Estimating Canopy Cover in Scots Pine Stands

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Rautiainen, M., Stenberg, P. & Nilson, T. 2005. Estimating canopy cover in Scots pine stands. Silva Fennica 39(1): 137–142.

The way canopy cover is defined and measured influences the obtained canopy cover percentage. Estimates of canopy cover are needed, for example, in canopy radiation modelling and remote sensing applications and as a tool for political decision-making. In this paper, we demonstrated the use of two methods, the LAI-2000 Plant Canopy Analyzer instrument and the Cajanus tube, in Scots pine stands for canopy cover estimation, and also assessed the number of measurement points required for reliable estimates. The Cajanus tube yielded slightly larger canopy closure values than the LAI-2000 instrument, but the values were nevertheless in good agreement. Both of the methods required approximately 250 measurement points for canopy closure estimates of a stand to become relatively stable. We also present the first measured effective canopy transmittance values for Scots pine stands in Finland and an example of tree pattern mapping with the Cajanus tube.

Keywords *Pinus sylvestris*, Cajanus tube, LAI-2000 Plant Canopy Analyzer
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Received 27 July 2004 **Revised** 13 January 2004 **Accepted** 2 February 2005

1 Introduction

Forest canopy cover, frequently defined as the percent area occupied by the vertical projection of tree crowns, is a common concept in forestry and of wide interest in both scientific studies and political decisions. Other, often synonymously used terms include canopy closure, crown closure or crown cover, however, there is no commonly accepted precise definition for the concept. For instance, the United Nations Food and Agricultural Organization has defined forest as land with tree crown cover over 10% and with tree heights over 5 meters covering an area over 0.5 ha (FAO 2000). This definition, which uses the term "tree crown cover", is used to monitor changes in forest area.

The way canopy cover (or any of the similar terms) is defined and measured influences the obtained canopy cover percentage. A central issue in the definitions is whether tree crowns are treated as solids which transmit or which do not transmit radiation, i.e. whether within tree crown gaps are included or excluded. The gaps can sometimes be rather large and thus will affect the canopy cover estimate. In order to be able to compare values of canopy cover of forests, we need to first understand the differences between the definitions used in each study as well as to gain an understanding of the errors and typical differences of the various measuring methods.

Our specific interest has been in determining leaf area index (LAI) in the boreal coniferous zone from both optical satellite data and as a ground truth variable determined from canopy gap fraction measurements. In such forest remote sensing applications, the signal from the understory usually needs to be separated from the signal of the tree layer. It is thus crucial to be able to estimate canopy cover as it determines the proportions of the reflected signals of the two components. In addition, distinguishing between gaps between tree crowns and gaps within tree crowns is important e.g. in physically based forest reflectance applications (e.g. Knyazikhin et al. 1998, Kuusk and Nilson 2000) and canopy radiation modeling (e.g. Nilson 1999).

In this study, our aim is to demonstrate the use of the Cajanus tube and the LAI-2000 Plant Canopy Analyzer (both instruments described in Materials and Methods) in Scots pine (*Pinus sylvestris* L.) stands for canopy cover estimation, to assess the number of measurement points required for a reliable estimate by the two methods and, finally, to discuss possible reasons for differences in their outcome.

2 Materials and Methods

For this study, seven pure Scots pine stands were selected and measured in July and August 2003 in the proximity of Suonenjoki Research Station (62°39´N, 27°05´E) of the Finnish Forest Research Institute. The area was Scots pine dominated and the understorey species were mainly *Calluna vulgaris* L. and *Vaccinium vitis-idaea* L. From each stand (Table 1), we had data collected by relascope sampling at the center of each stand, including stem number (stand density), diameter at breast height (dbh) and tree height. Diameter at breast height was measured from all trees in the relascope sample and tree height was measured from the median tree. The purpose of the stand data was merely to serve as a simple description of the stand structure, not as the basis of, for example, regression models. In the middle of each stand, a grid consisting of 500 points was set up. The points were laid out on five parallel transects with one meter between the points on each transect and five meters between the transects. The grid was then used to make canopy cover measurements with two methods: the Cajanus tube and the LAI-2000 instrument.

Table 1. Description of the stands.

Stand	Stand density, trees/ha	Diameter at breast height, cm	Median tree height, m
6	1830	12.0	10.0
193	1010	20.1	16.0
Stat	1950	21.8	16.8
SN	470	30.2	21.7
73	660	19.1	15.1
E4	1680	13.8	10.5
194	560	28.1	18.5

With the first method, canopy cover for the zenith direction was obtained from each of the 500 points with a device called the “Cajanus tube” or the “Cajanus cylinder”. This instrument was first introduced in Finland by a Finnish forest scientist, Cajanus, in the 1910’s for crown profile mapping and later on, in the 1940’s, reintroduced by another Finnish scientist, Sarvas, for assessing canopy cover using a new sampling design (Sarvas 1945, 1953). It is a simple hand-held instrument equipped with a mirror allowing the observer to look vertically upwards and record whether the exact point is beneath a gap between crowns, or subjected to shading by 0, 1, …, n crowns. Since it is an optical device, the ability of the operator to distinguish a gap will slightly depend on the height of the canopy, i.e. the vertical distance of the crown from the instrument. Nevertheless, the “resolution” of the instrument is very close to a point. The Cajanus tube (or some other instrument with the same principle) provides the only method for separating gaps within and between tree crowns, and it can also be used for mapping the spatial tree distribution pattern.

The second method for determining canopy cover at the same grid points was with the LAI-2000 Plant Canopy Analyzer (Li-Cor Inc., 1992). The LAI-2000 instrument has a pair of optical sensors which consist of five detectors arranged in concentric rings (7°, 23°, 39°, 53° and 68°) measuring radiation between 320 and 490 nm, where scattering from leaves is minimal. One of the sensors was placed in an open area and the other one under the canopy. Canopy gap fraction [GAP(θ)] in each of the five different zenith angle (θ) bands was then calculated as the ratio of below- and above-canopy (i.e. open area) readings by the corresponding detector rings. Below-canopy measuring height was 1.7 m above the ground (the same as the height used with the Cajanus tube), so that only trees were included in the field of view. Above-canopy measurements were collected by automatic logging every 30 seconds in an open area close to the study site. The measurements were made during standard overcast sky.

In this paper, we will use the following concepts.

Canopy cover (CC) is defined as the fraction of ground covered by the vertically projected crown envelopes. In this study, CC was obtained from the Cajanus tube measurements as the relative number of points that were not beneath a gap between crowns, mathematically expressed as CC = [points under tree crown] / [total number of points measured].

Effective canopy transmittance (ECT) is defined as the number of measurement points recorded in a gap within a tree crown divided by the total number of measurement points under a tree crown measured in the plot. ECT could only be obtained with the Cajanus tube in this study. If tree crowns do not overlap, this corresponds to single crown transmittance.

Effective canopy cover (CC_{eff}) takes into account both gaps between crowns and gaps within crowns.

Table 2. Effective canopy cover (CC_{eff}), canopy cover (CC) and single crown transmittance (ECT) for the study stands obtained with the two methods.

Stand	LAI-2000	Cajanus tube	
	CC_{eff}	CC	ECT
6	0.57	0.71	0.04
193	0.48	0.56	0.07
Stat	0.50	0.58	0.06
SN	0.55	0.64	0.17
73	0.43	0.51	0.04
E4	0.61	0.79	0.19
194	0.43	0.48	0.11

The LAI-2000 instrument measures only CC_{eff} (calculated as $1 - GAP(7°)$ and abbreviated as CC_{eff}, LAI-2000), which corresponds to the value $CC(1 - ECT)$ (from now on abbreviated as CC_{eff}, CAJANUS) calculated from the Cajanus tube measurements.

3 Results and Discussion

The relationship of CC obtained with the Cajanus tube and CC_{eff} obtained with the LAI-2000 instrument was approximately linear but the Cajanus tube yielded somewhat larger values (Fig. 1a).

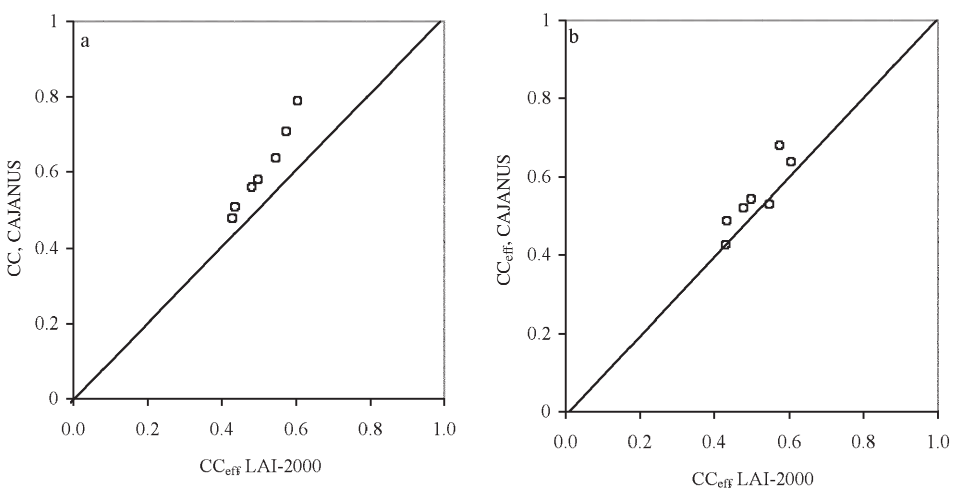


Fig. 1. A comparison of canopy covers obtained with different methods: a) CC with Cajanus tube and CC_{eff} with LAI-2000 Plant Canopy Analyzer b) CC_{eff} with Cajanus tube and CC_{eff} with LAI-2000 Plant Canopy Analyzer.

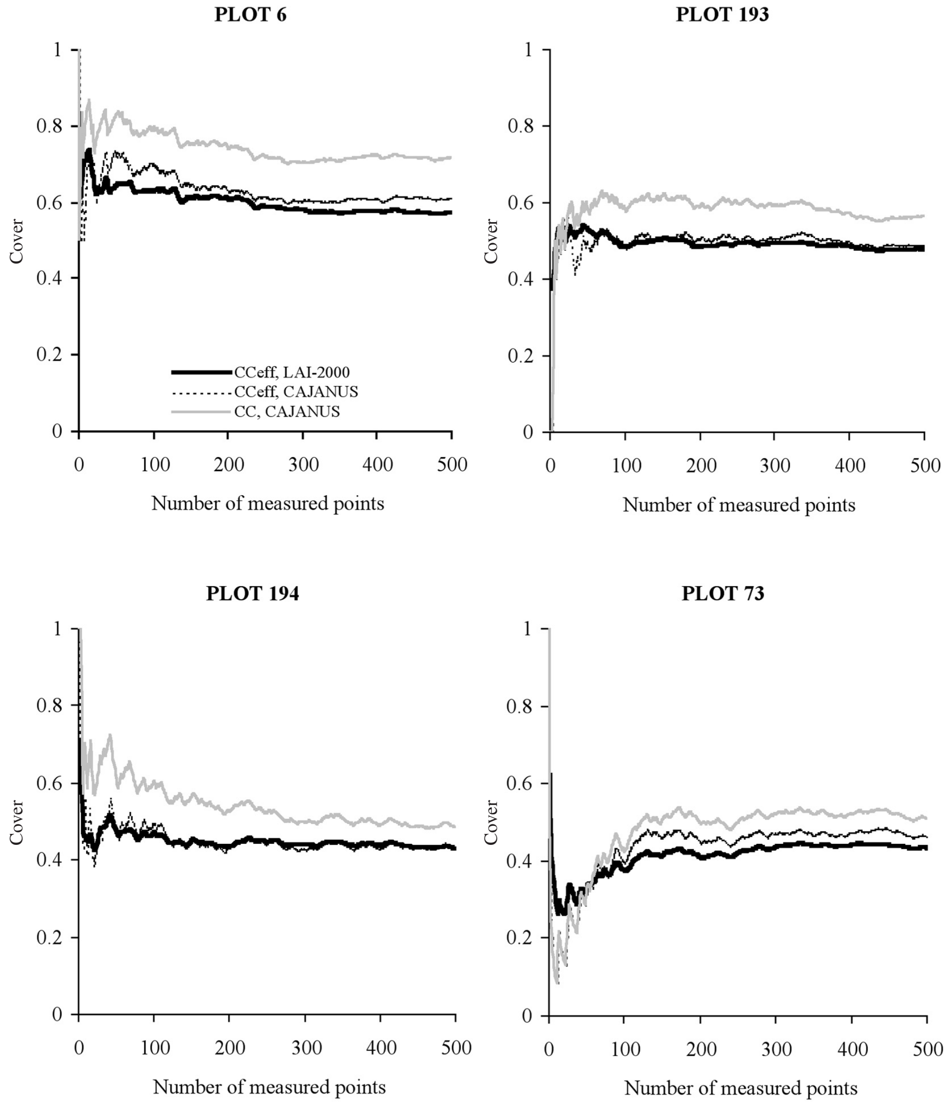
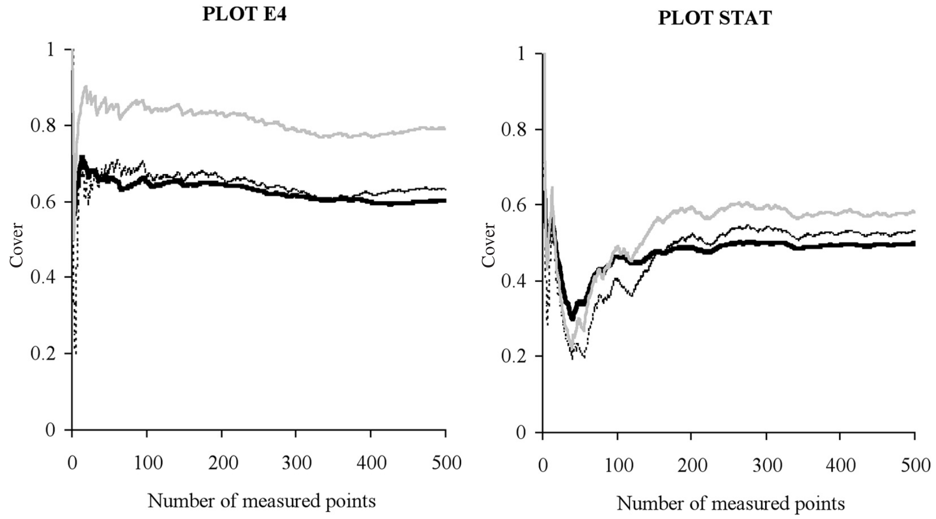


Fig. 2. The effect of the number measurement points on the effective canopy cover obtained with the LAI-2000 instrument and canopy cover from the Cajanus tube measurements for the study plots.

The difference can be explained by the fact that the LAI-instrument measures also the gaps within tree crowns. In other words, when we compare the CC_{eff} values from LAI-2000 with the CC values obtained with the Cajanus tube adjusted with ECT (which ranged from 4% to 19% in this study, see Table 2), the differences decrease (Fig. 1b). Another, though minor cause, may be that even though both methods measure canopy transmittance, the uppermost ring of the LAI-2000 instrument has a larger field-of-view (26°), i.e. radii of about 1.2 to 2.7 meters for the mid value of the zenith angle (7°) in this study. The results shown in Fig. 1 are very promising for estimating canopy cover with crown transmittance based methods – the obtained values have surprisingly good agreement.



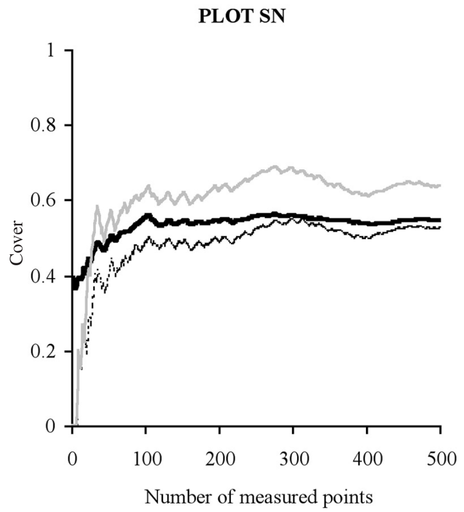


Fig. 2 continued.

Crucial for estimating canopy closure with either of the methods is information on the number of measurement points required for a reliable result. In this study, we increased the number of measurement points in a systematic grid form, starting from the center of the stand. First, with only a few measurements points, CC (or CC_{eff}) obtained with the Cajanus tube is less stable than CC_{eff} obtained with the LAI-2000 due to the binary nature of the data (Fig. 2). With less than 100 measurement points the value obtained with either of the methods fluctuates considerably: For both of the methods, approximately 250 measurement points are needed for the CC or CC_{eff} to become relatively stable. For example, with 100 points measured with the LAI-2000 instrument, the coefficient of variation for CC_{eff} ranged from 4% to 23%, and for 250 measured points the range became narrower and was from 4% to 12%. Visual judgement of the figures can also be used for estimating a satisfactory level of variation in CC or CC_{eff}. It must be noted in this context that if the LAI-2000 instrument is used to obtain an estimate of LAI – not CC_{eff} – fewer measurement points are needed for a stable result, since the canopy transmittance is measured at more than one angle (i.e. not only the 7° midpoint value zenith angle) and is thus less prone to fluctuations.

To summarize, we demonstrated the applicability of the Cajanus tube and LAI-2000 instrument for measuring canopy cover and assessed the number of points needed to obtain a reliable result. We also present the first measured gap fractions for within crown gaps (i.e. effective canopy transmittance) of Scots pine stands in Finland. Measuring canopy cover with the methods discussed in this paper is time consuming, and is thus not a realistic part of a routine inventory as such. However, deriving allometric models relating stand data and canopy cover, with the help of

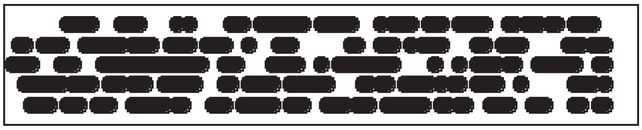


Fig.3. An example (Stand 193) of mapping tree distribution with Cajanus tube. Effective canopy transmittance ignored, black denotes area covered by tree crown (canopy cover).

the information provided on sampling strategy in this paper, would be the logical follow-up. Currently, the Cajanus tube is little used in Finland even though it offers good potential for improving existing (e.g. Kuusipalo 1985) and new allometric methods for estimating canopy cover, as well as possibilities for mapping and calculating tree distribution pattern (Fig. 3). For example physically based forest reflectance models used in remote sensing (e.g. Kuusk and Nilson 2000) could benefit from such generalized allometric models, since with the current methods the difference between measured and simulated canopy cover values can be relatively large. The Cajanus tube also provides more information than has been shown in this paper, for instance, the overlapping of crowns can be assessed, and therefore it would yield better input for canopy radiation model applications than the LAI-2000 instrument (e.g. Stenberg et al. 2003). The Cajanus tube could also be further developed so that canopy cover at other angles besides nadir could be measured and perhaps even photographed simultaneously – a 3D gap fraction distribution data of forests would be valuable for various canopy radiation modelling and remote sensing applications.

Acknowledgements

The authors wish to thank Dr. Heikki Smolander for scientific cooperation, Emeritus Professor Matti Leikola for providing historical information on the Cajanus tube, and Mr. Pekka Voipio, Ms. Tuula Väätäinen and Ms. Pille Aluoja for assisting in the field work. This study has been funded by the Foundation for Research of Natural Resources in Finland.

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