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REMOTE ESTIMATION OF VEGETATION FRACTION IN CORN CANOPIES

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ABSTRACT

The aim of the paper was to test two new techniques that make use of channels in the visible range of the spectrum only to estimate vegetation fraction in corn canopies. High spectral resolution radiometers were employed to measure spectral reflectance, and the information content of spectra was investigated. Radiances in spectral channels of MODIS and MERIS were used to calculate Visible Atmospherically Resistant Indices, $VARI_{green}=(R_{green}-R_{red})/(R_{green}+R_{red}-R_{blue})$ and $VARI_{700}=(R_{700}-1.7*R_{red}+0.7*R_{blue})/(R_{700}+2.3*R_{red}-1.3*R_{blue})$. The indices allowed for estimation of vegetation fraction with less than 10% error. One other technique was based on the well-documented approach for fully closed canopies involving the high degree of covariance for paired reflectances at 550 nm vs. 700 nm and at 500 nm vs. 670 nm. The coordinate location within the resulting spectral space was used as a measure of vegetation fraction.

INTRODUCTION

Spectral vegetation indices are widely used indicators of temporal and spatial variations in vegetation structure and biophysical parameters. They enable assessment and monitoring of changes in canopy biophysical properties such as vegetation fraction, leaf area index, fraction of absorbed photosynthetically active radiation, and net primary production (Asrar et al., 1984; Holben, 1986; Myneni et al., 1995; 1997a,b; Sellers, 1985, 1987; Tucker, 1979). Considerable effort has been expended in improving the normalized difference vegetation index (NDVI) and in developing new indices to compensate both for the atmosphere (e.g. Kaufman, 1989; Kaufman & Tanre, 1992), and canopy background (Huete, 1988; Huete et al., 1994). Most vegetation indices combine information contained in two spectral bands, red and near infrared (NIR). The indices have limitations, some of which are due to choices of band location and width. Examples include minimal sensitivity of the NDVI to moderate to high chlorophyll content (Gitelson & Merzlyak, 1996; Myneni et al., 1997b) and the minimal sensitivity of NIR reflectance to vegetation fraction at certain growth stages (Daughtry et al., 1980; Kanemasu, 1974; Stark and Gitelson, 2000). Techniques that use only the visible range of the spectrum for the quantitative estimation of vegetation fraction (VF) were suggested recently (Gitelson et al., 1999; 2000; Stark et al., 2000). These techniques take advantage of new satellite technologies including the high spectral and radiometric resolutions achieved in the recently launched SeaWiFS, MODIS, ASTER, MISR and imminent scanners such as MERIS. The aim of the paper is to test these techniques for VF estimation in corn, and compare results with established approaches such as NDVI.

MATERIALS AND METHODS

The study area was the University of Nebraska Agricultural Research and Development Center (ARDC), located near Mead, Nebraska. The specific study site was a one-acre field of corn planted in a randomized design consisting of 16 plots (Derry, 2000). Each plot measured 11.4 x 12.2 m or approximately 135 sq. m. Hyperspectral data for corn were collected at close-range using a Spectron Engineering SE-590 portable spectroradiometer. The system detects and records spectral data in 252 usable bands with a spectral range from 365 nm to 1126 nm. Average wavelength spacing between midpoints of adjacent bands is about 3 nm. The sensor was configured to acquire eight individual radiance measurements, which were internally averaged and stored as a single data file. The controller is connected to a portable computer, which initiates the scanning procedure, graphically displays the reflectance values of the target, and stores the data. The sensor was positioned at a height of 5.8 m above the canopy and pointed due south to reduce shadowing. Data were collected close to solar noon (between 11am and 3pm) when changes in solar zenith are minimal. The 15° optic resulted in an instantaneous field-of-view (IFOV) of 150 cm (diameter) at the top of the canopy. The sensor head was then positioned over six different sample locations within each plot and radiant flux was measured. A white Spectralon (Labshere, Inc., North Sutton, NH) reflectance standard was used to calibrate the spectroradiometer to the total incoming radiant flux. All canopy radiance data were imported into Microsoft's Excel Spreadsheet software and the bi-directional reflectance factor (%) was calculated as: $R_{\lambda corn}(\%)=(L_{\lambda\ corn}\ [\mu W\ cm^{-2}\ sr^{-1}\ nm^{-1}])/(L_{\lambda\ panel}[\mu W\ cm^{-2}\ sr^{-1}\ cm^{-1}])*100$, where $L_{\lambda\ corn}$ is measured radiance for corn per wavelength, λ, $L_{\lambda\ panel}$ is measured radiance for the calibration panel per wavelength, λ, $R_{\lambda\ corn}$ is canopy reflectance (%) for corn per wavelength, λ.

Spectral data were to be collected at regular intervals (every three weeks) throughout the growing season. Atmospheric conditions dictated whether or not data were actually collected on the scheduled dates and as a result, corn spectra were eventually collected at four stages of development. The reflectance values from the six sample locations within each plot were averaged, resulting in a single reflectance value, per wavelength, for each plot.

Digital camera images were acquired using a Kodak DC-40 system. The camera, mounted adjacent to the SE-590, provided above-canopy images from the view of the spectroradiometer. A digital image was acquired over each of the 16 plots concurrent with spectral data collection of the corn canopy. The digital camera images were imported into ERDAS Imagine (ver. 8.3.1) for processing. The area (size) and location of the SE-590 IFOV in each image was determined and a model was designed to exclude data outside the 152.5-cm diameter of the IFOV. The model also separated non-vegetation (soil) pixels from vegetation pixels by subtracting the green band from the red band. The images were recoded to create a file containing two classes: non-vegetation and vegetation.

RESULTS

<u>Visible Atmospherically Resistant Indices</u>

Corn reflectance in the visible spectrum decreased in an orderly fashion throughout the growing season. This decrease was most pronounced in the green and red ranges (550 to 710 nm) and least pronounced in the blue (400-500 nm). Beyond 750 nm, reflectance ranged from about 25% to nearly 35%. During the course of the growing period, the red and the NIR reflectance became virtually invariant to VF's between 50 and 100% (Fig. 1). As a result, the NDVI was non-sensitive to moderate to high VF % (Fig. 1).

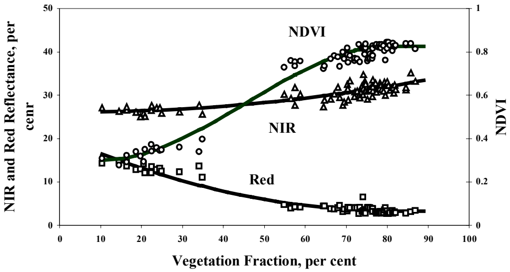


FIGURE 1. Reflectance in the red the near infrared regions and the NDVI plotted versus corn vegetation fraction.

Early in the growing season, the red reflectance (near 670 nm) was more sensitive to VF than the green (around 550 nm). However, when VF reached 50%, the R_{red} was noticeably less sensitive to VF; in fact, the sensitivity of the R_{red} to VF was at least three times lower than of the R_{green}. For VF exceeding 50%, reflectance in the blue and the red ranges provide almost the same information. Thus, in the visible spectrum for VF > 50%, we have, in reality, only two independent spectral bands: (1) either near 490 nm or 670 nm; and (2) either near 550 nm or 700 nm. The same information content for reflectance spectra in the visible range but at the leaf level was also found in earlier work (Gitelson and Merzlyak, 1996).

Following Gitelson et al. (1999), an index $(R_{green}-R_{red})/(R_{green}+R_{red})$ that employed only reflectance in the visible range of the spectrum was tested for estimating VF. Notice that with an increase in VF, the absolute difference between the green and red reflectance $(R_{green}-R_{red})$ also increased (Fig. 2)). The relationship between the sum $(R_{green}+R_{red})$ and VF tends toward hyperbolic, decreasing markedly with increase in VF. Thus, the ratio $(R_{green}-R_{red})/(R_{green}+R_{red})$ increased almost linearly with VF (Fig. 2). As it was reported for wheat (Gitelson et al., 1999), for corn, the normalization of the reflectance difference $(R_{green}-R_{red})$ to the sum $(R_{green}+R_{red})$ led to a quite linear relationship between the index and percent vegetation cover. The behavior of the reflectance near 700 nm, R_{700}, versus VF was the same as was the case for R_{green}. Thus, the relationship $(R_{700}-R_{red})/(R_{700}+R_{red})$ vs. VF was almost the same as that of $(R_{green}-R_{red})/(R_{green}+R_{red})$. Both indices correlated closely with VF ($r^2 > 0.91$) with standard error of estimation less than 7%.
In an effort to reduce atmospheric effects, the indices using only visible data were modified as (Gitelson et al., 1999):

$VARI_{green} = (R_{green}-R_{red})/(R_{green}+R_{red}- R_{blue})$, and

$VARI_{700} = (R_{700}-1.7*R_{red}+0.7*R_{blue})/(R_{700}+2.3*R_{red}-1.3*R_{blue})$.

In both cases, the coefficients of determination (r^2) for the relationships between the vegetation indices and VF were higher than 0.95. In both cases, the error in VF estimation was less than 7% (Fig. 3).

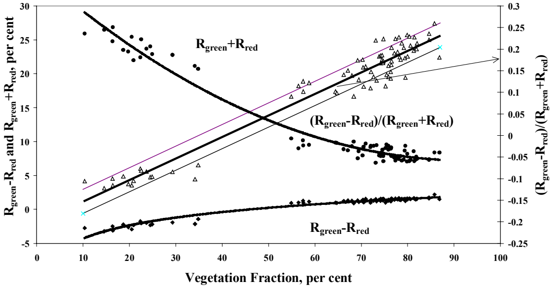


FIGURE 2. Sum and difference of the green and the red reflectance and vegetation index $(R_{green}-R_{red})/(R_{green}+R_{red})$ versus vegetation fraction.

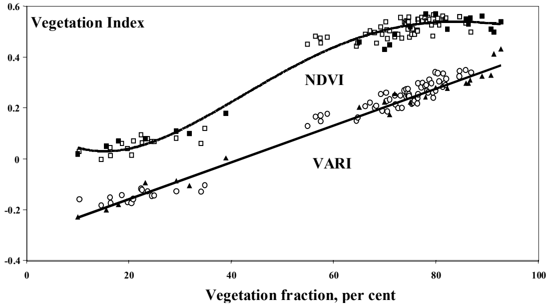
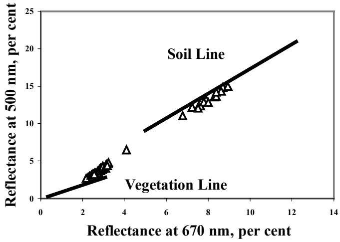


FIGURE 3. The Normalized Difference Vegetation Index and the $VARI_{green} = (R_{green}-R_{red})/(R_{green}+R_{red}-R_{blue})$ versus vegetation fraction for two corn data sets collected during the 1998 growing season.

Vegetation Line Technique

As it was found for wheat (Gitelson et al., 2000, Stark et al., 2000), for a closed corn canopy, the reflectances at 670 nm vs. 500 nm (R_{670}, R_{500}) and 550 nm vs. 700 nm (R_{550}, R_{700}) are confined to a line in two-dimensional spectral space. For closed canopies with a wide range of structures and pigment contents, both relationships (R_{700} vs. R_{550} and R_{670} vs. R_{500}) were linear with determination coefficients $r^2 > 0.92$. Thus, for a canopy (as it was found for green leaves, e.g., Gitelson and Merzlyak, 1996), "vegetation points" comprise, in reality, a "vegetation arc" or "line". Therefore, we can refer to this relationship as the "vegetation line." For soils, reflectances R_{670} and R_{500} as well as R_{700} and R_{550} correlated very closely, forming a "soil line". Vegetation and soil lines define a two-dimensional spectral construct within which canopy reflectance, regardless of vegetation fraction, may be located (Fig. 4).



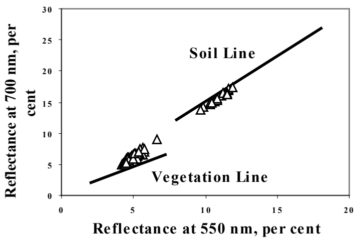


FIGURE 4. Reflectance R_{670} vs. R_{500} and R_{700} vs. R_{550} for corn with VF 0 to 92%.

When the VF is near zero, the plotted point is near or on the soil line. When the VF is near 100%, the plotted point is near or on the vegetation line. Thus, an increase in VF caused an orderly decrease in reflectance. The topology of this two-dimensional construct changes as vegetation brightness and soil color change. The position of a point within this construct with the same VF will also change as the vegetation brightness and soil color change. Thus, following Gitelson et al., 1999; Stark et al., 2000), we used the position of actually measured reflectance, as a measure of VF. Vegetation fraction retrieved from digital images was compared with VF predicted in coordinates R_{670} vs. R_{500}, and in coordinates R_{700} vs. R_{550}. The coefficient of determination, r^2, for both spectral spaces was higher than 0.9 and estimation error of VF prediction did not exceed 7% (Figure 5

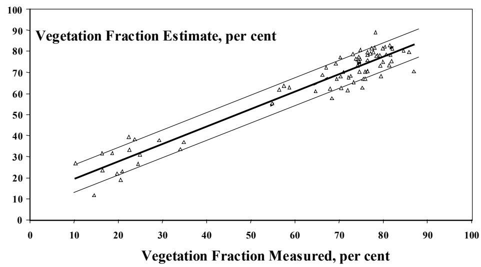


FIGURE 5. Vegetation fraction predicted versus measured in spectral space R_{670} vs. R_{500}

REFERENCES

Arsar, G, Fuchs, M, Kanemasu, E T, Hatfield, J L. (1984) Estimating absorbed photosynthetic radiation and leaf area index from spectral reflectance in wheat. *Agron. J.* 76:211-220.

Daughtry, C. S. T., Bauer, M. E., Crecelius, D. W., and Hixson, M. M. (1980) Effects of Management Practices on Reflectance of Spring Wheat Canopies. *Agron. J.* 72:1055-1060.

Derry, D. (2000) Monitoring Corn Development via Close-Range and Aerial Remote Sensing. Masters Thesis, Department of Geography, University of Nebraska Lincoln, 82 pages.

Gitelson A., Merzlyak, M N. (1996) Signature analysis of leaf reflectance spectra: algorithm development for remote sensing of chlorophyll. *J. Plant Physiol.* 148:494-500.

Gitelson, A., Stark, R., Kaufman, Y.J., Rundquist, D. (1999) A Technique for remote estimation of percent vegetation fraction, *Proceedings of the International Symposium on Spectral Sensing Research, Systems and Sensors for the New Millennium*, Int. Society Photogramm. & Remote Sensing, October 31–November 4, 1999, Las Vegas NV, pp.191-201.

Gitelson, A., Grits, U., Stark, R., Rundquist, D., Kaufman, Y.J. (2000) Novel algorithms for remote estimation of vegetation fraction. Proceedings of *The Second International on Geospatial Information in Agriculture and Forestry Conference*, pp. 1-8.

Holben, B N. (1986) Characteristics of maximum value composite images for temporal AVHRR data. *Int. J. Remote Sens*.7:1417-1437.

Huete, A R. (1988) A soil-adjusted vegetation index (SAVI). *Remote Sens. Environ*. 25:295-309.

Huete, A.R., Justice, C., Liu, H. (1994) Development of vegetation and soil indices for MODIS-EOS. *Remote Sens. Environ*. 49:224-234.

Kanemasu, E. T. (1974) Seasonal Canopy Reflectance Patterns of Wheat, Sorghum, and Soybean. *Remote Sens. Enivron*. 3:43-47.

Kaufman, Y. J. (1989) The atmospheric effect on remote sensing and its corrections. *Theory and Application of Optical Remote Sensing,* pp. 336-428. John Wiley & Sons, Inc., New York.

Kaufman, Y.J., Tanre, D. (1992) Atmospherically resistant vegetation index (ARVI) for EOS-MODIS. *IEEE Trans. Geoscience and Remote Sens.* 30:261-270.

Myneni, R.B., Hall, F.G., Sellers,P.S., Marshak, A.L., (1995) The interpretation of spectral vegetation indexes. *IEEE Trans. Geoscience and Remote Sens.* 33:481-486.

Myneni, R.B., Keeling, C.D., Tucker, C.J., Asrar, G., Nemani, R.R., (1997a) Increased plant growth in the northern high latitudes from 1981 to 1991. *Nature* 386:698-702.

Muneni, R.B., Nemani, R.R., Running, S.W. (1997b) Estimation of global leaf area index and absorbed par using radiative transfer models. *IEEE Trans. Geoscience and Remote Sens.* 35:1380-1393.

Sellers, P.J. (1985) Canopy reflectance, photosynthesis and transpiration. *Int. J. Remote Sens*. 6:1335-1372.

Sellers, P.J. (1987) Canopy reflectance, photosynthesis and transpiration. II. The role of biophysics in the linearity of their interdependence. *Remote Sens. Enivron*. 21:143-183.

Stark, R., Gitelson, A. (2000) Radiation regime in irrigated wheat. Proceedings of *The Second International on Geospatial Information in Agriculture and Forestry Conference,* pp. 89-96.

Stark, R., Gitelson, A., Grits, U., Rundquist, D., Kaufman, Y.J. (2000) New Technique for Remote Estimation of vegetation fraction: principles, algorithms and validation. *Aspects of Applied Biology,* 60: 241-246.

Tucker, J.C., (1979) Red and photographic infrared linear combination for monitoring vegetation. *Remote Sens. Enivron*. 8:127-150.