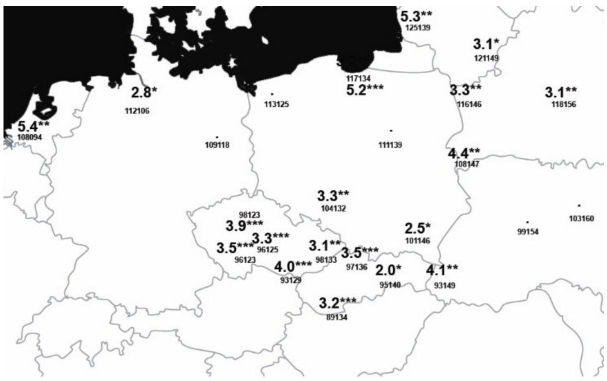


Fig. 10. Change in the number of days with infection pressure (days number per 10 years). For description see Fig. 4

of sprays with shortening the interval between individual treatments or using more intensive fungicides. For the same purpose, B a k e r et al. (2005) employed a number of five-day periods; during those the total of significance values reached 10. This parameter should express the frequency of periods with crop characteristics favourable for the development and penetration of late blight into tissues. In Great Lakes region of the USA a statistically significant trend was recorded at three out of seven localities, with an increase between 0.7 and 2.5 per 10 years. Fig. 9 illustrates changes in the number of infection periods for the processed region of Europe.

**Change in the number of days with infection pressure**. Change in the number of infection periods means a change in the number, but not in the duration. The number of days with infection pressure represents the total number of days from May to August with values of five-day index total exceeding 600. In those days more frequent late blight control is necessary in crops. For the same purpose, B a k e r et al. (2005) used the total of significance values in the growing season. Fig. 10 shows that the increase in the number of infection days approximately occurs at the same localities, where the number of infection periods is also increased.

## DISCUSSION

The results from the performed processing of trends in weather indicators influencing late blight occurrence and outputs from the calculated index in basic features are in relatively good consistency with the results obtained by other authors. However, the processing is done for a broader territory with various climatic conditions and the trends for late blight occurrence were obtained using another method, what shows that the newly constructed index method is at least suitable for similar types of assessment as the other methods usually applied in the world. For minimum temperatures we can expect prevention of dropping effective emission, especially at night. Therefore the mentioned trends in minimum temperatures are somewhat higher than values published for daily mean air temperature. As reported by B r a z d i l et al. (2008), a faster increase in minimum than in maximum temperatures results in reduction of daily air temperature amplitude, and these changes are associated with changes of cloudiness of atmospheric circulation probably caused by anthropogenic effects.

We may conclude that the trend in the minimum temperature increase is significant at the $P$ = 0.001 level in all processed points; lower significance level was detected just for one point. The range of this trend is also relatively balanced, around 0.5°C per 10 years. In accordance with the findings by S t r e s t i k et al. (2014b), it is more pronounced in Bohemia than Moravia, and in Bohemia and partly in North Slovakia it exceeds values from the rest of the processed European territory.

In consistency with published data, a more significant trend in the precipitation totals was not detected for most processed points, only at two sites trends of 23 and 25 mm per 10 years were significant at the $P$ = 0.01 level and at two sites trends of 25 and 31 mm per 10 years at the $P$ = 0.05 level. Precipitation totals were especially increased in points localized in South Bohemia, South Moravia, and South Slovakia. The great fluctuation in precipitation totals from year to year results in insignificant trends after statistical assessment by Mann-Kendall test. On most of the processed territory trends in precipitation totals are statistically insignificant. Trends in increasing the number of days with precipitation are more significant. In Ukraine, the number of days with precipitation is falling, while on the territory of Eastern Europe days with precipitation become more frequent.

In May to August of the years 1976–2016 we recorded very small changes for air humidity. In Moravia, positive statistically significant trends at the $P$ = 0.05 significance level are determined below 1% per 10 years, while in Poland and several other localities there is a slight relative air humidity decrease. For the remaining points humidity changes are statistically insignificant. We may conclude that air humidity changes will minimally affect the total change of conditions for late blight occurrence.

Various combinations of weather parameters changes differently impact the conditions for late blight occurrence.

It is evident that a statistically significant shift in the first treatment forecast is only seen for the localities in Bohemia and North Moravia, including one locality in southern Poland. In Bohemian localities the trend reaches significant values of 7.8–10 days per 10 years at the $P$ = 0.001 to $P$ = 0.01 level, the remaining two localities are only significant at the $P$ = 0.05 level. For the rest of the processed territory a statistically significant shift in the date of the first treatment is not seen. B a k e r et al. (2005) used a variant of NoBlight system for similar determination of a shift in the first treatment for 7 localities in Great Lakes region of the USA; for two localities a statistically significant shift was found at the $P$ = 0.05 level, by 4.8 and 6.4 days earlier first treatment. Therefore it is apparent that under ongoing climate changes the first late blight occurrence need not always set on earlier. The majority of the CR territory is a specific region, where this trend is significant, while no shift is recorded for the rest of the processed area.

If the shift in the first treatment forecast is mostly observable only on the CR territory, considering infection period changes, the contiguous area with most pronounced changes is situated on the territory of the CR and SR and the adjacent regions of Poland. The trend in the number of infection periods is mostly about 0.4–0.9 per 10 years and only in South Moravia reaching values up to 2, however, at the $P = 0.05$ significance level. Most trends on the CR and SR territory show a higher significance level, $P = 0.01$ and $P = 0.001$. An increase in the number of infection periods has also been observed in Belarus and partly in Latvia, in several regions of Poland and the Netherlands along the Baltic Sea. Similar results have also been obtained for a change in the number of days with infection pressure. The CR and SR form a contiguous region, where these changes are approximately 3–4 days per 10 years, mostly at the highest significance level of $P = 0.001$. A higher increase is seen at several localities on the Baltic coast (more than 5 days per 10 years).

## CONCLUSION

The paper focused on the processing of changes that occur during global and climate changes and of the critical weather indicators influencing the occurrence and severity of late blight, including detailed assessment of trends in the first infection period onset evaluated by the late blight index method and the number of periods and days with high infection pressure during season. In accordance with other researches it was confirmed that minimum air temperature indicates statistically significant trends on the whole processed territory, which is most often an increase of approximately 0.5°C per 10 years. Since late blight development is limited by low minimum temperatures, a temperature increase represents more favourable conditions for late blight emergence and progress. Although in recent decades the trend toward greater aridity has been recorded, as referred by Litschmann, Klementova (2004), it is rather caused by non-uniform distribution of precipitation totals throughout the year than by total decrease in precipitation totals. For most processed points we found no statistical changes in precipitation trends, at three localities a slight precipitation increase was detected. An increase in days with precipitation was also recorded; only for points located in Ukraine the number of days with precipitation was lower. Therefore, combined with other factors, a slight increase in late blight infection pressure can be expected.

For trends in relative air humidity very small changes were only determined, although they were statistically significant at some sites.

Interesting results were obtained regarding the trends in the shift of the first treatment forecast. Statistically significant differences toward earlier occurrence were only found on the CR territory and at one point in South Poland. We can conclude that higher attention should be paid to late blight monitoring in these regions. However, on substantially larger area the number of infection periods and the number of days with infection pressure were increased; these regions roughly copy the distribution of points with increased number of days with precipitation.

Despite the rare occurrence of dry years with very low precipitation totals we can expect that due to ongoing climate change suitable conditions for late blight will develop in most of the major growing regions processed in this study, except for Ukraine.

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