ACTA UNIVERSITATIS AGRICULTURAE ET SILVICULTURAE MENDELIANAE BRUNENSIS

Volume LXI 16 Number 1, 2013

http://dx.doi.org/10.11118/actaun201361010129

TRANSMITTANCE OF YOUNG NORWAY SPRUCE STAND CANOPY FOR PHOTOSYNTHETICALLY ACTIVE RADIATION DURING THE GROWING SEASON

Irena Marková, Jiří Kubásek

Received: June 22, 2012

Abstract

MARKOVÁ IRENA, KUBÁSEK JIŘÍ: *Transmittance of young Norway spruce stand canopy for photosynthetically active radiation during the growing season.* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 1, pp. 129–135

Analysis of transmittance of young Norway spruce stand canopy for photosynthetically active radiation (PAR) was made at the study site of Bílý Kříž (the Moravian-Silesian Beskids Mts., the Czech Republic) at different sky conditions during the growing season in 2010. For the description of PAR transmittance different phenological phases of the spruce stand development in clear and overcast days were chosen. The mean daily PAR transmittance of the spruce canopy was significantly higher in overcast days compared with clear ones. Diffuse PAR thus penetrated into lower parts of the canopy more efficiently than direct one. PAR transmittance of young Norway spruce stand canopy was different in individual phenological phases of the spruce stand canopy which was caused by changes in the stand structure during the growing season. Thus monitoring of transmittance of young Norway spruce stand canopy for PAR can help to describe the development of spruce stand canopy.

overcast and clear days, phonological phases

Biomass production of forest stands is determined by the assimilation activity and allocation of assimilates. The assimilation activity is strongly dependent on the accessibility of solar radiation and its absorption plays a key role in a set of physiological processes connected with forest stand biomass production. The radiation field within the forest stand canopy is spatially and temporally highly variable (Reifsnyder *et al.*, 1971; Baldocchi *et al.*, 1984; Grant, 1997; Shaw, 2002; Fladeland *et al.*, 2003; Hardy *et al.*, 2004; Leuchner *et al.*, 2011). The solar radiation distribution within and below the canopy of the forest stand depends on the seasonal/daily changes in the angle of incidence of solar beams, on the actual cloud cover leading to different ratio between direct and diffuse solar radiation, and on the seasonal changes in the stand canopy architecture (composition, density, phenological development etc.) (Baldocchi and Collineau, 1994; Gendron *et al.*, 2001; Hamberg *et al.*, 2009). Measurement of solar radiation below the forest canopy can characterize plant growth and morphology, estimates plant competition and documents temporal changes in plant structure (Gendron *et al.*, 1998; Gendron *et al.*, 2001; Prévost and Raymond, 2012). The aim of this article is to describe transmittance of young Norway spruce stand canopy for photosynthetically active radiation during the growing season and at the different sky conditions.

MATERIALS AND METHODS

The observations were performed in a young Norway spruce (*Picea abies* [L.] Karts.) stand located at the Ecological Experimental Study Site of Bílý Kříž in the Moravian-Silesian Beskids Mts. (the Czech Republic). Detailed description of the study site and the studied spruce stand is presented in Tab. I.

Different phenological phases of the spruce stand development in clear and overcast days were chosen for the description of transmittance of young Norway spruce stand canopy for photosynthetically active radiation. The 1st phase represented the canopy in dormant time or during a bud-burst time, the 2nd phases represented the shoots flushing and development of new shoots, and thus the most rapid increase of leaf area index (LAI), the 3rd phase represented the maximum LAI values during the growing season, and the 4th phase represented the decrease of LAI due to shoots fall.

Photosynthetically active radiation regime (PAR; wave band 400–700 nm) of investigated stand has been permanently measured during the whole growing season in 2010. The Quantum Sensor LI-190S (LI-COR, USA) was located four meters above the stand canopy on a steel meteorological mast and was used for a measurement of the amount of incident PAR (PARi). A set of special linear holder system equipped with quantum sensors (30 sensors placed every ca. 15 cm) were located at ca. 10% of the stand height in the East-West direction, i.e. transversally through the plot along altitudinal level line. This set of sensors was used for the measurement of the amount of PAR transmitted (PARt) through the canopy. The self-made quantum sensors (wave range 400–700 nm) used for the PARt measurements were based on the photocell BPW-21 (Siemens, Czech Republic). The sensors were cosine-corrected, and the maximum sensitivity was peaking at 550 nm. Possible differences in sensors sensitivity were accounted for a calibration routine based on a linear regression between the raw volts output of BPW-21 quantum sensors and the standard Quantum Sensor LI-190S (LI-COR, USA). The routine was performed twice per the growing season. The synchronized records of incident and transmitted PAR amount were carried out at 30-seconds intervals, and 10-minute average values of these records were automatically stored by a data-logger. Radiation values at the solar elevation higher than 10° were used for the consequent analyses.

Leaf area index (LAI) was measured using LAI-2000 Plant Canopy Analyser (LI-COR, USA) during the growing season in the 2010.

Descriptive statistics and correlation analysis were made by Statistica 9 version software (StatSoft Inc., Tulsa, USA).

RESULTS AND DISCUSSION

For the description of the transmittance of young Norway spruce stand canopy for PAR were chosen clear and overcast days from four different phenological phases of the spruce stand development (Fig. 1).

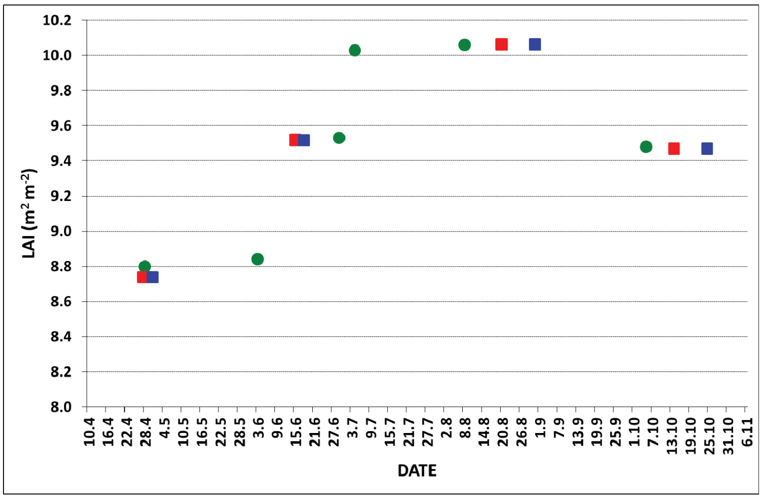
The measuring campaigns included days that primarily differed in the proportion of diffuse radiation. Mean daily clearness index (defined as the ratio of solar radiation incident on the top of the Earth atmosphere and the solar radiation incident on the study site) ranged between 0.68 and 0.72 during clear days, while it was only 0.05–0.08 during overcast days (Tab. II).

Chosen clear days differed in the amount of incident PAR (Tab. II, Fig. 2). In clear days it was caused by differences in solar elevation during the growing season and in overcast days it can be caused by differences in solar elevation and the atmosphere transparency.

The amount of transmitted PAR was higher in clear days compared with overcast ones (Tab. II, Fig. 3). The reason was the higher amount of PAR incident on the spruce stand canopy during the clear days.

I: *Description of the study site and the studied spruce stand*

	Bílý Kříž (Moravian-Silesian Beskids Mts., the Czech Republic)	
Study site	Geographic coordinates	18° 30´ E, 49° 30´ N
	Altitude	877 m
	Geological subsoil	flysh layer with dominant sandstone
	Soil type	typical humo-ferric podzol with mor-moder form of surface humus, medium depth up to shallow, loamy-sand or sandy loam, relatively low nutrient content, depth of 60–80 cm
	Mean annual air temperature	6.7 ± 1.2 °C
	Mean annual sum of precipitation	1374 ± 186 mm
Studied stand	***Picea abies* [L.] Karst** (planted out in 1981 using four-years old seedlings)	
	Exposure	SSE
	Slope	12.5°
	In the 2010:	
	Trees age	33 years
	Stand density	1400 trees ha^{-1}
	Mean stand height	13.7 m
	Mean diameter at breast height	16.5 cm
	Maximum leaf area index	10.1 $m^2 m^{-2}$



1: *Values of leaf area index (LAI; green points) and chosen clear (red square) and overcast (blue square) days used for a description of PAR transmittance of the spruce canopy at the study site of Bílý Kříž in 2010*

II: *Radiation characteristics of chosen clear and overcast days and studied spruce stand at the study site of Bílý Kříž in the 2010*

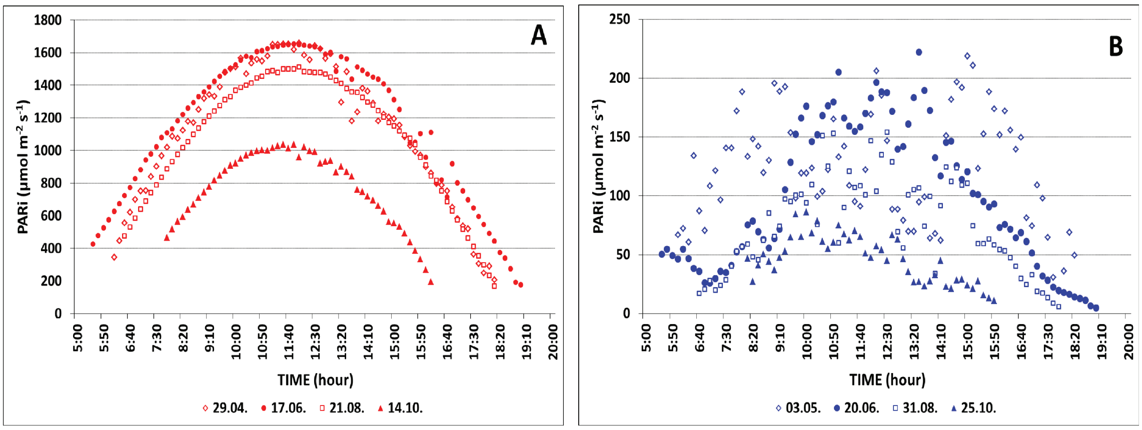
	CLEAR DAYS			
Date	29. 04.	17. 06.	21. 08.	14. 10.
Solar elevation > 10°	6:10–18:10*	5:30–19:00*	6:30–18:10*	7:50–16:10*
Daily ΣIex (kJ m^{-2})	34707	42039	33220	17271
Daily ΣSt (kJ m^{-2})	24977	29416	22677	12029
Daily ΣPARi (kJ m^{-2})	10984	12465	10214	5261
Daily ΣPARt (kJ m^{-2})	167	171	107	45
Mean daily transmittance (%)	1.5	1.4	1.1	0.9
	OVERCAST DAYS			
Date	03. 05.	20. 06.	31. 08.	25. 10.
Solar elevation > 10°	6:00–18:20*	5:30–19:00*	6:40–17:50*	8:10–15:50*
Daily ΣIex (kJ m^{-2})	35797	42094	30522	14328
Daily ΣSt (kJ m^{-2})	3009	2349	1512	679
Daily ΣPARi (kJ m^{-2})	1231	1061	678	290
Daily ΣPARt (kJ m^{-2})	59	38	29	11
Mean daily transmittance (%)	4.8	3.6	4.3	3.8

(Iex – solar radiation incident on the top of the earth atmosphere, St – solar radiation incident on the study site, PARi – photosynthetically active radiation incident on the studied spruce stand, PARt – photosynthetically active radiation transmitted through the studied spruce canopy; *– Central European Time)

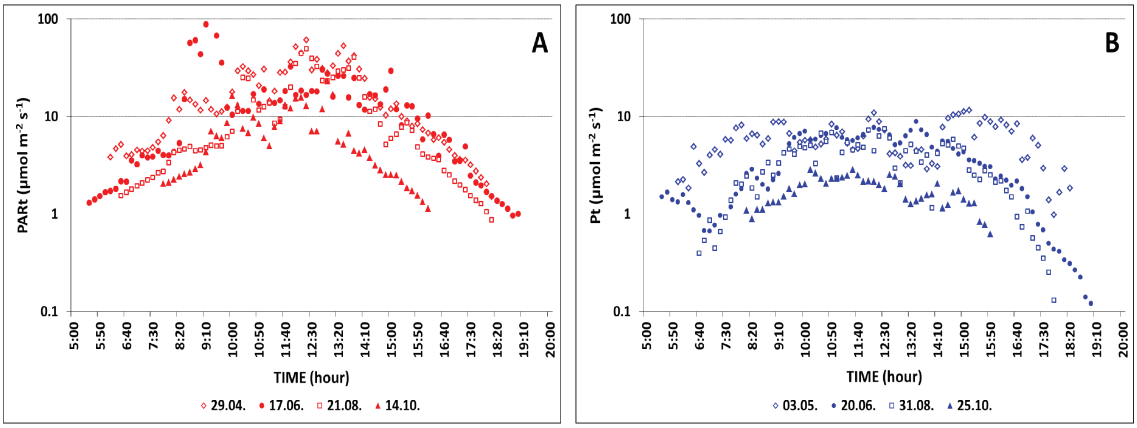
However, the mean daily PAR transmittance of the spruce canopy was significantly higher in overcast days ($P < 0.01$) compared with clear ones (Tab. I, Fig. 4). Diffuse solar radiation penetrates into the canopy more than direct one (Spitters *et al.*, 1986; Alados *et al.*, 2002; Leuchner *et al.*, 2007; Navrátil *et al.*, 2007; Leuchner *et al.*, 2011). Although PAR transmittance through canopies considerably depends on LAI (Wang and Baldocchi, 1989; Parker and Russ, 2004; Acem *et al.*, 2009), particularly after thinning of forest stand (Marek *et al.*, 1997; Pokorný *et al.*, 2008), relatively small changes in LAI during the growing season led to the negligible changes in PAR transmittance during clear as well as overcast days (Fig. 4).

PAR transmittance was different in individual phenological phases of the spruce canopy (Fig. 5) which was caused by changing of the stand structure during the growing season. Thus monitoring of PAR transmittance can help to describe the development of spruce canopy (Wang and Baldocchi, 1989; Chen *et al.*, 1997; Palva *et al.*, 1998; Domke *et al.*, 2007). PAR transmitted through the spruce canopy more in overcast days compared with clear days during the whole growing season.

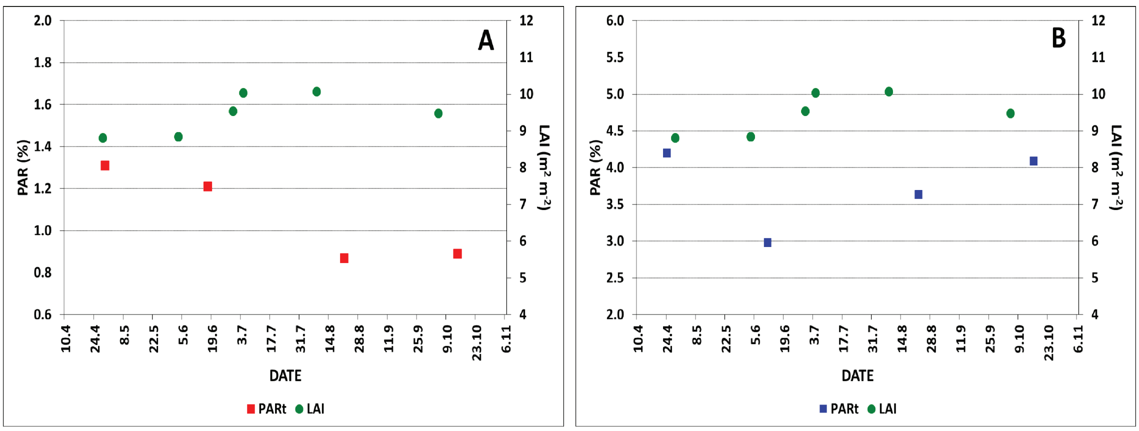
In overcast days PAR transmitted through the spruce canopy tightly correlated with PAR incident on the spruce canopy almost during the whole growing season (expected the 4th phenological phase) (Fig. 6). This was caused by higher homogenity of



2: *Daily courses of photosynthetically active radiation incident on the studied spruce canopy (PARi) at the study site of Bílý Kříž in chosen clear (A) and overcast (B) days in 2010*

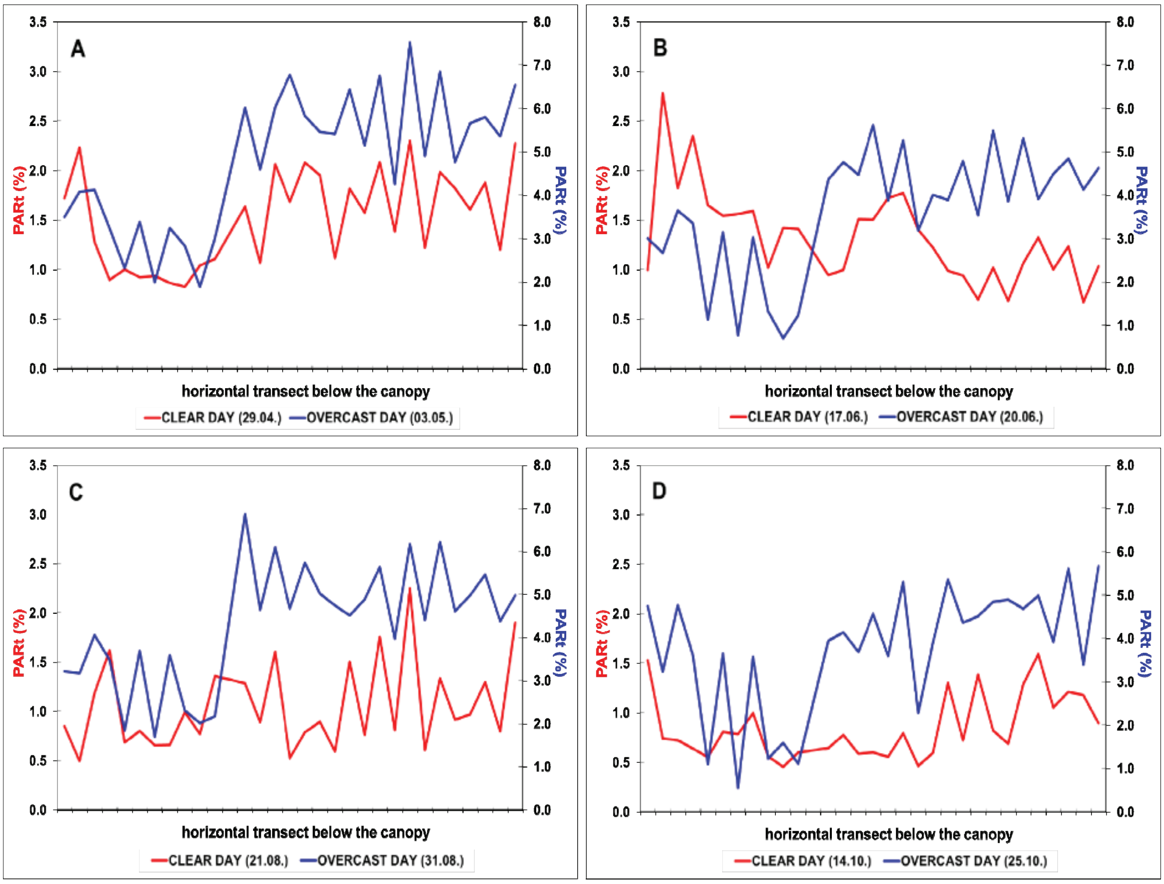


3: *Daily courses of photosynthetically active radiation transmitted through the studied spruce canopy (PARt; mean value calculated from the values mea sured by 30 sensors)) at the study site of Bílý Kříž in chosen clear (A) and overcast (B) days in 2010 (y axis is logarithmic)*



4: *Relationship of mean daily PAR transmittance (PARt) of the spruce canopy on the leaf area index (LAI) of the spruce stand at the study site of Bílý Kříž in clear (A) and overcast (B) days in 2010*

diffuse PAR and by improved penetration of diffuse PAR into the stand canopy (Vales and Bunnell, 1988; Comeau *et al.*, 2009; Lochhead and Comeau, 2012). In clear days correlation was very weak (Fig. 6). In clear days PAR penetration depends significantly on stand structure (effect of sunflecks and penumbra effect) (Gendron *et al.*, 2001; Matthew *et al.*, 2003; Hardy *et al.*, 2004; Yirdaw and Luukkanen, 2004; Leuchner *et al.*, 2011; Nilson *et al.*, 2011; Prévost and Raymond, 2012). Significantly different correlations in the 4th phenological phase, both in clear and in overcast day, could be due to a lower sun elevation, and therefore different PAR penetration into the stand canopy.



5: *Mean daily PAR transmittance (PARt) along the horizontal transect below the spruce canopy at the study site of Bílý Kříž during the growing season in chosen clear and overcast days in 2010 (A – 1st, B – 2nd, C – 3rd and D – 4th phenological phase)*

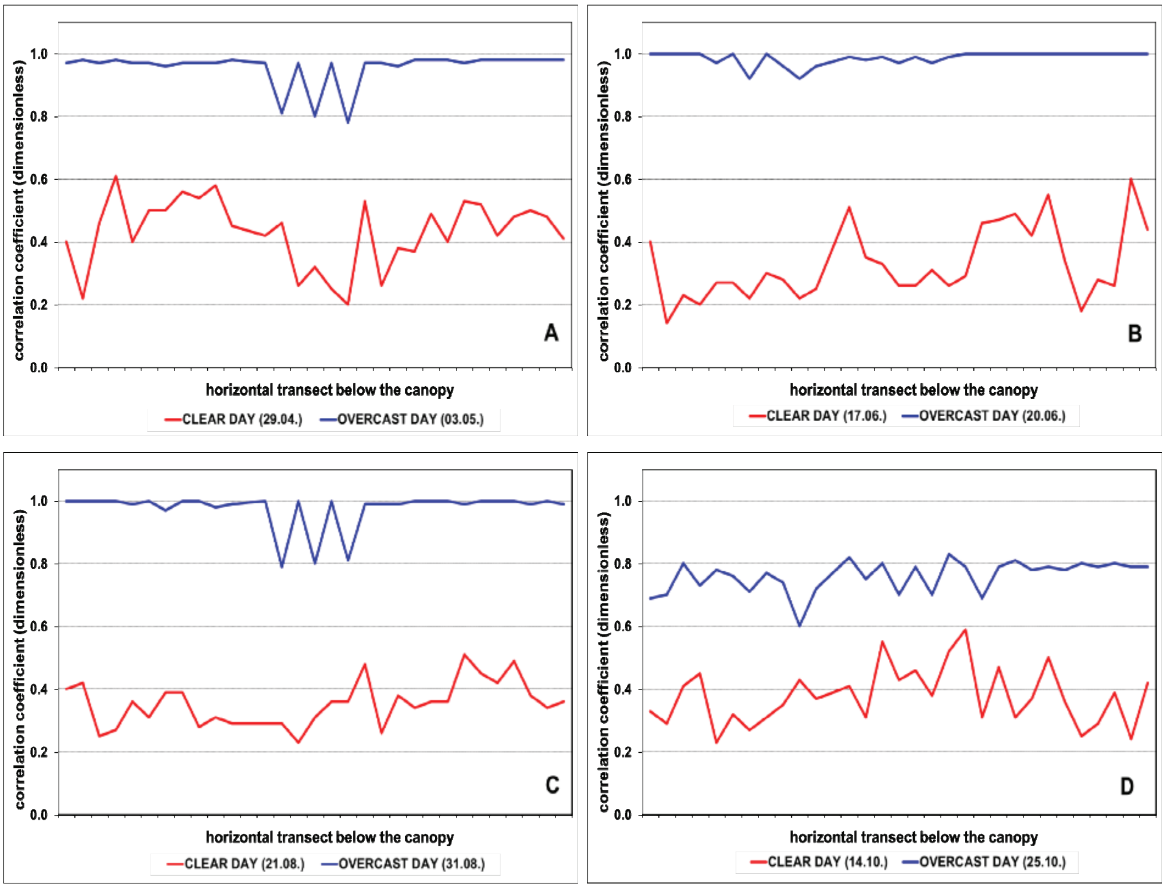
SUMMARY

Analysis of transmittance of young Norway spruce stand canopy for photosynthetically active radiation (PAR) was made at the study site of Bílý Kříž (the Moravian-Silesian Beskids Mts., the Czech Republic) at different sky conditions during the growing season in 2010. For the description of PAR penetration below the spruce canopy different phenological phases of the spruce stand development in clear and overcast days were chosen. The 1st phase represented the canopy in dormant time or during a bud-burst time, the 2nd phases represented the shoots flushing and development of new shoots, and thus the most rapid increase of leaf area index (LAI), the 3rd phase represented the maximum LAI values during the growing season, and the 4th phase represented the decrease of LAI due to shoots fall.

The amount of transmitted PAR was higher in clear days compared with overcast ones. However the mean daily PAR transmittance through the spruce canopy was significantly higher in overcast days compared with clear ones. Our results thus show that diffuse solar radiation penetrates into the canopy more efficiently than direct one irrespective of LAI and time of the growing season. PAR transmittance was different in individual phenological phases of the spruce canopy which was caused by changing of the stand structure during the growing season. Thus monitoring of PAR transmittance can help to describe the development of spruce stand canopy.

Acknowledgement

The authors are grateful for the financial support by grant No. MSMT 6215648902 of the Ministry of Education, Youth and Sports of the Czech Republic and by grant No. CZ.1.07/2.4.00/31.0056 of the Ministry of Education, Youth and Sports of the Czech Republic. The study site of Bílý Kříž is within the National Infrastructure for Carbon Observations – CzeCOS / ICOS supported by Ministry of Education of the Czech Republic (LM2010007).



6: *Correlation between mean daily PAR incident on the spruce canopy and mean daily PAR transmitted along the horizontal transect below the spruce stand canopy at the study site of Bílý Kříž during the growing season in chosen clear and overcast days in 2010 (A – 1st, B – 2nd, C – 3rd and D – 4th phenological phase)*

REFERENCES

ACEM, Z., LAMORLETTE, A., COLLIN, A., BOULET, P., 2009: Analytical determination and numerical computation of extinction coefficients for vegetation with given leaf distribution. *Int. J. Thermal Sciences*, 48(8): 1501–1509.

ALADOS, I., FOYO-MORENO, I., OLMO, F. J., ALADOS-ARBOLEDAS, L., 2002: Improved estimation of diffuse photosynthetically active radiation using two spectral models. *Agr. For. Meteorol.*, 111 (1): 1–12.

BALDOCCHI, D., COLLINEAU, A., 1994: *The physical nature of solar radiation in heterogeneous canopies: spatial and temporal attributes*. In: CALDWELL, M. M., PEARCY, R.W. (eds.): *Exploitation of Environmental Heterogeneity by Plants. Ecophysiological Processes Above- and Below-Ground*. Academic Press: San Diego: s. 21–70.

BALDOCCHI, D. D., HUTCHINSON, B. A., MATT, D. R., McMILLEN, R. T., 1984: Seasonal variations in the radiation regime within an oak-hickory forest. *Agr. For. Meteorol.*, 33: 177–191.

CHEN, J. M., BLANKEN, P. D., BLACK, T. A., GUILBEAULT, M., CHEN, S., 1997: Radiation regime and canopy architecture in a boreal aspen forest. *Agr. For. Meteorology*, 86(1–2): 107–125.

COMEAU, P. G., FILIPESCU, C. N., KABZEMS, R., DeLONG, C., 2009: Corrigendum to: Growth of white spruce underplanted beneath spaced and unspaced aspen stands in northeastern B. C. – 10 years results. *For. Ecol. Manag.*, 257(7): 1629–1636.

DOMKE, G. M., CASPERSEN, J. P., JONES, T. A., 2007: Light attenuation following selection harvesting in northern hardwood forests. *For. Ecol. Manag.*, 239 (1): 182–190.

FLADELAND, M. M., ASHTON, M. S., LEE, X., 2003: Landscape variations in understory PAR for a mixed deciduous forest in New England, USA. *Agric. For. Meteorol.*, 118 (1–2): 137–141.

GENDRON, F., MESSIER, CH., COMEAU, P. G., 1998: Comparison of various methods for estimating the mean growing season percent photosynthetic photon flux density in forests. *Agr. For. Meteorol.*, 92(1): 55–70.

GENDRON, F., MESSIER, CH., COMEAU, P. G., 2001: Temporal variation in the understorey photosynthetic photon flux density of a deciduou stand: the effect of canopy development, solar elevation, and sky conditions. *Agr. For. Meteorol.*, 106(1): 23–40.

GRANT, R. H., 1997: Partitioning of biologically active radiation in plant canopies. *Int. J. Biometeorol.*, 40: 26–40.

HAMBERG, L., LEHVÄVIRTA, S., KOTZE, D. J., 2009: Forest edge structure as a shaping factor of understorey vegetation in urban forests in Finland. *For. Ecol. Managem.*, 257(2): 712–722.

HARDY, J. P., MELLOH, R., KOENIG, G., MARKS, D., WINSTRAL, A., POMEROY, J. W., LINK, T., 2004: Solar radiation transmission through conifer canopies. *Agric. For. Meteorol.*, 126 (3–4): 257–270.

LEUCHNER, M., HERTEL, C., MENZEL, A., 2011: Spatial variability of photosynthetically active radiation in European beech and Norway spruce. *Agr. For. Meteorol.*, 151: 1226–1232.

LEUCHNER, M., MENZEL, A., WERNER, H., 2007: Quantifying the relationship between light quality and light availability at different phonological stages within a mature mixed forest. *Agr. For. Meteorol.*, 142: 35–44.

LOCHHEAD, K. D., COMEAU, P. G., 2012: Relationships between forest structure, understory light and regeneration in complex Douglas-fir dominated stands in south-eastern British Columbia. *For. Ecol. Manag.*, 284: 12–22.

MAREK, M. V., MARKOVÁ, I., KALINA, J., JANOUŠ, D., 1997: Effect of thinning on parameters of photosynthetic characteristics of Norway spruce canopy. I. Light penetration and photosynthesis. *Lesnictví – Forestry*, 43(4): 141–153.

MATTHEW, M., FLADELAND, M. S., ASHTON, X. L., 2003: Landscape variations in understory PAR for a mixed deciduous forest in New England, USA. *Agr. For. Meteorol.*, 118(1–2): 137–141.

NAVRÁTIL, M., ŠPUNDA, V., MARKOVÁ, I., JANOUŠ, D., 2007: Spectral composition of photosynthetically active radiation penetrating into a Norway spruce canopy: the opposite dynamics of the blue/red spectral ratio during clear and overcast days. *Trees*, 21: 311–320.

NILSON, T., KUUSK, A., LANG, M., PISEK, J., KODAR, A., 2011: Simulation of statistical characteristics of gap distribution in forest stands. *Agr. For. Meteorol.*, 151(7): 895–905

PALVA, L., GARAM, E., SIIVOLA, E., SEPPONEN, R., HARI, P., 1998: Quantifying spatial variability of photosynthetically active radiation within canopies using a multipoint measuring system. *Agr. For. Meteorol.*, 92: 163–171.

PARKER, G. G., RUSS, M. E., 2004: The canopy surface and stand development: assessing forest canopy structure and complexity with near-surface altimetry. *For. Ecol. Manag.*, 189(1–3): 307–315.

POKORNÝ, R., TOMÁŠKOVÁ, I., HAVRÁNKOVÁ, K., 2008: Temporal variation and efficiency of leaf area index in young mountain Norway spruce stand. *Eur. J. For. Res.*, 127(5): 359–367.

PRÉVOST, M., RAYMOND, P., 2012: Effect of gap size, aspect and slope on available light and soil temperature after patch-selection cutting in yellow birch-conifer stands, Quebec, Canada. *For. Ecol. Manag.*, 274(15): 210–221.

REIFSNYDER, W. E., FURNIVAL, G. M., HOROWITZ, J. L., 1974: Spatial and temporal distribution of solar radiation beneath forest canopies. *Agr. Meteorol.*, 9: 21–37.

SHAW, R. H., 2002: Radiation in plant canopies. In: ROSSI, F., DUCE, P., SPANO, D. *Advanced Short Course on Agricultural, Forest and Micrometeorology*. Roma: Consiglio Nazionale delle Ricerche: 99–108.

SPITTERS, C. J. T., TOUSSAINT, H. A. J. M., GOUDRIAAN, J., 1986: Separating the diffuse and direct component of global radiation and its implications for modeling canopy photosynthesis. Part I. Components of incoming radiation. *Agr. For. Meteorol.*, 38 (1–3): 217–229.

VALES, D. J., BUNNELL, F. L., 1988: relationships between transmission of solar radiation and coniferous forest stand characteristics. *Agr. For. Meteorol.*, 43(3–4): 201–223.

WANG, H., BALDOCCHI, D. D., 1989: A numerical model for simulating the radiation regime within a deciduous forest canopy. *Agr. For. Meteorol.*, 46: 313–337.

YIRDAW, E., LUUKKANEN, O., 2004: Photosynthetically active radiation transmittance of forest plantation canopies in the Ethiopian highlands. *For. Ecol. Manag.*, 188(1–3): 17–24.

Address

doc. RNDr. Irena Marková, CSc., Institut of Forest Ecology, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic, RNDr. Jiří Kubásek, Global Change Research Centre AS CR, v.v.i., Laboratory of metabolomic and isotopic analyses, Bělidla 4a, 603 00 Brno, Czech Republic, e-mail: markova@mendelu.cz, kubasek.j@czechglobe.cz