Spectral Data Analysis for Cotton Growth Monitoring

L. Toulios, M. Toulios and G. Zerva
National Agricultural Research Foundation (NAGREF)
Institute of Soil Classification and Mapping, 1 Theofrastou str., 413 35 Larissa, Greece

ABSTRACT

Since information technology was introduced in agriculture, there has been a great deal of interest in estimating terrestrial biophysical parameters such as vegetation with remotely sensed data. The empirical study presented in this paper focuses on the relationships between vegetation properties and reflectance measured on a cotton canopy throughout its phenological evolution by means of a hand-held spectroradiometer, during a field experiment. The objective was to produce relationships between spectral indices (such as normalized difference vegetation index (NDVI)) and biophysical parameters, such as leaf area index (LAI) and biomass that should be useful for cotton studies from remotely sensed data. The NDVI and the other spectral transformations were found useful to describe some phenological stages for a cotton canopy, because of the statistically significantly correlation with biophysical parameters such as LAI and biomass. Coefficients of determination (r^2) for the various relationships ranged in statistically significant levels (0.82-0.96) with leaf area index and better estimation of biomass from vegetation indices by exponential equations. The results show that estimated crop values agree well with field observations and there is a potential in applying this approach on an operational basis in practice with multitemporal remote sensing data.

Introduction

In agricultural planning and policy making in the European Union, knowledge of crop production at an early stage is very important at both national and regional levels. The two constituents of crop production are crop acreage and crop yield. Better estimates of crop yield and total biomass production are obtained if the growth of the crops is monitored during the season.

Remote sensing can provide information on the actual status of agricultural crops, thus calibrating the growth models for actual growing conditions (Maas, 1988; Bouman, 1991). Best results are obtained by using optical remote sensing data in estimating leaf area index (LAI) regularly during the growing season and subsequently calibrating the growth model based on periodic LAI estimates (Clevers *et al.*, 1994).

The interpretation of the radiometric information gathered on vegetation is mainly based on the spectral variation observed among the small number of broad wavelength bands of current satellites such as SPOT, Landsat TM, or NOAA AVHRR. Although some sensors have other spectral bands than the red and the near-infrared, most of the studies are limited to the use of these two wavebands because they exist in all satellite-borne optical sensors. Red and near-infrared also provide a high contrast between soil and vegetation optical properties that is used to evaluate the amount of vegetation (Richardson and Wiegang 1977; Toulios and Silleos, 1994; Toulios *et al.*, 1990; Toulios *et al.*, 1998; Tucker, 1979). Reflected red radiation is negatively correlated with chlorophyll concentration and thus to green leaf area, whereas reflected near-infrared radiation is positively correlated with the amount of multiple scattering at the interfaces between cells and the air, and therefore also to leaf area (Knipling, 1970).

There has been a great deal of interest in the estimation of vegetation properties via remote sensing. Several approaches have been made in relating remotely sensed data to LAI and biomass in the past (Asrar *et al.*, 1985; Clevers, 1989; Price, 1993; Qi *et al.*, 1995). The simple regression approach is based on the fact that the reflectance in the red spectral region decreases while that in the near-infrared (NIR) region increases when the vegetation density increases. By simple multiband regression to ground LAI measurements, a relationship between LAI and surface reflectance can be established that can be used in LAI estimation with remote sensing data. There are several limitations in using this to estimate LAI values. Many LAI measurements are needed at the same site and same time, the established reflectance-LAI relationship is vegetation type dependent and the approach is very vulnerable to measurement noise such as soil substrate effect, atmospheric effect and especially bidirectional properties of the vegetation.

To overcome these limitations, more than a dozen vegetation indices (VI) have been developed by linearly combining or rationing reflectance in the red and in the NIR spectral regions. The most commonly used VI is the normalized difference vegetation index (NDVI). Most VIs are qualitatively related to the vegetation amount (LAI, % cover, dry biomass) and have been used as an indicator of vegetation growth

(Tucker, 1979; Clevers, 1989; Malingreau *et al.*, 1989; Baret and Guyot, 1991; Wiegand *et al.*, 1991).

This study focused on the establishment of relationships between vegetation properties and reflectance of cotton, one of the most important crops worldwide and especially in Greece, to help its growth monitoring.

Material and Methods

The Experiment

A cotton experiment was conducted at Palamas, in Thessalia region in 1997, in a field of variety Zeta-2 grown in east-west row direction spaced at 0.95 m., to address these issues. This area was selected as one of the most important for cotton farming with more than 1.5 million stremmas planted to this crop each year.

The crop was grown on a clay-loam texture soil, with zero calcium carbonate content (0% at all depth), with an organic matter content around 1.7% that decreased at a greater depths. This soil type dominates the area. Cotton was seeded on April the 23th and sprinkler irrigated. The crop reached the bud formation stage in mid June and the flowering stage in early July. Crop setting occurred during July and ripening during September. The harvesting date was October the 6th.

Spectral Reflectance Measurements

Spectral reflectances were collected on a weekly basis, on almost clear days at different times (from 9:30 a.m. to 13:30 p.m. local time), with a Cimel type spectroradiometer that has 3 spectral bands similar to the SPOT HRV sensors (Guyot *et al.*, 1984). The instrument is composed of a radiance head for ground sighting, an irradiance head for sky sighting and an electronic box for direct reading of the three-reflectance factors. A telescopic support was used in the field with the two heads fixed on the support to remain vertical and mounted on the boom of a mobile aerial tower. The wavelengths for the three radiometer bands were 0.50-0.59 ìm for band 1, 0.61-0.69 ìm for band 2 and 0.79-0.89 ìm for band 3 (Guyot *et al.*, 1984). Measurements were taken vertically from 2.0 m above the soil surface, with the sensor viewing an area 1.0 m in diameter for more than ten close locations over each of three replicated 1x1 m field plots. The 10 measurements were then combined to obtain an average reflectance of the cotton canopy. The data were calibrated with reference panel measurements. The reflectance of the bare soil was also measured to spectrally characterize the canopy background. Table 1 presents the date, the day of the year (DOY) and the phenological stage of cotton, when the reflectance measurements were acquired.

The wet and the dry biomass for each spectral measurement date was estimated by weighing all the plants from 1 m_2 in fresh and in dry condition. The plants, including roots, were taken to the laboratory where they were desiccated in ovens at 800º C for at least 48 hours until a constant weight was obtained. Shoots, leaves and other parts were separated on different trays. Soil water content was also calculated each measurement time by taking a soil sample to the laboratory.

Ground LAI Measurements

During the experiment, a total of 8 LAI measurements were taken under the cotton canopy of the previously spectrally measured plots in the same field. The LAI values were obtained by taking the average of three repeated measurements in each plot each time. The dates of LAI measurements are designated with (*) in Table 1.

The SunScan canopy analysis system (Delta-T Devices Ltd, 1996) was used for the LAI measurements. The Sunscan probe is a portable instrument for measuring the light levels of photosynthetically active radiation (PAR) in plant canopies. It can measure the interception of solar radiation by the canopy and make estimates of canopy leaf area index (LAI). Numerous readings to can be taken to determine the average level of PAR beneath the canopy or make linear transects of the PAR distribution within the canopy. The light sensitive "wand" of the probe is 1 meter long with 64 photodiodes equally spaced along its length. The probe handle contains batteries and electronics for converting the photodiode outputs into digital PAR readings that are sent to the Data collection terminal via a RS 232 link. The Beam fraction sensor (BFS) measures PAR light levels that are used to monitor the light incident on the canopy at the same time as measurements are made beneath it. The BFS incorporates two photodiodes, one of which can be shaded from direct solar light by the shade ring. This allows necessary separation of direct and diffuse components of PAR for the computation of LAI.

At the time of each measurement, the cotton field was uniform and the cotton cover (%) was visually estimated.

Results and Discussion

The reflectance spectra were used to calculate the normalized difference vegetation index (NDVI) and the soil-adjusted vegetation index (SAVI) according to the expressions:

NDVI=[band3-band2]/[band3+band2] (1)
and

SAVI={[band3-band2]/[band3+band2+L]}x(1+L),

where L= 0.5 (Huete, 1988) (2)

Vegetation indices are more appropriate to characterize the canopy on specific dates than are reflectance factors (bands) as they are less affected by the acquisition time. The two indices were highly correlated (r_2=0.99) possibly due to the fact that all the vegetation data had almost the same soil background brightness. Consequently, only NDVI values will be discussed. The evolution of the vegetation index values as a function of the DOY (Figure 1) shows the those values increasing until they reach a maximum around mid August and then decrease as the crop enters senescence.

Figures 2 and 3 present the cotton biomass values in fresh condition as well as the percentage of the crop cover values corresponding to each date of measurement (DOY). The fresh biomass reaches a maximum around early September (DOY 244), followed by a rapid decrease. In contrast, the dry biomass reaches the maximum value at almost the same time as the fresh biomass but the decrease is not as rapid. Crop cover corresponds to fresh biomass, peaking in early September with a rapid decrease during ripening.

Figure 4 shows the evolution of LAI according to the date of measurement. LAI maximum value (3.05) was measured on August the 4th, corresponding to maximum photosynthetic activity stage. There is a very regular decline in LAI during senescence.

Figure 5 shows the NDVI values estimated from expression 1 versus measured LAI. Data corresponding to the development and maximum photosynthetic activity stages of the plants are represented with a logarithmic line (pre-Lmax data), whereas the others corresponding to the ripening of vegetation are shown with a line parallel to LAI axis (post-Lmax data). There is an obvious tendency for the NDVI to reach a plateau at high LAI levels (LAI>3) that is reached in early August. The trend indicates a temporary saturation of reflectance that remains almost steady for a long time during the subsequent senescence. Several authors (Baret *et al.*, 1989; Wiegand *et al.*, 1991) have reported an asymptotic behaviour of other crops that corresponds to a typical hysterisis phenomenon. The expression of this behaviour in cotton requires further study. This empirical approach depends on the phenological stage of the crop and identifies two growth periods of cotton, the pre-maximum-LAI and post-maximum-LAI periods.

The relation between NDVI and LAI (Figure 6) has been approximated by the exponential equation $y=0{,}0153e^{6{,}258x}$, where x refers to NDVI and y to the leaf area index. The coefficient of determination was $r^2=0.92$. The random-sampling schemes for LAI and NDVI measurements in cotton data might be the major cause for variations in the measured values. The 'noise' in reflectance measurements certainly influenced the prediction of the vegetation optical properties and, consequently, NDVI calculation. Both NDVI and LAI measurements, however, were shown to be dependent on the stage of the vegetative growth, the denser the canopy the larger the NDVI and LAI values.

A study of NDVI values versus biomass shows that both fresh and dry biomass are correlated to the NDVI values ($r^2=0.94$ and $r^2=0.96$, respectively) (Figures 7). This very good agreement was found between LAI and NDVI field measurements for other crops (Baret *et al.*,1989; Wiegand *et al.*,1991).

The relationship between crop cover percentage and LAI was very strong. The coefficient of determination reached 0.82 with the exponential approximation. The major cause for variations in the measured values is in the human (visual) estimation of crop cover.

The crop monitoring approach requires multitemporal remote sensing measurements. Since satellite remote sensors normally can provide multitemporal measurements over the same pixel or target, there is no limitation to extending this approach to operational vegetation monitoring. Within the multitemporal measurement period, a time window (e.g., 1-week) may be located when the vegetative growth is not fast enough to change its spectral properties substantially. The multitemporal data collected at this time may, therefore, be treated as if they were collected at the same time. This is very promising with the cotton experiment data. Another alternative may be to use data acquired with multiple sensors that is possible from a practical point of view. However, when using data collected with different sensors, differences in spectral resolution, spatial scales, and radiometric calibration should be taken into account.

Although this approach can potentially be used on an operational model to predict LAI and biomass with satellite remote sensing data such as those acquired with current or future sensors, the atmospheric effect must be sufficiently corrected, because the atmosphere can introduce substantial noise, resulting in errors in estimation of vegetation optical properties and, consequently, the LAI and biomass. To adapt this approach for operational uses, it may be necessary to incorporate an atmospheric model in this approach or perform atmospheric corrections before applications.

The accuracy of predicting LAI and biomass with this approach would certainly be dependent on the accuracy of the models that must be developed. Different models should be evaluated. Models that require fewer input parameters but result in good accuracy are preferred and should be identified. Application to other vegetation parameter and types of vegetation needs further investigation.

Conclusions

The establishment of relationships between VI and LAI, and VI and biomass that must follow the crop through all phenological stages is necessary for spectral data for crop growth monitoring to be used in estimating crop values such as leaf area index and biomass. Vegetation index values must first be calibrated to ground measurement values to fit a curve.

This curve can then be used in estimating LAI values with remote sensing data. The advantage of this approach is its simplicity while the disadvantage is the need of multitemporal remote sensing data.

This study proves that the relationships of spectral data with crop parameters such as LAI and biomass are very strong and can be used for the management of crop development. The results can also be used for the collection of the optimum time periods for satellite data acquisition. The development of models for LAI estimation and yield prediction is the next step.

However, at national and regional levels, for example in Europe, frequent cloud cover hampers the regular acquisition of optical remote sensing data. Fortunately, this does not apply to Mediterranean countries where cotton is cultivated so remote-sensing techniques can be applied to monitor crop cycles.

Acknowledgement

This work was carried out within the context of the project ‘Agrometeorological Models for Crop Yield Prediction’ funded by the Ministry of Agriculture, with the support of the European Commission. We would like to acknowledge the scientific team of the project ‘Estimation of Fields Crops Water Requirements’ also funded by the Ministry of Agriculture, for providing the LAI data.

References

Asrar, G., E.R. Kanemasu and M. Yoshida. (1985): Estimates of leaf area index from spectral reflectance of wheat under different cultural practices and solar angle, Remote Sens. Environ. 17:1-11.

Baret, F., G. Guyot and D.J. Major. (1989): Crop biomass evaluation using radiometric measurements. Photogrammetria. 43:241-256.

Baret, F. and G. Guyot. (1991): Potentials and limits of vegetation indices for LAI and APAR assessment. Remote Sens. Environ.35:161-173.

Bouman, B.A.M. (1991): Linking X-band radar backscattering and optical reflectance with crop growth models. Ph.D. Thesis, Wageningen Agricultural University, Wageningen, The Netherlands.

Clevers, J.G.P.W. (1989): The application of a weighted Infrared-Red vegetation index for estimating leaf area index. Remote Sens. Environ. 29:25-37.

Clevers, J.G.P.W., C. Buker, H.J.C. van Leeuwen and B.A.M. Bouman. (1994): A framework for monitoring crop growth by combining directional and spectral remote sensing information. Remote Sens. Environ. 50:161-170.

Delta-T Devices Ltd. (1996): Sunscan Canopy analysis system version 1.05. User Manual SS1-UM-1.05, England, UK

Guyot, G., J.F. Hanocq, J.P. Buis and G. Saint. (1984): Mise au point d' un radiometre de simulation de SPOT (Study of a spot simulation radiometer). 11e Coll. Int Signatures spectales d' objects en teledetection. Les Colloques de l' INRA. 23,P.I. 17, 233-242.

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

Knipling, E.B. (197O): Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation, Remote Sens. Environ.1:155-159.

Maas, S.J. (1988): Use of remotely sensed information in agricultural crop growth models, Ecol. Model. 41:247-268.

Malingreau, J.P., C.J. Tucker and N. Laporte. (1989): AVHRR for monitoring global tropical deforestation, Int.J. Remote Sens. 10:855-867.

Price, J.C. (1993): Estimating leaf area index from satellite data, IEEE Trans. Geosci. Remote Sens. 31(3):727-734.

Qi, J., F. Cabot., M.S. Moran and G. Dedieu. (1995): Biophysical parameter estimations using multidirectional spectral measurements. Remote Sens. Environ. 54:71-83.

Richardson, A.J. and C.L. Wiegang. (1977): Distinguishing vegetation from soil background information. Photogram. Eng. Remote Sens. 43:1541-1552.

Toulios, L.G., N.J. Yassoglou and M. Moutsoulas. (1990): Land use mapping in West Messinia, Greece, using satellite imagery. Int. J. Remote Sens. 11(9):1645-1661.

Toulios, L. and N. Silleos. (1994): Diachronic study of crop spectral response in Central Greece. In: Proc. Intl. Symp. Spectral Sensing Research (ISSSR'94): Volume II. San Diego, California, USA. Pp. 821-835.

Toulios, L.G., M.G. Toulios and E. Lipimenou. (1998): Soil Color Relationships with reflectance spectra. Geocarto International. 13(2) (in press).

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

Wiegand, C.L., A.J. Richardson, D.E. Escobar and A.H. Gerbermann. (1991): Vegetation indices in crop assessments. Remote Sens. Environ.35:105-119.

Table 1. The date, the day of the year (DOY) and the phenological stage of the cotton, during the reflectance measurements.

Date	DOY	Phenological Stage
19 May	132	2-leaf stage
26 May	139	4-leaf stage
2 June	146	6-leaf stage
9 June	153	8-leaf stage
17 June*	161	vegetative stage
23 June	167	vegetative stage
30 June*	174	bud formation
7 July*	181	bud formation
16 July	190	flower opening
21 July	195	flower opening
28 July	202	flower opening

Date	DOY	Phenological Stage
4 August*	209	yield formation
11 August*	216	yield formation
19 August	224	yield formation
25 August*	230	yield formation
1 September	237	ripening
8 September*	244	ripening
15 September*	251	ripening
23 September	259	ripening
29 September	265	ripening
6 October	272	harvesting

Figure 1. NDVI values evolution during cotton growth according to the day of the year (DOY).

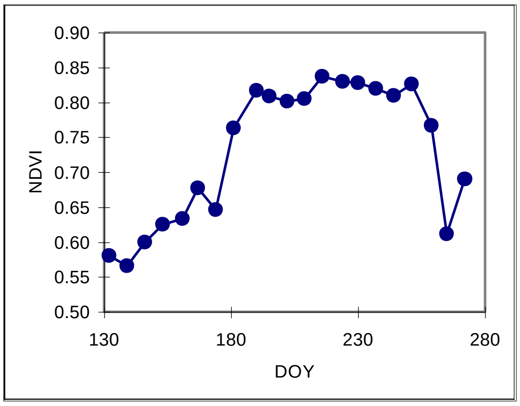

Figure 2. Temporal variation of fresh biomass of cotton as a function of the day of the year (DOY).

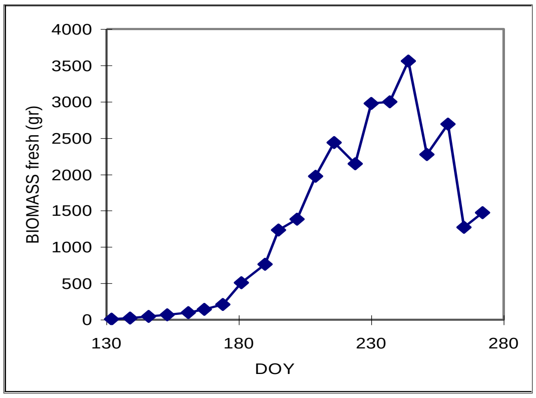

Figure 3. Temporal variation of the estimated crop cover percentage during the growing time of cotton (DOY).

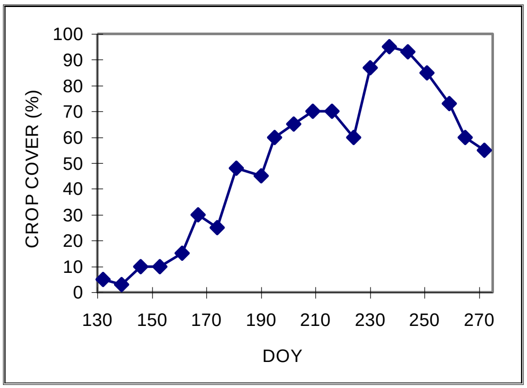

Figure 4. LAI values measured as a function of day of the year (DOY).

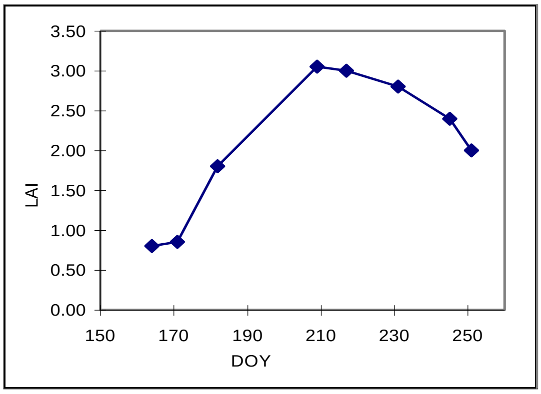

Figure 5. NDVI values versus LAI values. Two LAI periods are identified. One pre-maximum LAI and one post-maximum LAI period.

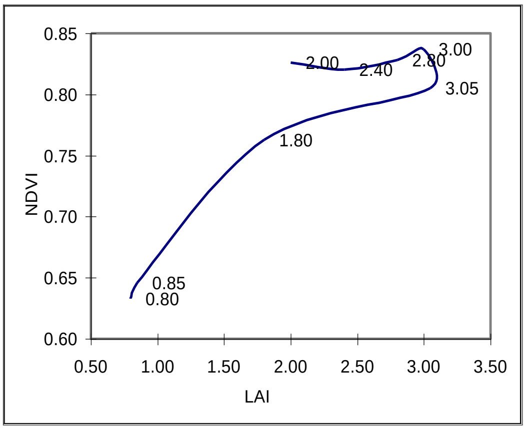

Figure 6. LAI values versus NDVI values. The exponential curve with the approximated equation and the coefficient of determination are also presented.

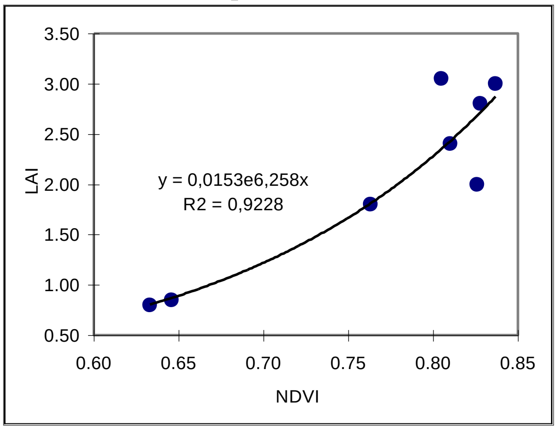

Figure 7. NDVI values versus biomass dry values during the phenological cycle of cotton. The fitted logarithmic curve and the statistics are also presented.