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BRIEF COMMUNICATION

Effect of Norway spruce planting density on shoot morphological parameters

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Abstract

Temporal and spatial variations of shoot structural parameters, including shoot silhouette to projected needle area ratio, are very important, *e.g.*, for the correction of leaf area index estimated by indirect methods. Here we bring few examples of their evolution within mountain spruce monoculture planted in two different densities.

Addititional key words: leaf area index, *Picea abies*.

Total amount of absorbed solar radiation by the tree canopy depends on its crown shape and geometry, number of shoots and its structural parameters. Moreover, these parameters describe a degree of mutual shading at the shoot level, which influences the net photosynthetic production. Therefore, they are widely used as correction factors for the accurate estimation of leaf area index (LAI) by indirect methods (Pokorný and Marek 2000).

The main goal of the presented paper is to evaluate spatial and temporal variation of correction factor SPAR (shoot silhouette area to projected needle area ratio) and other basic shoot morphological parameters. The main intention was focussed on the current shoots, because of their large surface area in the proportion to the rest bearing area of a tree, rapidly changing morphological properties of the current needles and shoots during the first vegetation season, and their high physiological activity.

Analyses were done on even-aged (18-year-old) Norway spruce (*Picea abies* [L.] Karst) monoculture in Beskydy Mountains. The stand consists of two plots with sparse (FS; 2100 trees ha^{-1}) and dense (FD; 2600 trees ha^{-1}) spacing. Four sampled trees representing median of the tree high and the basal branch length distribution at the both FD and FS plots were chosen. Current (*c*), 1-year-old (*c-1*), and older (*r*) shoots from 6 vertical positions, *i.e.* all odd whorls between IIIrd and XIIIth ones, were analysed (April - October). The following morphological parameters were estimated: shoot length (L), shoot width in the middle part (D), and cross-sectional shoot shape factor (B). Moreover, SPAR of the shoot was estimated using the *Portable Area Meter LI-3000* (*LI-COR*, Lincoln, NE, USA).

Shapiro-Wilks W test (*ANOVA*) was used to evaluate normality of data distribution. Sheffe`s test and Tukey`s HSD test (*ANOVA*) for unequal N (normal distribution) or Mann-Whitney U test (non-uniform distribution) were used to test the statistically significant differences among individual variants.

Dynamic differences of shoot structural parameters were expected in the springtime, *i.e.* during the intensive shoots growth period (May/June). Nevertheless, difficulties such as high water content in tissue and needles softness did not allow the analysis at this time. After the termination of the elongation growth (end of June), we did not observe any statistically significant

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Abbreviations: B - cross-sectional shoot shape factor; D - maximal shoot width; FD - plot with higher density (2 600 trees ha^{-1}); FS - plot with lower density (2 100 trees ha^{-1}); L - shoot length; LAI - leaf area index; SPAR - shoot silhouette to projected needle area ratio.

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differences within all individual parameters with regard to sampling over the rest of vegetation season.

All structural parameters of *c*, *c-1*, and *r* shoot age classes were summarized independently on their position within the tree crown (Table 1). We did not observe any statistically significant differences of *c-1* and *r* shoots parameters between FD and FS plots, as a result the uniform stand density before thinning (reduction ÷500 trees ha^{-1}) in previous season. Median of *r* shoots SPAR ($n = 15$), without the respect to their vertical position, was higher by 4 % ($P > 0.05$) comparing to *c-1* shoots. Moreover, median of *c-1* SPAR was higher by 13 % ($P > 0.05$) in comparison with *c* shoots (Table 1). SPAR difference between *c* and *r* shoots (18 %) was highly significant ($P < 0.01$). SPAR value increases with the shoot age as the result of a reduction of needles placed on the shoot (Oker-Blom and Smolander 1988). Because 1/SPAR is widely used as a correction factor for the LAI estimation by the optical methods (*e.g.* Pokorný and Marek 2000), its mean value should be determined according to the amount of the shoots of given age class by the weighted mean. Total leaf area of the canopy consists of *c* (by 26 %), *c-1* (by 23 %), and *r* (by 51 %) shoots in the both FS and FD plots (Pokorný and Marek 2000). Using the weighted mean procedure, SPAR values for FS and FD plots were estimated as 0.83 ± 0.03 and 0.92 ± 0.03 (mean ± SE). However, similar values of SPAR, *i.e.* 0.87 (Šubrtová 1994) and 0.84 (Leverenz and

Table 1. Structural characteristics of current (c), one-year-old (c-1) and older (r) shoots of sampled trees from sparse (FS) and dense (FD) plots independently on their position within the vertical canopy profile. SPAR - shoot silhouette to projected needle area ratio, D - maximal shoot width, L - shoot length, B - cross-sectional shoot shape factor.

Age	Character	Plot	Mean	Median	Confidential limits	
c	SPAR	FS	0.80	0.77	0.48	1.32
		FD	0.89	0.83	0.55	1.45
	D	FS	2.20	2.30	1.40	3.00
		FD	2.60	2.60	1.60	3.60
	L	FS	6.90	7.00	3.90	12.00
		FD	6.10	6.10	3.10	12.10
	B	FS	2.74	2.71	2.36	3.13
		FD	2.62	2.59	2.16	3.19
c-1	SPAR	FS	0.87	0.84	0.69	1.05
		FD	0.91	0.84	0.67	1.16
	D	FS	2.50	2.50	2.20	2.90
		FD	2.70	2.60	2.40	3.10
	L	FS	8.40	8.50	6.00	10.80
		FD	8.50	7.80	4.50	12.60
	B	FS	2.70	2.68	2.55	2.86
		FD	2.63	2.60	2.30	2.96
r	SPAR	FS+FD	1.00	0.94	0.78	1.23
	D	FS+FD	3.10	3.20	2.50	3.80
	L	FS+FD	7.70	7.50	5.70	9.80
	B	FS+FD	2.70	2.69	2.54	2.85

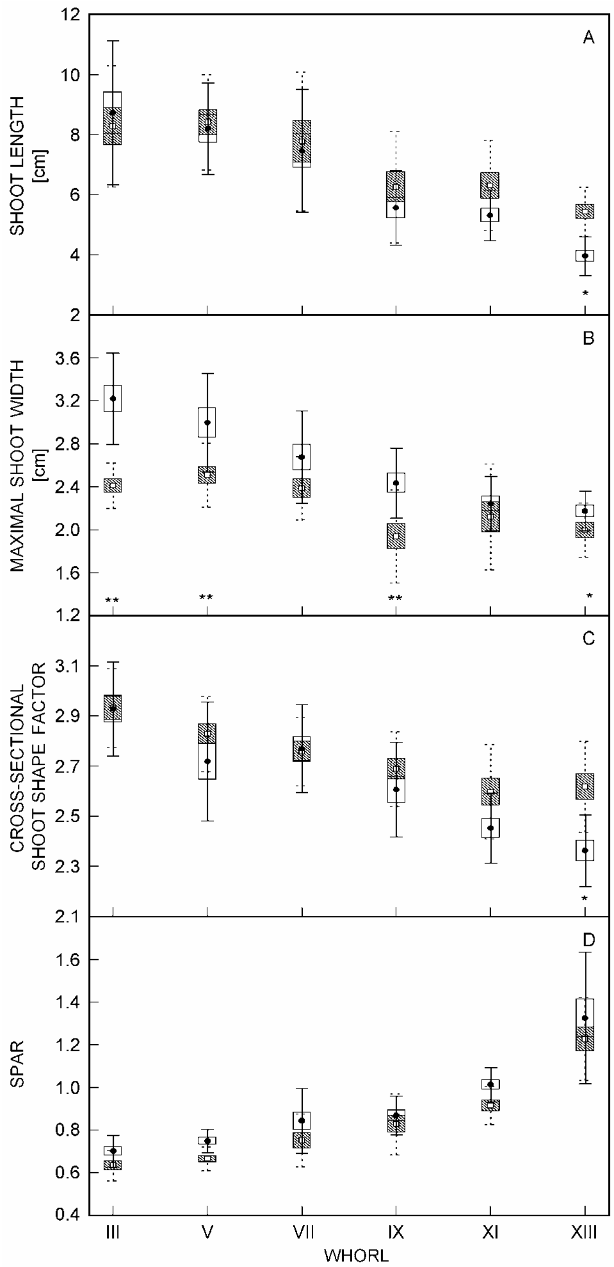

Fig. 1. Spatial variability of basic morphological parameter values (mean ± standard error); shoot length (*A*), maximal shoot width (*B*), cross-sectional shoot shape factor (*C*), and shoot silhouette to projected needle area ratio (*D*) of current shoots within the vertical canopy profile. Canopy profiles are represented by whorls (counted downward from the tree top) within sampled tree-crowns of sparse (FS; mean - empty cubic, SE - dashed columns, SD - dashed whiskers) and dense (FD; mean - full circles, SE - empty columns, SD - full whiskers) plots. N (per whorl and plot) varied within the interval from 26 to 30; * - statistically significant differences ($P < 0.05$), ** - highly significant differences ($P < 0.01$).

Hinckley 1990), were early directly determined for spruce stands.

Mean SPAR value of *c* shoots was lower by 10 % comparing FS to FD plot (Table 1). This supports the hypothesis that maximal LAI (LAI_{max}) depends on the stand density. Following the relation between LAI_{max} and SPAR (Leverenz and Hinckley 1990), maximal values of projected LAI are 11.5 and 13.2 for FS and FD (accounting *ca.* 15 % LAI overestimation for *P. abies*).

Variability of morphological parameters of *c* shoots in the vertical canopy profile (Fig. 1) was analysed after their elongation phase (end of June). All, L (Fig. 1*A*), D (Fig. 1*B*) and B (Fig. 1*C*) parameters demonstrated similar trends within the canopy. However, steeper decline was observed in FD plot. More flat shape of shoots situated in the lower parts of the canopy allows a reduction of mutual shading among the needles and subsequently higher interception of the solar radiation. Thus, the SPAR values increase with the depth into the canopy (Fig. 1*D*). Šubrtová (1994) referred linear decrease of spruce SPAR value from 0.6 (top) to 1.2 (down). Here presented data manifested tight linear correlation ($r \approx 0.75 - 0.80$) between SPAR and vertical position, however, non-linear relations were stronger ($r_S \approx 0.83 - 0.84$). This fact may correspond to an adjustment of shoot structure according to changes of radiation environment within the canopy. Because of no statistically significant differences between FS and FD plots for SPAR values of *c* shoots, the general equation of their spatial variations is:

$$SPAR = 0.4939\, e^{0.0625\, X}, \quad (r^2 = 0.93)$$

where X represents the order of tree whorls.

Comparing the shoots of FS and FD plots with the respect to their position in the vertical profile, significantly ($P < 0.05$) higher (up to 11 %) B values were observed below XIIIth whorl in the FS plot (Fig. 1*C*). It corresponds to the lower degree of canopy closure and higher incoming irradiances. Shoot length (Fig. 1*A*) decreased with the depth into the canopy by 33 % (FS) and 54 % (FD). The shoots from XIIIth whorl were significantly ($P < 0.05$) shorter (27 %) if comparing FD to FS plot. Similarly, the shoot width (Fig. 1*B*) increased from the bottom to the top of the canopy by 21 % (FS) and 48 % (FD). The shoot width, predicating needle lengths and their inclination angles, was lower by 14 % in FS plot.

Finally, we statistically analysed the differences of shoot structural parameters among individual whorls. Differences between FS and FD plots were neglected in that case. On the base of these results, individual parameters were separated into the homogenous groups (1 - 3). Changes of *c* shoots structural parameters (SPAR and B preferentially) within the canopy profile document that the transition between sun- and shade-adapted canopy parts is located among VIIth and IXth whorl.

Temporal analysis of the shoot morphological parameters in corresponding tree zones demonstrated strong variance in current shoots. Contrariwise, these variances are negligible over two growing seasons. Herewith, the shoot position within the canopy vertical profile influences its morphology more significantly. Especially, variation of B and SPAR parameters could be used for the differentiation of the canopy to sun- and shade- adapted zones. Moreover, SPAR values from plots with different densities demonstrate that the application of the uniform correction factor (1/SPAR) may lead to the underestimation (sparse plot) or overestimation (dense plot) of the total LAI estimated by indirect methods.

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