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Slope correction for LAI estimation from gap fraction measurements

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ABSTRACT

Digital hemispherical photography poses specific problems when deriving leaf area index (LAI) over sloping terrain. This study proposes a method to correct from the slope effect. It is based on simple geometrical considerations to account for the path length variation within the canopy for cameras pointing vertically. Simulations over sloping terrain show that gap fraction increases up-slope while decreasing down-slope. As a consequence of this balance between up- and down-slope effects, effective LAI estimates derived from inversion of the Poisson model are marginally affected for low to medium slopes (<25°) and LAI (LAI < 2). However, for larger slopes and LAI values, estimated LAI values may be strongly underestimated. The proposed correction was evaluated over four forested sites located over sloping terrain. Results indicate that in these conditions (LAI between 0.6 up to 3.0, clumped canopies with relatively erectophile leaf distribution), the effect of the slope (between 25° and 36°) was moderate as compared to other potential sources of problems when deriving LAI from gap fraction measurements, including clumping, leaf angle inclination and spatial sampling.

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1. Introduction

Leaf area index (LAI) is an important canopy structure variable governing vegetation processes and its interaction with soil and climate (Melillo et al., 1993). LAI is defined as half the developed area of green leaves or needles per unit horizontal soil (Chen and Black, 1992).

Direct and indirect methods were proposed to measure LAI. Direct methods are time-consuming, tedious and destructive. Therefore, they are difficult to apply for medium to large-scale experiments, or when monitoring LAI time course. Indirect methods, based on measurement of light transmission through the canopy, are non-destructive and relatively easy to implement, thanks to the development of several devices: SunScan ceptometer (Delta-T, UK), AccuPAR (Decagon, UK), Demon (CSIRO, Australia), LAI2000 Plant Canopy Analysis (Li-Cor, USA) provide real time LAI estimates. Conversely, digital hemispherical photography (DHP) based on more demanding image processing, provides off line LAI estimates in addition to other variables including cover fraction, fraction of photosynthetically active radiation intercepted by the canopy, canopy openness or leaf clumping. Several techniques were developed to retrieve LAI from the directional gap fraction measurements as reviewed by Bréda (2003), Jonckheere et al. (2004) and Weiss et al. (2004). These methods are based on the inversion of gap fraction models and are often limited by embedded simplifications such as spatial random distribution of leaves, neglecting the presence of non-photosynthetic canopy elements, or approximating the actual radiative properties of leaves (Hyer and Goetz, 2004). These

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problems were investigated by numerous authors to evaluate their impact and to propose possible corrections. The non-randomness of leaf spatial distribution corresponding to leaf clumping is solved by introducing an aggregation or dispersion parameter (Lemeur and Blad, 1974; Nilson, 1971) or clumping index (Chen and Black, 1992; Chen and Cihlar, 1995). For clumping at the shoot scale, Stenberg (1996) proposed to use the shoot-to-total area ratio (STAR) correction factor. To account for the difficulty in distinguishing among green and non-green canopy elements, departure from the original LAI definition was proposed in the literature to account for other elements than green leaves: ‘‘vegetation area index’’ (Fassnacht et al., 1994), ‘‘plant area index’’ (Neumann et al., 1989) or ‘‘foliage area index’’ (Welles and Norman, 1991).

Besides these problems, topography may strongly impact LAI estimation, since a large fraction of vegetation grows over non-flat areas. As a matter of fact, in most studies where LAI is evaluated with indirect methods in forested areas, the slope is not even mentioned: for example, Riano et al. (2004) analysing the correlation between LAI derived from DHPs and LIDAR measurements, find worse results over a forest in sloping areas than in flatter ones, attributing this result to the vegetation type, without referring to a possible slope effect.

This study investigates the effect of the slope when estimating LAI from vertically upward pointing digital hemispherical camera. The theoretical background used for estimating LAI from gap fraction as measured by photographs was proposed by Nilson (1971). Under the assumption of random leaf distribution within an horizontally infinitely extended canopy layer, the gap fraction $P_0(\theta, \phi)$, in direction $[\theta, \phi]$ is related to the effective LAI (L_e) by the Poisson model:

$$P_0(\theta, \phi) = e^{-G(\theta, \phi, g) L_e d} \quad (1)$$

where θ and ϕ are the zenith and azimuth angles, respectively, $G(\theta, \phi, g)$ is the projection function defined as the area of a unit LAI projected along direction $[\theta, \phi]$, g is the leaf orientation distribution function, and d is the path length or optical depth, i.e. the distance between the bottom and the top of the canopy along direction $[\theta, \phi]$, relative to canopy height. For canopies over flat terrain, path length is simply $d = 1/\cos\theta$ and does not depend on azimuth ϕ.

Note that because LAI is defined with regards to a unit horizontal ground area, if leaf area density is assumed constant, the height of the canopy should remain the same independently from the slope (Fig. 1). Inclining a canopy would mainly consist in deforming the parallelogram, plants keeping their vertical development. As a consequence, for a given LAI, the vertical gap fraction and that for azimuth perpendicular to the slope aspect should be independent from the slope angle α.

Hemispheric photography taken vertically upwards over flat terrain displays a disk representing all upward directions with the zenith direction in the centre. Conversely, over sloping terrain, part of the hemisphere is obstructed up-slope by the terrain, corresponding to the topographic mask. Frazer et al. (1997) were the first in correcting for the topographic mask when estimating LAI from DHP. Tilting the camera along the slope's normal prevents from observing the topographic mask, but forces anyway to account for the variation with azimuth of the path length due to the slope. However, no study reports results using this technique. Walter and Torquebiau (2000), using vertically pointing DHPs, proposed to replace zenith angles (relative to the vertical direction) by incident angles (relative to the normal to the slope) which consists in tilting the original horizontal reference plane to make it parallel to the slope. In these conditions, path length no longer depends on the azimuth if path length is defined relative to the normal of the slope. However, these authors confound the slope impact on the path length with that on the projection function. Because leaf inclination distribution function depends mainly on light climate and local gravity field, it might not depend directly on the slope and the projection function should still refer to the vertical direction. Nevertheless, this approximation is valid for a spherical leaf inclination distribution but may induce errors in other cases. More recently, Duursma et al. (2003) and Montes et al. (2007) proposed a correction method that explicitly accounts for variable path length due to the slope, while keeping the vertical reference direction for the projection function. Schleppi et al. (2007) proposed an alternative method for slope correction without analytical formulation of the variable path length. Most results derived from these studies conclude that the correction is marginal for small to moderate slopes (smaller than 20°). Conversely, for larger slopes, correction generally leads to increase the estimated LAI values significantly, particularly for the larger LAI values.

This study proposes in a first section, a geometrical model describing the path length directional variation on sloping terrain. A sensitivity analysis of the model is carried out on the directional distribution of P_0 and the associated estimation of LAI and average leaf angle inclination (ALA) used to characterize the leaf orientation distribution function (g, Eq. (1)). Then, the magnitude of the slope correction effect on LAI and ALA estimation is illustrated over actual canopies.

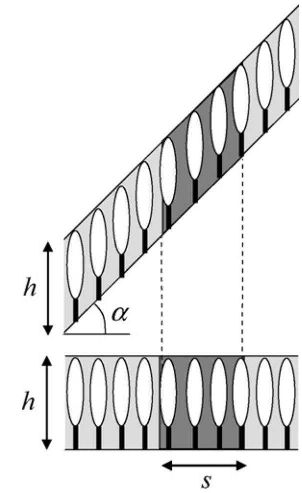

Fig. 1 – Scheme illustrating the definition of LAI over sloping terrain.

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