Use of Near-Infrared video for Localizing Nitrogen Stress in Peach Orchards

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Summary. Computer analysis of airborne, broad-band, near-infrared (NIR, 710 to 1100 nm) video imagery of peach tree canopies was used to determine spatial variability of cumulative stress in two peach orchards. A significant quadratic correlation was found between leaf-N content and the normalized mean pixel intensity (MPI) of the digital imagery of NIR canopy reflectance. This correlation was used to establish MPI estimates of N-stressed trees in the orchard. The relationship was used to localize site-specific spatial variability in a commercial peach orchard. The underlying soil type was found to be closely associated with the spatial variability in NIR imagery in the commercial peach orchard. Assessing spatial variability in the orchard with NIR video permits early localization of potentially low productivity regions within an orchard.

Many attempts have been made to use remotely sensed NIR images to assess productivity of fruit trees. However, only limited success has been achieved using satellite based images. Gordon and Philipson (1986) and Trolier et al. (1989) were unable to reliably detect and classify orchards or vineyards on Long Island, N.Y., with Landsat TM data due to the lack of image resolution and interference from background reflectance. SPOT (SPOT Image Corp., Reston, Va.) satellite imagery

(wavebands 2 and 3) was successfully used by Williamson (1989) in South Australia to broadly classify orchards as either irrigated or nonirrigated. However, the SPOT images did not have sufficient sensitivity to allow specific stress assessment within a given orchard.

In contrast, color-infrared photography has been used successfully for decades to localize and quantify pest and disease infestations in orchards (Blazquez and Horn, 1980; Payne et al., 1971). Recent improvements in video imaging systems such as the development of a color-infrared video camera (Meisner and Lindstrom, 1985), construction of false-color multispectral video systems (Nixon et al., 1987; Vlcek and Ring, 1985), and the ready availability of charge-coupled device (CCD), single-chip video cameras, has led to a number of agricultural applications of video technology (Everitt and Escobar, 1990 and references therein). Escobar and Villarreal (1990) reported that a single-chip CCD camera provides much the same information as multispectral systems at a much lower cost. An excellent review of video-imaging systems used in agriculture was recently prepared by Everitt et al. (1991).

Stutte et al. (1990) reported early detection of cumulative N stress in strawberry and peach canopies through the use of wide band NIR filters in conjunction with a CCD color video camera. Fouche and Booyen (1990) have used color video to evaluate stress status of citrus and avocado orchards in South Africa. Stutte (1991) reported the use of broad-band, single-channel NIR video images to localize N in orchards using classification techniques similar to those reported by Stutte et al. (1988) for assessing canopy stress in cotton, soybean, and rice.

In this study, NIR video imagery was used to localize and quantify spatial variability of cumulative stress development in mature peach orchards. We used foliar N content as an integrator of cumulative stress. The precision of the technique in assessing spatial variability was determined by comparing regression analyses of normalized digital video data of MPI from a test orchard against the leaf-N content of the tree canopies. In addition, the spatial variability of cumulative stress in peach orchards was also assessed through comparison with a "blind"

evaluation of a commercial peach orchard.

Imaging sites. Two orchards were used in this experiment. A 0.6 ha 5-year-old planting of *Prunus persica* L. Batsch 'Redhaven' on 'Lovell' rootstock at the Wye Research and Education Center (WREC), Queenstown, Md., was used to determine the relationship between NIR canopy reflectance and canopy N stress. The NIR reflectance from the peach canopy was inferred from analysis of the MPI of the digitized counts of the orchard. Disease-free, fruiting, irrigated trees with leaf N >3.5% were used as controls for data normalization. The planting of peach on Metapeake silty loam, pH 6.5, is a randomized complete-block evaluation of 10 ground-cover management systems with three 3-tree replicates of each treatment.

A mature, 15 ha, irrigated, commercial peach orchard in Caroline County, Md., was used to assess the accuracy of MPI of digitized images for NIR detecting spatial variability in the orchard. The orchard is located ≈40 km from the WREC and consists of nine cultivars (Early Redhaven, Slaybaugh Special, Tri-gem, Glohaven, Loring, Sunhigh, Red Alberta, and Rio-oso-gem).

Video acquisition and analysis equipment. Using a Panasonic Digital 5000 CCD color video camera with a 35- to 135-mm zoom lens set at 45 mm, vertical images were obtained from 1000 ft (300 m) from an airplane between 1000 and 1100 HR on a clear, haze free day (31 May 1990). The lens was equipped with a custom filter impregnated with Rohm and Haas FRF-700 dye that transmits only the wavelengths >710 nm. As a consequence, only far-red and NIR wavelengths were used. This filter was selected since it incorporated wavelengths associated with both NIR reflectance and the red-edge shift. The camera aperture and focus were manually controlled, and autogain was disabled. The resulting images were recorded on 0.5-inch VHS tape using a Panasonic AG2400 video tape recorder. All cables had gold plated tips to minimize signal loss.

Video images were digitized (256 × 256 pixels) using the Image Capture and Analysis System (ICAS) software and hardware in an IBM compatible 386 computer as previously described (Stutte and Stutte, 1988). MPI of

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individual trees was determined using the histogram function of the software before image enhancement. Following determination of pixel intensity, the images were equalized digitally and classified. The equalization process allowed the ready visualization of digital information obtained from the nonenhanced image.

Although a number of physiological, morphological, and environmental factors have been correlated with a change reflectance from the plant canopy, we considered light, wind, temperature, and moisture to be constant over the relatively short (<60 min) time associated with data acquisition since there was no signal enhancement associated with autogain. The MPI of canopy NIR imagery from the two orchards was normalized against the MPI of known, healthy control trees in the standardization ('Redhaven') orchard at the WREC by determining the difference between the MPIs. The difference in the MPI of the treatment and the standard was used to normalize data for a given acquisition period, and then was correlated with the stress level of the trees.

Stress Quantification. On 31 May, three samples of 10 recently mature leaves of 30 treatment trees were obtained from the 'Redhaven' orchard at the WREC. Total leaf N was determined with a Westcan N analyzer following micro-Kjeldahl digestion (Bowman et al., 1986). Canopy volume was determined within 2 weeks of imaging.

In this study, the MPI of digitized images of peach canopy reflectance was calibrated against the leaf-N content of known trees. By using trees of known stress level, such as the 'Redhaven' trees at the WREC, it is possible to normalize digital counts of the reflectance for a given set of environmental conditions. Leaf N is a desirable choice for calibration since it usually changes in response to any long-term stress, does not have daily fluctuations, and is readily obtainable by growers. Following calibration, leaf N was used as a physiological indicator of cumulative stress of the tree.

The images of the commercial orchard were digitized and analyzed before discussing the outcome with the manager $\approx$ 2 weeks after imaging. The unsupervised classification (using the normalization procedure developed from the experimental 'Redhaven'

orchard) was performed, and the resulting variability was discussed with the manager of the orchard.

High resolution, broad-band NIR video images can be obtained with a 710-nm cutoff filter on a CCD chip detector without autogain enhancement of the image. Obtaining image contrast is critical for the calibration (either in absolute or relative terms) of the video image with some known measure of stress (Stutte, 1990). Digitization of the video images produced a reasonable compromise between image detail, which increases the cv of the MPI in the canopy, and sample accuracy. Histogram analysis of individual tree canopies (40 to 128 pixels per canopy) was used to determine the MPI from the digitized image of NIR canopy reflectance.

Analysis of variance (ANOVA) of ground cover management systems revealed that the variability in both leaf-N content and MPI among the four replicates was greater than the variability among treatments. As a consequence, MPI of broad-band NIR reflectance could not be used reliably to target specific ground-cover treatments, despite a range of 35 MPI in canopy reflectance.

The inherent variability in the orchard was normalized against trees with leaf-N levels of 3.5 within the ground-cover block control trees. The control trees used for data normalization were characterized by a fully developed green canopy with leaf-N content of 3.5% dry weight. The transitional trees were characterized by a fully developed, but smaller canopy than the control trees. The low-N trees were smaller than either control or transitional trees, but typically had a fully developed canopy. There were no visible signs of severe stress (purple leaf margins, "shot holes") in the upper canopy. The difference in MPI of individual sample trees and controls was then regressed against leaf-N content of the sample tree. Regression analysis revealed a statistically significant quadratic relationship between leaf N and the difference in MPI ($r^2 = 0.66$, $n = 30$).

Although a highly significant statistical correlation existed between MPI and leaf-N content, it was not considered appropriate to use the relationship for quantitative purposes since leaf-N content is only one of a number of physiological and morpho-

logical factors that contribute to a decrease in canopy reflectance. However, the relationship could be used to classify the trees as low-N stress, transitional N, and high-N stress, based on the difference in MPI from the control in unenhanced digitized video images of NIR canopy-digital-count data (Fig. 1). ANOVA of N content and MPI of trees in each classification revealed highly significant differences between the low-N stress and high-N stress trees.

The MPI of nonenhanced broad-band NIR images obtained using this technique had a range of 35 pixel intensity units (range = 90 to 125) when the autogain disabled. This relatively narrow range is consistent with a previously described response of the effect of autogain on image contrast (Stutte, 1990).

Two phenomena must be recognized when interpreting the MPI of NIR imagery within each of the classifications. The first consideration is physiological. The change in canopy reflectance between nonstressed and stressed trees is on the order of 5 to 20 $\mu\text{W}/\text{cm}^2$ for a given wavelength in the NIR region. As a result, the contrast between the nonstressed and transient stress canopy images spans a limited range when autogain enhancement of the image is not used (Stutte, 1990). The second consideration is morphological. As the severity of stress increases and long-term effects of the stress accumulate, the absolute canopy volume was reduced (7.4 vs. 5.4 m^3), and the percentage of noncanopy (shoots, trunks, shadow soil) reflectance in the image increased. The noncanopy reflectance typically reduces MPI from five to seven intensity units.

The assessment of cumulative stress using broad-band NIR has some distinct management advantages as a supplemental technique for monitoring transient orchard stresses. Newell (1990) clearly demonstrated that significant cumulative stress effects (leaf N, canopy volume, shoot elongation, fruit size) were apparent in peaches under different cultural management systems, although short-term measures of canopy stress (canopy temperature, leafwater potential) and environmental stress (soil water potential) were not significantly different from controls through most of the season. Thus, site-specific variability in the orchard is detected more readily with NIR video

Fig. 1. Classification of stress severity in 'Redhaven' peach. The MPI of broad-band NIR (710 to 1100 nm) video imagery obtained from 330 m with autogain off was determined following ICAS digitization. The difference in MPI between treatment and control trees was correlated with leaf-N content.

imagery than with techniques designed to quantify transient-stress effects. A comparison of the relative strengths of reflectance-based vegetation indices were recently reviewed (Wiegand et al., 1991).

The reliability of the MPI of NIR canopy digital counts at localizing stress was evaluated following a "blind" classification of video imagery from the Caroline County orchard. For purposes of this analysis, light intensity, wind speed, and temperature were considered identical to those at the WREC, since the images were taken within 20 min of each other using the same camera settings. A review of the written and mental records of the orchard's owner indicated that the orchard consisted of seven cultivars from 9 to 11 years old. There were no statistically significant cultivar differences in MPI at this stage of development.

However, classification of the orchard as a whole unit revealed that about one-third of the area was transitional and the remainder low-N stress (Fig. 2a). The initial reaction of the grower was that he was not aware of obvious differences in tree performance in relation to the ICAS classified image. However, subsequent examination of records and individual trees revealed localized differences in canopy volume, fruit set, and tree vigor that were associated with the computer classifica-

tion of stress in the orchard. Spot sampling of soils in each of the regions suggested differences in soil type might contribute to the apparent stress of the trees classified as transitional.

The contrast in digital-count intensity between the transitional and low-N stress trees was increased by enhancement of the picture through equalization and an overlay of the soils of the site constructed (U.S. Dept. Agr., Soil Conservation Serv. 1964). This analysis suggested a strong empirical relationship between the relative stress level and the underlying soil type (Fig. 2b).

Generally speaking, trees planted on the Sassafras soil series (SsA and SmB) were classified as low-N stress and those on the Lakeland soil series (LaB and LaC) were classified as transitional. Following equalization, the spatial variability within each soil classification was apparent (Fig. 2b). Sassafras sandy loam (SsA) is a well-drained, fertile soil with a substratum of sandy clay or sandy clay loam. As a consequence, it has a higher water-holding capacity than the Sassafras loamy sand (SmB), which has a higher percentage of sand. However, both these soil series have higher water-holding capacities than the Lakeland loamy sand series that is characterized by excessively drained sandy soils with a clay substratum within 1 to 2 m of the

surface. (U.S. Dept. Agr., Soil Conservation Serv., 1964)

As a result of this work, it appears that NIR image acquisitions provide suitable information for localizing stress under commercial field conditions. The NIR sensitivity of the CCD detector (up to 1100 nm) permits the general classification of the orchard with respect to relative stress responses. Although sensitivity to small changes in stress levels is reduced when broad-band video filters are substituted for narrow-band filters (Stutte et al., 1990), the ability to dependably assess the spatial variability in NIR imagery associated with cumulative stress is increased. The correlation between the morphological and physiological manifestations of cumulative stress and the MPI of NIR imagery permits models to be developed as tools to increase the information available to make more efficient management decisions.

Further information on the cost and availability of the technology can be obtained by contacting either G.W.S. or Agri Imaging Systems, P.O. Box 560, Fayetteville, AR 72702.

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Fig. 2. (a) Localization of spatial variability in transitional (TR) and low-N stress (LS) regions using MPI of nonenhanced broad-band (710 to 1100 nm) NIR video imagery of canopy reflectance. (b) Relationship of the equalized digital image of broad-band (710 to 1100 nm) NIR canopy reflectance to orchard soil type (U.S. Dept. Agr., Soil Conservation Serv., 1964). The soil classifications are Sassafras sandy loam (SsA), Sassafras loamy sand (SmB), and lakeland loamy sands (LaB and LaC).

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