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THE BASIS FOR MATURE CITRUS NITROGEN FERTILIZATION RECOMMENDATIONS

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Abstract. **A survey of drinking water wells conducted in Florida between 1988 and 1991 found that nitrate nitrogen (NO_3-N) concentrations in surficial well water near citrus groves on Entisols in central Florida exceeded maximum contamination levels (MCL) of 10 mg L^{-1}. The proportion of wells in Florida contaminated with NO_3-N was similar to that of a nation-wide survey; however, the proportion of wells contaminated above MCL was an order of magnitude higher. Eighty-nine percent of wells contaminated above MCL were located in the central Florida counties of Lake, Polk, and Highlands. Citrus in these counties is grown on Entisols which are uncoated sands with low water holding capacities of 0.04 to 0.09 cm^3 cm^{-3}. Such sands are particularly vulnerable to nutrient leaching. To reduce potential ground water contamination due to citrus production, best management practices were established and UF/IFAS publication SP169 was written with a recommended nitrogen (N) fertilizer application upper limit of 240 kg ha^{-1} yr^{-1} for mature bearing citrus trees. Prior to publication of SP169, the UF/IFAS annual N rate recommendation was 18 kg ha^{-1} per 10 Mg ha^{-1} fruit production based on Bulletin 536D. Publication SP 169 is currently being revised and updated. Based on controlled experiments conducted since 1990, arguments are given for an annual N rate recommendation of 17 kg ha^{-1} yr^{-1} per 10 Mg ha^{-1} yr^{-1} based on a 5 yr running average of orange [*Citrus sinensis* (L.) Osbeck.] fruit yield and 24 kg ha^{-1} yr^{-1} per 1 Mg ha^{-1} yr^{-1} based on soluble solids yield. N rate studies on grapefruit (*C. paradisi* Macf.) were also reviewed, however, insufficient evidence exits for a size or yield based annual N rate recommendation.**

Adequate availability of N during the critical stages of fruit initiation and development is important to support optimum yield of good quality citrus fruit (Dasberg et al., 1983, 1984; Koo et al., 1984; Syvertsen and Smith, 1996). However, fertilizer applications in excess of that required to produce the maximum potential yield will encourage excessive vegetative growth (Alva et al., 2003: Schumann et al., 2003) or lead to nitrate leaching and contamination of surficial aquifers (Alva and Paramisivam, 1998; Alva et al., 2001; He et al., 2000). The U.S. Environmental Protection Agency, in a nation-wide survey, documented widespread nitrate contamination of shallow drinking water wells (Graham and Alva, 1995). In that survey, approximately 55% of wells were found to contain NO_3-N contamination above the background concentration. Approximately 1.2% and 2.4% of urban and rural drinking water wells, respectively, were found to contain NO_3-N concentrations above the maximum contamination level (MCL) of 10 mg·L^{-1} for drinking water. The proportion of wells in Florida contaminated with NO_3-N was similar to that of the nation-wide survey. However, the proportion of wells contaminated above MCL was an order of magnitude higher, suggesting that the sandy soils of Florida on average are vulnerable to NO_3-N leaching to groundwater. Eighty-nine percent of wells contaminated above MCL were located in the central Florida counties of Lake, Polk, and Highlands. Portions of these three counties comprise the central Florida ridge. Soils typical of the "ridge" are hyperthermic Entisols composed of uncoated sands with water holding capacities of 0.04 to 0.09 cm^3·cm^{-3}, hydraulic conductivities >50 cm·h^{-1}, cation exchange capacities of 1 to 5 cmol (+) kg^{-1}, and depths of more that 10 m.

A best management practice (BMP) for any agricultural commodity is an attempt to use the latest scientific data available to reduce the impact of agricultural operations on the environment while maintaining economically viable production. An interim BMP for the Ridge citrus production area was established in 1994 that was based on previous N rate studies and current IFAS recommendations. Citrus growers agreeing to abide by the interim BMP would not be held liable by the Florida Department of Environmental Protection for future costs of supplying drinking water to local users (Graham and Alva, 1995).

The terms of the interim BMP for orange trees 4 years or more of age were quite broad. Annual N applications were restricted to 134 to 269 kg·ha^{-1}·yr^{-1} with the stipulation that groves producing fruit yields less than 50.4 Mg·ha^{-1}·yr^{-1} should apply no more N than 202 kg·ha^{-1}·yr^{-1}. A minimum of two applications per year were required for bearing groves receiving N rates less than 168 kg·ha^{-1}·yr^{-1} N. Bearing groves receiving N rates greater than 168 kg·ha^{-1}·yr^{-1}were required to receive at least three applications. Those groves using fertigation were required to make a minimum of 10 applications. Application of at least half of the annual fertilizer N prior to the rainy season was encouraged. A UF/IFAS publication (Tucker et al., 1995) was produced to assist growers in determining the rate of N to apply, timing of application, and suggested irrigation scheduling.

In 2002, a revised Ridge citrus BMP established rates and timing of N applications based on tree age classes and method of applications. The two age classes are 4 to 7 years and >7 years. The methods of application are broadcast only, broadcast and fertigation, and fertigation only. All sources of N including dry granular, controlled release, suspension, solution, manure, compost, and municipal effluent applied

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to the grove must be included in calculating annual N rate. However, for the purposes of the BMP only 70% of the N from purely organic sources is counted in the year applied. No more than 34 kg·ha^{-1} N is to be applied at one time, and no more than 34 kg·ha^{-1} N may be applied from 15 June to 15 Sept. No fertigation application is to exceed 17 kg·ha^{-1} N and must be applied at a minimum of 1-wk interval.

Citrus BMPs have been established for the Indian River, Peace River and Gulf production areas. Manuals developed for these area address proper nutrient handling, and application in addition to annual N application rate. In these production areas, no set limits on annual or application amounts were established. However, recommendations in Tucker et al. (1995) are to be followed. The use of soil and leaf samples to avoid over application of nutrients is recommended.

The annual citrus N requirement is equal to the amount of N contained in the harvested fruit crop and vegetative tissue or biomass added to the tree (Alva et al., 2003). Thus, N must be added back into the grove on an annual basis to become part of the next citrus harvest. The bulk of the N within the grove; however, is really not in the harvested fruit, but in the actively growing trees (Morgan et al., 2006). Blooms, fruit, woody tissues (both above and below ground), and leaves all contain N and other nutrients. As leaf materials fall to the ground, some (approximately 50%) of the N they contain is recycled within the grove (Dasburg et al., 1984). Therefore, citrus trees must take up N in excess of the crop requirement for young trees to increase in size.

Nitrogen uptake efficiency (NUE) is defined as the percentage of applied N taken up by plants (Scholberg et al., 2002). The ability of crop plants to take up and utilize N efficiently is key to providing adequate N for crop growth while reducing N leaching. Mattos et al. (2003) estimated NUE for 6-year-old 'Valencia' trees grown in a sandy soil to be 40% and 26% for ammonium nitrate and urea respectively. Feigenbaum et al. (1987) reported that the NUE for a ^{15}N labeled KNO_3 applied to 22 year-old 'Shamouti' orange was 40%. Syvertsen and Smith (1996) estimated NUE to be 61% to 83% for 4-year old grapefruit trees grown in lysimeters. Nitrogen uptake efficiency decreased with increased N application rates. Lea-Cox and Syvertsen (1996) reported a similar finding of lower NUE with higher N application rate for greenhouse grown seedlings. The NUE reported ranged from 47% to 60% after an uptake period of 31 d. Lea-Cox et al. (2001) determined N uptake of 4-year-old grapefruit trees to range from 40% to 70% using ^{15}N labeled fertilizer. Spring flush leaves were found to be the predominant N sink.

Current N fertilizer recommendations for mature citrus trees grown in Florida are relatively broad ranges of 134-224 kg·ha^{-1}·yr^{-1} for oranges and 134-202 kg·ha^{-1}·yr^{-1} for grapefruit. No indication as to N rate and yield relationship is given. The objective of this paper was to present yield results of long term nitrogen rate studies on mature Florida groves as a basis of mature tree N recommendations.

Mature Orange Tree N Rate Studies

Effect of annual N rate on fruit nutrient content and quality of three orange varieties at three N rates ranging from 168 to 280 kg·ha^{-1}·yr^{-1} for three years was determined (Alva and Paramasivam, 1998; Paramasivam et al., 2000). Fruit diameter and weight were not significantly different among N rates. Likewise, average N content was not significantly affected by N rate and varied among varieties from 0.50 to 0.59 kg per 40 kg fresh weight box. Yield was not reported, however, N accumulation by fruit was determined to range from 32 to 40% of total N applied.

Schumann et al. (2003) measured a significant quadratic response for fruit and soluble solids yield of mature 'Hamlin' orange on Swingle citrumelo [*C. paradisis* Macf. × *Poncirus trifoliata* (L.) Raf.] rootstock with increased fertilizer N rate. Fruit and soluble solids yields were significantly different for the three N sources used. Dry granular produced lower yields than controlled release fertilizer. Fertigation was superior to either dry granular or controlled release sources. Yields initially increased with fertilizer N applied at 78 and 134 kg·ha^{-1}·yr^{-1} then decreased at the higher rates (190 and 246 kg·ha^{-1}·yr^{-1}). The inflection point of the quadratic curve describing the relationship of rate N to yield indicates the rate at which the maximum yield would have occurred. Maximum fruit yield based on these quadratic relationships are 25, 21, and 20 Mg·ha^{-1}·yr^{-1} at N rates of 140, 180, and 160 kg·ha^{-1}·yr^{-1} for fertigation, controlled release, and dry granular fertilizer sources, respectively. A similar relationship was determined for soluble solids yield. Maximum solids on a production area basis would be approximately 1.7, 1.3, and 1.3 Mg·ha^{-1}·yr^{-1} at N rates of 140, 185 and 175 kg·ha^{-1}·yr^{-1} for fertigation, controlled release, and dry granular N sources, respectively.

Alva et al. (2006) measured fruit quality and yield of 20-year-old 'Hamlin' orange trees on 'Cleopatra mandarin' (*C. reticulata* Blanco) for various N rates for a period of six years. Fruit weight and soluble solids changed from year to year, but was not affected by N rates within a given year. Fruit yield increased with increasing N with a maximum yield at the inflection point, and then decreased yields with increasing N rate. The inflection point was at an N rate of approximately 260 kg·ha^{-1}·yr^{-1} for all N sources. However the maximum yield varied by source. Fertigation average the highest maximum yield at 94 Mg·ha^{-1}·yr^{-1}, controlled release fertilizer gave the lowest maximum yield at 79 Mg·ha^{-1}. Dry granular fertilizer was nearer that of fertigation at 88 Mg·ha^{-1}. Mean soluble solids per 40 kg box of fruit was 2.9 kg across years and rates. Using this soluble solids value, maximum total solids would be approximately 6.7, 6.5, and 5.8 Mg·ha^{-1}·yr^{-1} for fertigation, dry granular and controlled release N sources, respectively.

Mature Orange Tree N Recommendation

Statewide fruit yields between 1999 and 2004 averaged 37.8, 42.9, and 33.0 Mg·ha^{-1}·yr^{-1} for all round oranges, early and mid season oranges, and 'Valencia' oranges, respectively (Florida Ag. Stat. Serv., 2005). These fruit yields were intermediate to the fruit yields documented in the two studies above. Assuming the fruit yield at the inflection points of the two studies represent the maximum potential yield for those two particular groves, it would seem reasonable to base N fertilizer recommendations on the N application rates associated with these two potential yields (Fig. 1). The range of N application to produce the potential yields in the two cited studies (140 and 260 kg ha^{-1} yr^{-1}) are nearly equal to the range recommended in Tucker et al. (1995) (134 to 224 kg·ha^{-1}·yr^{-1}), and within the limits established in the Ridge citrus BMP (134 to 269 kg·ha^{-1}·yr^{-1}). Therefore, we propose to establish a citrus N recommendation with a minimum annual N rate of 140 kg·ha^{-1} for groves producing fruit yields of 20 Mg·ha^{-1}·yr^{-1} with 17 kg·ha^{-1} additional N annually for every 10

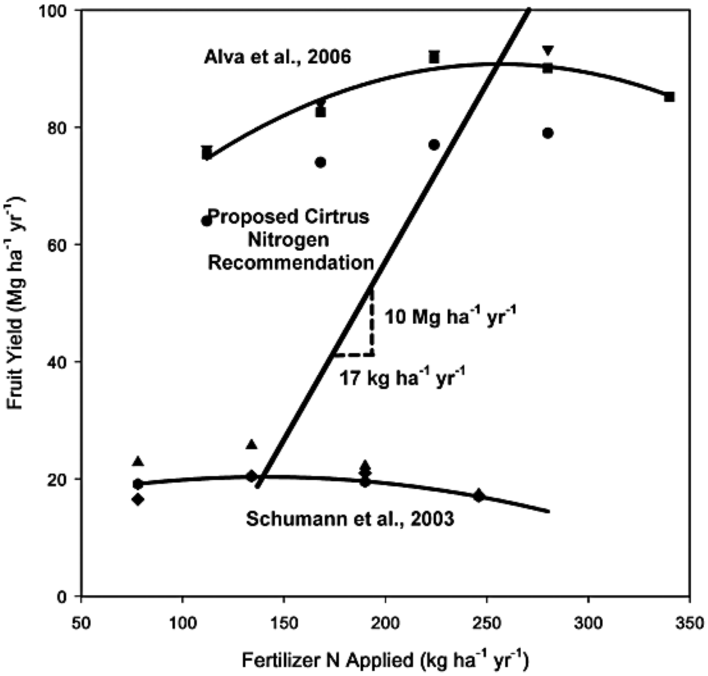

Fig. 1. Fruit yield as a function of fertilizer N applied to mature citrus trees in Central Florida. Alva et al., 2006 application rates were 112, 168, 224, 280, and 360 kg N / ha·yr^{-1} as dry granular (■), fertigation (▼), and controlled release (●). Schumann et al., applied N at 78, 134, 190, and 246 kg·ha^{-1}·yr^{-1} as dry granular (*), fertigation (▲), and controlled release (◆). Proposed orange N fertilizer recommendation is a linear regression between the inflection point data points in Schumann et al., 2003 (140 kg·ha^{-1}·yr^{-1}) and those in Alva et al., 2006 (260 kg·ha^{-1}·yr^{-1}).

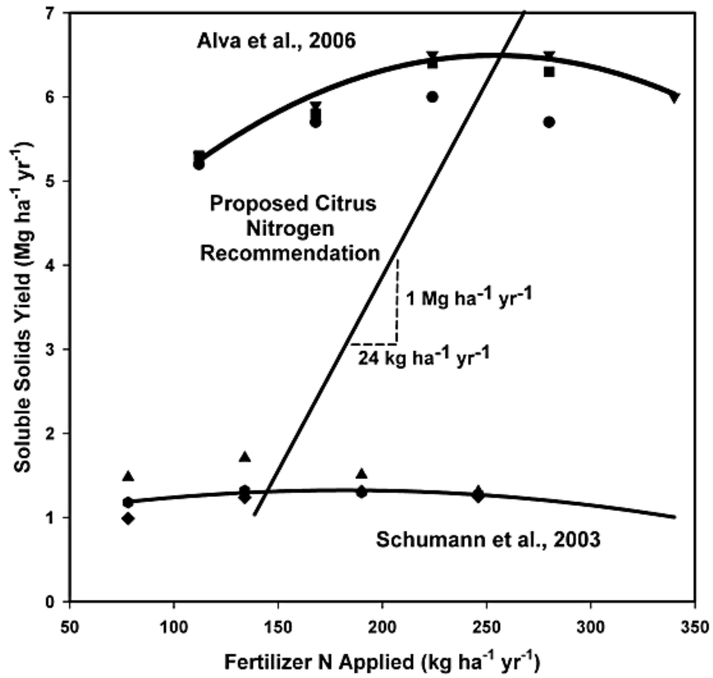

Fig. 2. Soluble solids yield as a function of fertilizer N applied to mature citrus trees in Central Florida. Alva et al., 2006 application rates were 112, 168, 224, 280, and 360 kg N / ha·yr^{-1} as dry granular (■), fertigation (▼), and controlled release (●). Schumann et al., applied N at 78, 134, 190, and 246 kg·ha^{-1}·yr^{-1} as dry granular (*), fertigation (▲), and controlled release (◆). Proposed orange N fertilizer recommendation is a linear regression between the inflection point data points in Schumann et al., 2003 (140 kg·ha^{-1}·yr^{-1}) and those in Alva et al., 2006 (260 kg·ha^{-1}·yr^{-1}).

Mg·ha^{-1}·yr^{-1} of fruit yield over the 20 Mg·ha^{-1}·yr^{-1}. The maximum annual N rate would be 270 kg·ha^{-1} for groves producing 100 or more Mg·ha^{-1}·yr^{-1} fruit yields.

A similar recommendation based on soluble solids production can also be made (Fig. 2). Growers with soluble solids yield of 1.3 Mg·ha^{-1}·yr^{-1} would apply N at a rate of 140 kg·ha^{-1}·yr^{-1}. Those growers producing more solids would apply additional N at 24 kg·ha^{-1}·yr^{-1} for each additional 1 Mg·ha^{-1}·yr^{-1} of soluble solids production to maximum N rate of 270 kg·ha^{-1}·yr^{-1}.

This N fertilizer recommendation will provide citrus growers with needed guidance to interpret the current recommendation (Tucker et al., 1995) of 134 to 224 kg·ha^{-1}·yr^{-1} and stay within the limits set in the Ridge citrus BMP. The previous N fertilizer recommendation (Koo et al., 1984) set a minimum annual N rate of 112 kg·ha^{-1}·yr^{-1} with the addition of 18 kg·ha^{-1}·yr^{-1} per 10 Mg·ha^{-1}·yr^{-1} fruit yield. The proposed N fertilizer recommendation is slightly greater than the fruit nitrogen content of 14 kg·10 Mg^{-1} (Alva and Paramasivam, 1998), and would thus provide additional N for maintenance of tree biomass. A five year average yield of 50 Mg·ha^{-1}·yr^{-1} would require an N fertilizer rate of 191 kg·ha^{-1}·yr^{-1} with a fruit N efficiency of 37% (example 1). Likewise, the recommendation for a grove with a five year average yield of 80 Mg·ha^{-1}·y^{-1} would be 242 kg·ha^{-1} of N fertilizer and have a fruit N efficiency of 45% (example 2). These recommendations are well within the range of published N uptake efficiencies for citrus (Feigenbaum et al., 1987; Lea-Cox and Syvertsen, 1996; Mattos et al., 2003; Syvertsen and Smith, 1996) even when additional N for biomass maintenance is added to the amount removed by the fruit crop. The previous N fertilizer recommendation was similar to the new proposed recommendation. Thus, the new recommendation provides citrus growers better nutrition application guidance and keep them compliant with current BMPs.

Example 1—Five year average production = 50 Mg ha^{-1} yr^{-1}

$$191\ \text{kg·ha}^{-1}\text{·yr}^{-1} = 140\ \text{kg ha}^{-1}\ \text{yr}^{-1} + \frac{50\ \text{Mg ha}^{-1}\ \text{yr}^{-1} - 20\ \text{Mg ha}^{-1}\ \text{yr}^{-1}}{10} * 17\ \text{kg Mg}^{-1}\ \text{yr}^{-1}$$

Example 2—Five year average production = 80 Mg ha^{-1} yr^{-1}

$$242\ \text{kg ha}^{-1}\ \text{yr}^{-1} = 140\ \text{kg ha}^{-1}\ \text{yr}^{-1} + \frac{80\ \text{Mg ha}^{-1}\ \text{yr}^{-1} - 20\ \text{Mg ha}^{-1}\ \text{yr}^{-1}}{10} * 17\ \text{kg Mg}^{-1}\ \text{yr}^{-1}$$

Mature Grapefruit Tree N Rate Studies

Futch and Alva (1994) applied N at 168, 224, and 275 kg·ha^{-1}·yr^{-1} for 3 years and found that rates greater than 168 kg·ha^{-1}·yr^{-1} should not be applied to mature grapefruit. Current N rate recommendation for grapefruit production (Tucker et al., 1995) is a range from 134 to 179 kg·ha^{-1}·yr^{-1}. He et al. (2003) conducted an N rate study (0, 56, 112, 168, and 224 kg·ha^{-1}·yr^{-1}) near Fort Pierce, Fla. Yields increased with fertilizer N rate, but did not decrease with higher application rates as did oranges (Alva et al., 2003; Schumann et al., 2003). Unlike oranges, most grapefruit produced in Florida are sold on the fresh market, thus size is an important factor in crop price. He et al. (2003) found that fruit size increased to a maximum at an N application rate of approximately 110 $kg \cdot ha^{-1} \cdot yr^{-1}$ and then declined, indicating that higher yield with increased N rate was obtained by producing larger numbers of smaller fruit. No yield based N recommendation can be established using these results, but indicate that the current N application range is appropriate.

Leaf Tissue Analysis

Leaf tissue testing is a valuable tool to examine the tree nutritional status, particularly with respect to mobile nutrients such as N and K (Obreza et al., 1992). The interpretation of leaf tissue mineral analysis depends on the physiological stage of leaves that are sampled for analysis, leaf decontamination procedure, and analytical methods (Tucker et al., 1995). For Florida citrus, the recommended plant tissue for mineral analysis is 4-6 month-old spring flush leaves form non-fruiting twigs (Koo and Sites, 1956; Koo et al., 1984; Smith, 1966). The current recommendations and guidelines for interpretations of mineral concentrations in 4-6 month-old spring flush leaves of citrus trees are published elsewhere (Koo et al., 1984; Tucker et al., 1995). Recent N application rate and yield studies on oranges (Alva et al., 2003; Paramasivam et al., 2000) and grapefruit (Boman, 1993; He et al., 2003) have reinforced the optimal leaf N concentration ranges for citrus production found in these recommendations and guidelines.

Conclusion

It has been shown that a relationship exists between annual N applications, yields of orange fruit and soluble solids. The range of annual N application rates recommended in this paper are based on experimental results found in the literature and agree closely with two previous recommendations. However, the N recommendation in this paper for mature citrus based on a five year average fruit or soluble solids yield would provide the citrus growers of Florida with a better interpretation of current recommendations and sustain their current yields. The yield-based recommendations would also fulfill the grower's obligations under current BMPs to reduce environmental impact on water quality. Unlike oranges, additional studies on the effects of N rate on grapefruit quality and yield are needed to provide a similar yield- or size-based N rate recommendation.

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