for the desired fertilizer in parts per million for each mineral nutrient (Fig. 2). The nitrogen level is further partitioned into ammonium and nitrate fractions. Using this information and the injection ratio input, MACRONUT calculates the number of grams per liter or grams per gallon required for each compound to formulate the concentrated stock solution.

As an example, a solution of 150 ppm nitrogen, 75 ppm phosphorus, 75 ppm potassium, 40 ppm magnesium, 52 ppm sulfur, and 0 ppm calcium is desired. Fifty percent of the nitrogen should be derived from NO_3^- . Compounds available for this solution are ammonium nitrate, magnesium sulfate, mono-ammonium phosphate, phosphoric acid, potassium carbonate, potassium chloride, urea, and sulfuric acid. Ranking for the nitrogen sources is ammonium nitrate 1, urea 2, and mono-ammonium phosphate 3. Ranking for the phosphorus compounds is phosphoric acid 1 and monoammonium phosphate 2. Ranking for the potassium sources is potassium carbonate 1 and potassium chloride 2. Ranking for the sulfur sources is magnesium sulfate 1 and sulfuric acid 2. Lastly, the injection rate is set at 1:100. The output for the applied solution is illustrated in Fig. 2.

The MACRONUT program and manual are available free of charge. The program can be downloaded from the New Mexico State University-Mora Research Center home page on the Internet (<http://taipan.nmsu.edu/aght/mora/mora.html>). Once at this site, go to the nursery research hyperlink. The nursery research page contains the information required to download the software and its corresponding manual. A second option for obtaining the MACRONUT program and manual is to send a stamped, self-addressed disk mailer and a 3 1/2-inch formatted (IBM) diskette to the Mora Research Center, P.O. Box 359, Mora, NM 87732.

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A Rapid Nondestructive Technique to Predict Leaf Nitrogen Status of Grapefruit Tree with Various Nitrogen Fertilization Practices

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ADDITIONAL INDEX WORDS. citrus, SPAD, dry fertilizer, fertigation, slow-release fertilizer

SUMMARY. The objective of this study was to evaluate the use of a leaf chlorophyll meter (SPAD-502) to predict nitrogen status and yield response of grapefruit trees. The study included two irrigation treatments, three sources, and four rates of fertilizer [dry soluble granular fertilizer broadcast or through fertigation with N rates either 50, 100, 150 lb/acre/yr (56, 112, or 168 kg·ha⁻¹·yr⁻¹), and controlled-release fertilizer with N rates either 25, 50, 100 lb/acre. Irrigation treatments did not affect SPAD readings and leaf N concentrations. Correlations between SPAD readings and leaf N were greater for the spring flush ($r^2 = 0.61$) than for

the summer flush ($r^2 = 0.49$). High correlations of SPAD meter readings with either fruit yields or leaf N suggests that SPAD meter reading is an acceptable index of N status and fruit production of the trees. SPAD readings can be made rapidly without destructive sampling of the leaves. This study demonstrates that the SPAD meter can be used to evaluate the tree N status and improve a N fertilization program for grapefruit trees.

Nitrogen fertilizer applied to citrus trees grown in deep sandy soils in excess of that required for annual tree growth and fruit production is subject to either surface runoff or leaching below the rootzone (Calvert, 1975). Soil and leaf analyses can be used as guidelines to adjust the N fertilizer program for citrus trees (Tucker et al., 1995). However, these analyses are costly, time consuming, and require trained technical personnel and a well-equipped laboratory. Leaf chlorophyll content is closely correlated to leaf N content (Wolfe et al., 1988; Wood et al., 1992a). Chlorophyll meters (SPAD-501 or SPAD-502, Minolta Corp., Ramsey, N.J.) are calibrated to estimate the chlorophyll content in the leaves rapidly and nondestructively. Studies on corn (Dwyer et al., 1991; Piekielek and Fox, 1992; Schepers et al., 1992; Wood et al., 1992a), cotton (Wood et al., 1992b), rice (Peng et al., 1995; Turner and Jund, 1991), peppermint (Westcott and Wraith, 1995), and wheat (Follett et al., 1992; Fox et al., 1994; Reeves et al., 1993) have shown that the SPAD meter can be used as an aid to predict N status of the crop and thus can be used as the basis to develop a precise N fertilization program. The photosynthetic rate of soybean leaves was correlated with SPAD meter reading at R4 (dough stage) and R5 (dent stage) growth states of 16 genotypes (Ma et al., 1995). Blackmer and Schepers (1995) reported a significant linear correlation between SPAD meter readings of corn leaves, measured at either R4 or R5 growth stages, and grain yield. The SPAD meter was also used as a tool for diagnosing iron chlorosis in citrus rootstocks (Sudahono et al., 1994).

The objective of this study was to evaluate the relationships between SPAD meter readings of grapefruit tree leaves, concentrations of leaf N, N fertilization rates, and fruit yields.

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Fig. 1. Relationship between the leaf N concentration and SPAD meter readings for 5-month-old spring flush (a) and summer flush (b) of white 'Marsh' grapefruit trees on sour orange rootstock grown in Riviera fine sand and received various sources and rates of N (n = 78).

Materials and methods

This experiment was conducted in a commercial orchard with 26-year-old white 'Marsh' grapefruit (*Citrus paradisi* MacFadyen) trees on sour orange (*C. aurantium* Lush.) rootstock, planted at 20 × 20-ft (6.1 × 6.1-m) spacing on a Riviera fine sand (sandy, siliceous, hyperthermic Arenic Glossaqualfs). Since this soil typically maintains a perched water table, the trees were planted on two-row raised beds with depth of water furrow ranging from 3 to 4 ft (0.9 to 1.2 m). The experiment included two irrigation treatments (25% and 40% depletion of available soil moisture content) as main plots and 10 N treatments as subplots [50, 100, and 150 lb/acre/yr (56, 112, or 168 kg·ha⁻¹·yr⁻¹)] as dry soluble granular broadcast and as fertigation treatments, and N at 25, 50, and 100 lb/acre/yr as controlled-release fertilizer plus a control treatment without fertilizer with four replications using a factorial split-plot design. Soil water characteristic curves were developed and tensiometers [6 and 12 inches (15 and 30 cm) depths] were used to schedule irrigation whenever soil tension reached 10 cbar (10 kPa) for the low depletion level (25%) and 20 cbar for the high depletion level (40%). The trees were irrigated using micro-sprinklers with one emitter per tree [delivery rate = 1.34 ft³/h (0.038 m³·h⁻¹), wetting area of 113 ft²]. The trees in one row on each two-row bed were used for treatments, while the other row was used as a buffer row. Each

Fig. 2. Relationships between fruit yield and (a) SPAD meter readings or (b) leaf N concentrations of 5-month-old spring and summer flush leaves of white 'Marsh' grapefruit trees on sour orange rootstock grown in a Riviera fine sand and received broadcast application of granular dry fertilizer at either 50, 100, or 150 lb N/acre/yr. Each data point represents mean of eight observations, and the vertical line is standard error of the mean.

Fig. 3. Relationships between fruit yield and (a) SPAD meter readings or (b) leaf N concentrations of 5-month-old spring and summer flush leaves of white 'Marsh' grapefruit trees on sour orange rootstock grown in a Riviera fine sand and received 15 applications per year of fertigation with either 50, 100, or 150 lb N/acre/yr. Each data point represents mean of eight observations, and the vertical line is standard error of the mean.

fertilizer treatment consisted of four subplots with five uniform trees each. The controlled-release fertilizer was applied in a single dose each year, i.e., 15 Mar. 1994 and 2 Mar. 1995. Dry soluble granular fertilizer was applied in three equal doses in March, May, and October. Liquid fertilizer was applied in 15 equal doses over the entire growing season. Nitrogen source in the dry granular and liquid fertilizer was ammonium nitrate, while polymer coated urea was used in the controlled-release fertilizer.

Five-month-old spring and summer flush leaves were sampled in August and December, respectively. Twenty leaves were sampled per tree from nonfruiting branches from each of the middle three trees within a subplot from all four replications. The chlorophyll meter (SPAD-502) readings were taken at the middle of each leaf immediately after sampling. The leaves were washed with 1% detergent (Liqui-Nox), rinsed several times in tap water, soaked in 5% HCl for 20 s, followed by several rinses in distilled water, dried at 158 °F (70 °C) for 48 h, and ground in a Wiley mill to pass through a 40-mesh sieve. The concentration of N in the ground leaf sample was analyzed using the Kjeldahl procedure (Hanlon et al., 1994). Fruit from the middle two rows per plot were picked, yields were measured on a volume basis, i.e., box = 85 lb, and then

Fig. 4. Relationships between fruit yield and (a) SPAD meter readings or (b) leaf N concentrations of 5-month-old spring and summer flush leaves of white 'Marsh' grapefruit trees on sour orange rootstock grown in a Riviera fine sand and received single broadcast application of controlled-release fertilizer with either 25, 50, or 100 lb N/acre/yr. Each data point represents mean of eight observations, and the vertical line is standard error of the mean.

Fig. 5. Relationships between N rates as broadcast application of dry granular fertilizer and (a) SPAD meter readings or (b) leaf N concentrations of 5-month-old spring and summer flush leaves of white 'Marsh' grapefruit trees on sour orange rootstock grown in a Riviera fine sand. Each data point is a mean of eight observations, and the vertical line is standard error of the mean.

calculated on weight basis per unit area. A statistical analysis system (SAS Institute, 1982) program was used to calculate linear regressions.

Results and discussion

Irrigation treatments did not significantly influence the SPAD readings and leaf N concentrations (data not presented). The annual rainfall during the course of this study was 79 inches, which was considerably greater than the normal rainfall of ≈ 55 inches, for this area. Different fertilizer treatments (0 to 150 lb N/acre/yr) contributed to variation in leaf N concentration (Fig. 1). Leaf N concentrations varied from 1.62% to 2.76% and 1.75% to 2.41% for the spring and summer flush, respectively. The correlation between SPAD readings and leaf N concentration was greater for the spring flush ($r^2 = 0.61$) than for the summer flush leaves ($r^2 = 0.49$).

Fruit yields increased with increases in SPAD readings and in leaf N for dry fertilizer as well as fertigation treatments (Figs. 2 and 3), and the linear coefficients ranged from 0.65 to 0.98. Ma et al. (1995) reported a significant linear correlation between the SPAD readings and photosynthetic rate. Therefore, high leaf N and SPAD readings indicate increased photosynthetic rate and consequently greater fruit yield. However, the r^2 value for the linear relationship between the fruit yield and SPAD readings was lower for the controlled-release fertilizer ($r^2 = 0.02$ to 0.40) than for the dry granular fertilizer or fertigation ($r^2 =$

Fig. 6. Relationships between N rates as fertigation and (a) SPAD meter readings or (b) leaf N concentrations of 5-month-old spring and summer flush leaves of white 'Marsh' grapefruit trees on sour orange rootstock grown in a Riviera fine sand. Each data point is a mean of eight observations, and the vertical line is standard error of the mean.

Fig. 7. Relationships between N rates as controlled-release fertilizer and (a) SPAD meter reading or (b) leaf N concentrations of spring and summer flush leaves of white 'Marsh' grapefruit trees on sour orange rootstock grown in a Riviera fine sand. Each data point is a mean of eight observations, and the vertical line is standard error of the mean.

the summer flush (Fig. 6).

In the case of the controlled-release fertilizer treatment, although the total quantity of annual fertilizer was applied in early spring due to its slow release, the total quantity of nutrients available during the early growth of spring flush was considerably lower than for the summer flush. This could explain, in part, the greater correlation between the leaf N and N rate for the summer flush than for the spring flush leaves (Fig. 7).

In conclusion, the results of this study demonstrate that SPAD meter readings of grapefruit spring flush provide a basis to predict the leaf N status and the fruit yield response to various rates of N application. Using the SPAD meter offers potential economic and environmental advantages since this provides a nondestructive and less-tedious technique to evaluate N nutrition of the trees to manage the fertilizer program to increase N fertilizer efficiency and minimize risk of yield reduction. However, it is important to note that other factors, such as deficiencies and/or excesses of other elements, the presence of diseases, and water logging, could modify the relationship between the fruit yield and SPAD meter readings. Further research should be conducted to define these limitations for using the SPAD meter to predict N status and yield of citrus under variety of production conditions.

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0.65 to 0.98) treatments (Fig. 4). The longevity of nutrient release from the controlled-release fertilizer used in this study was 270 d (at 77 °F). This release duration could be considerably shorter in the field condition. However, the controlled-release fertilizer characteristically releases nutrients in equal proportion over the entire duration of release period. Therefore this formulation may have provided a lower amount of available nutrients during the early spring, i.e., flowering and fruit set stages of the trees than that provided by dry granular broadcast or fertigation treatments. For optimal production of citrus trees, ≈50 to 65% of the total annual N requirement must be available during the flowering and fruit set stage (Tucker et al., 1995). This requirement was not satisfied in the case of the controlled-release fertilizer treatments. This could explain the low correlation between the fruit yield and SPAD readings.

Concentrations of N or SPAD meter readings of 5-month-old spring and summer flush leaves in relation to N rates using either dry fertilizer, fertigation, and controlled-release fertilizer are presented in Figs. 5-7, respectively. The SPAD meter read-

ings and leaf N concentrations of spring and summer flush leaves increased significantly with increasing N rates regardless of N sources ($r^2 = 0.29$ to 0.97 for leaf N and $r^2 = 0.52$ to 0.99 for SPAD readings).

In the case of the dry granular fertilizer broadcast treatment, the leaf N vs. N rate correlation was greater for the spring flush compared to the summer flush (Fig. 5). This could be attributed to timing of fertilizer application. Dry granular fertilizer was applied in three equal doses per year, with first two applications being made in March and April. This period corresponds to initial stages of spring flush development. The third dose of fertilizer application was made in September. In the case of the fertigation treatment, the annual fertilizer rate was divided equally into 15 applications during the entire growing season. The total amount of fertilizer applied during the early growth of spring flush for a given N rate was much lower for the fertigation treatment compared to the dry fertilizer treatment. This may explain the lower correlation between N rates and leaf N concentrations of fertigated trees for the spring flush compared to that for

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Potted Sunflower Growth and Flowering Responses to Foliar Applications of Daminozide, Paclobutrazol, and Uniconazole

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ADDITIONAL INDEX WORDS. *Helianthus annuus*, growth retardant

SUMMARY. Plant growth retardant (PGR) foliar sprays (in mg·L⁻¹) of daminozide at concentrations from 1,000 to 16,000; paclobutrazol from 5 to 80; and uniconazole from 2 to 32 were applied to 'Pacino' potted sunflowers (*Helianthus annuus* L.) to compare their effectiveness at chemical height control. Plants were grown in 650-mL or 1.2-L pots. When the first inflorescence started to shed pollen, number of days from seeding until anthesis, total plant height measured from the pot rim to the top of the inflorescence, inflorescence diameter, and plant diameter were recorded. There was no significant difference in plant height between 'Pacino' plants grown in 650-mL or 1.2-L pots. Total plant height, plant diameter, inflorescence diameter, and days until flowering were significant for the PGR treatment main effect. Marketable-sized plants grown in the 1.2-L pots were produced with uniconazole concentrations from 16 to 32 mg·L⁻¹ or with daminozide concentrations

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