The impact of agricultural land afforestation on air temperatures near the surface

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Abstract: Many studies showed that afforestation increases carbon storage and it can have effects on physical, chemical and biological properties of soil. Afforestation can affect local and regional climate and these effects differ between tropical, temperate and boreal areas. Forests are also efficient in protecting soils against erosion and their flood mitigation functions or other benefits are described in different publications. In this study, the pattern of air temperatures (20 cm, 40 cm and 60 cm above the surface) was studied 10 years after the afforestation of agricultural land (warm, mild dry region of the Czech Republic) with a mixture of broadleaved tree species (Quercus robur L., Quercus rubra L. and Acer platanoides L.) or monospecific Pinus sylvestris L. stand. The aim of our study was to find out the pattern of air temperatures (20 cm, 40 cm and 60 cm above the surface) on two plots (one of the plots – old beech trees, the other plot – clearing) in a beech (Fagus sylvatica L.) forest in a mildly warm, mildly wet region of the Czech Republic. The afforestation of agriculturally used land led to air temperature cooling and to a reduction of the amplitude of maximum and minimum temperatures. The average air temperature (from April 2021 to the beginning of November 2021) decreased by 0.7–1.1 °C on the afforested plots compared with the agriculturally used plot. In the beech forest, the average temperature decreased on the plot with clearing compared with the old beech trees (from the middle of September 2021 to the middle of November 2021). Our results confirm the benefits of afforestation to climate change mitigation; buffering of extreme temperatures is important for the human thermal comfort.

Keywords: air temperature variations; climate; conifers; European beech; Scots pine; vegetation cover

In the Czech Republic, afforestation of agricultural land has been supported by providing subsidies from the government and the European Union (Ministry of Agriculture of the Czech Republic 2018). Different reasons for afforestation of agricultural land, criteria (and identified areas in the Czech Republic), suitability of forest tree species or wood quality are described in the publication by Vopravil et al. (2021a) and in the publications by Vopravil et al. (2015, 2017), Cukor et al. (2020), Gallo et al. (2020), Vacek et al. (2021a, b). For example, different studies showed that afforestation increases carbon storage and can affect local and regional climate; forests have lower albedos

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than grasses or cultivated crops (e.g. Kirschbaum et al. 2011). For example, the values of albedo for forests (5–20%) or pine and spruce (10–14%), crops – winter wheat, winter barley, winter rapeseed and rye, spring wheat and barley, oats, peas, sunflower, sugar beet, rice etc. (10–25%) or stubble fields (15–17%), grass or different types of grass-clover ley (16–22%) etc. were reported in different publications (Kuusinen et al. 2012; Bakanoğulları et al. 2022; Sieber et al. 2022a, b); Sieber et al. (2022a, b) concluded that barley had the highest albedo from all studied cereals (22%).

Forests are also efficient in protecting soils against erosion and their flood mitigation function was also described (Gomyo, Kuraji 2016); the effect of afforestation on soil erosion is described in different publications (Chirino et al. 2001; Porto et al. 2009; Romero-Diaz et al. 2010; Xu et al. 2019). Rainfall interception ratios differ according to forest tree species etc. (Poleno et al. 2011); litter cover influences infiltration rates and it was described that vegetation litter mostly prevents overland flow etc. Forest cover types were reported to influence runoff and its components – surface runoff, interflow and groundwater flow (e.g. Ding et al. 2022).

Effects of agricultural land afforestation on soil properties, hydrological cycles (e.g. different effects on rainfall interception, transpiration) are also described in different publications; vegetation litter (or grazing) and harvesting of forests etc. were found to influence soil temperatures and forest tree species litter can protect soils from frosts (e.g. Jackson et al. 2005; Ilisted et al. 2007; Kupka, Podrázský 2010; Holubík et al. 2014; Vopravil et al. 2014, 2021a, b; Yao et al. 2016; Jia et al. 2017; Hrabovský et al. 2020). For the vegetation season, Bedina (1977) reported higher soil temperatures in the fields and meadows compared with forests. Effects of mulching, soil types etc. on soil temperature are described in different publications (Allmaras et al. 1964; Li et al. 2021). Yang et al. (2021) studied the effect of cover crops on soil temperature at depths of 15 cm, 30 cm, 45 cm and 60 cm. Song et al. (2013) observed a reduction in the vegetation cover at increased soil temperatures of grasslands (due to decreased shading of the ground). Also, Poleno et al. (2011) found out lower average annual temperatures of the soil surface in forests compared with fields. Coutts (1955) studied soil temperature (at depths of 1 inch, 6 inches, 12 inches and 18 inches which corresponded with the boundaries of natural horizons) and air temperature (4 ft above ground) – afforestation with conifers (8 to 10 ft high). For example, the author showed the weekly true mean temperatures. At a depth of 1 inch, the author found values below 0 °C in January–April and November–December. The author gave an example of the rain storm which caused a decreased soil temperature (0.9–2.7 °C) at depths of 1 inch and 6 inches; the author also described the efficiency of spot readings etc. Different effects on the land surface temperature were described in tropical, temperate or boreal forests (Bala et al. 2007); Li et al. (2015) stated that tropical forests have a cooling effect throughout the year and temperate forests (or boreal forests) have a net cooling effect annually (or a net warming effect annually). Lal and Cumming (1979) reported that deforestation of tropical rainforest (in southern Nigeria) increased the value of maximum air temperature by 5–8 °C and the value of maximum soil temperature at a depth of 1 cm by 25 °C. In different publications on soil (and air) temperature, the values are given using different scales including Celsius (°C), Kelvin (K) or Fahrenheit (°F) – see Allmaras et al. (1964), Wang et al. (2018), Jin et al. (2019).

In this study, the effect of agricultural land afforestation (for the period of 10 years) on air temperatures 20–60 cm above the surface (the period from April to the beginning of November 2021) was determined in the conditions of Czech Republic. We also attempted to determine differences in air temperatures (20–60 cm above the surface) between two plots in a beech forest (one of the plots = old beech trees, the other plot = clearing) in the period from the middle of September 2021 to the middle of November 2021. As described by Poleno et al. (2011) or Tang et al. (2018), we hypothesized the occurrence of lower average air temperatures (20–60 cm above the surface) in the afforested stands compared with agriculturally used land. We also hypothesized lower maximum temperatures and higher minimum temperatures as well as higher average air temperatures on the plot with old beech trees compared with the clearing (e.g. Kubín, Kemppainen 1991; Barna, Schieber 2011).

**MATERIAL AND METHODS**

As described by Vopravil et al. (2021a), the experimental plots were established near Hovorčovice (north of Prague) in the Czech Republic.
on Haplic Chernozem (IUSS Working Group WRB 2015). This area (warm, mildly dry region of the Czech Republic) is characterised by the mean annual air temperature of 8–9 °C, mean annual precipitation of 500–600 mm and by the sum of average daily air temperatures above 10 °C between 2 600 and 2 800. The afforestation was performed in 2011. As described by Vopravil et al. (2021a), one of the experimental plots was afforested with Scots pine (*Pinus sylvestris* L.) and the other plot with a mixture of pedunculate oak (*Quercus robur* L.), red oak (*Quercus rubra* L.) and Norway maple (*Acer platanoides* L.). The control plot is used for agriculture. The volumetric water content, soil temperature at depths of 20 cm, 40 cm and 60 cm and air temperature (20 cm, 40 cm and 60 cm above the ground level) were continuously measured on each of the experimental plots using TMS–4 datalogger (TOMST, Czech Republic). A rain gauge (Pronamic Professional Rain Gauge, 200 cm², accuracy 0.1 mm, Minikin ERi datalogger (EMS Brno, Czech republic)) was placed on the control plot. The measurement was performed from April to the beginning of November 2021. Only the effect of afforestation on air temperatures (20–60 cm above the surface) is described in this publication. Selected physical and chemical soil properties on the study plots including the seasonal changes of temperature and volumetric water content at depths of 20 cm, 40 cm and 60 cm (and precipitation) in the period from April to the beginning of November 2020 were described by Vopravil et al. (2021a). The experimental plots were also established near Lipnice (a part of Dvůr Králové nad Labem) in the Hradec Králové Region of the Czech Republic. This area (mildly warm, mildly wet region of the Czech Republic) is characterised by the mean annual air temperature of 7–8 °C, by the mean annual precipitation of 550–650 (700) mm and the sum of air temperatures above 10 °C between 2 200 and 2 500. One of the plots in beech (*Fagus sylvatica* L.) forest consisted of old beech trees and the other plot was a clearing. The measurement (20–60 cm above the surface) was performed from the middle of September 2021 to the middle of November 2021.

The differences in the values of air temperature were subjected to testing by one-way ANOVA and Tukey HSD test. All statistical analyses were performed with STATISTICA Cz software (Version 10, 2011).

## RESULTS AND DISCUSSION

The average air temperatures (from April to the beginning of November 2021) on the afforested (and control) plots are shown in Table 1. Significant (*P* < 0.05) differences were found on the plot afforested with broadleaves when compared with the control plot or on the plot afforested with Scots pine compared with the control plot (20 cm, 40 cm and 60 cm above the surface). The maximum and minimum values of air temperature on the afforested (and control) plots are shown in Table 2. On the control (agriculturally used) plot, the minimum values were measured on April 27 (20 cm) or April 4 (40 cm and 60 cm above the surface);

### Table 1. Average values of air temperature on the afforested plots (and the control plot)

<table>
<thead>
<tr>
<th>Plot</th>
<th>Above-ground height (cm)</th>
<th>Average air temperature above the surface (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control plot</td>
<td>20</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>14.3</td>
</tr>
<tr>
<td>Pedunculate oak + red oak + Norway maple</td>
<td>20</td>
<td>13.5</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>13.4</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>13.6</td>
</tr>
<tr>
<td>Scots pine</td>
<td>20</td>
<td>13.4</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>13.5</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>13.5</td>
</tr>
</tbody>
</table>

### Table 2. Maximum and minimum values of air temperature on the afforested plots and the control plot

<table>
<thead>
<tr>
<th>Plot</th>
<th>Above-ground height (cm)</th>
<th>Air temperature above the surface (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>minimum</td>
<td>maximum</td>
</tr>
<tr>
<td>Control plot</td>
<td>20</td>
<td>–4.1</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>–3.9</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>–4.1</td>
</tr>
<tr>
<td>Pedunculate oak + red oak + Norway maple</td>
<td>20</td>
<td>–3.5</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>–3.6</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>–3.5</td>
</tr>
<tr>
<td>Scots pine</td>
<td>20</td>
<td>–2.5</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>–2.5</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>–2.6</td>
</tr>
</tbody>
</table>
the maximum values were measured on June 19 (20 cm) and June 20 (40 cm and 60 cm) (Figure 1). On the plot with broadleaves, the minimum values were obtained on April 4 (20 cm, 40 cm and 60 cm) and the maximum values on May 11 (20 cm) and May 10 (40 cm and 60 cm) (Figure 2). Concerning the plot with Scots pine, the minimum values were measured on April 6 (20 cm, 40 cm and

Figure 1. The course of air temperature on the control agriculturally used plot (A) 20 cm above the surface; (B) 40 cm above the surface; (C) 60 cm above the surface
60 cm above the surface) and the maximum values on June 21 (20 cm and 40 cm) and June 18 (60 cm) (Figure 3). The average air temperatures 8.6 °C (20 cm) and 8.7 °C (40 cm and 60 cm above the surface) were measured on the plot with old beech trees. On the
presented in Table 3. On both plots, the minimum temperature values were registered on November 7 (20 cm, 40 cm and 60 cm) (Figures 4 and 5). On the plot with old beech trees, the maximum tempera-
ture values were measured on September 26 (20 cm and 40 cm) and September 27 (60 cm); concerning the clearing, the maximum temperature was found on September 27 (20 cm, 40 cm and 60 cm). Significant ($P < 0.05$) differences between the plots were found at a height of 20 cm, 40 cm and 60 cm above the surface.

Voprávil et al. (2021a) studied the effect of agricultural land afforestation (for the period of 9 years) with a mixture of broadleaves or monospecific *Pinus sylvestris* L. culture on temperature and volumetric soil water content at different depths (20 cm, 40 cm and 60 cm) in the period from April to the beginning of November 2020 – the same experimental plots as in this study. The authors also found lower temperatures in the soil of afforested plots (all studied depths) compared to agriculturally used land; higher temperatures in forested soils in autumn and winter (compared to field soils) were found by Michelsen-Corra and Scull (2005). Poleno et al. (2011) stated that the values of average annual temperatures 25–200 cm above the surface (and soil surface) were lower in a mixed forest (pine, beech and oak) compared with arable land. The authors found the average annual temperature increased from the soil surface (6.5 °C) to 200 cm above the surface (6.7 °C) in the forest; in the field, the authors revealed the surface had the highest temperature (7.7 °C) and the temperature of 7.4 °C was found 200 cm above the surface (see Poleno et al. 2011). Poleno et al. (2011) reported that the average annual air temperature measured 25 cm above the surface was 0.7 °C lower (6.6 °C versus 7.3 °C) in the forest compared with the field – in this study, the average air temperature measured 20 cm (or 40–60 cm) above the surface was 0.9–1.0 °C (or 0.7–1.1 °C) lower on the afforested plots compared with the agriculturally used plot.

Jin et al. (2019) studied the effect of afforestation on soil (at depths of 10 cm, 20 cm, 40 cm, 60 cm and 100 cm) and air temperatures (1 m above the ground) on the Chinese Loess Plateau. For example, the authors measured lower daytime and nighttime temperatures at all studied soil depths on the afforested sites compared to grasslands (regardless of topography); the annual average daytime soil temperatures were 0.57–1.40 °C (and the annual average nighttime soil temperatures

<table>
<thead>
<tr>
<th>Plot</th>
<th>Above-ground height (cm)</th>
<th>Air temperature above the surface (°C)</th>
<th>minimum</th>
<th>maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old beech trees</td>
<td>20</td>
<td>-1.1</td>
<td>23.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>-1.1</td>
<td>24.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>-1.3</td>
<td>23.1</td>
<td></td>
</tr>
<tr>
<td>Clearing</td>
<td>20</td>
<td>-3.0</td>
<td>27.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>-2.1</td>
<td>26.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>-2.8</td>
<td>27.0</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. The course of air temperature on the plot with old beech trees (20 cm, 40 cm and 60 cm above the surface)
Effects of afforestation on the soil surface temperature (cooling or warming) differ according to latitude, daytime or nighttime, topography, precipitation etc. (Tang et al. 2018). Tang et al. (2018) realized a study to analyze the effect of forests on land surface temperature and air temperature in Europe and the effect of background climate. For example, they investigated daily net cooling in most areas of Europe. Concerning the effect of forests on air temperatures, forests tend to decrease the values of mean annual maximum temperature and increase the values of mean annual minimum temperature. In this study, we found lower maximum air temperatures and higher minimum air temperatures on the afforested plots compared with the control. Song et al. (2013) studied the effect of vegetation height and density (the authors used dried reed stalks to simulate different vegetation height and density) on air temperature at 10 cm above the surface and soil temperatures at depths of 5 cm and 20 cm. The authors showed that both soil and air temperatures decreased as the height and density of reed stalks increased probably due to the interception (or reflection) of solar radiation by reed stalks; the authors also reported that differences between maximum and minimum values (both soil and air temperatures) decreased with increasing height and density of reed stalks. Also, lower height and density of reed stalks led to lower differences between the values of air and soil temperature (Song et al. 2013). Tesař et al. (2006) studied
The afforestation of agriculturally used land significantly \((P < 0.05)\) decreased air temperatures 20–60 cm above the surface. The average air temperature (from April 2021 to the beginning of November 2021) decreased by 0.7–1.1 °C on the afforested plots compared with the agriculturally used land (with small differences between broadleaves and Scots pine); we proved a reduction of the amplitude of maximum and minimum temperatures on the afforested plots. In the beech forest, the average temperature (from the middle of September 2021 to the middle of November 2021) decreased by 0.7–1.0 °C on the plot with clearing compared with the old beech forest; an increase in the amplitude of maximum and minimum temperatures was also found on the clearing. Our results confirm the benefits of afforestation to climate mitigation. According to knowledge from literature, the cooling effects on afforested plots are given by changes of albedo and evapotranspiration due to the afforestation. Buffering of extreme temperatures is important for the human thermal comfort.

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