COMPARISON OF DIFFERENT GROUND TECHNIQUES TO MAP LEAF AREA INDEX OF NORWAY SPRUCE FOREST CANOPY

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ABSTRACT:

The leaf area index (LAI) of three monocultures of Norway spruce (*Picea abies* (L.) Karst), different in age and structure, was measured by means of two indirect optical techniques of LAI field mapping: 1/ plant canopy analyser LAI-2000, and 2/ digital hemispherical photographs (DHP). The supportive measurements with the TRAC instrument were conducted to produce mainly the element clumping index. The aim of the study was to compare the performances of LAI-2000 and DHP and to evaluate effect of three different sampling strategies on field estimation of leaf area index. One of the suggested sampling designs introduced spatial oversampling around one-point measurement. The oversampling was expected to reveal the importance of sampling point position with respect to surrounding trees. In general, the LAI-2000 instrument produced higher estimates of effective leaf area index than DHP in all experimental stands. On the other hand, the higher "true" estimates of LAI were obtained from DHP. All three sampling strategies produced consistent estimates of effective and "true" LAI in all forest sites. The spatial oversampling of LAI measurement point did not significantly improve the LAI estimate of the canopy subplots.

1. INTRODUCTION

Leaf area index (LAI) of coniferous species is defined as one half the total green leaf/needle area per unit ground surface area (Chen and Black, 1992). It is a dynamic key parameter for interpreting tree or canopy gas, water and energy exchange between photosynthetically active tissue and the atmosphere. It is also important input parameter for eco-physiological models, when up-scaling these canopy fluxes to larger spatial scales.

Many indirect ground measurements techniques have been proposed and tested for mapping of forest LAI (Bréda, 2003; Jonckheere et al., 2004). These techniques are less time consuming and labour-intensive than direct methods of LAI estimations, nevertheless their applicability is still spatially limited. The state-of-art of physically based approaches enable the LAI estimation from optical airborne or satellite remote sensing data at larger scales (Gascon et al., 2004; Wang et al., 2004). The accuracy of these quantitative methods is usually validated by comparison with ground measured LAI. Most frequently used instruments for field LAI mapping are Li-Cor plant canopy analyser LAI-2000 and recently also digital hemispherical photographs.

When working with airborne remote sensing data, their very high spatial resolution (pixel size about 1 meter) needs to be considered. A forest stand appears to be rather heterogeneous at such spatial scale, due to gaps and tree clumping within the canopy. Therefore, a spatial distribution of LAI ground sampling points and their position within a forest stand (especially in a dense young forest canopy) become important aspects for validation of the LAI estimates from RS data of very high spatial resolution.

The objectives of the study are:

1. To compare the performances of two indirect LAI ground mapping techniques:
   - digital hemispherical photograph (DHP),
   - Li-Cor plant canopy analyser LAI-2000.
2. And to evaluate the effect of three different sampling designs on mapping of leaf area index within three structurally different montane Norway spruce forest stands.

2. METHODS

2.1 Site description

The study site is located at the experimental research site Bily Kriz in the Moravian-Silesian Beskydy Mountains, in the eastern part of the Czech Republic bordering with Slovakia (18.54°E, 49.50°N, altitude of 936 m a.s.l.). The description of the site environmental conditions is given in Kratochvilová et al. (1989). The area is characterized by montane Norway spruce (*Picea abies* (L.) Karst.) forest ecosystems. Three Norway spruce stands of different age and structure (table 1) were selected in the close surroundings of the Bily Kriz experimental site.

Forest stand code	Age	DBH [cm]	Height [m]	trees/ha
YOUNG	28	14	12.5	1436
OLD1	100-110	53	40.1	160
OLD2	75	-	27	420

Table 1. The basic characteristics of three Norway spruce forest stands selected for LAI mapping.

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2.2 Indirect optical techniques of LAI measurements and data processing

All ground measurements of leaf area index were acquired within the frame of the complex field-airborne campaign over the Bily Kriz research site at the turn of August and September 2006.

All optical instruments, used in the study for indirect field estimation of LAI, produced so called effective leaf area index (LAI_e). Correction parameters, according the methods proposed by Chen (1996), were required to convert LAI_e to the values of "true" leaf area index (eq. 1). The needle-to-shoot area ratio (γ_e) was obtained from destructive branch analyses conducted at Bily Kriz research site in 2004 (Homolová, 2005). The element clumping index (Ω_e) was produced by the TRAC instrument and from the DHPs analyses. The value of woody correction parameter (α) for young Norway spruce trees was derived from destructive sampling conducted by Pokorný (2002). LAI-2000 measurement of totally defoliated mature Norway spruce trees (unpublished) was used to calculate the α parameter for OLD1 and OLD2 mature Norway spruce forest stands.

$$LAI = (1-\alpha)*LAI_e*\gamma_e/\Omega_e \qquad (1)$$

where α = woody-to-total area ratio
γ_e = needle-to-total area ratio
Ω_e = element clumping index

The leaf area index estimation with Plant Canopy Analyzer PCA LAI-2000 (LI-COR, Inc., Lincoln, NE, USA) is based on measurement of diffuse radiation attenuation caused by canopy in blue part of spectra, which is driven by gap fraction. The measurements with one LAI-2000 unit were taken always under diffuse radiation condition, either in the evening or early morning. A reference measurement to determine above canopy irradiance was taken at meto-towers in the young stand and in canopy openings in case of mature stands. The 45° view cap was used to avoid the influence of the operator and block remaining direct light. The measurements were acquired always above understory, preferably 0.5 m above ground. To avoid multiple scattering effects at larger zenith angles and to reduce the instrument's footprint, the rings 4 and 5 were ignored using C2000 software (Li-Cor, 1992) during the data processing. The view zenith angle of the sensor was thus restricted to 43°. LAI_e was directly produced by C2000 software. LAI-2000 measurements of LAI_e were combined with TRAC-derived element clumping index to calculate "true" values of LAI.

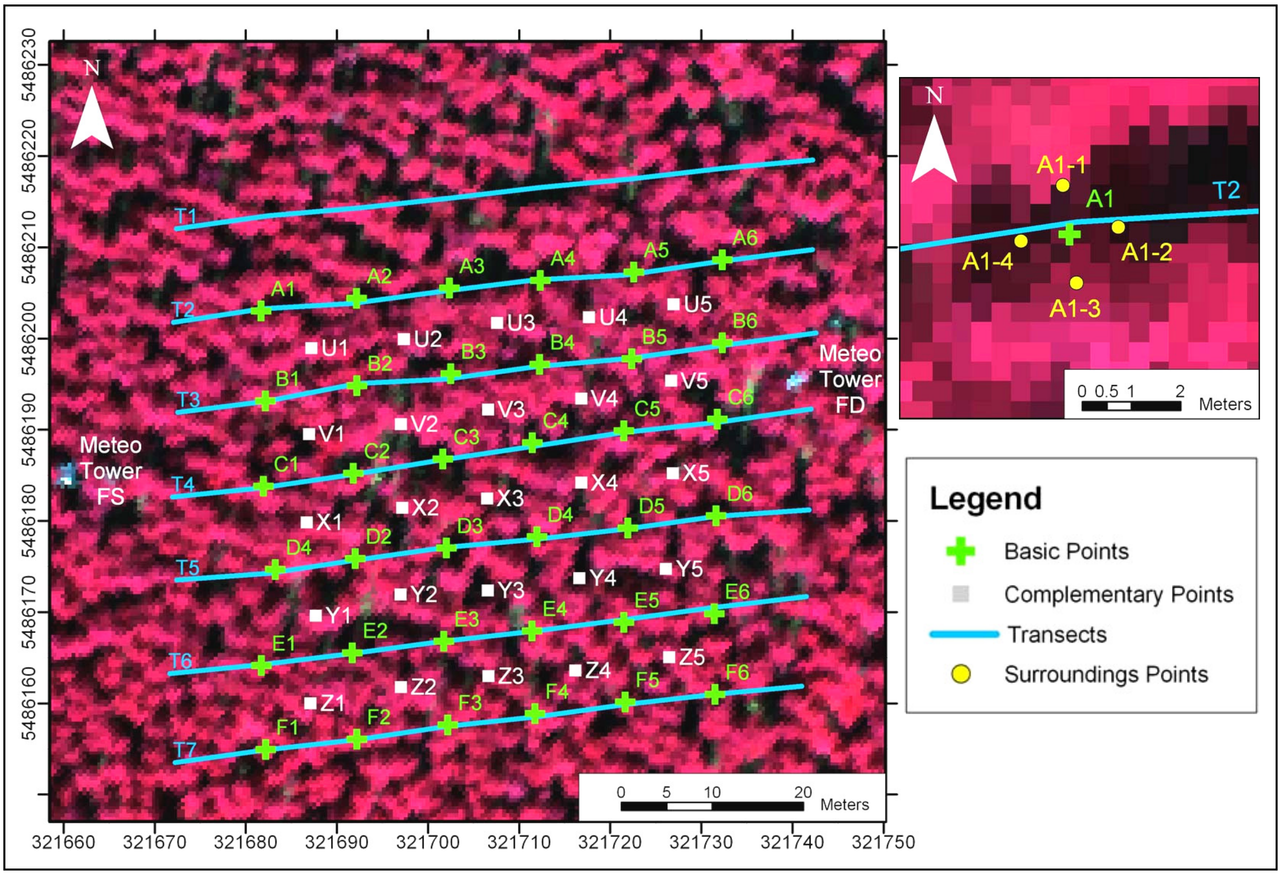

Figure 1. Representation of spatial distribution of basic and complementary LAI sampling points used for DHP and LAI-2000 measurements and TRAC transects in YOUNG forest site. Each basic sampling point was oversampled with another four measurement points as shown in the zoomed image. Background is false RGB colour composite (R859, G653, B551 nm) of AISA Eagle airborne hyperspectral image with pixel size equal to 0.4 m. The AISA image subset is displayed in UTM 34N (WGS-84) coordinate system.

Hemispherical photographs (DHP) were acquired at the same position as LAI-2000 measurements, using digital camera Nikon Coolpix 8700 equipped with Nikon FC-E9 0.2x fisheye converter. The camera was mounted on a tripod in fixed height of 1.5 m above ground. The manual mode to set the camera exposure was used. We kept the fixed lens aperture and adjusted the shutter speed, one or two stops of overexposure relatively to the in-stand automatic exposure (Zhang et al., 2005). The images were processed by the CAN-EYE v5.0 software (Baret and Weiss, 2004). The software produces effective as well as "true" estimates of LAI. In CAN-EYE, the element clumping index is computed using the Lang and Yueqin (1986) logarithm gap fraction averaging methods.

The measurements with the TRAC instrument (3rd Wave Engineering, Ottawa, ON, Canada) (Leblanc et al., 2002) require direct solar radiation. It was measured at constant walking pace along several parallel transects, each 70 to 80 m long and oriented preferably in E-W direction. Distance markers were registered each 5 m. The TRAC data record was processed by TracWin software. It calculates effective LAI based on gap fraction and element clumping index Ω_e (Chen, 1996) based on the analyses of gap size distribution (Chen and Cihlar, 1995).

2.3 LAI sampling scheme

A regular grid pattern of LAI sampling points combined with several parallel TRAC transects was established at each experimental forest stand. The schema of the sampling design for young Norway spruce forest stand is presented in figure 1. The similar pattern (grid of 3x3 basic sampling points) was established in mature forests. The distance between basic sampling points was driven by mean tree height and view zenith angle of the instruments. The distances were set to be 10 m in young and 20 m in mature forest stand, which corresponded to the zenith view angle of 45°. The sampling scheme was designed in such a way to ensure the spatial comparability between the LAI-2000 measurements and digital hemispherical photographs, acquired per sampling point.

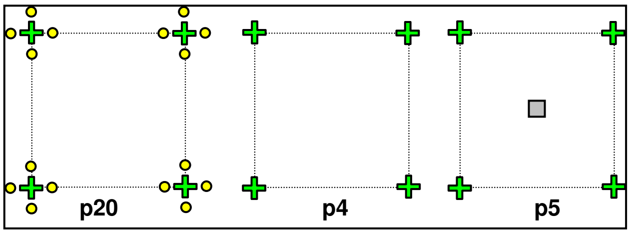

Figure 2. Schematic representation of three different spatial distributions (scenario p20, p4 and p5) of LAI sampling points within a subplot. Crosses represent basic, squares represent complementary and circles represent surroundings (oversampling) LAI sampling points.

Three different scenarios (p20, p4 and p5) of LAI sampling points' distributions were tested within the study (see figure 2). Only four basic point measurements were considered for scenario p4. Each basic LAI sample point was oversapmpled by four surrounding measurements point in case of scenario p20. Sampling scenario p5 represented five point measurements; four basic sampling points as in the scenario p4, but one more measurement was added to the centre of a subplot (complementary sampling point). In total 20, 4 and 5 measurements, respectively, were processed per subplot in case of p20, p4 and p5 sampling strategy.

In total 21 subplots (one subplot was composed out of 4 basic sampling points) were selected to test the effect of different spatial distributions of LAI sampling points on the estimation of effective and "true" LAI.

3. RESULTS AND DISCUSSION

3.1 Correction parameters: needle-to-shoot area ratio, clumping index and woody-to-total area ratio

Correction of the optical estimates of leaf area index is trade-off between correction for clumping, which causes LAI underestimation, and correction for the woody materials, which causes its overestimation. Thus proportion of woody area and clumping of green elements, especially in coniferous canopies, are important parameters for LAI measurement, however, it is difficult to quantify them properly. The mean values of woody-to-total area ratio (α), needle-to-total area ratio (γ_e) and element clumping index (Ω_e) for each investigated Norway spruce stand are presented in table 2.

In general, the element clumping index derived from TRAC (Chen and Cihlar, 1995) was higher than its estimation from DHPs (Lang and Yueqin, 1986). The largest bias was observed in dense young Norway spruce canopy. Leblanc et al. (2005) reported that the TRAC algorithm produces higher estimates of Ω_e than Lang and Yueqin method, though gap fraction measurements performed with TRAC and from DHP were well correlated. The possible explanation of the difference is that in very dense canopies is hard to meet an assumption of the Lang and Yueqin method that analysed segments of DHP contain gaps. Secondly, hemispherical photographs and TRAC are instruments with different field of views representing different parts of forest canopies. The mean correction factor (TRAC-based clumping index combined with woody-to-total area ratio) for young forest was equal to 1.49, which agreed well with the correction factor presented by Pokorny and Marek (2000) for the same canopy. This fact suggests that the canopy element clumping index derived from TRAC would be considered as more reliable estimate.

Forest code	LAI_e			correction parameters				LAI		
	LAI-2000	DHP CAN-EYE	TRAC	α	γ_e	Ω_e (TRAC)	Ω_e (DHP)	LAI-2000 + TRAC	DHP	TRAC
YOUNG	4.94±0.46	3.90±0.77	4.62±0.04	0.133	1.526	0.89±0.04	0.58±0.04	7.42±0.72	8.89±1.17	6.98±0.06
OLD1	2.71±0.05	2.32±0.25	2.58±0.22	0.228	1.422	0.66±0.02	0.57±0.03	4.49±0.05	4.47±0.63	4.18±0.55
OLD2	3.33±0.09	3.10±0.10	3.96±0.13	0.228	1.422	0.67±0.01	0.67±0.01	5.44±0.16	5.10±0.26	6.47±0.01

Table 2. Summary of mean values and standard deviations of forest stand LAI_e, correction parameters (α – woody-to-total area ratio, γ_e – needle-to-total area ratio, Ω_e – element clumping index) and "true" forest stand LAI observed in three Norway spruce canopies.

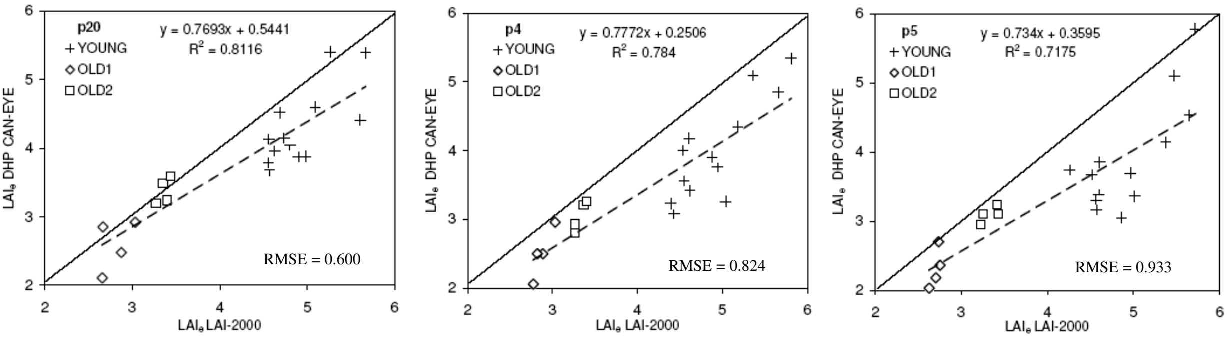

Figure 3. Direct comparison of effective leaf area index values produced by PCA LAI-2000 and hemispherical digital photographs processed in CAN-EYE software, per each investigated Norway spruce forest stands, using three spatial designs (scenarios p20, p4, and p5).

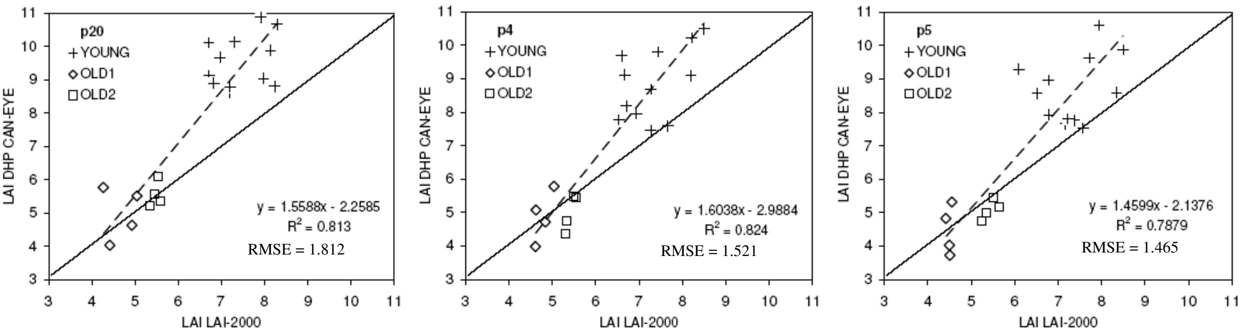

Figure 4. Direct comparison of "true" leaf area index values produced by PCA LAI-2000 and hemispherical digital photographs processed in CAN-EYE software, per each investigated Norway spruce forest stands, using three spatial designs (scenarios p20, p4, and p5).

Digital hemispherical photographs, as a permanent record of canopy structure, can be a suitable tool for quantifying the effect of light blocking woody materials (e.g. trunks, branches). The possible improvement can be the adaptation of a digital camera to acquire images in near infra-red wavelengths (Chapman, 2007), where reflectance of woody materials is higher than reflectance of green biomass.

3.2 Optical indirect estimation of LAI_e and LAI

Mean stand-level values of effective and "true" leaf area index estimates, for three Norway spruce forest stands different in structure and age, are presented in table 2. The estimates of LAI_e produced by hemispherical digital photographs were generally lower, in comparison to LAI-2000 estimates, in all investigated forest stands. The largest difference of 21% between LAI-2000 and DHP LAI_e estimates was observed in dense YOUNG forest stand. These results correspond to Jonckheere et al. (2005a), who reported similar underestimation of DHP effective leaf area index for even-aged forest stand of Scots pine. Also Zhang et al. (2005) observed similar behaviour of LAI_e estimates from DHP, especially for higher values of LAI. Variability in illumination conditions during DHP acquisition could possibly explain this underestimation, because LAI-2000 measurements were always acquired under more stable diffuse radiation conditions. The sun exposed parts of canopy captured on hemispherical images appeared to be brighter than shaded parts. These sun exposed elements tended to be classified as part of sky and thus caused overestimation of canopy gap fraction. According to (Cescatti, 2007; Jonckheere et al., 2005b), threshold between canopy elements and bright sky is the most important and at the same time most uncertain aspect in determination of canopy gap fraction from hemispherical photographs. The CAN-EYE software offers only manual thresholding, which is applied over the entire image (or set of images). For instance the automated thresholding system can eliminate a possible bias caused by an operator. The application of different threshold values to separated zenith rings can eliminate the brightness gradients, which were observed within the images with increasing view zenith angle.

Several authors (Leblanc and Chen, 2001; Weiss, 2004) recommended to obtain the gap fraction measurements at view zenith angle of 57.5° (corresponding to the LAI-2000 fourth ring). This gap fraction measurement is supposed to be independent on leaf (needle) angle distribution and allows direct estimation of the effective leaf area index. The above mentioned authors recommended this method as a robust and suitable for canopy LAI_e estimation.

On the other hand, results of "true" LAI estimates showed opposite trend, i.e. DHP-based estimates were higher than leaf area index obtained from LAI-2000. This can be explained by different methodological approaches of element clumping index determination, discussed in the section 3.1.

3.3 Effect of a sampling strategy on LAI_e and LAI estimation

One-to-one relationship between LAI-2000 and DHP estimates of canopy leaf area index for three sampling strategies (p20, p4, p5) are presented in figures 3 and 4. The graphs indicate that there are no important differences between all tested sampling strategies. The spatial oversampling, applied at each basic sample point (see scenario p20), did not improve the LAI estimation. The results revealed that exact position of one-point measurement seems to be less important than the spatial location of whole sampling unit (a subplot) within a forest stand.

Although suitable sampling strategy is an important issue when performing field measurements, very little literature is dedicated to this topic. The LAI sampling design is dependent on the study purpose and canopy characteristics (e.g. canopy height and canopy closure). Main purpose of our LAI measurements was to create ground truth data for validation of LAI maps derived from airborne hyperspectral remote sensing data (spatial resolution of about 1m). Nevertheless, more sampling plots would be needed to validate the satellite based products of medium spatial resolution (pixel size of about 10-30 m). The LAI sampling design developed within the frame of VALERI project (Baret et al., 2007) seems to be an appropriate approach to validate these satellite products.

4. CONCLUSIONS

In general, the plant canopy analyser LAI-2000 produced slightly higher estimates of LAI_e than obtained from the analyses of DHP in all three age-diverse but structurally homogenous Norway spruce forest stands. On the other hand the "true" estimates of leaf area index obtained from DHP were slightly higher than LAI estimates from PCA LAI-2000. The highest bias between LAI-2000 and DHP based estimates of effective and "true" leaf area index was observed in case of young dense forest stand. It is evident, that both instruments can provide reasonable estimates within an expected range of LAI values. However, there are large uncertainties in estimation of the canopy clumping index, which is an important parameter to correct estimates of LAI_e obtained from LAI-2000 and DHPs.

The spatial over-sampling, applied at each basic sample point, did not significantly improve values of LAI_e and LAI measured in all three investigated Norway spruce forests. The results indicated that one-point measurements organized in the regular grid were sufficient enough to properly represent canopy leaf area index.

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