A simplified methodology for the correction of Leaf Area Index (LAI) measurements obtained by ceptometer with reference to *Pinus* Portuguese forests

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Received: May 17, 2011 - Accepted: Oct 08, 2013

Citation: Lopes D, Nunes L, Walford N, Aranha J, Sette C, Viana H, Hernandez C, 2014. A simplified methodology for the correction of Leaf Area Index (LAI) measurements obtained by ceptometer with reference to *Pinus* Portuguese forests. iForest (early view): e1-e7 [online 2014-02-17] URL: http://www.sisef.it/iforest/contents/?id=ifor0096-007

Communicated by: Roberto Tognetti

Forest leaf area index (LAI) is an important structural parameter controlling many biological and physiological processes associated with vegetation. A wide array of methods for its estimation has been proposed, including those based on the sunfleck ceptometer, a ground-based easy-to-use device taking non-destructive LAI measures. However, use of ceptometer in pine stands leads to the underestimation of LAI due to foliage clumping of this species. Previous studies have proposed a correction of biased LAI estimates based on the multiplication by a constant factor. In this study, a new method for obtaining a correction factor is proposed by considering the bias (the difference between the ceptometer measure and the reference LAI) as a function of the stand structural variables, namely the basal area. LAI data were collected from 102 sampling plots (age range: 14-74) established in *Pinus pinaster* forests all across northern Portugal. Data from 82 sampling plots were used for the adjustment of the LAI ceptometer correction model, while the remaining 20 plots were used for the model validation. The observed LAI ranged from 0.34 to 6.4 as expected from the large heterogeneity of the sampled pine stands. Significant differences were detected between LAI values estimated by ceptometers and LAI reference values. Different correction methods have been compared for their accuracy in predicting LAI reference values. Based on the results of the statistical analysis carried out, the new proposed LAI correction outperformed all the other methods proposed so far. The new approach for bias reduction proposed here has the advantage of being easily applied since the basal area is almost always available from forest inventory or can be inferred from remote sensing surveys. However, the bias correction model obtained is site-specific, being dependent on stand species composition, soil fertility, site aspect, etc. and should therefore be applied only in the study area. Nonetheless, the development of a correction methodology based on an allometric approach has proved to greatly improve LAI ceptometer estimations.

Keywords: Leaf Area Index, Ceptometer, Correction, *Pinus pinaster*

Introduction

Jonckheere et al. (2004) and Zarate-Valdez et al. (2012) refer to LAI as a dimensionless variable, which was originally defined as the total one-sided area of photosynthetic tissue per unit ground surface area. Gower & Norman (1991) defined LAI as the projected leaf area per unit ground area, which means half of the total leaf area per unit of ground surface (Chen & Cihlar 1995). According to Chen & Black (1992), both definitions are unproblematic for flat broadleaf species, but are less applicable to coniferous species, whose leaves may be cylindrical or nearly hemicylindrical, and grouped in foliar clumps of various shapes (*e.g.*, spherical or ellipsoidal). These difficulties have led to numerous studies defining LAI on the basis of projected leaf area. Jonckheere et al. (2004) suggested that half of the total interception area per unit ground surface would be a more suitable definition of LAI for non-flat leaves than projected leaf area.

LAI is a fundamental characteristic of terrestrial ecosystems because it is an important canopy structure variable affecting vegetation processes and their interactions with soil and climate (España et al. 2008). As reported by Zarate-Valdez et al. (2012), this parameter is essential for modeling the processes occurring in the soil-plant-atmosphere continuum. LAI is highly related to rates of evapotranspiration and photosynthesis, forest production and site water balance (Larcher 1977). LAI is also an important variable in carbon balance models (Chen & Cihlar 1996, Eriksson et al. 2006). Bréda (2003) summarizes the importance of LAI. According to this author, it drives both the within and the below canopy microclimate, determines and controls canopy water interception, radiation extinction, water and carbon gas exchange and therefore is a key component of biogeochemical cycles in ecosystems. Hence, it is a critical variable for forest management (Hernández et al. 2014).

LAI can be estimated either directly or indirectly (Gower & Norman 1991, Deblonde et al. 1994, Chen & Cihlar 1995, Dufrêne & Bréda 1995, Bréda 2003). Direct methods are naturally destructive of the forest stands and involve analysis of canopy dimensions, which implies that they are laborious and time consuming. Alternatively, indirect methods such as point quadrant, allometric and non-contact methods, have been developed. As reported by Chianucci & Cutini (2013), over the last two decades much attention has been given to indirect measurements of canopy properties in forest ecosystems using ground-based instruments, mainly because harvesting of trees for direct measurement is labor-intensive, time-consuming, destructive, and practical only over small areas.

Pompelli et al. (2012) reported that allometric models can be very accurate and proved their capacity to produce results with