AN OPTIMIZED BROAD-BAND LEAF CHLOROPHYLL ESTIMATOR

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1. INTRODUCTION

Nitrogen stress is one of the main driver of crops yield but excess nitrogen may impact the environment. Vegetation indices (VI) can be used to gather the information basis for variable rate nitrogen fertilization in precision agriculture. Narrow-band VI, requiring high spectral resolution reflectance data, have proved to be sensitive at the canopy scale to leaf chlorophyll concentration, a valuable nutritional status indicator [1, 2, 3, 4, 5]. Currently, however, the operational use of airborne hyper-spectral sensors for this application is expensive and the availability of high spatial resolution space-borne hyper-spectral sensors is limited. We developed from a field spectrometric experiment conducted on sugar beet canopies the Chlorophyll Vegetation Index (CVI), a broad-band vegetation index specifically sensitive, in the original experimental conditions, to leaf chlorophyll concentration at the canopy scale [6]. The results of the analysis of synthetic reflectance data indicated that the broad-band CVI index could be used as a leaf chlorophyll estimator for planophile (i.e., with low average leaf angle) crops in most soil conditions [7].

We have proposed an optimized version (OCVI) of the CVI by using a large synthetic dataset [7]. A single correction factor is incorporated in the OCVI to take into account the different spectral behaviours due to crop and soil types, sensor spectral resolution and scene sun zenith angle. The present work addresses a comparison between the sensitivity to leaf chlorophyll concentration of the broad-band OCVI, obtained estimating the values of the correction factor from the slope of the green-red soil line and sun elevation, and of different broad-band VI and of narrow-band VI specifically proposed as leaf chlorophyll estimators. The sensitivity analysis is conducted on a large synthetic dataset obtained by using the coupled PROSPECT+SAILH leaf and canopy reflectance model in the direct mode.

2. METHODS

The Chlorophyll Vegetation Index (CVI) is obtained from the "green simple ratio", the ratio of the reflectances in the NIR and green parts of the spectrum, by introducing the red/green ratio to minimize the sensitivity to differences in the canopy LAI before canopy closure [6]:

$$CVI = \frac{\rho_{NIR}}{\rho_{green}} \cdot \frac{\rho_{red}}{\rho_{green}} \quad (1)$$

We have proposed an optimized version (OCVI) incorporating a single correction factor to take into account the different spectral behaviors due to crop and soil types, sensor spectral resolution and scene sun zenith angle [7]:

$$OCVI = \frac{\rho_{NIR}}{\rho_{green}} \cdot \left(\frac{\rho_{red}}{\rho_{green}} \right)^{c} \quad (2)$$

In principle the OCVI correction factor can take into account the different spectral behaviours due to crop and soil types, sensor spectral resolution and scene sun zenith angle. For a given combination of sensor spectral resolution, crop type (i.e., average leaf angle) and, for erectophile crops, scene sun elevation, the “optimum” value of the correction factor of the broad-band OCVI can be obtained using the slope of the green-red soil line as a practical indicator of the soil spectral behaviour [8]. We have proposed three equations, used in the present work, for the estimation of the *c* correction factor for planophile (5), intermediate (6) and erectophile (7) leaf orientation respectively. The equation, intended for OCVI calculation from reflectances in the SPOT spectral bands, are based on the use of the slope of the green-red soil line as a practical indicator of the soil spectral behaviour and, for erectophile canopies, on scene sun elevation [8].

A large synthetic dataset was obtained by using The PROSPECT+SAILH leaf and canopy coupled reflectance model in the direct mode. The synthetic reflectance was then used to compare the sensitivity of several broad-band and narrow-band vegetation indices (VI). Broad-band indices included classical slope-based VI (i.e.: NDVI – Normalized Difference VI and SR – Simple Ratio) and some indices incorporating green reflectance (i.e.: Green NDVI, Green SR and the newly proposed CVI and OCVI), whereas narrow-band indices included VI specifically proposed as leaf chlorophyll estimators at the canopy scale (i.e.: MCARI – Modified Chlorophyll Absorption in Reflectance Index, TCARI – Transformed CARI, TCARI/OSAVI ratio – TCARI/Optimized Soil Adjusted VI – and REIP, Red Edge Inflection Position).

Changes in sensitivity of a VI over the range of leaf chlorophyll concentration were analysed by traditional regression-based statistics (r^2 coefficient of determination, and Root Mean Square Error – RMSE) and by using a sensitivity function. The sensitivity function (Equation 8), obtained according to the method proposed by Ji and Peters [9], is calculated as the ratio of the first derivative of the regression function (Equation 3) – using leaf chlorophyll concentration as the independent variable (x) and the VI values as the dependent variable (y) – and the standard error $\sigma_{\hat{y}}$ of the predicted value ($\hat{y}$):

$$s = \frac{d\hat{y} / dx}{\sigma_{\hat{y}}} \tag{3}$$

3. RESULTS AND DISCUSSION

The OCVI r^2 values confirmed that leaf chlorophyll concentration in erectophile crops can be effectively estimated using the broad-band OCVI. The highest correlation levels between VI and leaf chlorophyll concentration were obtained for all considered soil and sun zenith conditions by the narrow-band TCARI/OSAVI ratio or by the broad-band OCVI. In Figure 1 the OCVI and TCARI/OSAVI sensitivity functions vs. leaf chlorophyll concentration are reported for erectophile canopies (Average Leaf Angle 70°), Portneuf soil dry (ie., one of the six soils included in the soil reflectance database used) and two sun zenith angles. As shown by the sensitivity functions the broad-band OCVI, in comparison with the narrow-band TCARI/OSAVI ratio, tended to be more sensitive for higher leaf chlorophyll concentration ranges, more realistic for usual crops nutritional status.

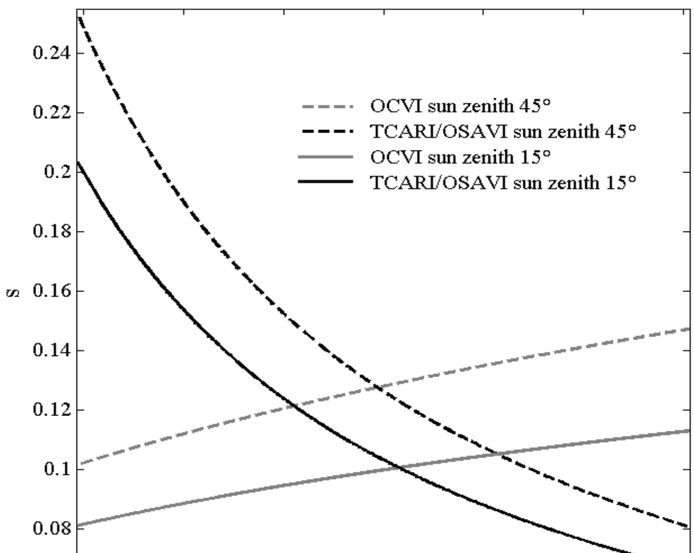

Fig. 1 OCVI and TCARI/OSAVI *s* sensitivity functions vs. leaf chlorophyll (a+b) concentration (μg cm^{-2}) for erectophile canopies (Average Leaf Angle 70°), Portneuf soil dry and two sun zenith angles.

4. CONCLUSIONS

Despite their wide use for operational applications, the reliability of empirical vegetation indices is limited by the fact that usually they account poorly for scene and sensor-specific factors affecting canopy reflectance and its acquisition. The portability of empirical relationships between the different vegetation indices and crop biophysical parameters to different conditions is therefore limited. The results of the analysis of a large synthetic dataset seem to indicate that leaf chlorophyll concentration, a valuable nutritional status indicator, can be effectively estimated at the canopy scale using the broad-band OCVI, incorporating a single *c* correction factor to take into account the different spectral behaviours due to crop and soil types, sensor spectral resolution and scene sun zenith angle.

5. REFERENCES

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