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Relationship between tree bark surface temperature and selected meteorological elements

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Abstract: The results were obtained by measurements in 2014 and 2015 in an apple orchard in Starý Lískovec and Těšetice (South Moravia, Czech Republic, Central Europe) into fertile planting of apple trees. The results show that the bark surface temperature during the year slightly differs from the surrounding air temperature. In addition, it is in average a few tenths of a °C higher in the period before the onset of the vegetation and several tenths of a degree lower during vegetation. Causes of these differences appear to be associated with the flow of sap as well as with foliage. Although it can be reasonably assumed that the temperature of the bark surface on the south side will be significantly affected by the global radiation, our measurements did not demonstrate this dependency. It appears that the wind speed had significantly larger influence on the temperature differences in the non-vegetation period as at speeds over 3.5 $\mathrm{m\,s^{-1}}$, the drop of temperature is so significant that the bark surface is colder than the surrounding air. Comparison of the development of sums of daily and hourly effective temperatures above 10 °C has shown that where daily values do not show significant differences, hourly values differed so prominently that the calculated date of emergence of adult codling moth in the bark surface was approximately one week earlier than with the use of data for air temperatures.

Key words: orchards, bark temperature, microclimate, solar radiation, air temperature, phenology

1. Introduction

As opposed to the conditions on a standard climatological station, stand microclimate is characterized by reduction of temperature extremes, more humid environment with less frequent oscillation, different levels of precip-

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itation interception in the vegetation, reduced air flow velocity, incidence of diffuse solar radiation and different composition of the air (*Středa et al., 2011*). Stand microclimate thus differs from conditions at a standard climatological station even when it is placed in the immediate surroundings of the monitored stand. In addition, orchards are also influenced by the design and shape of planting, farming techniques of land in alleyways, measures taken against frost, etc.

Středa et al. (2011) indicate that an apple orchard and its nearest standard climatological station show differences in average (about 0.2 °C) and differences of maximal air temperature about 0.1 °C. The absolute minimum varies by 2.8 °C. A similar conclusion was observed by *Fukalová et al. (2010)* – the difference in average annual air temperature was 0.3 °C (higher temperature at the station than in the orchard), the absolute maximal daily temperature at the station increased by 1.1 °C and the absolute minimal temperature was lower by 0.5 °C than in the orchard. Consequently, the same authors, when analysing the next orchard, state its absolute daily maxima higher by 0.7 °C and the absolute minima at the station lower by 2.2 °C. *Kalma and Stanhill (1972)* indicate the absolute difference between the temperature at a standard climatological station and inside an orange orchard at max. 2 °C and humidity in the orchard higher by 8%. *Landsberg et al. (1973)*, when comparing an apple orchard microclimate and climatic conditions at a station, found a relatively small effect on temperature and air pressure.

Standard epidemiological models and forecasting of pests generally do not count with the influence of vegetation microclimate (for fruit trees, for example see *Samietz et al. (2007)* and others). To better understand the interactions between the plant – pathogen – and microclimate the meteorological elements need to be measured directly in the stand (*Krédl et al., 2012*). Exact estimation of the influence of abiotic factors (agrometeorological elements) and related biotic effects (epidemiological processes) on the plant production can be done by microclimate monitoring of the crop. In this context the key variables are air temperature and humidity and precipitation.

Orchards represent a varied mosaic of surfaces consisting of different materials and their thermal balance is dependent on many factors such as the orientation to the cardinal directions, cooling by transpiration or evaporation, etc. Bark is one of these surfaces, consisting of live and necrotic tissues. In case of tree trunks, it is essentially a surface oriented to all cardinal directions. Bark functions as an important shelter for overwintering of various developmental stages of a wide range of pests. Models of signalling based on the summation of air temperatures (effective temperatures) above a certain threshold have been created for a number of these pests.

It can be assumed that if the models used air temperatures significantly different from temperatures of shelters where the hiding pests overwinter, there would be more significant differences between the signalling date and the actual date of achieving the predicted development stage, especially in the early stages. There is relatively little information on the differences between the temperature of the surface of the bark and the air temperature over a long period of time in the current scientific literature, despite the fact that it is technically possible to perform such measurements. As a result of that we decided to undertake a long-term experiment and monitor the temperature of the surface of the bark and also the temperature of the air at several levels within a single tree, planted in an apple orchard that corresponds to current trends in fruit growing.

Although the method of infrared thermometry is currently widely used in a wide range of mostly technical activities (building energy audits, medical applications, fire detection, night vision optics etc.) its use for tree bark surface temperature monitoring is relatively rare (*Temina et al., 2009; Bowie and Bowie, 2003; Wittmann and Pfanz, 2007; Burcham et al., 2011*). In particular, continuous monitoring of the surface temperature of the tree bark surface is unique.

The paper evaluates the results of measurements of bark surface temperature taken by an infrared thermometer on the southern sunlit side of an apple tree and its comparison with the air temperature measured at different levels of the tree.

2. Material and Methods

The below specified results were obtained by measurements in 2014 and 2015. At the beginning of 2014, the measuring device was placed in an apple (*Malus domestica* Borkh.) orchard in Starý Lískovec (Brno, Czech

Republic, Central Europe, GPS location: 49.1603500 N, 16.5581339 E, altitude 250 m a.s.l.) into a young fertile planting of apple trees in the shape of a slender stem on a wire. Towards the end of the year, the equipment was moved to older planting in Těšetice in Znojmo region (Czech Republic, Central Europe, GPS location: 48.8834061 N, 16.1482144 E, altitude 265 m a.s.l.), where the variety Golden Delicious alternates in ten-row blocks with the variety Idared. It is a kind of stripe-shaped Italian Palmeta planting with 5×3 m spacing planted in 1979; tree height 3m on average; rootstock M4.

The surface temperature of the thick branch bark was measured by an OS210 type infrared thermometer (Omega Engineering, USA) with a temperature range of –20 to 500 °C and the emissivity set at 0.95, in 1.3 m height. The IR thermometer was connected to MeteoUni data logger (AMET, Velké Bílovice) which also registered a number of other meteorological variables. Data on air temperature at a height of 0.5 m, 1 m and 3m above the ground was used for the purposes of the analysis. Measurements were taken at ten-minute intervals. The infrared thermometer was in both cases positioned so that it captures the temperature of the bark on the south side of the tree trunk. In addition to the above mentioned measurements, the experiment uses data on wind speed captured by an automatic weather station (AMET, Velké Bílovice) placed several tens of meters away.

The measured temperature data was used to calculate hourly, daily and monthly averages for each day and subsequently to determine extreme daily values. The hourly and daily average temperatures consequently determined sums of effective temperatures above 5 and 10 °C.

3. Results and Discussion

Differences between the measured temperatures of air and bark surface are shown in Figs 1 and 2. In the case of Starý Lískovec, the biggest variances were recorded in April when the difference between the air temperature at the level of 1 m and the bark surface temperature was 1.2 °C. In the coming months the differences decreased and in the summer months the temperature of the bark surface was equal to or lower than the air temperature at the level of 1 m. In Těšetice, the differences between measured temperatures in the individual months are not very significant, from January to

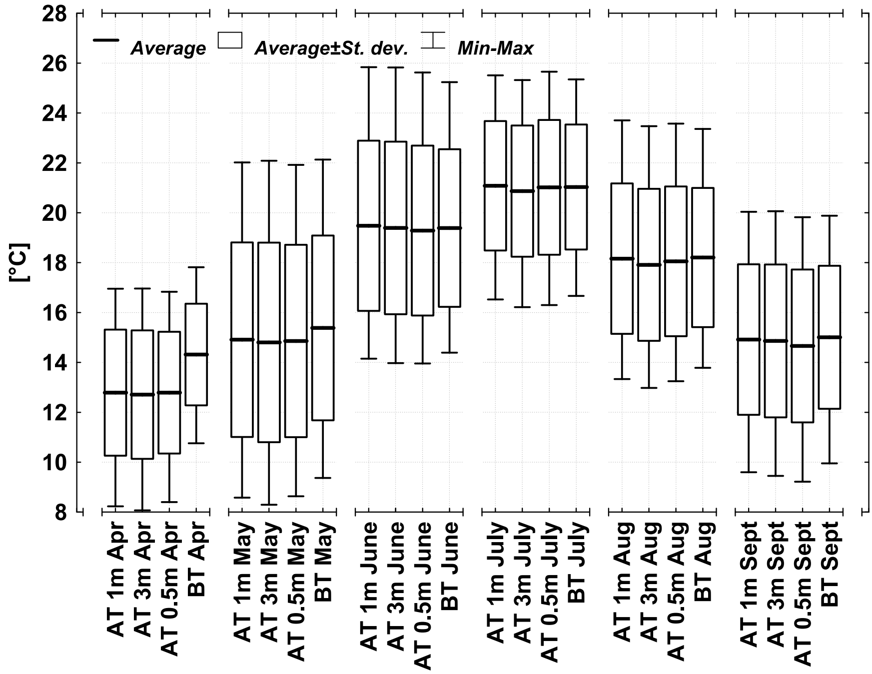

Fig. 1. Mean monthly air temperature (AT) and bark surface temperature (BT) – Starý Lískovec, 2014.

March 2015, the temperatures on the surface of the bark were 0.2 to 0.5 °C higher than the air temperature. From May on, the surface temperature of the bark started to be 0.3 to 0.4 °C lower than the air temperature. It can be assumed that the dynamics of the differences will be closely linked to the manifestation of the life processes of apple trees, especially with foliation and flow of sap. This can be clearly demonstrated on the development of differences between the temperature of air at the level of 1 m and the surface temperature from the beginning of the year in Těšetice shown in Fig. 3. Onset of the phenophase and its duration is commonly influenced by variety (earliness of the variety), meteorological conditions of the year (for example April 2014 was significantly windier), locality (e.g. terrain configuration), agricultural practices (inter-row management etc.) and other factors (fruit tree pruning etc.). Due to these facts the comparison of years 2014 and 2015 is not emphasised. Onset of phenophases influencing bare shadow-

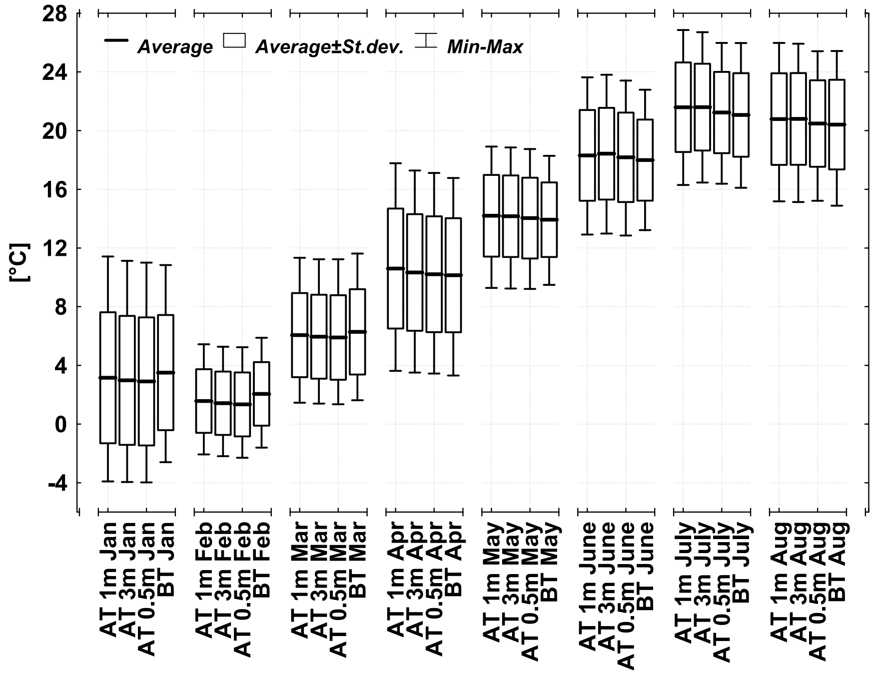

Fig. 2. Mean monthly air temperature (AT) and bark surface temperature (BT) – Těšetice, 2015.

ing (i.e. Principal growth stage 1 "Leaf development" and growth stage 3 "Shoot development"; *Meier (1997)*) in April 2014 was markedly later than in 2015.

Kührt et al. (2006) measured the air temperature within the apple orchard, the temperature of bark of tree trunks and of apple fruits. The surface temperature of bark exceeded air temperature at noon. This temperature excess was higher in dwarf trees than in tall trees, particularly on sunny days and for the south-facing bark surface. On sunny days, the mean temperature excess of the bark facing south was 3.4 °C in dwarf trees and 3.1 °C in tall trees, and the maximum temperature excess in spring was 13.9 °C and 19.6 °C, respectively.

Fig. 3 shows the movement of daily sums of effective temperatures above 5 °C which, according to *Litschmann et al. (2014)*, determine the development of leaves in rosettes and young wood. It is obvious that the transition

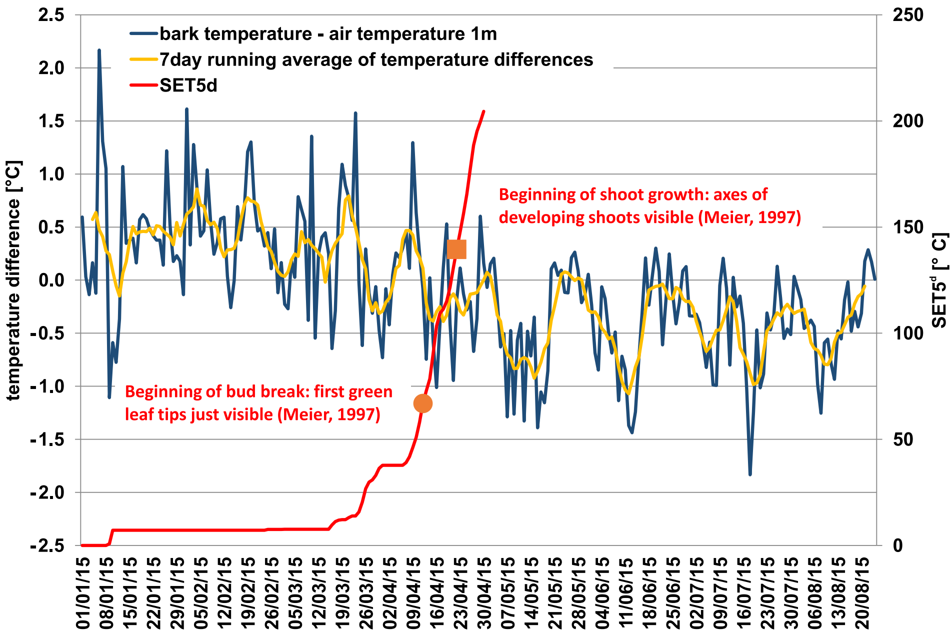

Fig. 3. Difference of bark and air temperature in relation to SET5^{d}, Těšetice.

from the positive deviations, when the bark surface is generally warmer than the air, to the negative ones, occurs approximately when the development of leaf rosettes starts, and this is associated with the beginning of vegetation of apple trees that is manifested by, among other signs, restoring the flow of sap in tissues and heat transfer between different parts of the tree. Another factor that might contribute to reduction of the bark surface temperature in relation to the air temperature is the presence of leaves that shade the trunk. The fact that there are two different modes of bark surface temperature is indicated by the comparison of the daily development of bark temperatures and air temperatures in April and July (Figs 4 to 7). In both locations these have the same course, in April when the bark surface is not yet shaded by leaves, it exhibits greater amplitude than the surrounding air, while the daily maxima are substantially higher. The minima are either identical to or slightly lower than the minimum air temperatures. In contrast, in July, the bark surface is colder than the surrounding air until its daily maximum is reached. Subsequently, it almost replicates the air

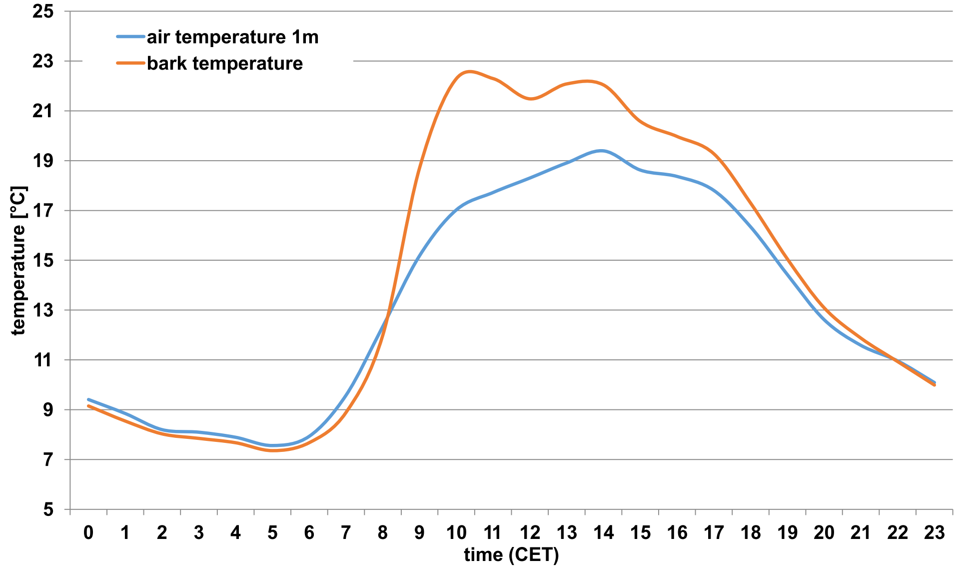

Fig. 4. Average daily course of air and bark temperature in April; Starý Lískovec, 2014.

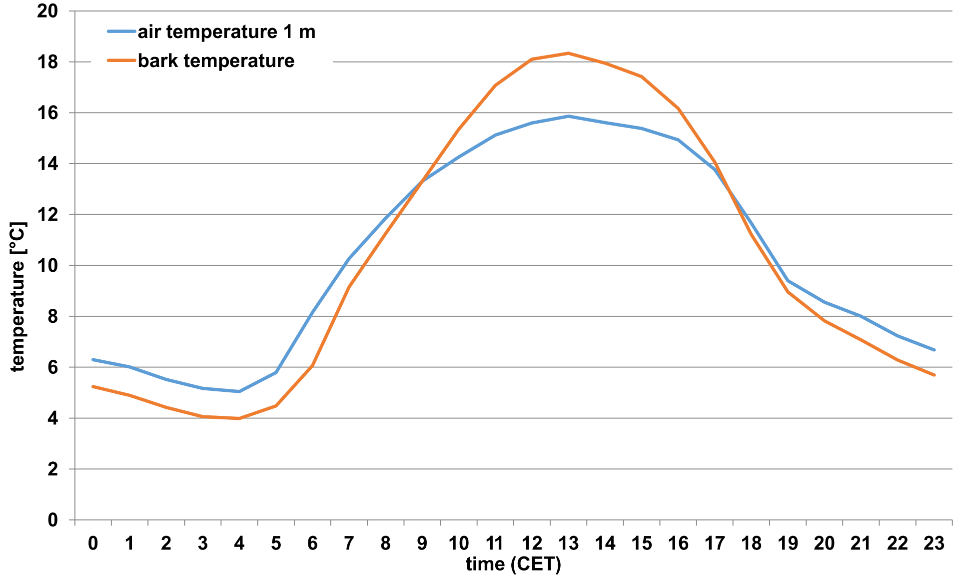

Fig. 5. Average daily course of air and bark temperature in April; Těšetice, 2015.

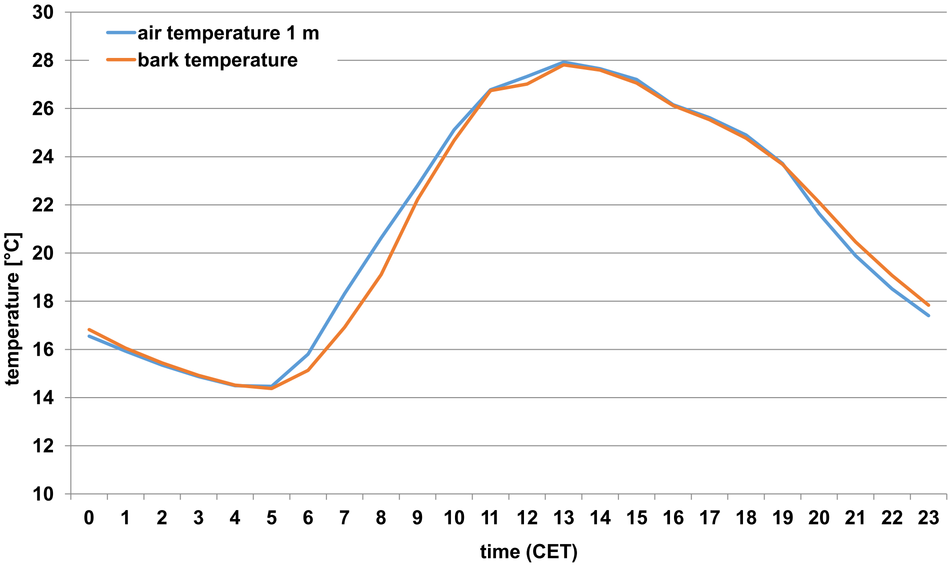

Fig. 6. Average daily course of air and bark temperature in July; Starý Lískovec, 2014.

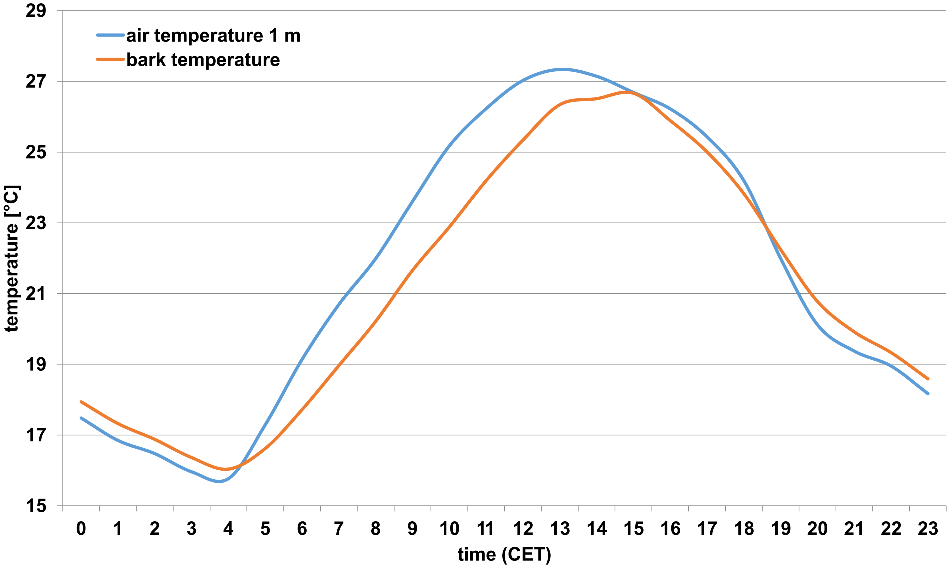

Fig. 7. Average daily course of air and bark temperature in July; Těšetice 2015.

temperature until the morning minimum.

When analysing the agents influencing the differences between the bark temperature and the air in the spring season, it turned out that wind speed measured at a weather station has a greater impact than global radiation. At speeds up to about 3.5 $\mathrm{m\,s^{-1}}$, the bark surface is warmer, while at higher speeds it is lower than the air temperature. Even at lower wind speeds up to 2 $\mathrm{m\,s^{-1}}$, it is not possible to conclude that there is a significant dependence of the temperature differences to global radiation. In the period from April to August 2015, the dependence of the temperature differences on the wind speed is very weak ($R^2 = 0.03$). In connection with the assumption that trees flowering may be affected by buds heating by solar radiation, *Středa et al. (2009)* analysed the influence of sunshine duration. However, any fundamental influence on the apricot flowering useable for predicting the phenophase onset was not proven. It might probably be caused by radiation days at the north-eastern anticyclone circulation occurring in the early spring season. These days are characterized by lower minimum temperature, so that the overall effect of buds heating can be limited.

From the above mentioned findings, it can be judged that the mode of the bark surface temperature in relation to the surrounding air temperature in intensive fruit orchards consists of two parts, non-vegetation and vegetation. In the vegetation stage, the bark surface temperature approximates to the air temperature, while in the non-vegetation stage, the differences are more significant and the bark surface temperature is usually higher. Based on the observed meteorological elements, it can be concluded that the differences are mainly influenced by the wind speed.

The main aim of the measurements was to assess to what extent it is a mistake to use only air temperature during modelling of development of pests using the sum of effective temperatures and not to take into account that some pests overwinter under bark or on it, thus in places, which can have different temperature conditions, especially in the spring. For these purposes, daily and hourly effective temperatures above 10 °C were calculated from the data on bark and air temperatures obtained in Těšetice since the beginning of 2015. The comparison showed that there are minimal differences in daytime temperatures throughout the vegetation period. The sums of hourly temperatures suggest that the temperatures of the bark surface at the beginning of the growing season are lower and approximate to the air temperature during the course of vegetation. Consequently, by the end of the growing season, the sums of bark temperatures determined from the obtained data are lower than the air temperatures as is shown by the graphs in Fig. 4 and 5.

4. Conclusion

The results show that the bark surface temperature during the year slightly differs from the surrounding air temperature. In addition, it is on average a few tenths of a °C higher in the period before the onset of the vegetation and several tenths of a degree lower during vegetation. The causes of these differences appear to be associated with the flow of sap as well as with foliage. Although it can be reasonably assumed that the temperature of the bark surface on the south side will be significantly affected by the solar radiation, our measurements did not demonstrate this dependency. It appears that the wind speed had a significantly larger influence on the temperature differences in the non-vegetation period as at speeds over 3.5 $m\,s^{-1}$, the drop of temperature is so significant that the bark surface is colder than the surrounding air. Comparison of the development of sums of daily and hourly effective temperatures above 10 °C has shown that where daily values do not show significant differences, hourly values differed so prominently that the calculated date of emergence of adult codling moth in the bark surface was approximately one week earlier than with the use of data of the air temperatures. A mass capture of butterflies in pheromone traps, however, occurred only after the date calculated using the air temperatures, there were very rare instances of earlier captures. This fact can infer that despite the difference in temperature of tree bark surface, serving as a shelter for overwintering pests, the major part of their population can be modelled based on air temperature.

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