Field Assessment of a Fiber Optic Spectral Reflectance System

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Summary Spectral reflectance measurements were taken from immature and mature leaves of 'Rio Red' grapefruit 'McCarty' grapefruit 'Minneola' tangelo, 'Satsuma' mandarin, 'Dancy' tangerine, 'Nagami' oval kumquat, and 'Valencia' orange from 1330 to 1530 hr 1 day at the Florida Citrus Arboretum, Division of Plant Industry, Winter Haven, Fla. A PS-1000 spectrometer was used with fiber optic cables and a lens source (visible range of the spectrum 400–800 nm) coupled with a tungsten halogen light source. A data acquisition card was connected to a notebook computer with a SpectraScope computer program for processing and data storage. Immature and mature leaves of 'Minneola' tangelo had greater percentage reflectance in the 400–800 nm range than the other cultivars and leaf ages measured. More detailed information was obtained with the PS-1000 than with conventional spectrometers. The slope of the citrus spectral curves in the 800 nm range was not as sharp as conventional spectrometers, but had a much higher reflectance value than those obtained with a different spectrometer. The system used here was convenient to transport and use in the field and produced clear, interpretable data.

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Table 1. *Citrus cultivar characteristics.*

Common name	Taxonomic name	Date planted (rootstock)	Ht (m)
Rio Red grapefruit	<i>Citrus xparadisi</i> Macfad. 'Rio Red'	4/11/90 (Cleo)	4
McCarty grapefruit	<i>Citrus xparadisi</i> Macfad. 'McCarty'	6/8/78 (Rusk)	6
Minneola tangelo	<i>Citrus reticulata</i> Blanco x <i>Citrus paradisi</i>	10/4/94 (C. obo)	2
Satsuma mandarin	<i>Citrus reticulata</i> Blanco 'Satsuma'	3/2/78 (F80-19)	4
Dancy tangerine	<i>Citrus reticulata</i> Blanco	3/2/78 (Cleo)	6
Nagami oval kumquat	<i>Fortunella margarita</i> (Lour.) Swingle 'Nagami'	3/12/78 (Cleo)	4
Valencia orange	<i>Citrus sinensis</i> L.	7/8/78 (Carrizo)	6

The atmosphere surrounding Earth allows radiation penetration in three major wavelengths: visible-near infrared (0.4–0.95 μ), mid-infrared (3–5 μ), and far-infrared (8–14 μ). These wavelengths reach Earth's atmosphere and are termed atmospheric windows (Colwell, 1972). Vegetation absorbs some of this radiation and reflects much of it in the far-infrared region. The color of plants is due to the reflected light in specific regions (Colwell, 1972). Considerable efforts have been made by horticultural scientists in the past to measure reflectance, transmittance, and absorbance of light by plants (Gates and Keegan, 1965; Gausman et al., 1975; Maas and Dunlap, 1989). Most instruments available were derived from chemical and physics laboratories and were expensive, difficult to operate, and not practical for field use (Dyer et al., 1991; Rodriguez and Gausman, 1977), e.g., the Beckman DK-2 spectrophotometer, (Blazquez and Edwards, 1986; Colwell, 1972; Gausman et al., 1975). Spectrophotometers also were developed for field use. These were large, required considerable vehicle support, and were very expensive to purchase and operate. However, these had limited field use due to soil conditions such as furrows, soft sand, and irrigation ditches, e.g., model 20, Exotech, Gaithersburg, Md.; telespectro-radiometer, Spectral Data Corp., Hauppauge, N.Y. A portable spectrometer (LI-1800, LI-COR, Lincoln, Neb.) has been available for the past 5 years for measuring narrow bandwidth spectral measurements such as reflectance, absorption, and transmission. It is a more versatile instrument than previous spectrometers, but it is expensive, complicated, and requires additional components to visualize data in the field. Advances in computer technology and fiber optic production

have made smaller and less expensive instruments possible, which combined with computer programs, have allowed quick and easy measurement of light parameters.

The purpose of this study was to assess the performance of a new, portable, computer-linked scanning spectroradiometer to differentiate Florida citrus cultivars under field conditions.

Materials and methods

Spectral reflectance measurements were made from 'Rio Red' and 'McCarty' grapefruit, 'Minneola' tangelo, 'Satsuma' mandarin, 'Dancy' tangerine, 'Nagami' oval kumquat, and 'Valencia' orange citrus cultivars at the Conservation Arboretum, Division of Plant Industry, Florida Dept. of Agriculture and Consumer Services, Winter Haven, Fla. This arboretum supplies certified budwood for the Florida citrus industry. Cultivar characteristics are listed in Table 1. Trees had been irrigated by microjet irrigation for the preceding 3 days and showed no signs of wilting. The cultivars used had flushed about 2 weeks before mea-

surement. The mature leaves were from the summer flush, that is, about 8 months old. Five branches with a fully expanded flush were selected from each cultivar. Two mature and two fully expanded immature leaves contiguous on the same branch were used for measurements. Individual branches were removed immediately before the spectral reflectance was measured. A hand-held clamp was used to hold the optical fiber light at a 45-degree angle, 1 cm from the sample (constructed by R.J. Hedley, Winter Haven, Fla.). Measurements were taken from 1330 to 1530 HR on a clear, sunny day, ambient temperature 30C. The spectrometer was set to scan each leaf 10 times, averaging the scans into a single curve. These 10 individual curves (one per leaf) then were averaged to produce one curve per leaf age and cultivar for the figures. The individual data sets were analyzed statistically by ANOVA

Fig. 1. Average spectral reflectance curves from mature leaves of citrus cultivars in the visible and near-infrared bands of the spectrum (400–800 nm) measured with a PS-1000 spectrometer; n = 10 per curve.

Fig. 2. Average spectral reflectance curves from immature leaves of seven citrus cultivars in the visible and near-infrared bands of the spectrum (400–800 nm) measured with a PS-1000 spectrometer; $n = 10$ per curve.

and Tukey's honestly significant difference test (Hochberg and Tamhane, 1987).

A PS-1000 miniature, fiber optic spectrometer (Ocean Optics, Dunedin, Fla.) was used with a fiber optic reflection probe with a potential spectrum range of 361–900 nm coupled with a miniature tungsten halogen lamp (independently powered in the field from a gel-cell battery). The PS-1000 was connected to a field portable notebook 485-DX/50 personal computer. SpectraScope software, supplied with the PS-1000 spectrometer, controlled the grating and thus wavelength. Resulting reflectance data were stored in an ASCII file in the notebook PC. The PCMCIA card provided 5 V of power and a clock cycle to the spectrometer from notebook PC. The architecture of this system is a crisscross Czerny-Turner design with the first optic mirror projecting light in parallel beams to a flat holographic grating. The system was equipped with a size 600 grating that determined the range and dispersion of light projecting onto a positioning mirror, which then focused the lamp onto a 1024 element, charged, coupled array CCD. Signals were recorded at 400–800 nm at 0.5-nm intervals giving a resolution of 10 nm (pixels) with 1024 light pixels and 74 dark pixels. The clock cycle provided a software control integration time to maximize the light energy being re-

turned from the sample. The PCMCIA A/D card converted an analog serial stream of data to digital information and handed it to the SpectraScope software. SpectraScope then converted raw data to percentage transmission. The transmission information was stored in an ASCII file. A single strand of optical fiber with a 0.22-mm aperture emitting light in a 25-degree cone from the tungsten halogen fiber optic lamp was connected to the spectrometer with a standard SMA connector. Eleven-hundred measurements were taken for each spectral curve. A spreadsheet program allowed greater flexibility in the analysis of the curves than the SpectraScope software, making it possible to compare different spectral ranges without altering data. Analysis of the data was made at 400–800 nm to select specifically the visual region of the electromagnetic spectrum identified in the literature (Dyer et al., 1991; Gausman et al., 1975; Malthus and Madeira, 1993).

Results

Reflectance measurements from immature and old leaves from five of the cultivars tested ('Valencia' orange, 'McCarty' and 'Rio Red' grapefruit, 'Dancy' tangerine, and 'Nagami' oval kumquat) were quite similar in overall reflectance curves (Fig. 1) and were not statistically different from each other in an ANOVA test (Table 2) at 400–800 nm. However, the spectral reflectance of immature leaves of 'Valencia' was higher than mature 'Valencia' leaves at about 550–600 nm, and immature tangelo leaves were higher than mature tangelo leaves at about 550–650 nm.

Significant differences in the 700–800 nm red shoulder region were observed in the spectral curves of mature leaves of the cultivars tested. Grapefruit ('Rio Red', 20% reflectance, and 'McCarty', 50% reflectance) were very distinct from one another at about 780 nm. 'Minneola' tangelo had the highest reflectance (70% at 750 nm).

Mature 'Valencia' orange leaves were quite similar to other cultivars overall (Figs. 1 and 2, Table 2). 'Minneola' tangelo had a spectral curve higher than other cultivars in percentage reflectance values by 40% to 45% for immature and mature leaves (Table 2). The sharp, almost vertical, slope in reflectance values at 700 nm reported by Gausman et al. (1975) was not observed. In our experiments, the combined curves had a lesser slope at 700–800 nm, but had reflectance values up to 70% rather than the 60% found previously (Gausman et al., 1975). Mature 'Minneola' tangelo leaves had values up to 80% (average 58%) (Table 2). Mature and immature 'Minneola' tangelo leaves were significantly differ-

Table 2. Overall mean percent reflectance values from immature and mature leaves of seven citrus cultivars (400–800 nm).

Cultivar	Immature leaves mean	Mature leaves mean
Minneola tangelo	61.3 A ^z	58.0 A
Valencia orange	21.0 B	12.0 B
McCarty grapefruit	14.4 BC	10.0 BC
Rio Red grapefruit	13.0 CD	11.0 BC
Dancy tangerine	12.3 CD	9.4 BC
Nagami oval kumquat	9.2 CD	6.6 BC
Satsuma mandarin	6.1 D	4.0 C

^zMeans within columns followed by a common letter are not significantly different at $\alpha = 0.05$ by ANOVA and Tukey's HSD test. $n = 10$.

ent from other citrus cultivars tested ($P = 0.01$). 'Satsuma' mandarin had significantly lower overall mean percent reflectance values for mature leaves. Immature 'Satsuma' mandarin leaves overall mean percentage reflectance was statistically different from 'Minneola' tangelo, 'Valencia' orange, and 'McCarty' grapefruit (Table 2).

Generally, immature leaves of all cultivars had higher overall mean percent reflectance values than mature leaves, with 'Minneola' tangelo values significantly different from the others from 400 nm to the chlorophyll dip near 700 nm (Table 2). Overall, differences in reflectance intensity of immature leaves separated into four groups, with 'Minneola' tangelo in one group, 'Valencia' orange and 'McCarty' grapefruit in a second group, 'McCarty' and 'Rio Red' grapefruit, 'Dancy' tangerine, and 'Nagami' oval kumquat in a third group, and 'Satsuma' mandarin in the last group with the least reflectance values of all the cultivars tested (Table 2). For mature leaves, 'Minneola' tangelo was highest in spectral reflectance intensity and 'Satsuma' mandarin was lowest. However, mature leaf mean percentage spectral reflectance intensities essentially formed only two groups, with 'Minneola' tangelo in one group and the other cultivars in a second group.

The PS-1000 spectrometer was a more sensitive instrument for measuring spectral curves of citrus foliage, as both the slope of the curves and the intensities obtained had considerably more detail than those obtained with a DK-2 spectrophotometer (Gausman et al., 1975). One advantage of the PS-1000 and fiber optic sensors is the ability to measure reflectance with or without a standard light, eliminating the need to have a separate instrument measuring light incidence when measuring reflectance in the field. The compact PS-1000 system, including the required number of notebook batteries, and the gel cell battery for the

light source, was transported easily to and in the field. Data collection was very rapid as the fiber optic lenses and light source could be moved easily to different foliage of each tree. Spectral curves are instantly obtained and may be viewed and stored. The overall speed and convenience of the PS-1000 should allow many other scientists to use spectral reflectance data in their field research.

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