Technology & Product Reports

Evaluating Airborne Normalized Difference Vegetation Index Imagery for Citrus Orchard Surveys

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ADDITIONAL INDEX WORDS. airborne digital imagery, NDVI, south Texas, citriculture

SUMMARY. The normalized difference vegetation index (NDVI) provides relative estimates of vegetation vigor, density, and health. Little information is available on the application of NDVI imagery for citriculture. The

We thank Rene Davis and Fred Gomez for image acquisition, Isabel Cavazos for image processing, and Les Nonmacher and Tom Aderhold for allowing us to conduct studies in their orchards. Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture or the Texas A&M University System.

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objective of this study was to evaluate airborne NDVI imagery for assessing tree conditions in citrus (*Citrus* spp.) orchards. Images of two south Texas citrus groves with stressed and nonstressed trees were qualitatively evaluated. Stressed trees were easily detected from nonstressed trees in the images. The images were also helpful for developing survey plans of the citrus groves. Our results indicated that airborne NDVI images could be used as a tool to assess tree conditions in citrus orchards. Findings should be of interest to citrus growers, extension agents, agricultural consultants, and private surveying companies.

Imagery acquired by airborne sensors has been used to detect and assess stresses affecting citrus trees. Airborne color-infrared imagery has been primarily used for these surveys (Blaquez and Horn, 1980; Blaquez et al., 1988; Everitt et al., 1994; Fletcher et al., 2001; Richardson and Blaquez, 1989). Vegetation indices have been developed that reduce multispectral observations to a single numeric index for examining vegetation conditions (Jensen, 2000). Little information is available on the application of a vegetation index image for assessing citrus tree conditions within an orchard.

Vegetation indices are calculated from the sum, difference, ratio, or other linear combinations of two or more spectral bands. Numerous vegetation indices have been developed (Jensen, 2000); however, the normalized difference vegetation index (NDVI) has been used extensively to evaluate vegetation conditions. It is derived from the following equation: $NDVI = (\text{near-infrared light reflectance} - \text{red light reflectance}) / (\text{near-infrared light reflectance} + \text{red light reflectance})$ (Rouse

et al., 1974). NDVI values range from negative one to positive one. Increases in positive values signify increases in green vegetation. Vegetated surfaces typically have NDVI values that range from 0.1 to 0.6. Zero and negative values represent dead plant material or nonvegetated surfaces such as soil, water, rocks, and man-made features. NDVI images have been used to evaluate vegetation characteristics on global, regional, and local scales (Bartlett et al., 1988; Jackson and Gaston, 1994; Lozano-Garcia et al., 1995; Reed, 1997). The objective of this study was to evaluate airborne NDVI imagery for assessing tree conditions within citrus orchards.

Materials and methods

SITE DESCRIPTIONS. Two citrus groves, designated as site one and site two, were evaluated for this study. Site one (lat. 26°05'37"N long. 97°26'33"W), a 5.7-ha (14-acre) orchard located north of Los Fresnos, TX, contained 14-year-old 'Rio Red' grapefruit (*C. paradisi*) trees grafted to sour orange (*C. aurantium*) rootstock. Soils mapped for this site are Laredo silty clay loam (fine-silty, mixed, hyperthermic Fluventic Haplustolls; 0% to 1% slope) and Olmito silty clay (fine, montmorillonitic, hyperthermic, Vertic Calciustolls) (USDA, 1977). Site two (lat. 26°27'06"N long. 97°59'31"W), a 4.0-ha (10 acres) orchard located north of Hargill, Texas, has a mixture of 4- and 10-year-old 'Rio Red' and 'Longwell' red grapefruit trees growing on sour orange rootstock. Soils mapped for this site are Delfina fine sandy loam (fine-loamy, mixed, hyperthermic, Pachic Argiustolls, 0% to 1% slope) and Hargill fine sandy loam (fine-loamy, mixed, hyperthermic, Udic Paleustolls, 1% to 3% slope) (USDA, 1982).

These groves were selected because they had been surveyed and diagnosed with disease problems caused by foliar and soilborne pathogens and evaluated by the personnel at the Texas A&M University, Kingsville Citrus Center. Trees at site one had foot rot (*Phytophthora parasitica*) and/or greasy spot infections (*Mycosphaerella citri*); whereas, trees at site two were mainly affected by foot rot. These diseases are common in south Texas citrus groves. Foot rot and greasy spot infections reduce tree vigor and decrease vegetation density of tree canopies

(Graham and Timmer, 1994; Klotz, 1978; Whiteside, 1972).

IMAGE ACQUISITION. Imagery of the groves was obtained with a three-camera multispectral digital imaging system (Escobar et al., 1997) that acquired near-infrared [NIR (0.845 to 0.857 μm)], red [R (0.623 to 0.635 μm)], and yellow-green (0.555 to 0.565 μm) gray scale images. For image acquisition, the system was flown on-board a single-engine airplane. Imagery of site one was collected on 20 July 2000 and 24 Jan. 2001 under sunny and overcast conditions, respectively, and imagery of site two was obtained on

27 Sept. 2002 under sunny conditions. Images were acquired between 1100 and 1500 HR Central Day Time at an altitude of 762.0 m (2500 ft) above ground level.

IMAGE PROCESSING AND ANALYSIS. In the laboratory, the imagery was qualitatively assessed using the Adobe Photoshop Software (version 5.0; Adobe Systems, Inc., San Jose, Calif.). A subscene of site one was selected for each date for further analyses; whereas, the whole grove was analyzed for site two. For each image acquisition date, a NIR and R gray scale image pair was selected, saved as TIFF files (Tagged

Image File Format), and transferred to IDRISI32 software (version 2; Clark Labs, Worcester, Mass.) or ERDAS Imagine Software (version 8.5; ERDAS, Inc., Atlanta, Ga.) for image-to-image registration. The NIR image was registered to the R image for each respective date. This procedure was done to assure that ground areas in the NIR image coincided with ground areas in the red image, thus reducing errors in the derived NDVI images. Imagery registered using ERDAS was transferred to IDRISI for further processing.

The NDVI images were created using the VEGINDEX module of IDRISI. These images can have up to 256 gray levels or colors, representing vegetation conditions. Human eyes cannot distinguish between that many levels; therefore, the RECLASS module was used to develop NDVI images consisting of ten levels. These images were displayed in color, using a palette designed specifically for this study. The rescaled color-coded NDVI images were visually assessed. NDVI values and colors of tree canopies were used as indicators of tree conditions. Other researchers have used rescaled color-coded NDVI images for qualitative assessment of vegetation characteristics (Lozano-Garcia et al., 1995; Reed, 1997).

Results

The 20 July 2000 NDVI (Fig. 1) image of site one was effective in enhancing the detection of stressed trees (white circles). Highly stressed trees typically had NDVI values ranging from 0.1 to 0.3 and were scattered throughout the orchard. The most vigorous trees were located in the southwestern portion of the grove (Fig. 1, white arrow). In addition to the detection of stressed trees, the NDVI image also detected weed-infested areas within the grove (Fig. 1, black arrow).

More than 50% of the trees appeared to be stressed on the 24 Jan. 2001 NDVI image of site one (Fig. 2, white circles and squares). Defoliated areas were observed in some of the stressed trees (white squares). Portions of their canopies were blue, indicating the absence of vegetation. The NDVI image detected the most vigorous trees in the southwestern portion of the grove (Fig. 2, white arrow).

The NDVI image of site two (Fig.

Fig. 1. Rescaled color-coded normalized difference vegetation index (NDVI) image showing a portion of site one (20 July 2000). The white arrow points to the densest and most vigorous tree canopies. Stressed trees (foot rot-infected trees) are enclosed in white circles. The black arrow points to a weed patch. Blue color represents nonvegetated surfaces (NDVI < 0.1).

3) showed that older trees (black arrow) had vigorous canopies (NDVI values 0.6 to 0.7). Among the younger trees (smaller canopies), it detected vigorous (white arrow) and stressed (white circles) trees. Young stressed trees were mostly concentrated in the west side of the orchard. These results indicated that the NDVI images distinctly showed where stressed and nonstressed trees occurred in the groves.

Discussion

Near-infrared light is strongly reflected by leaf tissues, and R light is strongly absorbed by chlorophyll (Horler and Barber, 1981; Curran, 1981; Tucker et al., 1985), resulting in positive NDVI values for healthy vegetation (Figs. 1–3, green tree canopies).

Plant stresses reduce leaf area, cause green foliage to turn yellow, induce leaf drooping, and/or decrease foliage density, leading to a decrease in the difference between NIR and R light reflectance, thus causing a reduction in NDVI values (Figs. 1–3, reddish-brown tree canopies). The diseases affecting the trees in this study reduced the difference between the NIR and R image responses of their canopies, resulting in their lower NDVI values and their distinction in the imagery. Our results concurred with other studies conducted by researchers who have suggested that stressed vegetation can be differentiated from nonstressed vegetation using NDVI imagery (Jackson and Gaston, 1994; Lozano-Garcia et al., 1995; Reed, 1997).

Field survey plans can be easily developed from NDVI images shown in Figs. 1–3, using trees with the highest relative vigor and density as the standard for comparison (Figs. 1–3, white arrows). For example, trees with NDVI values lower than the standard are identified and marked in the NDVI imagery, indicating that these trees may be affected by some type of stress (Figs. 1–3, white circles and squares). In addition, trees that have the highest NDVI values should be considered for ground surveying to confirm that they are healthy (Figs. 1–3, white arrows). Furthermore, known bare soil areas covered with vegetation on the imagery should be marked for ground surveying because these areas probably contain unwanted vegetation, such as weeds (Fig. 1, black arrow). Once these images are qualitatively assessed, they can be taken to the field and used as maps by growers, extension agents, and agricultural consultants, thus expediting surveys of citrus groves.

Conclusions

Our results suggested that airborne NDVI imagery could be used for citrus surveys to assess tree status. The imagery provided general estimates of vegetation vigor, health, and density that were used to detect stressed trees and develop ground survey plans. Weed patches were also detected using NDVI imagery.

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Fig. 2. Rescaled color-coded normalized difference vegetation index image (NDVI) showing a portion of site one (24 Jan. 2001). Arrow points to the densest and most vigorous tree canopies. Stressed trees (foot rot and/or greasy spot infected trees—foliar symptoms of greasy spot infection occurred during the winter months for this orchard) are enclosed in white circles and squares (partially defoliated). Blue color represents nonvegetated surfaces (NDVI < 0.1).

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Fig. 3. Rescaled color-coded normalized difference vegetation index image (NDVI) of site two (27 Sept. 2002). Arrows point to the densest and most vigorous tree canopies (black and white arrows point to older and younger trees, respectively). Stressed trees (foot rot infected) are enclosed in white circles. Blue color represents nonvegetated surfaces (NDVI < 0.1).