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Estimation of vegetation LAI from hyperspectral reflectance data: Effects of soil type and plant architecture

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Abstract

The retrieval of canopy biophysical variables is known to be affected by confounding factors such as plant type and background reflectance. The effects of soil type and plant architecture on the retrieval of vegetation leaf area index (LAI) from hyperspectral data were assessed in this study. *In situ* measurements of LAI were related to reflectances in the red and near-infrared and also to five widely used spectral vegetation indices (VIs). The study confirmed that the spectral contrast between leaves and soil background determines the strength of the LAI–reflectance relationship. It was shown that within a given vegetation species, the optimum spectral regions for LAI estimation were similar across the investigated VIs, indicating that the various VIs are basically summarizing the same spectral information for a given vegetation species. Cross-validated results revealed that, narrow-band PVI was less influenced by soil background effects ($0.15 \leq RMSE_{cv} \leq 0.56$). The results suggest that, when using remote sensing VIs for LAI estimation, not only is the choice of VI of importance but also prior knowledge of plant architecture and soil background. Hence, some kind of landscape stratification is required before using hyperspectral imagery for large-scale mapping of vegetation biophysical variables.

Keywords: Hyperspectral; Vegetation index; LAI; Plant architecture; Soil effects; Biophysical variables

1. Introduction

Over the past decades, the tools for vegetation remote sensing have evolved significantly. Optical remote sensing has expanded from the use of multi-spectral sensors to the use of imaging spectrometers. Imaging spectrometry is a unique type of optical remote sensing, because the surface radiance is sampled in many contiguous narrow spectral bands with band-widths of a few nanometers (nm). Imaging spectrometers typically acquire radiance information between 400 and 2500 nm, ideal for monitoring plant growth and estimating the biophysical properties of vegetation.

A large number of relationships have been discovered between remote sensing data and the biophysical properties of vegetation (e.g. Baret et al., 1987; Broge and Leblanc, 2001; Elvidge and Chen, 1995; Gilabert et al., 1996; Jackson and Pinter, 1986; Rondeaux and Steven, 1995; Schlerf et al., 2005; Wang et al., 2005). To minimize the variability due to external factors such as underlying soil, leaf angle distribution and leaf optical properties, remote sensing data have

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been transformed and combined into various spectral vegetation indices (VIs). Broadband VIs calculated as combinations of near-infrared and red reflectance have been found to be well correlated with biophysical properties of vegetation such as canopy cover, leaf area index (LAI), and absorbed photosynthetically active radiation (Baret and Guyot, 1991; Elvidge and Chen, 1995; Turner et al., 1999). However, it has been suggested that most VIs are sensitive to soil background, particularly when the LAI is low (Huete, 1989; Huete et al., 1985).

Here LAI is defined as the one sided surface area of leaves per unit ground area, and it is the key biophysical variable influencing land surface photosynthesis, transpiration, and energy balance (Bonan, 1995; Running et al., 1989). Previous studies have shown that VIs have considerable sensitivity to LAI, but more so at relatively low LAI values (Asrar et al., 1984; Chen and Cihlar, 1996; Fassnacht et al., 1997; Friedl et al., 1994; Turner et al., 1999). VIs typically increase over an LAI range from 0 to about 3 to 5 before an asymptote is reached. The upper limit of this sensitivity apparently differs among vegetation types (Turner et al., 1999). Simulation studies involving radiative transfer models suggest that saturation is more pronounced for planophile canopies (Atzberger, 2004; Baret and Guyot, 1991). On the other hand, compared with erectophile canopies of the same LAI, planophile canopies are less influenced by soil brightness variations.

Although VIs resulting from remote sensing data have been successfully used for estimating vegetation LAI, previous studies have demonstrated that variations in biophysical and biochemical features affecting plant canopy reflectance, such as vegetation type and related optical properties, background soil reflectance, and atmospheric quality, are bounding the generality and significance of their relationships with LAI (Baret and Guyot, 1991; Colombo et al., 2003; Huete, 1989; Nagler et al., 2004; Ridao et al., 1998; Turner et al., 1999; Wang et al., 2005).

Researchers have shown that, in comparison with broad-band VIs, narrow-band VIs may be crucial for providing additional information for quantifying the biophysical characteristics of vegetation (Blackburn, 1998; Elvidge and Chen, 1995; Gong et al., 1992; Lee et al., 2004; Mutanga and Skidmore, 2004). However, only a few studies deal with the effect of exterior features on the estimation and prediction of vegetation LAI using hyperspectral reflectance data. The study of Broge and Leblanc (2001) relied exclusively on simulated data from reflectance models rather than on actual imagery and field data. Using AVIRIS data, Lee et al. (2004) studied LAI estimation for four different biomes. However, their main objective was to compare hyperspectral data with multispectral data. Hence, considering confounding effects such as plant architecture and soil types, it is difficult to infer from existing studies whether, compared with broad-band indices, narrow-band VIs (combination of wavelengths that are not available with a limited number of broad bands) offer an improved sensitivity to LAI.

Our study aims to address this knowledge gap by investigating whether the estimation of LAI from hyperspectral reflectance measurements is significantly affected by soil type and/or plant architecture (e.g., leaf shape and size). We analyzed the effects of these factors (i) on the characterization of canopy reflectance behavior in visible to near-infrared bands, and (ii) on the stability of linear LAI–VI relationships. The study is based on canopy spectral reflectances measured during a controlled laboratory experiment using four types of plants, with two different soil backgrounds and destructive LAI measurements. The plants differed widely in leaf size and shape.

2. Materials and methods

2.1. Experimental setup

Four different plant species with different leaf shapes and sizes were selected for sampling: *Asplenium nidus*, an epiphytic fern that has apple-green leaves about 50 cm in length and 20 cm in width; *Halimium umbellatum*, a Mediterranean procumbent shrub that has crowded leaves at the apex of branchlets, the leaves being linear and about 25 mm in length; *Schefflera arboricola Nora*, a shrub with palm-shaped leaves, dark green in color, and palmately compound, with seven to nine leaflets, each about 5 cm to 7 cm in length; and *Chrysalidocarpus decipiens*, a single trunked or clustering palm with slightly plumose leaves, each about 25 cm in length and 2 to 3 cm in width. A total of 24 plants were used for the study, 6 plants per species. The plants were kept in a greenhouse. Photos taken from nadir (Fig. 1) show the four plant species and illustrate their variability in leaf size and shape.

Canopy spectral reflectance in visible to mid-infrared regions has been revealed to be affected by many factors, such as LAI, pigment concentration, canopy architecture and soil brightness (Gitelson et al., 2003; Jackson and Pinter, 1986). In order to generate a wide variability within each species, we artificially induced variations in LAI and canopy chlorophyll content, as well as in background brightness. To obtain