Climate response to forest management in beech stands

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Abstract

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This work summarises the climatic data assembled in five submountain beech forest stands with different cutting patterns. The highest mean monthly air temperature values in March–July were obtained on a plot with 20-year-old beech thicket (T); in August–October on a stand after light shelterwood cuts (L) and in November–February in a closed stand (C – control). On the contrary, in the summer months June–July the C manifested the lowest temperature values, while in the winter (October–February) the temperature was the lowest on the open area (OA). The maximum one-hour (12-min averages were recorded) temperature increased with decreasing stand density of parent trees. The highest temperature value making 33.3 °C was measured in T, in OA reaching at the same time 32.9 °C, while on the C only 28.9 °C. The highest mean daily temperature showed a similar trend. Maximum soil temperature at a depth of 5 cm on the C occurred from the end of July to the beginning of September. The same hold for this variable on T but with the values lower by about 0.5 °C. The soil temperature at 20 cm had the peak not sooner that in the first ten-day period of September. During the whole period, the difference between the rainfall on OA and the throughfall in the C was statistically significant ($P \leq 0.05$). The highest monthly air humidity was always found on the OA, or on the T without parent stand (with variation from 72% in April to 95% in November). The lowest mean air humidity was observed in the densest adult stands: in March–October on plot L and in November–February (after the leaf fall) on the control.

Key words

air and soil temperature, humidity, shelterwood cut, stand density, throughfall

Introduction

Beech forest stands belong to the stand types considerably influencing the site microclimate. Due to diverse architecture of forest ecosystems, solar radiation displays diverse distribution patterns inside the ecosystems (Reitmayer et al., 2002; Zrak and Jaloviar, 2009) which is also reflected in vertical microclimate heterogeneity (Střelcová et al., 2003). The gradient of natural solar radiation serves a major role in growth of regeneration, as well as in forming plant communities in these ecosystems. Temperature resulting from the radiation affects most of the biological processes requiring a specific temperature range to function, with intensity much influenced namely by the temperature. Therefore, temperature is an essential external controlling factor significantly affecting e.g. phenophase timing in beech regeneration (Schieber, 2006; Jazbec et al., 2007; Barna et al., 2009) and in herb synusia (Schieber, 2007). In this context, such a phenomenon as late spring frosts represents a limiting factor for development of leaves and shoots and so also for the whole growth process in the given year (Dittmar et al., 2005). The harmful effect may to some extent depend on the site microclimate. The microclimatic diversity in a given ecosystem controls also the biodiversity in this ecosystem (De Freitas and Enright, 1995; Glončák, 2009). Temperature and humidity have been suggested by Zlatník (1976) as the main characteristics for the species-specific classification of forest environment in terms of so called vegetation tiers. In process of transformation of precipitation water has a key role interception – trapping rainfall and snow by crowns of trees and shrubs and by the ground vegetation. The interception is commonly expressed as the negative difference between the throughfall and rainfall on the open area. Interception in forest stands is mostly determined by the species composition, canopy density, stocking density and stand age. The leaf area structure is the background of high variability in water penetration through tree crowns. The total precipitation amount trapped by the tree crowns displays a wide range, reaching up to 60% (Mráček and Krečmer, 1975). The largest precipitation amounts are trapped by dense, multiple shaded spruce and beech forest stands (Tužinský, 1999, 2000; Jost et al., 2004).

It is evident that microclimate in forest stands is much influenced by the stand species composition, age, but especially by the stocking and canopy density. The effect concerns primarily the light supply into lower stand stories, air and soil temperature and uptake, distribution and evaporation of water – that means the water cycle comprising also runoff. These processes, however are complicated and interconnected, and as such, not always easy to explain. The aim of this paper is to quantitatively express selected climatic variables (air temperature and humidity, soil temperature, rainfall) in beech ecosystems with diverse structure resulted after regeneration cutting interventions.

Material and methods

The research ran in a 110-year-old beech forest stand in the Kremnické vrchy Mts (48°38‘ N and 19°04‘ E). The stand is situated at 470–490 m a.s.l. The study area belongs to the moderately warm region, moderately warm and humid hilly sub-region (Lapin et al., 2002). The long-term (1951–1980) mean annual air temperature is about 6.8 °C with a mean of 17 °C in the warmest month (July) and –4 °C in the coldest month (January). The long-term mean annual precipitation is 780 mm. About 55% of the annual rainfall falls from April to September (Střelec, 1992). The prevailing soil type is Andosolic cambisol with a high skeleton content (20–60%; Kukla, 2002).

Detailed research on influence of stand density on temperature and humidity in the stand was carried out over one year (from 1 March 2008 to 28 February 2009), in five beech forest stands differing in stand density – modelled by different regeneration cutting methods. The open area – OA, representing a clearing after clear cut; thicket (T) aged 20 years formed by natural regeneration after removal of parent shelter by cuts performed in 1989 and 2004; stand subjected to heavy shelterwood cuts (H) in 1989 and 2004 with stocking degree (G/G_{max}) of 0.3 (stand density 86 stems ha^{-1}, and with natural regeneration of more than 77,000 individuals ha^{-1}); stand after light shelterwood cuts (L) – stocking degree 0.5, 174 stems ha^{-1}, 35,000 ind. ha^{-1}; control – no cuts (C) – stocking degree 1.0, 613 stems ha^{-1}, 25,000 ind. ha^{-1} (Barna, 2008). Before the cuts, the dominant woody plant was beech (65–90%), associated species were fir, hornbeam and oak. The cutting was primarily focused on the admixed species, dying and ill trees and trees of a very low quality.

One-hour continual measurements of air temperature and humidity we carried out with using a digital data-logger (equipped with a temperature and humidity sensor EMS 33, Brno) placed at 2 m above the ground. The one-hour average values were determined as the average values from five point data (12-min interval). The fixed-time soil temperature at depth of 5 and 20 cm was measured with bent mercury soil thermometers and recorded always in the same time (9:00 a.m.). The throughfall amount was measured by the rain gauges installed with uniform spacing across the plot. There was measured only precipitation fallen in form of rain, so the evaluation concerns only the period March–November 2008.

Results and discussion

Air temperature

Table 1 illustrates that the mean values of monthly air temperature in March–July were the highest on the plot covered with thicket without parent stand (plot T), in August–October on the plot with partially (light) opened parent stand (L), and in November–February on the open plot. The lowest monthly values were recorded in October–February on the open area (OA), in March–May and August–September on the plot with parent stand opened with heavy cut (H), and in summer in June and July on the control plot (C). As for temperature extremes, the absolute 60 min minimum (–16.0 °C) was recorded in January on the OA situated close to beech natural regeneration. The value of this variable increased with stand density up to the plot with complete closed stand (C, –15.3 °C). The observation of the lowest temperature values on forest clearings has also been confirmed with the lowest mean daily (24-h) value recorded on the open area –12.1 °C, compared to the corresponding value in closed stand (C) –11.7 °C. The maximum one-hour temperature showed the opposite trend: increasing with decreasing stand density. The highest value of 33.3 °C was measured in the stand with natural regenerated beech thicket aged 20 years (T), in the OA reached 32.9 °C, in the C 28.9 °C. The highest mean daily temperature showed the similar course: in the thicket reaching 22.1 °C, in OA 22.6 °C, and in control plot only 22.5 °C (Fig. 1).

Table 1. Average monthly air temperature (°C, March 2008–February 2009) on beech plots with different regeneration cutting intensity (plots: OA and T – without parent stand, H – (stand density 86 stems ha^{-1}), L – (174 stems ha^{-1}), C – (613 stems ha^{-1})

	Open area (OA)	Thicket (T)	Heavy cut (H)	Light cut (L)	Control plot (C)
March	3.16	**3.40**	*3.14*	3.40	3.38
April	9.36	**9.89**	*9.28*	9.65	9.55
May	14.14	**14.64**	*13.83*	14.22	13.85
June	17.39	**17.58**	16.95	17.36	*16.89*
July	17.73	**17.83**	17.42	17.80	*17.42*
August	17.66	17.85	*17.49*	**17.91**	17.61
September	12.41	12.59	*12.41*	**12.70**	12.59
October	*9.16*	9.30	9.17	**9.42**	9.41
November	*4.57*	4.68	4.68	4.85	**4.92**
December	*0.55*	0.57	0.78	0.90	**0.99**
January	*–4.09*	–3.96	–3.98	–3.75	**–3.69**
February	*–1.33*	–1.06	–1.27	–1.05	**–1.02**

max; *min*

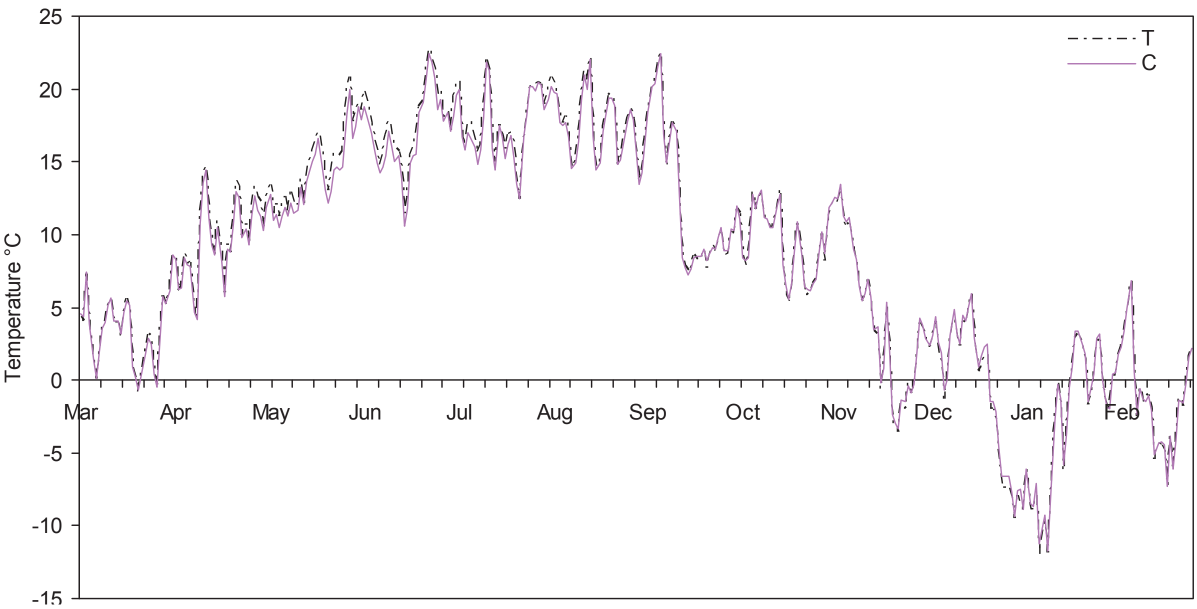

Fig. 1. Course of mean daily (24-h) temperatures (1 March 2008–28 February 2009) in a 110-year-old beech stand (C) and 20-year-old beech thicket (T) in the Kremnické vrchy Mts (470 m a.s.l.). Scaling on x-axis represent 7-day periods.

Figure 1 illustrates the course of the mean daily temperature values over 12 months in a closed beech stand aged 110 years (C), and in 20-year-old thicket (T). The variance of temperature was the smallest in May, the largest in September–February. The figure shows an evident raise in the mean 24-h temperature value from the end of the first April 10-day period, and, on the other hand a conspicuous decrease in the second 10-day period of September with a decrease in 24-h mean temperature by almost 15 °C within a single week. In the winter (December–February), there were alternating noticeably warm periods with the mean daily temperature exceeding 5 °C and relative cold periods with daily means even under –10 °C. Comparing the values between the stands C and T, there is no distinct difference in the temperature course. Slight differences are discernible since the first April days to the first September days – with higher values in the thicket. Then, there is practically no difference until the mid-October when the temperature becomes higher in the closed adult stand.

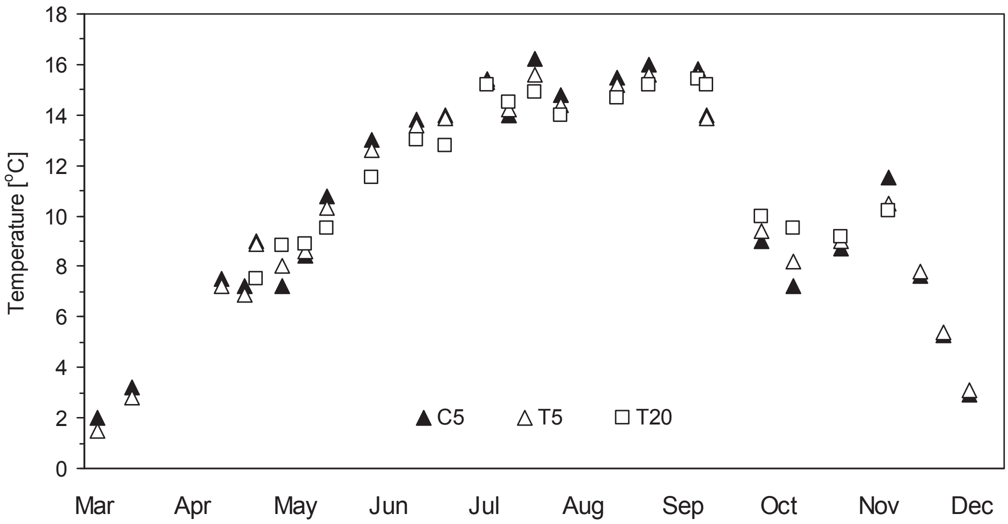

Fig. 2. Fixed-time soil temperature (9:00 a.m.) in March–November 2008 at soil depth of 5 cm and 20 cm on control plot with 110-year-old stand (C) and on plot with 20-year-old thicket (T).

Soil temperature

Figure 2 shows that the soil temperature at a depth of 5 cm reached minimum values ranging 1.5–2.0 °C at the beginning of March. On the other hand, the maximum at the same depth was observed on the control plot (110-year-old stand) in the mid-July and at the beginning of the third ten-day period of August, reaching the values of 16.2 °C, and 16.0 °C, respectively. On the plot with thicket (20-year-old stand) were maximum values at 5 cm soil depth observed on the same dates as on the control, but lower by about 0.5 °C. The soil temperature at 20 cm reached the peak only in the first ten-day period of September, with a value of 15.4 °C. In this period when the mean daily air temperature exceeded the long term average values by about 5 °C, the soil temperature at 20 cm was higher than at 5 cm by more than 1 °C. In a 10-day period from the mid-September, the soil temperature values in the two depths decreased by about 5 °C. Then followed a relative stable period – until the end of the first ten-day period of November, with comparatively small fluctuations in soil temperature and fixed-time values at depths of 5 and 20 cm oscillating about 8.5 °C and 9.5 °C, respectively. An exception was the first five-day period of November with a short term temperature increase at both depths by almost 2 °C, at 5 cm exceeding 11.5 °C. This phenomenon was connected with above-normal warm weather with daily air temperature values reaching 10–13 °C (Fig. 1) which means ca. +6 °C compared to the long term normal. Since the mid-November, there followed a distinct decrease again, with the fixed-time values towards the end of November fallen down to 3.0 °C.

Throughfall

The throughfall is rainfall or snow water not intercepted by tree crowns and fallen through gaps in vegetation onto the ground. Figure 3 illustrates how the stand

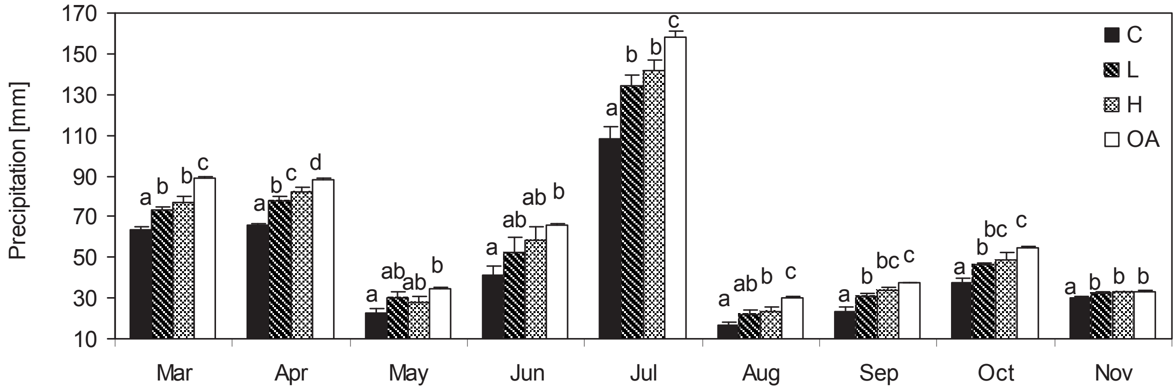

Fig. 3. Monthly rainfall totals on selected plots (C, control; L, light cut; H, heavy cut; OA, open area). Different letters indicate statistically significant differences between the means; Duncan's test applied ($P \leq 0.05$).

density affects the throughfall. The difference in throughfall between the open area (OA) and the closed adult stand (C) was statistically significant (P ≤ 0.05) over the whole study period. In the spring and summer months when the monthly precipitation totals were above 60 mm, there were found also significant differences in comparison with the two other plots (L and H). The differences between the stands were reduced to minimum in November after the leaf fall. The difference between throughfall in the stand L with stocking degree 0.5 (50% of basal area of the parent stand according to table values), and the rainfall on OA (stocking degree 0.0) was not statistically significant; the difference with the C (stocking degree 1.0) was significant (Fig. 3, November). In each month, the throughfall values increased from C to OA, only in May was observed an insignificant drop in H compared to L – due to inhomogeneous canopy and various sized gaps in stands H and L, created after the cutting.

Figure 4 presents percentage values of throughfall obtained in individual forest stands compared to the open plot over the study period. The throughfall total in the closed stand (C) was 409 mm, representing 69% of the total amount fallen on the open area, in the other stands the throughfall values were 84% (L), and 89% (H).

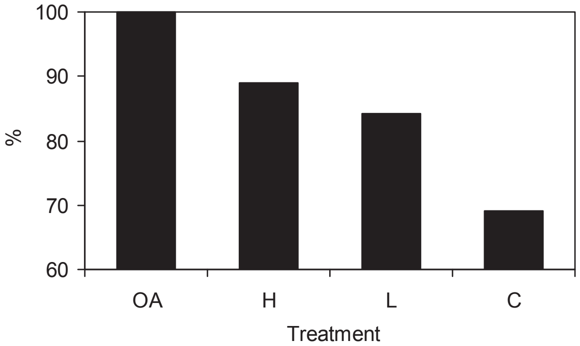

Fig. 4. Percentages of throughfall on individual forested plots compared to the open area (OA, open area; H, heavy cut; L, light cut; C, control).

Humidity

The highest mean monthly air humidity was always on plots OA and T, that means on the clearing and the plot without parent stand (Fig. 5). The variable displayed seasonal variations, with minimum in April (72%), and maximum in November (95%). On the other hand, the lowest mean monthly air humidity values were obtained in the densest stands: in March–October on plot L (on average 78%), later (November–February) after the leaf fall on plot C (on average 90%, Fig. 5). Minimum 60 min humidity decreased with decreasing stand density, the lowest value, however, was observed in April in the stand treated by light cut (L) – 8%, and the highest minimum humidity was found on the open area – 9%. Similar was the case of the 24-hour mean humidity: L – 46 %, OA – 50 %.

Discussion

The results manifest that the diverse stand density considerably affected the selected stand climate variables. The highest mean monthly temperature values in the vegetation period (April–September) were mostly observed on the plot with thicket (T), or in the stand with the stocking degree of 0.5 (L). Outside the vegetation period (October–March), the highest mean monthly temperature values were measured on the plot treated with heavy cut (H), or on the control plot (C), in the cold half of year, on the other hand, on the plot OA

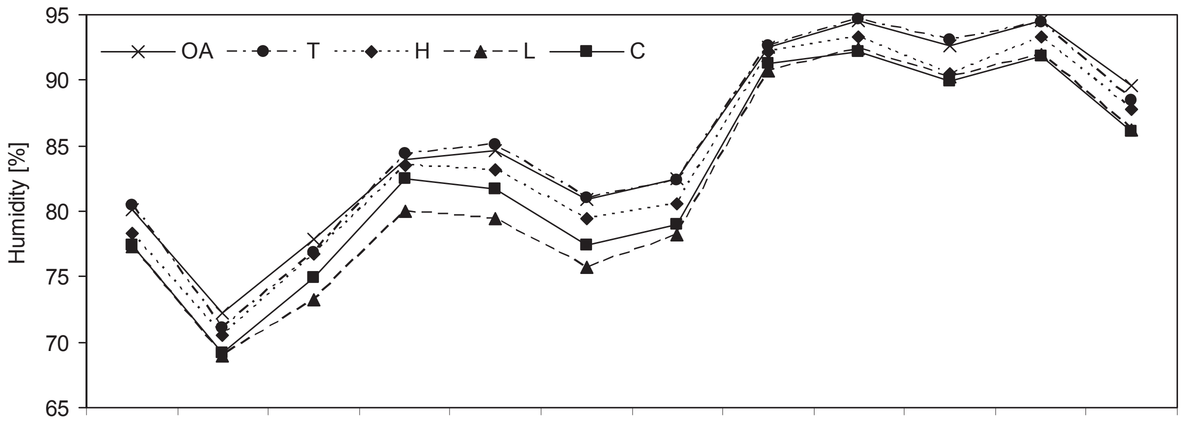

Fig. 5. Mean monthly air humidity in stands subjected to different regeneration cuts (OA, open area; T, thicket; H, heavy cut; L, light cut; C, control).

without forest cover. Also occurrence of air temperature extremes depended on the stand structure. The absolute minimum of one-hour temperature as well as the lowest mean daily temperature were recorded on plot OA, on the other hand, on the control plot reached these variables their maxima. On the contrary, the absolute one-hour maximum and the highest mean daily temperature showed an opposite course: their values were the highest in the stand with natural regeneration consisting of beech thicket aged 20 years (T), or on OA; while reaching the lowest values on the C. Open plots or plots with much released canopy in forest environment manifest wider amplitudes of air temperature compared to adult closed stand. Such a stand, thanks to its structure, has a damping effect on positive as well as negative temperature extremes – which is in accordance also with our results. Střelec (1991) obtained by analysing the impact of harvest-regeneration cuts on temperature in ground layer in submountain beech stands on the same plots after the first regeneration cut in 1989 a significant shift in the daily course of air temperature between the clear cut plot and the control plot without intervention. The daily air temperature extremes (min, max) were noticeably lower compared to the clearing. Similar results were obtained by Potter et al. (2001). Morecroft et al. (1998) report, that differences in air temperature between clearing and forest stand were more distinct in summer than in winter. Ritter et al. (2005) measured in a beech stand with clearings the highest values of mean or maximum daily temperature in the centre of a clearing. The values in the centre were by 5–10 °C higher than in other parts of the clearing.

Fixed-time temperature values at the soil depth of 5 cm in March–September were higher on the plot with adult stand than on the plot grown with thicket. In autumn, there was observed a reverse trend. By comparing soil temperature values between the depths of 5 cm and 20 cm within the same plot, it was revealed that in March–September was the soil temperature higher at 5 cm, while in September–December at 20 cm. Deeper soil layers warm more slowly in the spring and summer, on the other hand, the heat loss in autumn is less abrupt compared to the surface. Petrík (1988) comparing the measurements between the primeval forests Badín and Dobroč reports the differences between open area and forest stand making up to 5.1 °C in case of maximum, 2.5 °C in case of minimum and 5.1 °C in case of the range. Holst et al. (2004) have found that soil temperature in beech stands with varied density, growing on slopes varying in exposition is affected equally by the stand density and slope exposition, especially in the growing season. Janík (2005, 2009) reports light conditions and soil temperature varying with varying stand density. The author observed that the soil temperature at 5 and 20 cm had significant influence on the herb layer production.

Also the rainfall amounts measured on the individual plots have confirmed that the rainfall distribution to the ground stand layer depends on the stand structure. The most distinct difference in the precipitation totals over the period March–December was found between the precipitation on the open area (OA) and throughfall in the completely closed adult stand (C) in which the interception value was above 30%. The values on the other plots ranged from 11 to 16% compared to OA. Gregor (1991) obtained in the same forest stands in the Kremnické vrchy Mts one year after the cutting intervention (1989) the following interception values: 9% at stocking degree 0.3; 19% at 0.5; 29% at 0.7; and even 34% at 0.9. Dubová (2001a, b) reports that the summary interception in the same stands analysed 5 and 10 years after the cutting intervention manifested the most evident changes on plots with stocking degree 0.5 and 0.7. This was probably caused by the largest increment in crown volume and leaf area in these stands. The data provided by Kantor (1984) inform that the mean interception value in 120-year-old beech stand with 1.0 stocking degree was only about 8% – thanks to presence of abundant horizontal precipitation. In May–October periods 2005–2008 interception was 6–16% of the total atmospheric precipitation (25-year-old beech stand). Tužinský (2004) obtained for adult beech stands situated at lower altitudes a mean interception value ranging between 21–27%, while the value at higher altitudes was 9–27% representing on average 18% of the total fallen on the open ground. These data show that the rather high variability of interception values in beech stands is, apart from the just discussed factors, affected by the leaf area architecture and by the phenophase. The overall water balance in beech stands is also influenced by stem flow. Some authors (Tužinský, 2004; Kantor and Šach, 2008) suggest that the stem flow values may attain or even exceed 10% of the total amount fallen on open area.

Interesting is the fact that the lowest mean monthly air humidity was in the densest adult beech stands. Bublinec (1990) writes about more evaporation and drying in the stands with dominant beech (Querceto-Fagetum) than in the stands with dominant oak (Fageto-Quercetum). The primary cause is permanent air ventilation in stands with prevailing beech and simple architecture without shrub storey, on the other hand, very well developed in natural oak forest stands.

The climate change expected in the near future implies more frequent occurrence of vegetation periods with low rainfall totals and with temperature extremes. This will entail changes in bioclimatic environment required for occurrence of individual woody plants: primarily gradual retreat of spruce and expansion of beech in the 4-th and 5-th forest vegetation tiers (Škvarenina et al., 2004). More frequent and longer lasting soil water cycles with limited accessible soil water reserves may exert adverse effects on the moisture control, health condition and production in beech trees, especially in lower situated forest vegetation tiers (3rd f.v.t.) with dominant oak (Tužinský, 2004). The danger associated with the soil water regimen in beech stands is present also in case of excessive and longer lasting soil wetting; most often when soil defrosts in winter – when the beech trees may have impaired stabilising performance of their root systems and be prone to mechanical damage by extreme winds (Kodrík, 1996).

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Vplyv hospodárenia na klímu v bukových porastoch

Súhrn

V príspevku sú kvantifikované vybrané klimatické faktory (teplota a vlhkosť vzduchu, teplota pôdy, podkorunové zrážky) v bukových porastoch s diferencovanou štruktúrou (holina – OA, mladina – T, dospelý porast so zakmenením 0,3 – H, 0,5 – L, 1,0 – C), ktoré vznikli po ťažbovo-obnovných zásahoch rôznej sily. Najvyššie priemerné mesačné teploty vzduchu za mesiace marec–júl boli na ploche s 20 ročnou bukovou mladinou (T), v období august–október v poraste s čiastočne preriedeným materským porastom (L) a v zimnom období (november–február) v zapojenom dospelom bukovom poraste (C). Naopak v letných mesiacoch jún–júl v tomto poraste (C) boli najnižšie teploty, v zimnom období (október–február) to bolo na otvorenej ploche (OA). Maximálna hodinová teplota bola tým vyššia, čím redší bol materský porast. Najvyššia hodnota 33,3 °C bola nameraná v mladine (T), na otvorenej ploche dosahovala 32,9 °C, kým na kontrole len 28,9 °C. Najvyššia priemerná denná teplota mala tú istú tendenciu. Maximálne teploty pôdy v hĺbke 5 cm boli na kontrolnej ploche (C) koncom júla až začiatkom septembra. Na ploche T boli maximálne hodnoty v hĺbke 5 cm pozorované v tých istých termínoch ako na C, ale približne o 0,5 °C nižšie. V hĺbke 20 cm teplota kulminovala až v prvej septembrovej dekáde s hodnotou 15,4 °C. V tomto období, kedy boli priemerné denné teploty vzduchu vyššie asi o 5 °C oproti dlhodobému priemeru (1951 –1980), dosahovala teplota pôdy v hĺbke 20 cm vyššie hodnoty v porovnaní s hĺbkou 5 cm a rozdiel predstavoval viac ako 1 °C. V podkorunových zrážkach, medzi úplne zapojeným dospelým porastom (C) a zrážkach na voľnej ploche (OA), bol zistený štatistický významný rozdiel ($P \leq 0,05$) počas celého obdobia. V novembri, po opade listov, boli zistené najmenšie rozdiely v zrážkach medzi porastmi. V zapojenom poraste (C) predstavoval úhrn 409 mm, čo tvorilo 69,2 % z úhrnu na voľnej ploche. Najvyššia priemerná mesačná vlhkosť vzduchu bola vždy na plochách OA a T, tzn. na holine, resp. na ploche bez materského porastu. Jej hodnota sa menila počas roka,

najnižšie hodnoty dosahovala v apríli (72 %), najvyššie v novembri (95 %). Na druhej strane najnižšia priemerná vlhkosť bola v najhustejších porastoch: v období marec – október na ploche L, v neskoršom období (november – február) po opade listov – na ploche C. Minimálna hodinová vlhkosť klesala s hustotou porastu, ale najnižšia bola zistená v apríli v poraste po miernej ťažbe (plocha L) – 8 % a najvyššia minimálna hodinová vlhkosť bola na voľnej ploche – 9 %. Podobne to bolo aj s najnižšou priemernou dennou vlhkosťou: L – 46 %, OA – 50 %.

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