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Water content in soil afforested with a mixture of broadleaves or Scots pine

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Abstract: Afforestation of agriculturally used land has many benefits which are described in different publications. As stated in these publications, afforestation of agricultural land can influence soil water content because of rainfall interception and concentration, transpiration, and properties of forest floor layer and soil; also, hydraulic lift may occur. In this study, we attempted to find changes in volumetric soil water content values (at depths of 20 cm, 40 cm, and 60 cm) on agriculturally used land afforested with a mixture of forest tree species (*Quercus robur* L., *Quercus rubra* L., and *Acer platanoides* L.) or *Pinus sylvestris* L. in the year 2011 (and on agriculturally used land = control). This study was performed in the period from the end of March 2021 to the beginning of April 2022. In this study, we proved our hypothesis on the reduction of volumetric soil water content after afforestation; it is probably because of higher rainfall interception and evapotranspiration as described in different studies. Concerning the afforestation, the average volumetric water content was higher on the plot afforested with broadleaves compared with Scots pine. It was especially in the period after defoliation when the proportion of throughfall (and stemflow) increased on the plot with broadleaves. Our results indicate a higher water-storage capacity of forests compared with agriculturally used land. During the leafless period, this capacity was found to be higher after afforestation with Scots pine.

Keywords: chernozem; conifer; oak; potato; precipitation; temperature

Afforestation of agriculturally used land has many benefits, which are described in different publications, including the effects on local and regional climate or carbon storage (see the Introduction in Vopravil et al. 2021, 2022). Carbon stocks in tree biomass, mineral soil, organic layer on afforested land are described in the publications by Podrázský and Remeš (2008), Hiltbrunner et al. (2013), Wasak and Drewnik (2015), Cukor et al. (2017), Vacek et al. (2021) etc.; effects of afforestation on soil and air temperatures are described by Michelsen-Correa and Scull (2005), Poleno et al. (2011) etc.

Afforestation of agriculturally used land has also hydrologic effects. It can influence water resources, stream flows (peak flows, mean flows, low flows), water yields and quality, transport of pollutants, the occurrence of floods and landslides etc. Reduction of stream salinity after afforestation was also found (van Dijk, Keenan 2007); healthy and undisturbed forests usually protect soil from erosion. Because

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of higher rainfall interception and transpiration, surface runoff, groundwater recharge or streamflows are usually lower in the case of forests compared with arable land or grasslands (van Dijk, Keenan 2007; Hughes et al. 2020).

Also, forest litter was reported to influence the hydrologic cycle (Walsh, Voight 1977; Gomyo, Kuraji 2016; Zhou et al. 2018). Gomyo and Kuraji (2016) studied the effect of litter layer removal in the case of a forested watershed on runoff and evapotranspiration (the weight of removed litter ranged from 1.0 kg·m^{-2} to 1.5 kg·m^{-2}); for example, the value of a 3-year runoff increased after the removal of the litter layer. Throughfall and stemflow typically form 70–90% of gross precipitation in temperate forests; stemflow was found to form from < 5% to > 10% of gross precipitation (Levia Jr., Frost 2003). Transpiration differs among tree species (and ages); concerning understorey vegetation, it can be important because of rainfall interception and transpiration (Poleno et al. 2011). Özhan et al. (2010) studied evapotranspiration of oak-beech forest ecosystems; for example, the authors state that evapotranspiration formed 69% (potential evapotranspiration) or 72–80% (water balance method) of precipitation.

Water content in soil may change because of hydraulic lift. In this case, water is transported from deeper and wetter soil to drier surface soil. Hydraulic lift may occur in case of different plant species from arid, semiarid and other environments (Emerman, Dawson 1996; Caldwell et al. 1998; Muñoz et al. 2008; Zapater et al. 2011); it typically occurs at night and may lead to transfer of large quantities of water (e.g. mature maple tree = 102 L per night) – from 14% to 100% of daily evapotranspiration. For example, Zapater et al. (2011) studied hydraulic lift in the case of *Quercus petraea* and *Fagus sylvatica* using ^{18}O-enriched water; concerning the hydraulic lift, the authors describe the role of *Quercus petraea*. Also, foliar uptake of water was described; the findings indicate that absorbed water can also be transported to soil. Schreel et al. (2019) studied the capacity for foliar water uptake in the case of *Alnus glutinosa*, *Betula pendula*, *Fagus sylvatica, Liquidambar styraciflua*, *Quercus robur*, *Robinia pseudoacacia*, *Sorbus aucuparia*, *Tilia cordata*, and *Populus tremula*. For example, the authors found that there was no water uptake via the leaves of *Quercus robur*.

Ameliorative materials (e.g. alginite) can be used for successful afforestation of agriculturally used land. After their application, soil water content can be improved. For example, Gömöryová et al. (2009) found that soil water content increased with alginite content in the used mixture (soil + alginite). Podrázský et al. (2014) studied the effect of alginite on the initial growth (and mortality) of forest tree species (English oak, red oak, Norway maple, Scots pine). According to the authors, the application of alginite decreased the mortality of all studied forest tree species and led to higher increments (oaks, maple).

In this study, the effect of agricultural land afforestation (with a mixture of pedunculate oak, red oak and Norway maple or with Scots pine) on volumetric water content at depths of 20–60 cm was determined (the period from the end of March 2021 to the beginning of April 2022). Changes of volumetric water content on the same plots and at the same depths were studied by Vopravil et al. (2021) – the period from April to the beginning of November 2020. As stated in different publications, changes in volumetric water content vary between individual years (Tužinský 2005; Wieser et al. 2018). In this study, we hypothesised that afforestation of agriculturally used land will lead to lower volumetric water content in soil (Hiltbrunner et al. 2013; Vopravil et al. 2021). We also hypothesised lower volumetric water content in soil after afforestation with Scots pine (compared with a mixture of broadleaves) in the period after defoliation (Nordén 1991).

MATERIAL AND METHODS

As described by Vopravil et al. (2021, 2022), the used experimental plots were established near the Hovorčovice village in the Czech Republic on Haplic Chernozem (IUSS Working Group WRB 2015) – a mean annual air temperature of 8–9 °C, mean annual precipitation of 500–600 mm, and a sum of air temperatures above 10 °C between 2 600 and 2 800 (warm, mildly dry region of the Czech Republic). The afforestation of agricultural land with Scots pine (*Pinus sylvestris* L.) or with a mixture of pedunculate oak (*Quercus robur* L.), red oak (*Quercus rubra* L.), and Norway maple (*Acer platanoides* L.) was performed in the year 2011 – three squares 10 m × 10 m (1 m × 1 m spacing, 100 trees per square) in case of each of the variants, the alternation of lines with individual forest tree species in the mixture of broadleaves. The control variant was agricul-

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turally used land with the cultivation of potatoes in the period April–September 2021; after ploughing (October 10), the plot was left without any cover till April of the year 2022. A rain gauge [Pronamic Professional Rain Gauge, 200 cm^2, accuracy 0.1 mm, datalogger Minikin ERi (EMS Brno, Czech Republic)] was placed on the control plot. As described by Vopravil et al. (2022), volumetric water content and 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 the experimental plots using TMS-4 (TOMST, Czech Republic); see www.tomst.com). Selected physical and chemical soil properties on the study plots including seasonal changes in soil temperature and volumetric water content (and precipitation) in the period from April to the beginning of November 2020 are described by Vopravil et al. (2021); seasonal changes of air temperature in the period from April to the beginning of November 2021 are described by Vopravil et al. (2022). In this study, changes in volumetric water content at a depth of 20 cm (the control plot) or at depths 20 cm, 40 cm, and 60 cm (both afforested plots) in the period from the end of March 2021 to the beginning of April 2022 are presented.

The differences in the values of the studied properties were submitted to testing using a one-way ANOVA (analysis of variance) and Tukey HSD (honestly significant difference) test. When the assumptions about parametric tests were not met, a non-parametric Kruskal-Wallis ANOVA and Kruskal-Wallis multiple-comparison *z*-value test with Bonferroni correction for multiple testing were used. All statistical analyses were performed with STATISTICA Cz software (Version 10, 2011).

RESULTS AND DISCUSSION

During the period from the end of March 2021 to the beginning of April 2022, the minimum temperatures (a depth of 20 cm) for every day ranged from 1.0 °C to 24.3 °C on the control plot, from 1.4 °C to 18.3 °C in case of broadleaves, and from 1.4 °C to 17.6 °C on the plot with Scots pine (Figure 1). The course of air temperatures (20–60 cm above the ground) in the period from April to the beginning of November 2021 is described by Vopravil et al. (2022). Concerning air temperatures in the period from the end of March 2021 to the beginning of April 2022, the minimum daily values on the control plot (60 cm above the ground level) ranged from –12.8 °C to 18.1 °C and the maximum daily values from –4.3 °C to 36.9 °C (Figure 2 and Figure 3); the average daily temperatures ranged from –7.5 °C to 26.3 °C (Figure 4). On the plot with broadleaves, the minimum daily temperatures ranged from –11.5 °C to 18.9 °C, the maximum daily temperatures from –4.0 °C to 31.5 °C and the

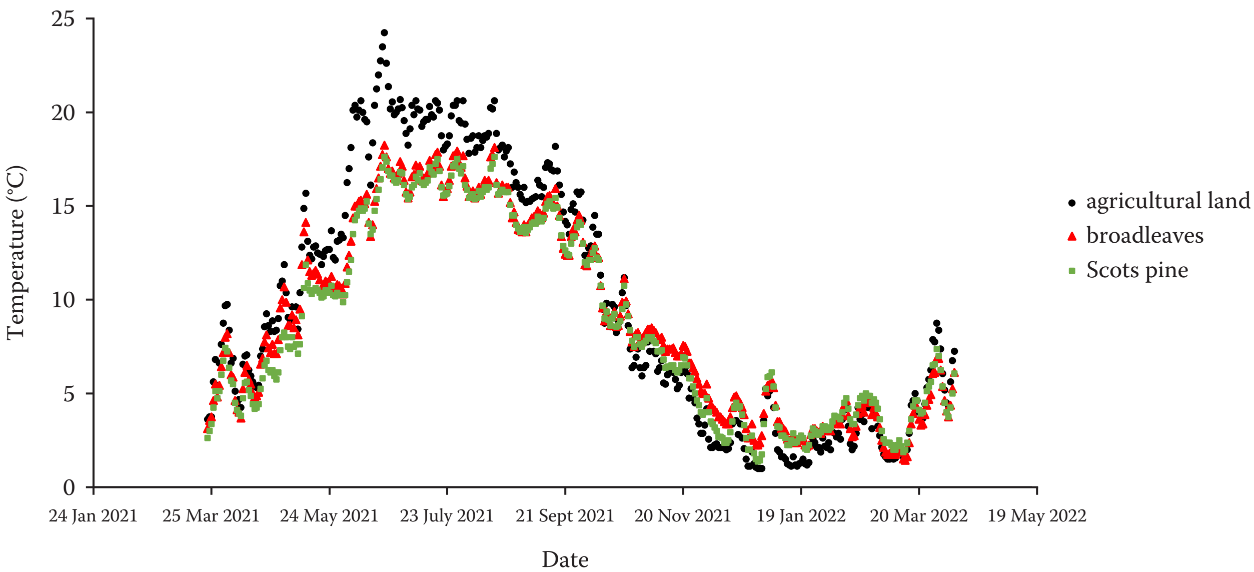

Figure 1. The values of minimum daily soil temperature at a depth of 20 cm on the studied plots

No significant ($P > 0.05$) differences between the studied plots were found

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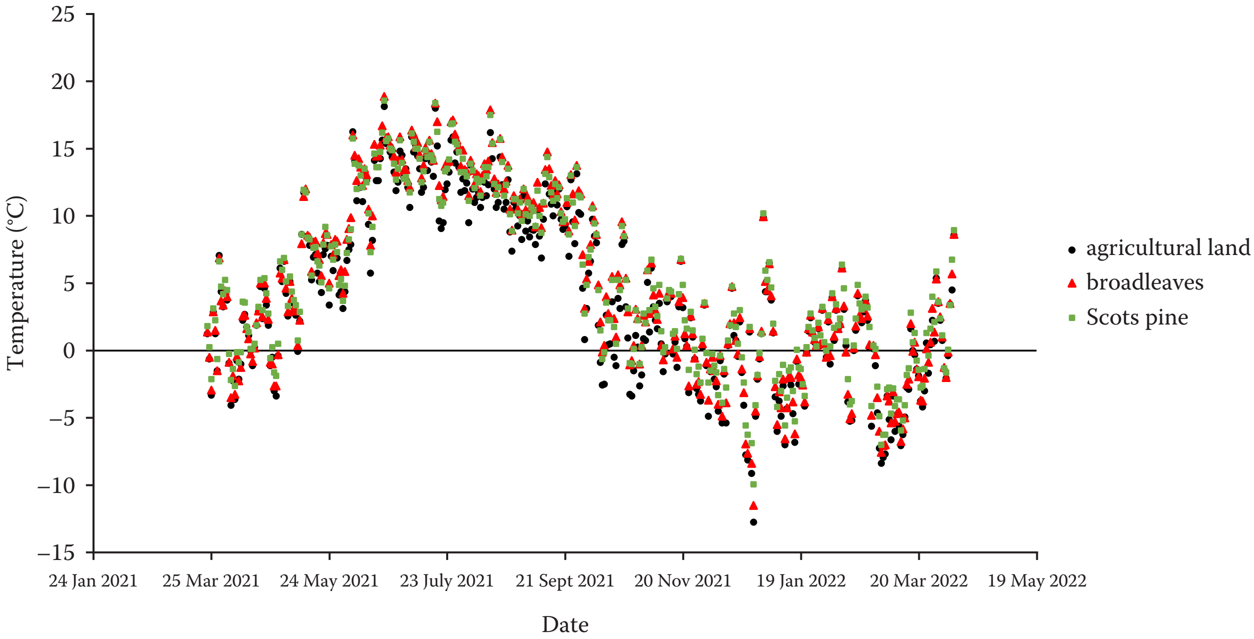

Figure 2. The values of minimum daily air temperature 60 cm above the ground

No significant ($P > 0.05$) differences between the studied plots were found

average daily temperatures from −7.1 °C to 23.7 °C. Concerning *Pinus sylvestris*, the minimum daily temperatures 60 cm above the ground level were from −9.9 °C to 18.6 °C and the maximum daily values ranged from −3.9 °C to 31.5 °C (Figure 2 and Figure 3); the average daily temperatures on the plot with Scots pine ranged from −6.5 °C to 24.2 °C (Figure 4).

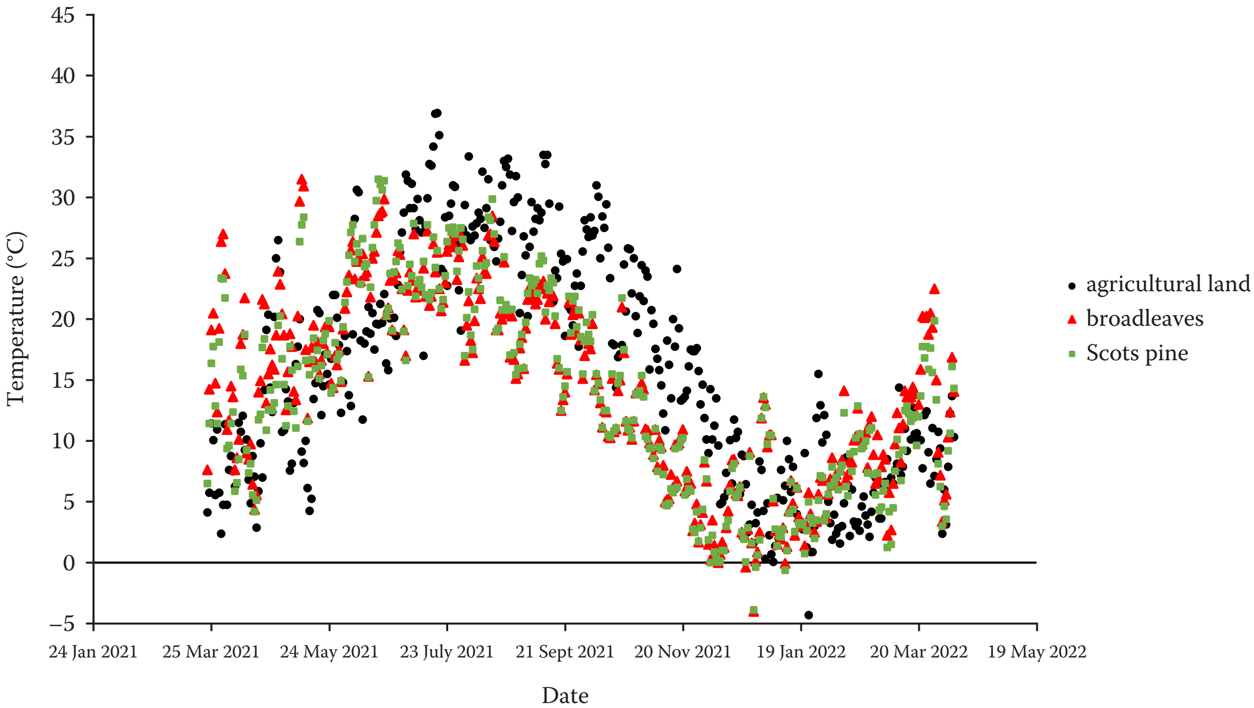

Figure 3. The values of maximum daily air temperature 60 cm above the ground

Significant ($P < 0.05$) differences between the plot afforested with Scots pine and the control (agriculturally used) plot were found

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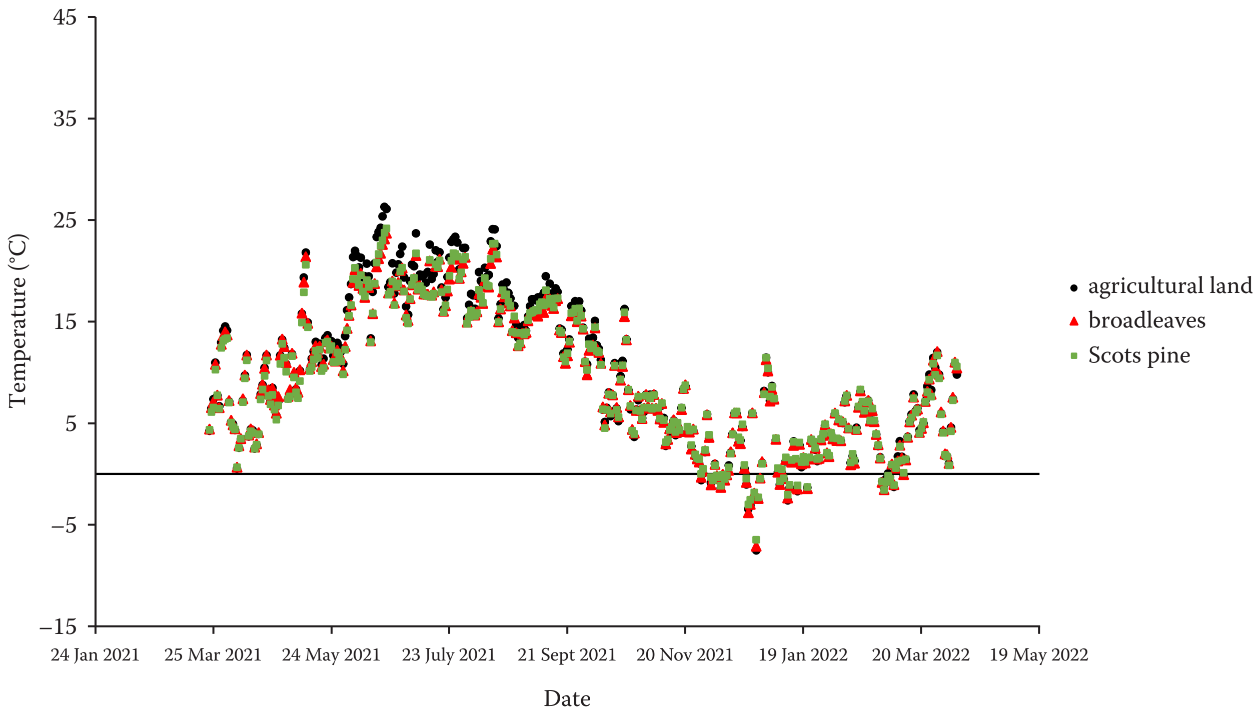

Figure 4. The values of average daily air temperature 60 cm above the ground

Daily sums of precipitation obtained on the control plot ranged from 0 mm to almost 30 mm; the highest values were found on May 2 and June 29 (Figures 5–7). On this plot, Vopravil et al. (2021) found that the value of total precipitation in the period from April to the beginning of November 2020 was 437.4 mm. Concerning this study, the value of total precipitation in the period from April to the beginning of November 2021 was 454.8 mm. The value of total precipitation in the period from the end of March 2021 to the beginning of April 2022 was 555.6 mm. Concerning individual months, the highest precipitation was recorded in June (119.4 mm), July (117.2 mm), August (102.2 mm), and May (72.4 mm). In the year 2021, the total precipitation at the end of March and through April was 10.6 mm; in September, October, November, and December, the monthly sums of precipitation ranged from 21.2 to 27.6 mm. Concerning the year 2022, the sums of precipitation were 17.8 mm (January), 9.8 mm (February), 12 mm and 7 mm (March and the beginning of April).

The highest average value of volumetric water content at a depth of 20 cm was found on the agriculturally used plot (0.397 $m^3 \cdot m^{-3}$) and the lowest value was on the plot afforested with Scots pine (0.285 $m^3 \cdot m^{-3}$); on the plot afforested with broadleaves, the average value of volumetric water content at a depth of 20 cm was 0.339 $m^3 \cdot m^{-3}$ (the period from the end of March 2021 to the beginning of April 2022). At a depth of 40 cm, the average volumetric water content was similar in the case of both afforested plots (broadleaves = 0.265 $m^3 \cdot m^{-3}$, Scots pine = 0.266 $m^3 \cdot m^{-3}$); at a depth of 60 cm, the average water content was 0.252 $m^3 \cdot m^{-3}$ (afforestation with Scots pine) and 0.330 $m^3 \cdot m^{-3}$ (afforestation with *Quercus robur*, *Quercus rubra*, and *Acer platanoides*). The values of volumetric soil water content at a depth of 20 cm were significantly ($P < 0.05$) different when all studied plots were compared. At depths of 40 cm or 60 cm, significant ($P < 0.05$) differences were found when both afforested plots were compared. At a depth of 20 cm, the lowest and the highest values of volumetric water content were 0.305 $m^3 \cdot m^{-3}$ and 0.541 $m^3 \cdot m^{-3}$ (the control plot), 0.263 $m^3 \cdot m^{-3}$ and 0.442 $m^3 \cdot m^{-3}$ (the plot with broadleaves), 0.222 $m^3 \cdot m^{-3}$ and 0.463 $m^3 \cdot m^{-3}$ (the plot with Scots pine). At a depth of 40 cm (the afforested plots), the lowest and the highest values of volumetric water content were 0.242 $m^3 \cdot m^{-3}$ and 0.300 $m^3 \cdot m^{-3}$ (the plot with broadleaves) and 0.225 $m^3 \cdot m^{-3}$ and 0.429 $m^3 \cdot m^{-3}$ (the plot with Scots pine). Concerning a depth of 60 cm, the lowest and highest values were 0.296 $m^3 \cdot m^{-3}$ and 0.343 $m^3 \cdot m^{-3}$ (the plot with broadleaves) and 0.221 $m^3 \cdot m^{-3}$ and 0.359 $m^3 \cdot m^{-3}$ (the plot

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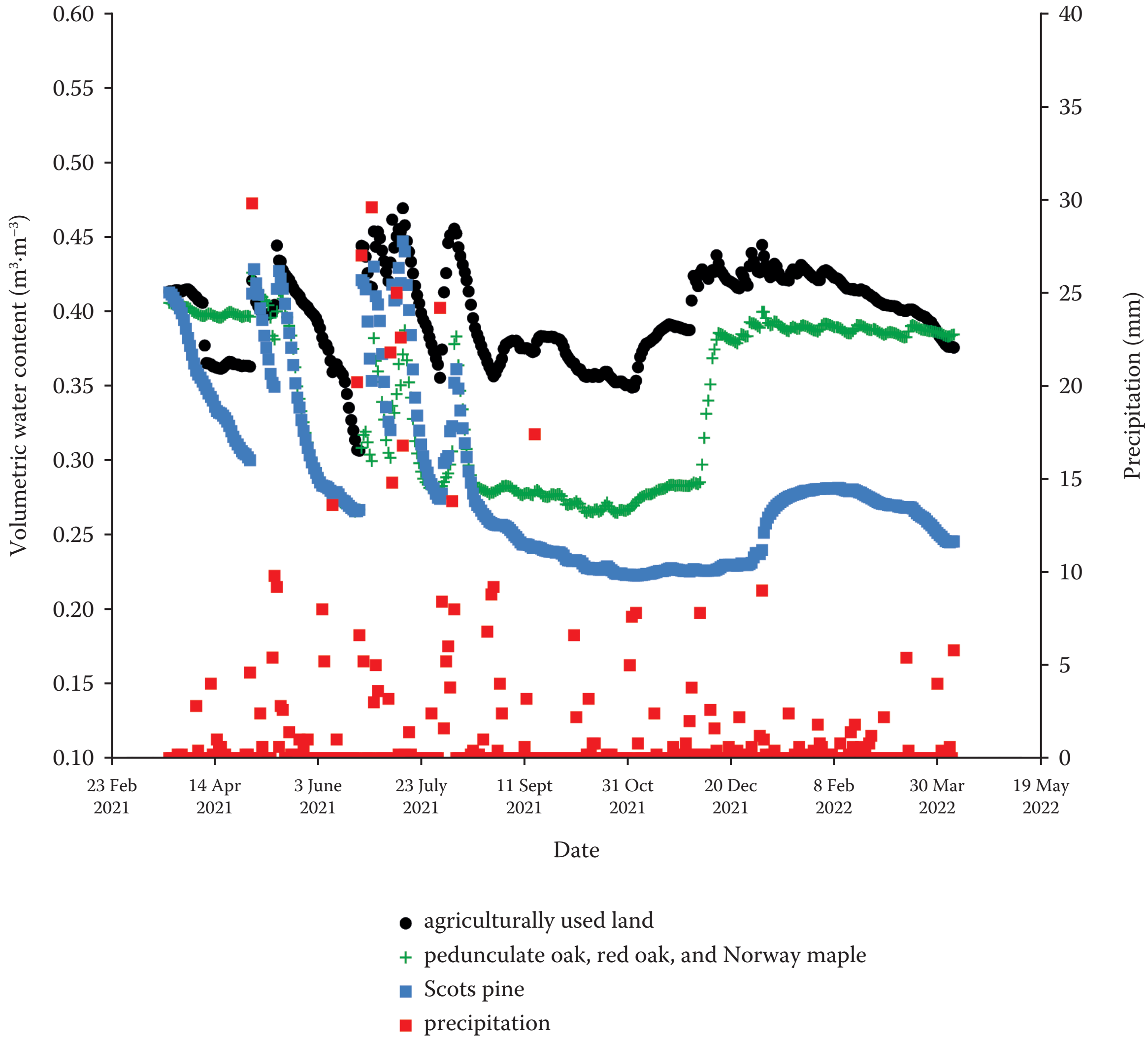

Figure 5. The average daily values of volumetric water content at a depth of 20 cm on the studied plots

with Scots pine). Concerning the average daily volumetric water content, the highest and lowest values are stated in Table 1. On the control (agriculturally used) plot, the lowest value at a depth of 20 cm was recorded on June 23; the maximum value at the same depth was obtained on July 14 (Figure 5). In the case of the plot with pedunculate oak plus red oak plus Norway maple, the lowest value of average daily volumetric water content was found on June 21, October 11, October 13 and October 14, October 25 and October 26 (20 cm), from October 14 to October 15, from October 18 to October 19, from October 25 to November 2 (40 cm), from July 12 to July 16 (60 cm). The maximum value of average daily volumetric water content was found on May 2 (20 cm), May 2 and 3 (40 cm) and May 3 (60 cm; Figures 5–7). On the plot with Scots pine, the minimum value was recorded in the period from October 29 to November 8 (20 cm) and on December 9, 10 and 12 (40 cm), December 1 and 2, from December 5 to December 17, and from December 23 to December 31 (60 cm). The maximum value of average daily volumetric water content was found on July 21 (20 cm), July 15 (40 cm) and July 15 (60 cm; Figures 5–7). The highest difference between maximum and minimum values of average daily volumetric water content at a depth of 20 cm was found in the case of the plot afforested with Scots pine (0.224 $m^3 \cdot m^{-3}$); these differences were similar in the case of the control and broadleaved tree species plot (0.163 $m^3 \cdot m^{-3}$ and 0.161 $m^3 \cdot m^{-3}$; Table 1). At depths of 40 and 60 cm, the highest differences between maximum and minimum values of average daily volumetric water content were also on the plot afforested with Scots pine (0.168 $m^3 \cdot m^{-3}$ and 0.136 $m^3 \cdot m^{-3}$). The differences

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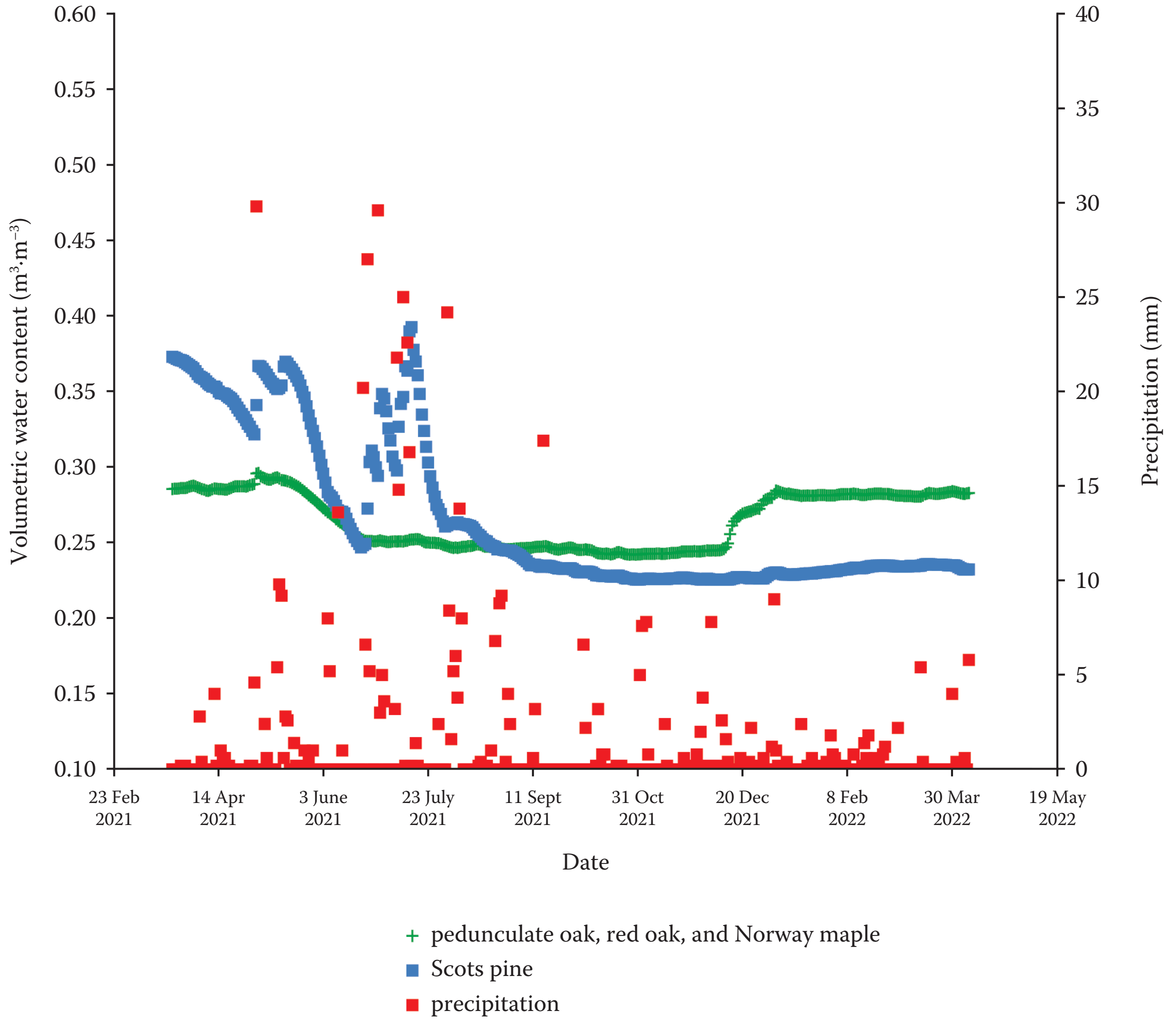

Figure 6. The average daily values of volumetric water content at a depth of 40 cm on the studied plots

were lower on the plot with broadleaved tree species (0.054 m^3·m^{-3} = 40 cm; 0.047 m^3·m^{-3} = 60 cm).

In this study, we found higher average volumetric water content at a depth of 20 cm in the case of the agriculturally used plot compared with the afforested plots. Also, Kupka and Podrázský (2010) found lower actual soil moisture in the upper 10 cm of mineral soil in the case of afforested plots compared with agriculturally used soil. Lower moistue in forest soil (with lower variability) compared with grassland soil was found by Chen et al. (2003); also, Hiltbrunner et al. (2013) found lower volumetric water content in afforested soil compared with pasture soil. Mei and Ma (2022) found that afforestation with *Robinia pseudoacacia* led to lower soil water content compared with natural grassland or natural forestland.

Yao et al. (2016) state that the effect of afforestation on soil water content can depend on the used forest tree species. Vopravil et al. (2021) found higher average water content on the Scots pine plot compared with broadleaves (depths 20 cm and 40 cm); concerning the mentioned broadleaves, the value was higher only at a depth of 60 cm. Contrary to the findings presented in the publication by Vopravil et al. (2021), we found the average value of volumetric water content was higher after afforestation with broadleaves compared with Scots pine (depths 20 cm and 60 cm); at a depth of 40 cm, the values were similar on both plots (the period from the end of March 2021 to the beginning of April 2022). In the case of the period from April to the beginning of November 2021, the average volumetric water content at depths 20 cm and 60 cm was also higher on the plot with broadleaves compared with Scots pine; at a depth of 40 cm, the average water content was higher under Scots pine compared with broadleaves. Thus, changes in vol-

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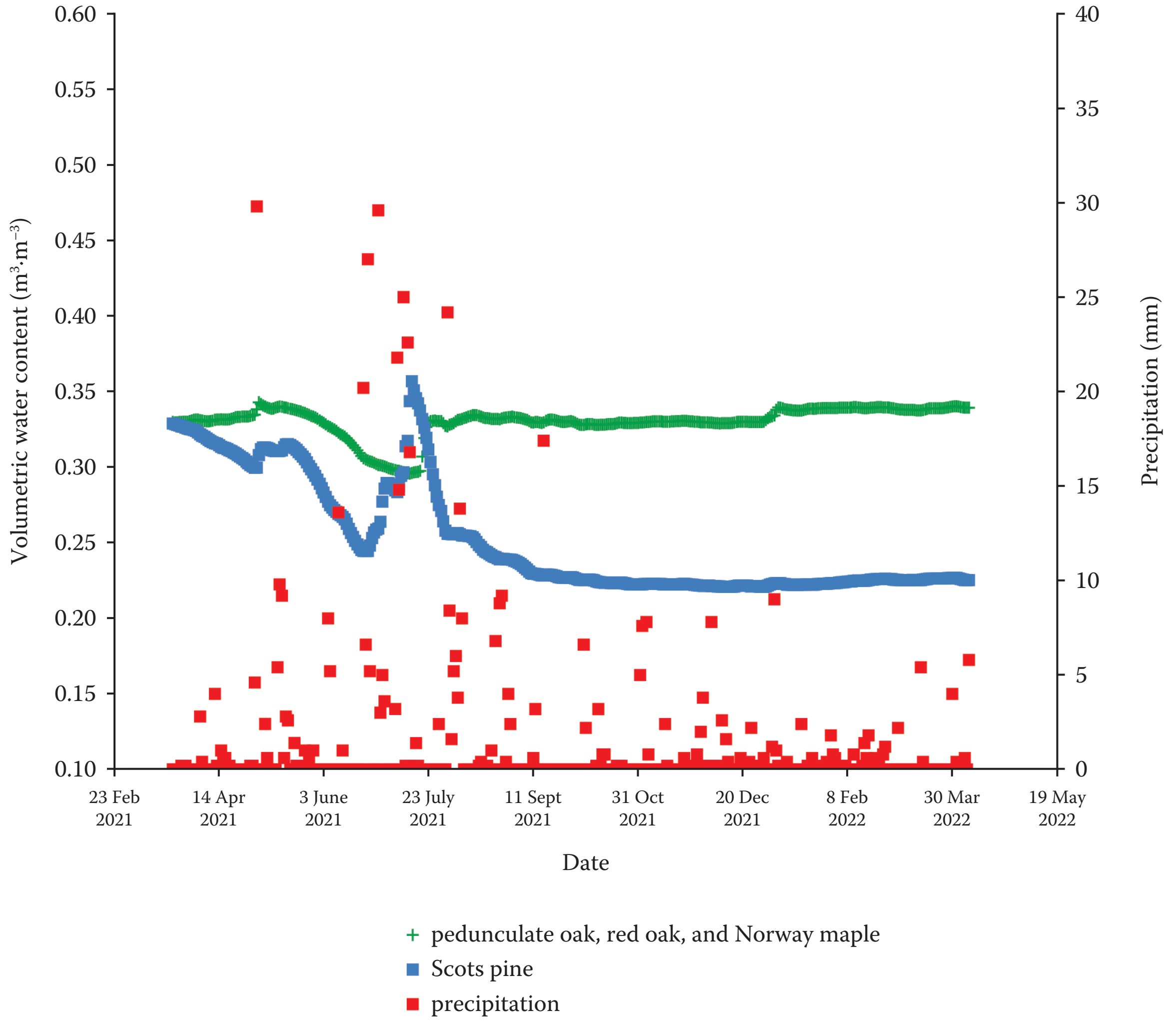

Figure 7. The average daily values of volumetric water content at a depth of 60 cm on the studied plots

umetric water content varied between individual years (see the study of Wieser et al. 2018 on the components of water cycle in *Pinus sylvestris* forest).

Except for the higher volumetric soil water content found after afforestation with Scots pine, we also found higher fluctuations of water content

Table 1. Maximum and minimum values of average daily volumetric water content on the afforested plots (and the control plot)

Plot	Soil depth (cm)	Average daily volumetric water content	
		minimum ($m^3 \cdot m^{-3}$)	maximum ($m^3 \cdot m^{-3}$)
Control plot	20	0.306	0.469
	40	np	np
	60	np	np
Pedunculate oak + red oak + Norway maple	20	0.265	0.426
	40	0.242	0.296
	60	0.296	0.343
Scots pine	20	0.223	0.447
	40	0.225	0.393
	60	0.221	0.357

np – not presented

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(all depths) on the plot with Scots pine compared with broadleaves (see also Vopravil et al. 2021). Differences in soil water content on the plots afforested with Scots pine versus broadleaves can be given by different rainfall partitioning (interception, throughfall, stemflow) and concentration, transpiration (forest tree species, understorey vegetation); also, litter or soil properties etc. can play a role (Reynolds, Henderson 1967; Putuhena, Cordery 1996; Vincke et al. 2005; Poleno et al. 2011; Nazari et al. 2020). The effect of spatial variability of soil properties, throughfall and root systems etc. can also be important [see the study of Sturm et al. (1996) on soil water content changes etc. in a *Pinus sylvestris* stand]. Vincke and Thiry (2008) or Keleş (2019) state higher rainfall interception by pine (29–31%) compared with oak (15–20%). In this study, significantly lower volumetric soil water content after afforestation with Scots pine (compared with broadleaves) was found in the period after defoliation. In this period, the proportion of throughfall (and stemflow) is expected to increase on the plot with broadleaves (Nordén 1991; Levia Jr., Frost 2003).

In this study, evapotranspiration was not limited by water content (agriculturally used plot, the plots afforested with broadleaves or Scots pine) during the vegetation season of the year 2021. Concerning transpiration, Ozcelik and Sengonul (2021) found higher transpiration of oak compared with pine. On the other hand, Poyatos et al. (2005) found higher transpiration of pine compared with oak. Most of pine roots were reported to occur in the upper 20 cm (Vincke, Thiry 2008; Geris et al. 2015; Johnson-Maynard et al. 2022). Concerning pine and oak, Bello et al. (2019), for example, reported utilisation of soil water mainly from near the surface (pure stands) or from 30–45 cm (the mixture of oak and pine). Contrary to the plot with broadleaves, understorey vegetation occurs on the plot afforested with Scots pine and can use water for transpiration (and interception). According to Poleno et al. (2011) or Wieser et al. (2018), understorey transpiration plus forest floor evaporation can form a significant part of total evapotranspiration (Gobin et al. 2015). For example, Wieser et al. (2018) estimated that forest canopy transpiration, understorey transpiration plus forest floor evaporation and interception formed 33%, 40%, and 27% of growing season cummulative evapotranspiration; understorey transpiration can form 19–90% of total evapotranspiration in temperate and boreal forests [see the Introduction of the publication by Gobin et al. (2015)].

Litter protects soil aggregates from direct impacts of raindrops; its production and decomposition were found to be influenced by climate, species, age of vegetation, stand density etc. (production) and climate (temperature, rainfall etc.), conifers versus broadleaves etc. (decomposition). Thus, water infiltration in forests was found to be higher compared with grasslands or arable land (e.g. Neary et al. 2009). Concerning water retention by litter, leaves retain more water than needles – it is given by the higher surface/weight ratio of leaves and the storage of water in depressions on the leaves; however, in some cases, higher water retention by needles compared with leaves (or no differences between needles and leaves) was found (Walsh, Voight 1977; Floriancic et al. 2023). Water retention was found to depend on the degree of litter decomposition (Ilek et al. 2019). Both semidecomposed and undecomposed litter can have a higher capacity for water retention depending on the type of forest (Chen et al. 2018; Zhou et al. 2018; Tu et al. 2022). Concerning our experimental plots (and as described in different publications), water retention by litter also depends on its amount on the ground (Walsh, Voight 1977).

Also, soil structural and hydraulic properties can be modified by the activity of earthworms; for example, Johnson-Maynard et al. (2022) state higher total porosity, macroporosity and hydraulic conductivity in soil under scrub oak compared with Coulter pine (absence of earthworms). Nevertheless, some other studies showed that afforestation with Scots pine (or with oaks – *Quercus petraea*, *Q. robur*) can have positive effects on earthworm abundance and biomass (Schwarz et al. 2015).

CONCLUSION

In this study, higher rainfall interception and evapotranspiration (and possibly litter with water-retention properties) led to lower volumetric soil water content on the afforested plots compared with the control. Our results also indicate that especially higher rainfall interception led to lower soil volumetric water content after afforestation with Scots pine compared with broadleaves. This was especially evident in the period after defoliation. Another question is the role of tree transpiration or litter. Rather than transpiration, Hughes et al. (2020) re-

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ported rainfall interception as the main reason for peak flows or total stormflows (and water yields) reduction after afforestation. Our results indicate a higher water-storage capacity of forests compared with agriculturally used land. During the leafless period, this capacity was found to be higher after afforestation with Scots pine.

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