LEAF CHLOROPHYLL *a+b* AND CANOPY LAI ESTIMATION IN CROPS USING R-T MODELS AND HYPERSPECTRAL REFLECTANCE IMAGERY

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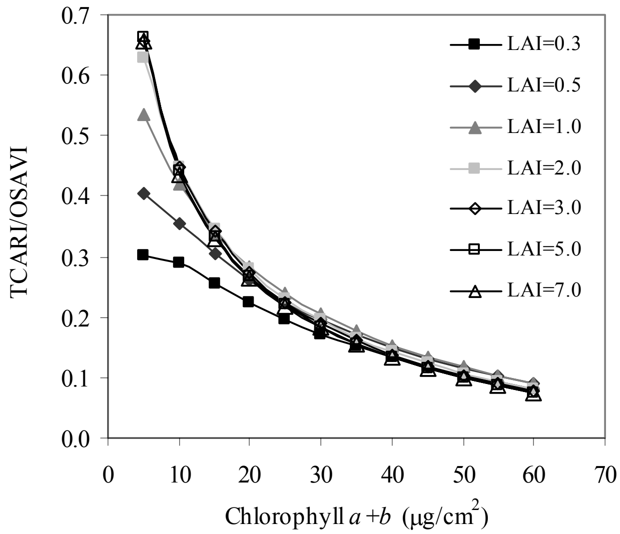
Introduction

Recent studies have demonstrated the usefulness of optical indices from hyperspectral remote sensing reflectance in the assessment of vegetation biophysical variables both in forestry (Zarco-Tejada *et al.,* 2001) and agriculture (Haboudane *et al.,* 2002). Those indices are, however, the combined response to variations of several vegetation and environmental properties, such as leaf area index (LAI), leaf angle distribution function (LADF), leaf chlorophyll *a+b* content (C_{ab}), canopy shadows, background reflectance, and illumination-observational conditions. Of particular significance to precision agriculture is C_{ab}, which is related to the nitrogen concentration and serves as a measure of crop response to nitrogen application. We present a modeling approach to predict C_{ab} from hyperspectral remote sensing while minimizing soil reflectance (ρ_s), shadow effects, and considering LAI variations. This method was developed using simulated data, followed by assessment using hyperspectral airborne imagery. Simulations consisted of leaf and canopy reflectance modeling with PROSPECT and SAILH radiative transfer (RT) models and developing optical indices that minimize bi-directional and soil background effects.

Methods

The study area is an experimental site of the *GEOmatics for Informed Decisions* (GEOIDE) project for precision agriculture, Agriculture and Agri-Food Canada, in Quebec, Canada. Corn was grown on four adjacent experimental fields with four experimental blocks, each containing four 20 x 20 m plots of 27 rows, to which the nitrogen fertilizer treatments were randomly assigned. Nitrogen fertilizer treatments were supplied in two applications, at the time of seeding and topdressing six weeks later, comprising a total of 64 experimental plots. Four major treatments were supplied: no fertilization (A), intermediate fertilization with uniform nitrogen application at top dressing (B), variable nitrogen application at top dressing (C), and over-fertilization (D). Hyperspectral images were acquired by the *Compact Airborne Spectrographic Imager* (CASI) during summer 2000. At the same time ground truth measurements included (i) leaf sampling for determination of leaf C_{ab}, (ii) corn leaf reflectance (ρ) and transmittance (τ) measurements using integrating sphere and spectrometer, (iii) LAI measurements using the LAI-2000 instrument, and (iv) crop growth measures. Leaf samples from 4 plants per experimental unit were used for analysis of C_{ab}. CASI airborne images were collected using a multispectral mode of operation, with 1 m spatial resolution and 7 spectral bands (489.5, 555.0, 624.6, 681.4, 706.1, 742.3, and 776.7 nm), and a hyperspectral mode, with 2 m spatial resolution and 72 channels covering the spectral range 408 to 947 nm. The processing of CASI imagery included radiance calibration, atmospheric corrections and reflectance retrieval, removal of aircraft motion, geo-referencing, and flat field spectral anomaly removal. Leaf optical properties were simulated with PROSPECT model for radiation fluxes between 400 and 2400 nm to relate biochemistry and scattering parameters to ρ and τ spectra with a leaf structure parameter (N) derived from laboratory measurements, and values of C_{ab}, water thickness C_w, and dry matter content C_m. Canopy reflectance were simulated using SAILH turbid-medium model, with inputs such as LAI, LADF, ρ, τ, and ρ_s. MCARI *(Modified Chlorophyll Absorption Index)* was modified to minimize background effects (TCARI), calculated as TCARI = $3\cdot[(R_{700}–R_{670})–0.2\cdot(R_{700}–R_{550})\cdot(R_{700}/R_{670})]$. To minimize soil effects on reflectance, TCARI was combined with OSAVI (*Optimized Soil-Adjusted Vegetation Index*) calculated as OSAVI = $[(1+0.16)\cdot(R_{800}–R_{670})/(R_{800}+R_{670}+0.16)]$ and used in a *scaling-up* approach with PROSPECT and SAILH RT models to study its relationship with C_{ab} and LAI (Figure 1).

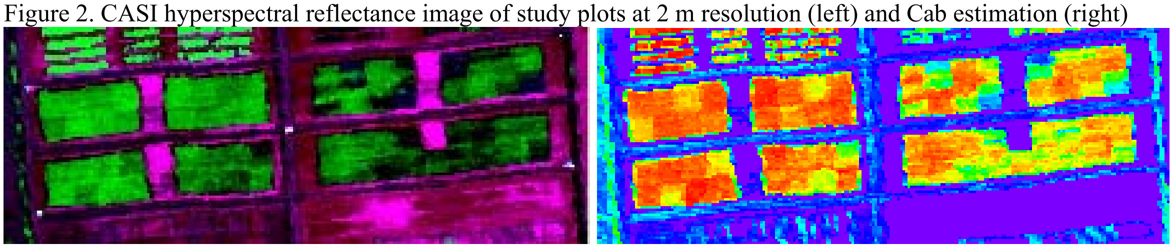
Figure 1. TCARI/OSAVI as a function of Cab and LAI



Results

Simulated data show that TCARI/OSAVI reflectance index is very sensitive to C_{ab} variations and resistant to changes of LAI. A predictive equation to estimate leaf C_{ab} from the combined optical index TCARI/OSAVI derived from canopy reflectance was developed. This relationship was evaluated by application to hyperspectral imagery from corn plots. Images of predicted leaf C_{ab} were generated (Figure 2), showing retrieval accuracies of RMSE = 4.6 $\mu g/cm^2$. Assessment showed chlorophyll variability over crop plots with various levels of nitrogen fertilization, and revealed an excellent agreement with ground truth, with a correlation of r^2=0.81 between estimated and measured C_{ab}.

Figure 2. CASI hyperspectral reflectance image of study plots at 2 m resolution (left) and Cab estimation (right)



Conclusions

Leaf and canopy RT models PROSPECT and SAILH were employed to simulate C_{ab} and LAI effects on crop canopy reflectance. A methodology for predicting C_{ab} status from hyperspectral reflectance data, based on combining optical indices through *scaling up*, was developed and tested with airborne CASI hyperspectral reflectance data of 2 m spatial resolution over a corn crop. This method was used to investigate the effects of non-photosynthetic materials and LAI on the retrieval of leaf chlorophyll at the canopy level. To address these issues, we transformed the MCARI optical index, called TCARI, more sensitive to low C_{ab} values and resistant to vegetation non-photosynthetic materials. An index that minimizes soil effects (OSAVI) was integrated with TCARI to remove LAI influence on C_{ab} predictions through RT modeling. The study shows that C_{ab} is correlated with TCARI/OSAVI which is insensitive to LAI from 0.5 to 8.

References

Haboudane *et al.,* 2002, Remote Sensing of Environment, 81, 1-11.

Zarco-Tejada *et al.,* 2001, *IEEE Trans. on Geoscience and Remote Sensing*, 39(7), 1491-1507.