CROP GROWTH AND YIELD PREDICTION USING CANOPY REFLECTANCE - A REVIEW

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ABSTRACT

The reflecting power of crop canopy gets changed with plant species. The reflection from leaves increases with increasing soil salinity, leaf moisture deficit and chlorophyll content. Environmental factors such as soil salinity, moisture availability and nutrient toxicity or its deficiency affects the optical and radiation properties of plants. The reflection in the red spectral region from plant leaves is dependent on the chlorophyll content and in the near infra red spectral region it is dependent on Leaf Area Index and green biomass only. The reflectance increases with senescing of leaves and reduction in chlorophyll content. Pre-harvest estimation of crop yields are important in planning procurement, distribution, import and export of agricultural commodities. The canopy albedo measurements are adequate to delineate the critical periods of crop growth making the technique potentially adoptable to predict crop yield.

Precision agriculture is a recently developed crop management technique, which requires an understanding of spectral variability of crop yields and the causes. Yield maps are the basis of making precision management decisions. Through accumulated yield maps during the past seasons, maps for field management can be produced.

Light absorptance by leaves in the visible region of the spectrum depends primarily on the concentration of the chlorophyll and carotenoids. Ordinary green leaves absorb 75 to 90 per cent of the light in the blue (about 450nm) or red (about 625nm) part of the spectrum. Absorptance is smallest in the wavelength region around 550nm, where the reflectance peak is usually less than 20 per cent (Thomas and Oerther, 1971). Benedict and Swidler (1961) reported an inverse relationship between reflectance and the chlorophyll content of soybean (Glycine max (L)) and citrus leaves showed that reflectance measurements could be used to follow a change in chlorophyll concentration.

The deficiency of any one of several nutrient elements decrease pigment formation and subsequent leaf colour, limiting these elements would increase reflectivity because of decreased radiation absorption. Reflectance in the near infra red portion of the spectrum is primarily depending on the water content and internal structure of the leaves. Reflectance in the visible portion of the spectrum (500 to 700nm) increased as nitrogen deficiency symptoms became more pronounced. Light absorption in this region depends primarily on pigment concentration, limiting N apparently reduced the concentration of chlorophyll and carotenoids and thereby decreased radiation absorption (Thomas and Oerther, 1971). Thomas et al., (1967) found that cotton leaf reflectance at 550nm wavelength decreased from 11.9 to 12.5 per cent as turgidity decreased from 80 to 60 per cent.

Red and photographic infrared reflectance and linear combinations of these bands are correlated with the photosynthetic active portions of plant canopies for various cover types (Tucker et al., 1979). Near infra red analysis (NIRA) is a well established rapid spectroscopic method of analysis, especially to agricultural and food products (Shenk et al., 1992). The reliability in NIRA method as an analytical tool has been established for total nitrogen determination in leaves of potato, sugarcane by Meyer, (1997) and Batten and Blakeney, (1996). Leaf blade nitrogen concentration provides a better measure of the plants nitrogen status than the petiole method (Gerik et al., 1994).
Spectral properties of crop:

Crop canopy reflectance: The reflecting power of canopy gets changed with the plant species. Under field condition, the reflecting power was determined by foliage density, plant height, growth habit, plant vigour, and its maturity. Environmental factors such as soil salinity, moisture availability and nutrient toxicity or its deficiency affected the optical and radiation properties of plants. Remote sensing of energy reflected or emitted from plant canopy offered a possible mean for determining crop species, its maturity, vigour, disease incidence and probable yield to be obtained (Thomas et al., 1967).

The reflectance from leaves increases with increase in soil salinity, leaf moisture deficit and chlorophyll content since, the same plant and soil factors affected the yield in cotton. The regression equation developed between reflectance and yield accounted for 51 to 71 per cent of the variation in yield (Mass, 1997).

Gausman et al., (1969) reported that osmotic stress caused a slight decrease in reflectance and a greater increase in transmittance of cotton plants. Young cotton leaves have lower reflectance than matured leaves in the near infrared region.

Abbas et al., (1974) reported that the characteristics of plant spectral reflectance and transmittance were the function of leaf geometry, morphology, physiology, and biochemistry of the plants. They were also influenced by soil and climatic condition and nutrient status. Excess or deficiency of an essential element might cause visible abnormalities in pigmentation, size, and shape of leaves and thus led to appearance of various other symptoms.

Leamer et al., (1978) reported that the proportion of the ground, covered by plants was more important than developmental stages of the plants in determining spectral responses except at the end of the season when the plants got senesced and lost pigmentation. Kollenkark et al., (1982) indicated that cultural practices produced differences in soil cover and leaf area index which in turn manifested in the spectral reflectance characteristics of crop canopies.

Jackson and Pinter (1986) reported that during the period of peak green leaf area index, the ratio of infrared/red reflectance for the erectophile canopy was about 30 per cent higher than for the planophile canopy. The red reflectance values were higher at the beginning and at the growing season than in the middle when the visible radiation absorbing pigments were at a maximum (Lord et al., 1988).

Gupta and Krishna Rao (1989) reported that in red spectral region, the reflectance from plant leaves was dependant on the chlorophyll content while in near infrared spectral region the reflectance was primarily related to Leaf Area Index (LAI) and green biomass only.

Spectral reflectance in different bands:
Mostly in all the crops the reflectance in red region decreases, whereas increase in infrared region as the crops grew up to a certain stage. This was because of the chlorophyll concentrations and green leaf biomass which increased with plant growth, absorbed more radiation in red regions, and reflected more in near infrared region of the spectrum. At maturity stage, the vegetation got senesced, in the near infrared, reflectance tended to decrease while the breakdown of leaf pigments caused a rise in red reflectance (Sanger, 1971).

Hinzman et al., (1986) reported that the crop deficient in nitrogen showed greater reflectance in the visible and middle infrared wavelengths and lower reflectance in the near infrared wavelength than those with adequate or high nitrogen fertility.

In cotton green, red and infrared reflectance are closely related to the agronomic and physiological properties of the plant such as plant height, crop cover percentage, green...
leaf biomass, and chlorophyll content. Further the green/red ratio seemed to be ineffective for vegetation discrimination, (Hamdi et al., 1991).

**Nutrient assessment:** The leaf chlorophyll concentration was associated with reflectance ratios. Leaf reflectance can be used for real time monitoring of cotton plant N status and N fertilizer management and also reported that, improved ratios for two band reflectance and algorithms are needed to estimate leaf N in cotton (Zhao et al., 2005). The feasibility of using leaf N concentrations monitored by near infrared analysis as guide for N fertilization was reported by Saraga et al., (1998).

The different temporal spectral responses under fertilized and nutrient deficient plots can be used for detecting nutrient stress in maize and also studied the normalized difference between the first derivatives at 525 and 570 nm, as well as the red edges which showed a strong association with chlorophyll content. Spectral reflectance measurements hold promise for on the assessment the effect of N stress and water stress at the leaf level. (Mahey et al., 1990).

**Crop condition assessment:**

**Crop growth and Stage:** Badhwar and Henderson (1981) concluded that spectral data could be used as an input for crop development model to predict the developmental age of corn with an accuracy of 96.4 per cent. Richardson et al., (1982) reported that the vegetation indices worked out from spectral data are of use to monitor seasonal development of sorghum crop. The relationship between spectral response and soil cover, LAI, biomass and plant water content which demonstrated the potential of multispectral remote sensing to monitor crop growth and its condition and also showed the use of remote sensing data to obtain an estimate of the solar radiation intercepted by canopies and dry matter accumulation (Doughty et al., 1983).

Asrar et al., (1985) estimated the ground phytomass value of wheat from spectral measurements and found a strong correlation between observed and estimated values. Major et al., (1986) reported the ability of canopy reflectance to provide accurate and non-destructive estimate of LAI for growth analysis. However, due to complex association between leaf area and biomass a single measurement of canopy reflectance could not be used to estimate biomass or final grain yield.

Tara Sharma and Navalgund (1989) estimated the growth stages of wheat from agrometeorological model using spectral reflectance data as an input. Mass (1998) indicated that cotton canopy ground cover could be accurately estimated from reflectance in the red and near infrared wave bands using simple equation derived from linear mixture modelling. Further it would be particularly useful in application where other field information such as plant size, row spacing and orientation was unavailable.

**Leaf area index:** Field measurement of green leaf area index was tedious and time consuming, and it was sample dependent and subjected to sampling bias. An overall LAI estimate was difficult by non-destructive method. The reflectance measurements in the visible and near infrared regions of electromagnetic spectrum were indicators of the amount of vegetation present. Hatfield et al., (1983) compared several spectral reflectance transformations and confirmed that LAI of wheat could be estimated best from a ratio of near infrared (NIR) to red (R) reflectance and also suggested the possibility that reflectance measurements might substitute the tedious and labour involved measurements like leaf dry matter and leaf area measurements based on the relationship between green leaf dry matter and IR/R ratio. Combination of NIR and red reflectance was defined as normalized vegetation index (NDVI), and it was used by Asrar et al., (1984) to predict the LAI of wheat.
King et al., (1986) reported that reflectance measurements had the potential advantage to estimate herbage mass and LAI of rye grass. Rao et al., (1987) observed significant correlation between LAI and ratio of IR/R reflectance of maize crop. Redelf et al., (1987) postulated that the relationship between greenness and LAI was general to several crops and not crop specific.

The spectral component analysis did provide additional analytical tool for characterizing and assessing crop development, growth and yield (Wiegand and Richardson 1990). Price (1992) observed a direct relationship between crop reflectance and well defined vegetation parameters from which LAI was estimated. Subba Rao and Sastri (1992) reported that vegetative index could be used to predict LAI in mustard crop under stressed and non stressed conditions.

Patel et al., (1995) used the spectral re-vegetation indices like normalized difference vegetation indices (NDVI) and IR/R ratio to predict the LAI and found a highly significant result to define the variation upto 90 per cent. Niwas and Satri (1995) showed that LAI could be estimated by using regression equations from spectral indices. Qi et al., (1995) reported that estimated LAI values agreed well with field observations and there was a potential for applying multitemporal remote sensing data on an operational basis. Niwas and Satri (1995) also reported estimation of LAI using normalized difference vegetation indices (NDVI).

Ghosh et al., (2003) stated that leaf area index can be estimated using vegetation index particularly Ratio Vegetation Index to predict LAI at earlier stage and normalized difference vegetation indices (NDVI) at later phase of crop growth. Samui et al., (2003) reported that LAI can be estimated using vegetation indices.

**Leaf chlorophyll content:** The reflectance spectrum of vegetation is the visible region of the spectrum and manifestation of the light absorption. The pigments making the greatest contribution to light absorption in this region are those which were intimately involved in photosynthesis namely chlorophyll ‘a’ and carotenoids. The reflectance increased with senescing of leaves and reduction in chlorophyll content. For most of the crops, chlorophyll was the most important independent factor affecting the reflectance of light. The canopy reflectance at 550 nm was a good indicator of chlorophyll and carotenoids concentration for different crops (Thomas and Gausman, 1977).

Nageswara Rao (1984) reported that whenever there was a stress, the leaf pigment system was more readily affected accompanied by changes in the internal leaf structure which ultimately leads to overall changes in the spectral response. The estimation of pigment concentration by using reflectance spectra of leaf extract was in good agreement with the concentration analyzed through chemical process (Chappelle et al., 1992). Curran et al., (1992) observed a significant correlation between reflectance and the concentration of chlorophyll, starch, sugar, protein, amaranthine and water.

**Plant nitrogen content:** Nitrogen is one among the main limiting factors in crop production. An improvement in the ability to measure plant nutrient content could lead to an upgrading of yield forecast. Current results from research indicate the feasibility of using aircraft or satellite for in the monitoring of crops. For such works, ground based information is warranted to demonstrate the reliability of such remotely sensed data.

Reflectance spectra of nitrogen deficient leaves were similar to those of normal leaves, but percentage reflecting power differed depending on the severity of nitrogen deficiency (Myer, 1970). The change in nitrogen concentration of sweet pepper from five per cent to four per cent was detectable through reflectance measurements (Thomas and Oerther 1972). The major cause
of altered spectral response from nitrogen deficient wheat was due to differences in total biomass (Stanhill et al., 1972).

Walburg et al., (1982) indicated that changes in canopies due to nitrogen treatment resulted in detectable reflectance variations which demonstrated the potential for detecting crop stress by use of multispectral remote sensing. Richardson et al., (1983) used red and near infrared measurements to compute vegetation indices to correlate nitrogen content of Alicia grass.

Ajai et al., (1984) reported much lower values of IR/R Reflectance ratio and the normalized difference vegetation index (NDVI) for nitrogen deficient wheat crop as compared to that of nitrogen fertilized crop over the complete growth cycle. In rice, a decrease in the peak of the temporal and spectral profile with reduced level of nitrogen supply was observed (Panigrahy et al., 1986) and fertilized and nutrient deficit plots of maize (Mohey et al., 1990). Mani et al., (1992) confirmed the effectiveness of the use of remote sensing methods to determine the nitrogen content of potato crop. A strong correlation between light reflectance and nitrogen content of maize indicated the possibility of assessing crop nitrogen requirement status (Blackmer et al., 1994).

Blackmer et al., (1996) reported around 550 nm and 710 nm for best detection of nitrogen deficiency using reflected short wave radiation in corn. Ma et al., (1996) suggested light reflectance measurements predicting grain yield and reflected light for in-season indication of nitrogen deficiency. Sanaga et al., (1998) reported that near infrared analysis could safely be used for on the spot decision making in respect of fertilizer nitrogen application in cotton. This information could be used to prevent excessive nitrogen application for the benefit of farmer's revenue and the environment.

**Yield determination**: Pre harvest estimates of crop yields are important in planning procurement, distribution, import, and export of agricultural commodities. Present methods of forecasting yield are inadequate. From remote sensing data, it is possible to make a quick assessment of yield and to provide timely and accurate yield forecast for very large areas.

The canopy albedo measurements appeared adequate to delineate the critical periods of crop growth, making the technique potentially adaptable to predict crop yield. Aase and Siddoway (1981) reported a strong relationship between normalized vegetation index and total wheat dry matter. This clearly established the potential of remote sensing for predicting total dry matter.

The relationship between canopy spectral data and degree of senescence would be of potential use to assess the crop yield and also indicated that remotely sensed canopy temperature based Crop Water Stress Index (CWSI) and Stress Degree Days (SDD) could be used to predict the wheat grain yield and biological yields (Nageswara Rao et al., 1985). Rudorf and Bastista (1990) arrived at an agro-meteorological spectral models to estimate sugarcane yield.

Medhavy et al., (1995) precisely estimated the wheat yield of Punjab, using normalized difference vegetation indices (NDVI) derived from satellite data and historical yield trend. Singh and Ibrahim (1996) reported that reliable forecast of wheat yield with standard error less than five per cent could be done by using spectral data collected after two or three months of sowing. Ray et al., (1999) estimated the lint yield of cotton from remotely sensed spectral profile which differed by around 13 per cent from ground estimate Surendre Nagar district of Gujarat.

The cotton seed yield can be predicted during vegetative stage i.e., 2.5 – 3.5 months before harvest using spectral data (Shamim Ansari et al., 1999). Singh et al., (2001) reported that greenness vegetation index was the best index for yield estimation. Chang et al., (2005) stated
that the derived regression equations successfully predicted rice yield using canopy reflectance measured at booting stage. Singh et al., (1996) found that Markov chain model predicted yield using satellite data which can be used for crop yield forecast.

Ravi et al., (1992) proposed that district wide rice yield can be estimated using satellite data by deriving vegetation indices. Medhavy et al., (1995) suggested that wheat yield model had been developed based on vegetation index and better prediction of yield can be done using the vegetation indices. Mukherjee et al., (2004) stated that fruit yield can be predicted using spectral and hyper spectral indices. Berardo (1997) reported that quality parameters of white clover can be studied using spectral reflectance.

Daughtry et al., (1995) concluded that reflectance technique did provide a method to discriminate crop residues from many agricultural soils and could be used to quantify crop residue cover. Dubey et al., (1996) indicated that the healthy and diseased plants of banana, grapes, brinjal, and tomato crops could be better distinguished through their vegetation indices rather than their simple reflectance values in red and NIR region. Gupta et al., (1989) reported a linear relationship between the surface temperature of the wheat cropped area and NDVI values when the crop cover was more than 70 per cent.

Benchalli and Prajapathi (1998) showed the possibility of using satellite data to assess the growing stock from time to time for effective management of the resources and monitor the changes in the biomass. Prasad et al., (1999) suggested the possibility of monitoring forest fire using Defense Meteorological Satellite Programme (DMSP) and Operational Linescan System (OLS), over central Himalayan region of India where extensive fire event had been reported during May/June month. Thus it is evident that through spectral reflectance studies and various vegetation indices, the crop growth parameters and nutrient content of crop and moisture stress could be estimated. Based on the area estimation and conditions of the crop growth, yield forecasting for many crops is possible.

REFERENCES