Angular dependence of maize and sugar beet VIs from directional CHRIS/Proba data

Massimo Vincini, Ermes Frazzi, Paolo D'Alessio

CRAST, Centro Ricerca Analisi Spaziale e Telerilevamento – Università Cattolica del Sacro Cuore
Via Emilia Parmense, 84 – 29100 Piacenza, Italy
Email: massimo.vincini@unicatt.it

ABSTRACT

In the framework of the CITIMAP precision farming research program at the Vittorio Tadini experimental farm the values of some Vegetation Indexes (simple ratio – SR, triangular vegetation index – TVI, modified TVI1, Modified TVI2 and the newly developed spectral polygon vegetation index – SPVI) have been determined for maize and sugar beet experimental crops with different fertilization levels and seeding dates, from 36°, 0° and +36° along track zenith angles CHRIS/Proba observations. Biophysical crop parameters relevant to nutritional status and nitrogen variable rate fertilization (LAI and leaf chlorophyll concentration) measured close to the multi-angular CHRIS/Proba acquisition date were available for maize experimental plots. The relative angular dependence of VIs, as determined from CHRIS/Proba data, is addressed.

INTRODUCTION

Many studies have indicated that broad-band vegetation indexes (VIs), obtainable from multi-spectral data, and narrow-band indexes, requiring hyper-spectral data, can be effectively used, due to their sensitivity to leaf chlorophyll concentration, for gathering the information basis for variable rate fertilization. Several optical vegetation indexes have been proposed in the literature and exhaustive comparative studies [1, 2] have been carried out to assess their prediction power and sensitivity to vegetation biophysical parameters such as the leaf area index (LAI), leaf chlorophyll concentration and canopy chlorophyll density (CCD, a measure of photosynthetic potential at the canopy level calculated as the product of LAI and leaf chlorophyll concentration).

Much effort has been expended to render vegetation indices insensitive to variations in illumination conditions, observing geometry, and soil properties. In general, however, different VIs show specific sensitivity to such external factors. With the development of across-track and along-track sensors pointing capabilities increasing amounts of high spatial resolution data collected by off-nadir observations are being made available. For the application of vegetation indexes obtained from off-nadir observations to crops characterization the sensitivity of the various VIs to the observation angle may be quantitatively relevant and should be taken into account.

The present preliminary work addresses the relative angular dependence of some VIs in their narrow-band form as determined from a CHRIS/Proba multi-angular acquisition. Selected VIs, including in particular new indexes incorporating green reflectance, can be obtained from multi-spectral data in their broad-band form (i.e. they do not strictly require hyper-spectral data) .

METHODS

In the framework of the CITIMAP (centre for the application of remote sensing in precision agriculture) research program at the Vittorio Tadini experimental farm, the values of some vegetation indexes have been determined from a multi-angular CHRIS/Proba acquisition, for maize and sugar beet experimental crops with different pre-seeding nitrogen fertilization levels and different seeding dates. The single CHRIS/Proba acquisition available was for June 28th 2005, mode 5, 17 m spatial resolution, multi-angular with -55°, -36°, 0°, +36° and +55° along track zenith angles (54.9°, 33.6°, 11.7°, 38.3° and 57.5° observation zenith angles); for the +55° angle the acquisition failed the target due to mispointing. Atmospheric correction has been applied to CHRIS/Proba data using the ENVI FLAASH tool (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) based on the MODTRAN4 algorithm. Biophysical crops parameters relevant to nutritional status (LAI and leaf chlorophyll concentration) have been determined by multi-temporal measures collected directly in the field (leaf optical thickness by Minolta SPAD 502 and LAI by Licor LAI 2000) and leaf samples collection for laboratory analysis. LAI and leaf chlorophyll concentration measures collected close to the multi-angular CHRIS/Proba acquisition date were available for maize experimental plots.

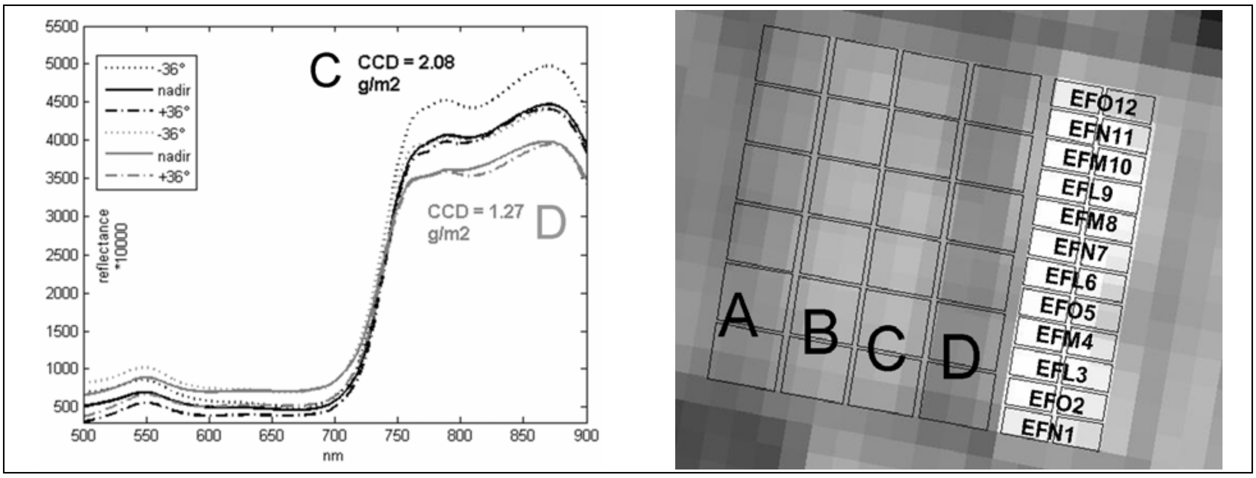

Fig. 1. Average spectra for three Chris/Proba nominal observation angles and average canopy chlorophyll density (CCD) of two maize experimental plots (left); NIR Chris/Proba image (796 nm) for maize (A, B,C,D) and sugar beet (EFxn) experimental plots (right)

In Fig. 1 the average spectra for three Chris/Proba nominal observation angles of two maize experimental plots along with the average CCD levels (left) and the NIR Chris/Proba image (796 nm) for maize and sugar beet experimental plots (right) are reported. Maize plots B and C, planted 14 day before plots A and D, were characterized by a higher Canopy Chlorophyll Density (CCD) mainly due to the higher LAI. Sugar beet plots received four levels of pre-seeding nitrogen fertilization (O, N, M and L) providing respectively 0, 90, 180, 270 Kg N/ha as slow release fertilizer (EFO<EFN<EFM<EFL). A minimum of seven pixels was considered for the determination of VIs' plot average values for each CHRIS/Proba observation geometry. Among the experimental treatments and plots only the sugar beet maximum fertilization EFL plots did not matched the required minimum number of pixels and was therefore not considered for VIs' comparison.

Vegetation Indexes

The considered vegetation indexes included a slope-based index (the simple ratio - SR) and recent indexes incorporating green reflectance (the triangular vegetation index - TVI, the modified TVI1, the modified TVI2 and the newly developed spectral polygon vegetation Index – SPVI). The indexes, calculated in their "narrow-band" form from CHRIS/Proba data in the present work, can be obtained in their broad-band form from multi-spectral sensors with suitable bandwidths and band central wavelengths.

The classic Ratio Vegetation Index [3] or Simple Ratio (SR) is calculated as the ratio of the reflectances in the NIR (800 nm) and Red (670 nm) parts of the spectrum and represents the slope of the line that joins the origin and the vegetation point in Red/NIR space (1). SR has been reported as the best estimator of both LAI and CCD for low vegetation densities [2].

$$SR = \frac{\rho_{800}}{\rho_{670}} \tag{1}$$

The vegetation indexes incorporating bands in the green [2, 4, 5, 6, 7] have recently proved to be effective LAI and chlorophyll concentration estimators. The general idea [2] behind the triangular vegetation index (TVI), calculated as the area of the triangle defined by the green peak, the red chlorophyll absorption maximum (i.e. minimum reflectance), and the NIR shoulder in spectral space (2), is to describe the radiative energy absorbed by the pigments as a function of the relative difference between red and NIR reflectance in conjunction with the magnitude of reflectance in the green region. Both chlorophyll absorption causing a decrease of red reflectance and leaf tissue abundance causing increased NIR reflectance will increase the total area of the triangle.

$$TVI = 0.5\left[120(\rho_{750} - \rho_{550}) - 200(\rho_{670} - \rho_{550})\right] \tag{2}$$

Haboudane et al. [7] noticed that the increase of chlorophyll concentration results in the decrease of the green reflectance, leading, therefore, to a relative decrease of the triangle area, and that canopy reflectance at 750 nm is still influenced by leaf chlorophyll content. On the basis of the latter observation they developed two modified versions of TVI for LAI estimation from remote sensing data, the Modified TVI1 (3) and the Modified TVI2 (4). Such indexes should be less sensitive to chlorophyll effects and more responsive to green LAI variations. MTVI1 was obtained [7] by introducing a scale factor and replacing the 750 nm wavelength by the 800 nm wavelength to make TVI suitable for LAI estimations:

$$MTVI1 = 1.5\left[1.2(\rho_{800} - \rho_{550}) - 2.5(\rho_{670} - \rho_{550})\right] \tag{3}$$

To reduce soil contamination effects a soil adjustment factor was incorporated in MTVI2 [7] using the concept developed by Huete [8]:

$$MTVI2 = \frac{1.5\left[1.2(\rho_{800} - \rho_{550}) - 2.5(\rho_{670} - \rho_{550})\right]}{\sqrt{(2\rho_{800} + 1)^2 - (6\rho_{800} - 5\sqrt{\rho_{670}}) - 0.5}} \tag{4}$$

In order to obtain a vegetation index incorporating the spectral information of the green band with enhanced sensitivity to canopy chlorophyll density (CCD calculated as the product of LAI and leaf chlorophyll concentration) we have developed the spectral polygon vegetation index (5):

$$SPVI = 0.4\left[3.7(\rho_{800} - \rho_{670}) - 1.2\left|\rho_{550} - \rho_{670}\right|\right] \tag{5}$$

The SPVI index is based on the general idea of the triangular vegetation indexes but it takes into account the variation of green reflectance as a function of chlorophyll concentration (i.e. SPVI increases for decreasing green peak reflectance values). For vegetated pixels, with green reflectance values higher than red reflectance, SPVI is a measure of the area of the polygon defined in the spectral space by the green peak, the minimum reflectance in the red region, the NIR shoulder and the point of coordinates given by the green peak wavelength (550 nm) and the reflectance of the NIR shoulder. A graphical illustration of SPVI and TVI, the latter with 800 nm NIR wavelength as suggested for LAI estimation [7], is reported in Fig. 2. A scale factor is introduced to express the index as the ratio of the polygon area and an area of 125 (250 nm x 0.5 reflectance units) in the spectral space. The introduction of the absolute value (5) for the green-red reflectance difference is intended to minimize the index sensitivity to soil brightness for pixels with green reflectance lower than red reflectance (i.e. bare soil or scarcely vegetated pixels). First results [9] of the application of the SPVI index to multi-spectral QuickBird data conducted in the framework of the CITIMAP research program seem to indicate a high sensitivity of the index to sugar beet CCD.

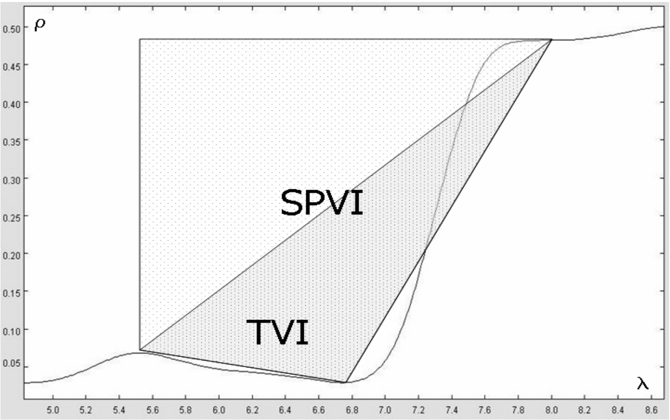

Fig. 2. Graphical illustration in the spectral space of the TVI, triangular vegetation index (with 800 nm NIR wavelength) and of the novel spectral polygon vegetation index, SPVI

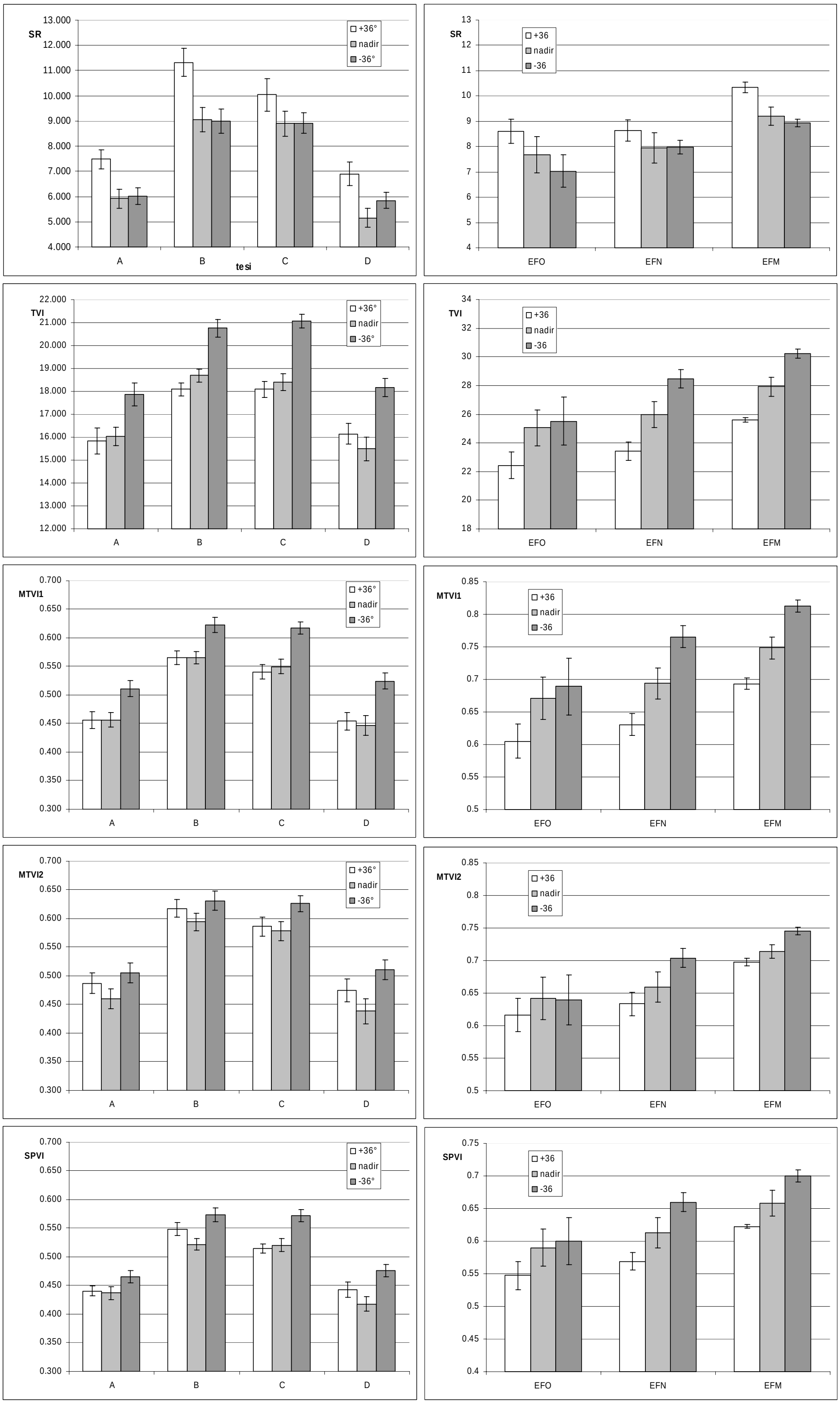

Fig. 3. VIs' average and standard deviation values of maize (left) and sugar beet (right) experimental plots for +36°, 0° and -36° CHRIS/Proba along track zenith angles

RESULTS

In Fig. 3 the VIs' average and standard deviation values of maize (left) and sugar beet (right) experimental plots are reported for +36°, 0° and - 36° nominal CHRIS/Proba observation angles. The similar NIR spectral reflectance values visible in Fig. 1 for the noticeably different CCD values of maize C and D plots, respectively for the 0° and -36° (close to the hot spot zone) nominal observation angles, can describe the quantitative relevance of the observation geometry for VI calculation. A similar directional spectral behaviour has been observed for all thesis and both sugar beet and maize experimental crops. With regard to the relevance of such directional reflectance behaviour is important to notice that CHRIS/Proba makes along-track multi-angular observation and that across track off-nadir observations, farther from the principal plane, would probably be less affected by changes of the bidirectional reflectance factors.

The plot average and standard deviation values of the vegetation indexes reported in Fig. 3 tended in general to reflect the higher vegetation biomass of maize early planting plots (B, C) and of sugar beet plots with higher N fertilization levels (EFO<EFN<EFM). However, SR, TVI and MTVI1 indexes showed a marked dependence on the observation geometry with levels of variability caused by the observation angle for each plot noticeably higher than the internal dispersion of each observation geometry and comparable, for maize plots, to those caused by large variations of the CCD level. Band ratioing doesn't seem to be effective at minimizing the angular dependence of the simple ratio (SR) which showed (Fig. 3) higher values for the +36° nominal observation angle for both sugar beet and maize plots, possibly caused by non–proportional variations of NIR and red reflectances (Fig. 1, left).

As visible in Fig. 3 similar TVI and MTVI1 (the latter specifically proposed as a LAI estimator) values have been obtained for -36° A-D (average LAI 3.2) and 0°, +36° B-C maize plots (average LAI 5.0). The similarity of the triangular vegetation indexes can be explained by the increase of NIR reflectance for the observation geometry close to the hot-spot zone, leading to similar area of the triangle (green, red, near infrared shoulder) measured in the spectral space.

In contrast the newly proposed SPVI and the MTVI2, a ratio obtained dividing MTVI1 by a soil adjustment factor, seem to be affected to a lesser extent by the observation geometry with variations caused by the observation angle for each plot in general comparable to the internal variability for each observation angle (Fig. 3).

CONCLUSIONS

A preliminary comparison among SR, TVI, MTVI1, MTVI2 and the newly proposed SPVI vegetation indexes obtained from a single multi-angular CHRIS/Proba acquisition for maize and sugar beet experimental crops with different fertilization levels and different seeding dates seem to indicate a lower sensitivity of MTVI2 and SPVI to the observation angle.

References

[1] F. Baret and G. Guyot, "Potentials and limits of vegetation indices for LAI and APAR assessment," *Remote Sens. Environ*., vol. 35, pp. 161–173, 1991.

[2] N.H. Broge and E. Leblanc, "Comparing prediction power and stability of broadband and hyperspectral vegetation indices for estimation of green leaf area index and canopy chlorophyll density," *Remote Sens. Environ*, vol. 76, pp. 156–172, 2000.

[3] C.F. Jordan, "Derivation of leaf area index from quality of light on the forest floor," *Ecology*, vol. 50, pp. 663–666, 1969.

[4] M.S. Kim, C.S.T. Daughtry, E.W. Chappelle, J.E. McMurtrey III and C.L. Walthall, "The use of high spectral resolution bands for estimating absorbed photosynthetically active radiation (Apar)," *Proceedings of the 6th Symp. on Physical Measurements and Signatures in Remote Sensing*, Val D'Isere, France, pp. 299–306, Jan.17–21, 1994.

[5] C.S.T. Daughtry, C.L. Walthall and M.S. Kim, E. Brown de Colstoun and J.E. McMurtrey III. Estimating corn leaf chlorophyll concentration from leaf and canopy reflectance. *Remote Sens. Environ*., vol. 74, pp. 229– 239, 2000.

[6] D. Haboudane, J.R. Miller, N. Tremblay, P.J. Zarco-Tejada and L. Dextraze, "Integrated narrow-band vegetation indices for prediction of crop chlorophyll content for application to precision agriculture," *Remote Sens. Environ*., vol. 81, pp. 416– 426, 2002.

[7] D. Haboudane, J.R. Miller, E. Pattey, P.J. Zarco-Tejada and I.B. Strachan, "Hyperspectral vegetation indices and novel algorithms for predicting green LAI of crop canopies: Modeling and validation in the context of precision agriculture," *Remote Sens. Environ*., vol. 90, pp. 337-352, 2004.

[8] A.R. Huete, "A soil-adjusted vegetation index (SAVI), *Remote Sens. Environ*., vol. 25, 295-309, 1988.

[9] M. Vincini, "Comparison of narrow-band and broad-band Vegetation Indexes for canopy chlorophyll density estimation in sugar beet," Unpublished.