VARIABLE RATE NITROGEN APPLICATION IN FLORIDA CITRUS BASED ON ULTRASONICALLY-SENSED TREE SIZE

Q. U. Zaman, A. W. Schumann, W. M. Miller

ABSTRACT. *Most Florida citrus groves are still managed as large contiguous uniform blocks, despite significant variation in fruit yield and tree canopy size. Site-specific grove management by variable rate delivery of inputs such as fertilizers on a tree size basis could improve horticultural profitability and environmental protection. Tree canopy sizes were measured real-time in a typical 17-ha Valencia grove with an automated ultrasonic sensor system equipped with Differential Global Positioning System (DGPS). Prescription maps for variable application of nitrogen fertilizer were generated from ultrasonically scanned tree sizes on a single tree basis using ArcView GIS and Midtech Fieldware. Leaf samples from trees with different canopy sizes, which had been fertilized at a conventional uniform rate of 270 kg N/ha/y, were analyzed for nitrogen concentration. Analysis of 2980 tree spaces in the grove showed a skewed size distribution, with 62% in the 0- to 100-m^3/tree volume classes and a median volume of 79 m^3/tree. The tree volumes ranged from 0 to 240 m^3/tree. Regression analysis showed that trees with excess leaf nitrogen (>3%) had canopies less than 100 m^3. These trees receiving excess nitrogen are likely to have lower fruit yields and quality, and wasted fertilizer nitrates may leach beyond the root zone to groundwater. In order to rectify the excess fertilization of smaller trees, a granular fertilizer spreader with hydraulically powered split−chain outputs controlled with a MidTech Legacy 6000 controller was used for variable rate application of nitrogen in one−half of the grove. A 38% to 40% saving in granular fertilizer cost was achieved for this grove when variable N rates were implemented on a per-tree basis ranging from 135 to 270 kg N/ha/y.*

Keywords. *Precision agriculture, Ultrasonic sensors, Prescription map, DGPS, GIS.*

The mobility of nitrates in deep, sandy, infertile, and low-organic matter soil of Florida's Ridge region combined with a high (~1300 mm/y) annual rainfall (NRCS, 2001) makes any excess residual N vulnerable to leaching. Most Florida growers apply N on an average basis without considering the internal variation within a grove, mainly in tree canopy size. The cause of tree size variability in groves is repeated resetting over many years due to tree loss from freezes and disease. Other factors such as soil series and rootstock can also modify tree size and therefore N consumption is only partially dependent on age. The uniform application of N, based on tree age (FDACS, 2002; Tucker et al., 1995), may not match with the requirement of individual trees and result in over- or under-application. Local over-fertilization may pollute ground water, reduce profit margins, and induce deficiency of other elements and also decrease yield (Schumann et al., 2003). It is expected that site-specific application of N on a per tree basis would improve horticultural profitability and eliminate prolonged nitrate excesses in the root zone which can potentially leach to ground water. Therefore, it is important to measure and map tree sizes in variable groves to produce prescription maps for the site-specific application of N on a single tree basis.

Manual tree size measurement using several tree dimensions (Albrigo, 1975; Wheaton et al., 1995) is laborious and time consuming. Ultrasonic sensors can be used to quantify tree canopy volumes reliably and rapidly (Roper, 1988; Giles et al., 1988; Tumbo et al., 2002; Zaman and Salyani, 2004). Schumann and Zaman (2005) developed and evaluated a Windows software application for a Durand-Wayland ultrasonic tree size measurement system and Trimble AgGPS132 DGPS (Differential Global Positioning System) that could allow reliable real-time sensing, monitoring, calculation, storage, and mapping of citrus tree canopy volume and height in the grove. Therefore, ultrasonically sensed data on tree sizes in citrus groves could be used to generate GPS-guided prescription maps for variable rate delivery of N based on a single tree volume using a variable rate fertilizer spreader.

Variable rate fertilization is one of the useful nitrate-conserving fertilization techniques available for Florida spatially variable ridge groves and is available as standard commercial equipment for handling dry granular fertilizer (Miller et al., 2003a; Schumann, 2003). Miller et al. (2003a; 2003b) tested a variable rate granular fertilizer spreader with both GPS-guided prescription mapping and real-time tree size measurement with photoelectric sensors in citrus groves. The variable rate fertilizer unit performed well for site-specific fertilizer application to large-scale variability within a grove. As a result, technological barriers to managing groves with variable rate fertilization have largely been overcome. The objectives of this study were:

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- To measure and map tree canopy volume real-time in a commercial grove with an automated ultrasonic sensor system.
- To apply variable rate N on a single tree canopy volume basis using a GPS-guided prescription map, produced from ultrasonic canopy volume for the improvement of horticultural profitability and environmental protection.

METHODOLOGY

GROVE HISTORY

An experiment for variable-rate application (VRT) of nitrogen (N) was initiated in a commercial citrus grove (Gapway Groves, Auburndale Fla.) near Fort Meade, Polk County, Florida (27.74789°N, 81.69509°W) in 2003. The 17.0-ha grove was planted with >40-year-old 'Valencia' sweet oranges [*Citrus sinensis* (L.) Osb.] on Carrizo citrange (*Poncirus trifoliate* × *C. sinensis*) rootstock. The tree spacing was 10.7 × 5.3 m and tree canopies were not topped or hedged at the time of measurement. The soil type in the grove was Candler sand. Ground inspection revealed that there was large spatial variability in tree canopy sizes within the grove. The cause of tree size variability in this grove is repeated resetting over many years due to tree loss from freezes and disease (Strang, 2004).

ULTRASONIC TREE VOLUME MEASUREMENTS

Each tree canopy volume was measured with an automated ultrasonic system (Durand-Wayland, Inc., Lagrange, Ga.) equipped with a Trimble AgGPS132 DGPS (Trimble Navigation Limited, Sunnyvale, Calif.) using Coast Guard beacon correction June, 2003. The system consisted of a microprocessor controlling 10 ultrasonic sensors that were mounted on a vertical mast. The mast was mounted on a custom trailer that was hitched behind a pickup truck. The system was moved at the average ground speed of 1.3 m/s to get adequate vertical and horizontal samples per tree. The technical design of the system (hardware and software) and detailed procedure for the measurement and mapping of tree volume real-time in a grove was reported earlier in Schumann and Zaman (2004). A comprehensive survey of the grove was conducted again in September 2004 (after hurricanes) to measure and map tree sizes with ultrasonic system.

LEAF NITROGEN ANALYSIS

Twelve trees with different canopy sizes (four trees in each of small, medium, and large tree size classes) were selected randomly to collect leaf samples for nitrogen concentration measurement to examine the nitrogen level in different tree sizes. Four-month old (mature) spring-flush leaf samples from non-bearing branches were collected during July from each tree according to procedures described by Obreza et al. (1992). Leaves were washed, dried at 70°C for 48 h and ground to pass a 0.38-mm sieve. Leaf N was determined by the Kjeldahl method (Obreza et al., 1992).

VARIABLE RATE APPLICATION OF NITROGEN

A prescription map for VRT fertilization was generated on the basis of ultrasonically sensed tree canopy volume (UVs) and dividing the grove into five tree size classes. The prescription map was revised based on the September 2004 ultrasonic survey before October fertilization. The highest N rate, equal to the grower's previous uniform rate (270 kg/ha/y), was allocated to the largest size class, and the remaining four classes received diminishing amounts of N down to a minimum of 50% of the maximum (236, 202, 168, 135 kg/ha/y). Resets (one to two years age) received no fertilizer through VRT spreading but were fertilized individually (25.6 kg N/ha/y) by hand (FDACS, 2002; Tucker et al., 1995), assuring that the granules are accurately placed adjacent to the tree. For comparison purposes, the eastern half of the grove received the full uniform grower's rate of 270 kg N/ha/y. Fertilizer was applied in four equal splits during the dry part of the year, 2004 using different fertilizer materials. However, the delivered amount of N was the same in each fertilizer application. The granular fertilizer material ($N:P_2O_5:K_2O$, 10:00:12) was used in February. The fertilizer material ($N:P_2O_5:K_2O$, 15:00:17) was delivered in April, May, and October and was used to calculate the difference between VRT and uniform fertilization for this study. The difference in overall fertilizer material amounts, target (calculated from prescription maps) versus as-applied (calculated from Mid-tech controller data logger) were calculated for all fertilizer applications. Five fertilizer rates were derived assuming a linear relationship between tree canopy volume and N requirement.

A granular fertilizer spreader (M&D, Arcadia, Fla.) equipped with a control package (Chemical Containers, Lake Wales, Fla.) was utilized to apply five fertilizer rates in the grove. A MidTech Legacy 6000 controller and radar speed sensor (Midwest Technologies; Springfield, Ill.), 10-Hz Trimble AgGPS132 (Trimble; Sunnyvale, Calif.), six Banner QMT42 long-range diffuse photocells (Banner Engineering, Minneapolis, Minn.) to detect tree canopy on each side of the spreader and a switch box (Chemical Containers, Lake Wales, Fla.) comprised the main control elements external to the fertilizer unit. The unit was equipped with modulating hydraulic control valves, positioned by a 12-V signal, to

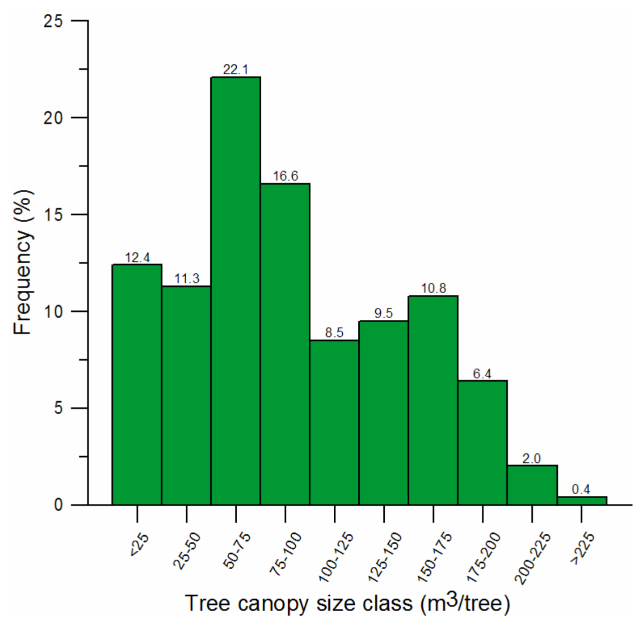

Figure 1. Tree canopy size distribution determined with ultrasonic sensors for the 2980 trees in the grove.

regulate chain speed for left and right side discharge. Miller et al. (2003b) described the procedure for VRT fertilization using a GPS-based prescription map with the variable-rate dry fertilizer spreader (VRT spreader).

Data Analysis

The linear regression method was used to find the relationship between N concentration and UVs of selected trees with Genstat statistical software (Genstat 5, Lawes Agricultural Trust, Rothamsted, UK). Tree volume data were analyzed to produce a histogram frequency distribution of different tree size classes in the entire grove using Genstat software. Student's paired t-test was performed to test whether the target fertilizer rates were significantly different from the as-applied fertilizer rates for all fertilizer applications. The survey data files of DGPS and UVs, were imported into ArcView GIS software (ESRI, Redlands, Calif.) to map each tree canopy volume. Prescription maps were generated from ultrasonically scanned tree sizes on a single tree volume basis for variable rate application of N using ArcView GIS and Midtech Fieldware (Midwest Technologies; Springfield, Ill.) These maps were in a format readable by the VRT spreader system (Midtech Fieldware).

Results and Discussion

Analysis of the 2980 tree spaces in the grove showed a skewed distribution, with 62% in the 0 to 100 m^3/tree size classes and a median size of 79 m^3/tree (fig. 1). Ten percent of the grove area contained resets (volume < 4.0 m^3), which were hand fertilized.

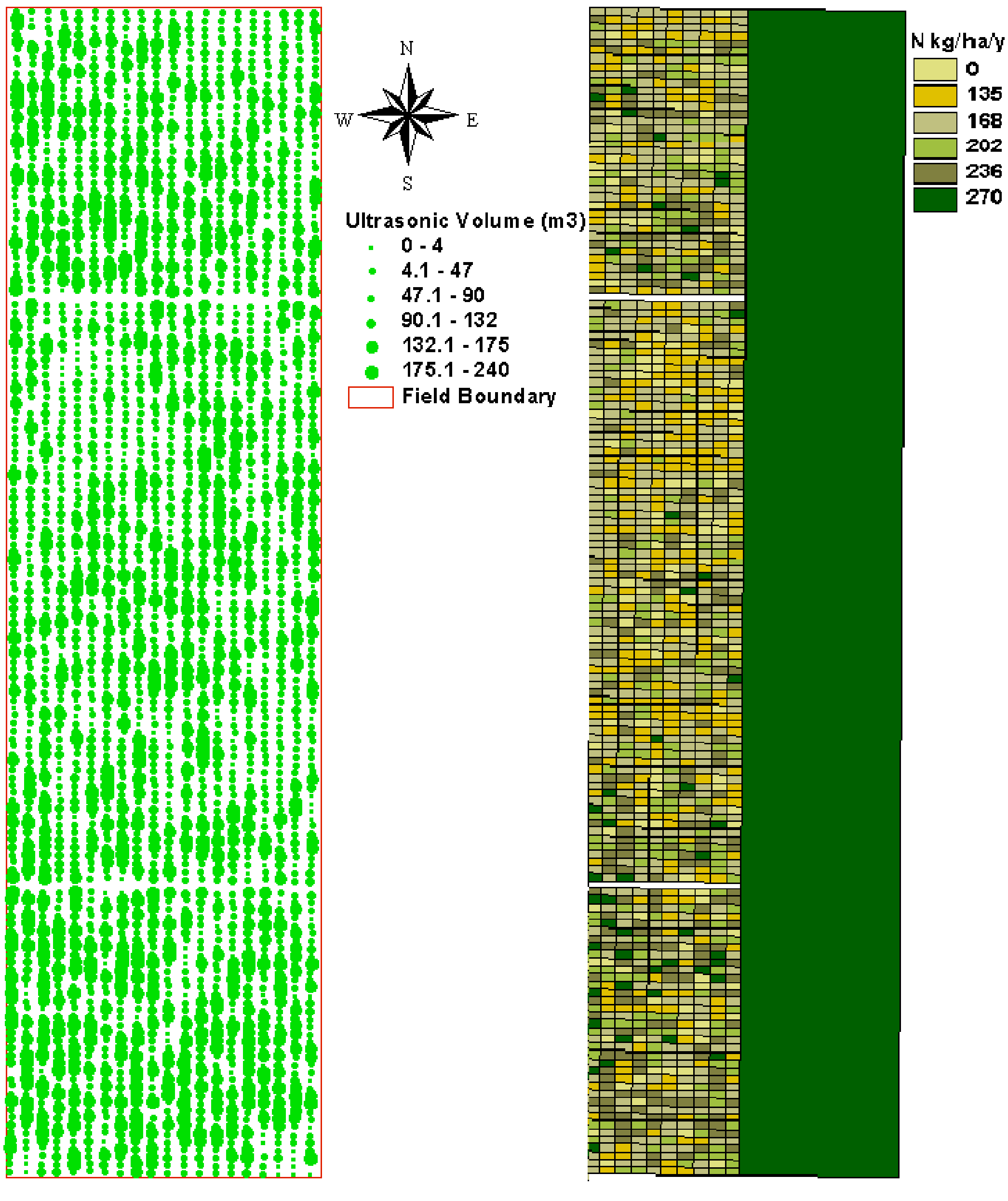

Figure 2. (a) Ultrasonic volume of each tree and (b) prescription map of the grove showing variable N rates developed for different tree sizes in the western half of the experimental area.

Tree canopy volumes were measured and georeferenced real-time, at a mean speed of 1.3 m/s, taking 4 h to complete the survey of 17.0 ha (~4.25 ha/h). The UVs varied from 0 to 240 m^3. The reason for large tree size variation was repeated resetting over many years due to tree loss from freezes and disease in the grove (Strang, 2004). The substantial variation in tree sizes within the whole grove (fig. 2a), emphasized the need for real-time tree size measurement and mapping using the automated ultrasonic system for the accurate variable application of agrochemicals within the grove.

At a uniform fertilization rate of 270 kg N/ha/y, the leaf N concentration of 12 trees with different canopy volumes showed optimal levels in the large trees and excess levels (>3%; Tucker et al., 1995) in most of the medium to small trees (fig. 3). The trees with excess N had canopies <100 m^3/tree and constituted 62% of the entire grove (figs. 1 and 3). Trees receiving excess nitrogen generally have lower fruit yield and quality, increased production cost and nitrate leaching (Schumann et al., 2003). Nitrogen Best Management Practices (N-BMPs) have been implemented throughout the state for judicious N fertilizer application to reduce contamination of the soil through nitrate leaching and to optimize the fruit production. These fertilizer guidelines are calendar-based, indicating upper N limits for generalized average tree ages only. The results of this study indicated that N rates should be calculated considering tree sizes because many extraneous factors (e.g., rootstock, soil series) can modify tree size and therefore N consumption is only partially dependent on age. For example, an invigorating rootstock may outgrow a standard rootstock by 100% at age 5 y, and by 25% at age 10 y (Castle, 2004). However, the main cause of tree size variability in this grove is repeated resetting over many years due to tree loss from freezes and disease.

The applied VRT rates of N were less than a uniform rate for each class except the largest tree size class. The variable rate application of N on a per-tree basis, ranging from 135 to 270 kg/ha/y reduced granular fertilizer consumption by 38% (fig. 2b; table 1). No fertilizer was provided with the spreader to skips or resets of one-to-two years of age. The resets received only 21.2 kg N/y with VRT, while the conventional method provided 223.6 kg N/y (table 1). Similarly, each class received excess N with the conventional method except the largest tree size class. Less fertilizer material was applied in October 2004 (fig. 4). The reason is that trees were damaged by the hurricanes and some completely damaged trees were removed from the grove. Consequently, VRT fertilization saved 40% fertilizer as compared to the conventional method in October. Ground inspections revealed that N rates assigned to each tree in the prescription map matched with each tree UV in the grove. The difference in overall fertilizer material amounts, target versus as-applied by VRT spreader was negligible (0.13% to 1.63%) for all fertilizer applications. The t-test results indicated no significant differences between target and as-applied rates. Hence, this study confirms the VRT spreader is able to apply different N rates using a GPS-guided prescription map in citrus groves. The application of fertilizer through VRT shows the potential to match the 32% to 43% rate reductions that were needed in previous N-BMP studies to lower groundwater nitrate concentration to acceptable levels (Lamb et al., 1999).

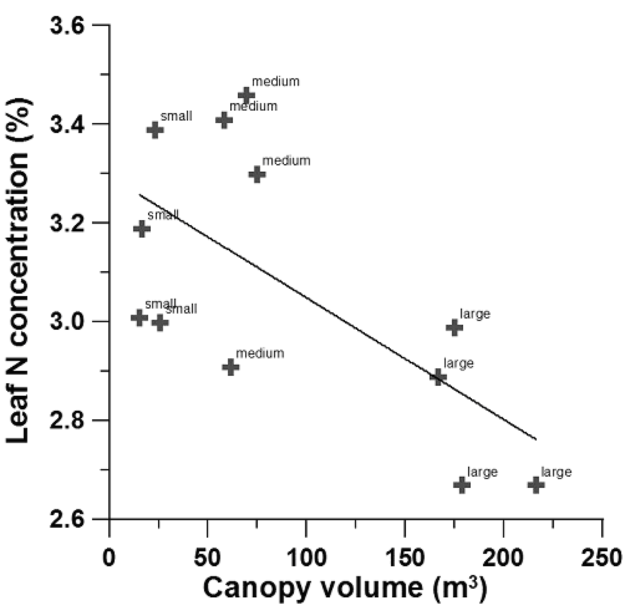

Figure 3. Leaf N concentrations of different size trees fertilized with granular fertilizer at a uniform rate of 270 kg N/ha/y.

CONCLUSIONS

The following conclusions can be made based upon the initial results of this experiment:

- The substantial variation in tree canopy volume (0 to 240 m^3) and the excess levels of N in the medium to small trees within the grove emphasize the need for variable rate application of N on a single tree basis.
- The tree sizes can be measured real-time and mapped with an automated ultrasonic system to generate prescription maps for the accurate application of agrochemicals based on single tree canopy volumes within the grove.
- The VRT spreader with hydraulically powered split-chain outputs controlled from a MidTech Legacy 6000 controller could be used for VRT fertilization on a per tree canopy volume basis.
- In this study, VRT fertilization saved 38% to 40% fertilizer as compared to the grower's uniform rate of 270 kg N/ha/y. Therefore, VRT fertilization could be one of the most

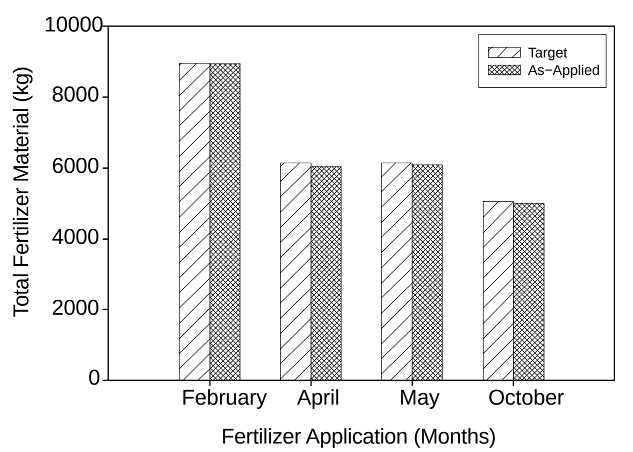

Figure 4. Difference between target and as-applied fertilizer materials at variable rate fertilizer applications.

Table 1. Amount of N required based on VRT compared with the grower's previous uniform fertilization in the western half of the grove.

	VRT			Uniform		
Area (ha)	Classes, Tree Vol. (m^3)	N Rate (kg/ha/y)	Total N Required (kg)	N Rate (kg/ha/y)	Total N Required (kg)	Total Difference N (kg)
0.83	0-4 (by hand)	25.6	21.2	269.5	223.6	202.4
1.74	4.1-47	134.7	234.4	269.5	468.8	234.4
3.02	47.1-90	168.4	508.6	269.5	813.7	305.1
1.22	90.1-132	202.1	246.7	269.5	328.7	82.2
1.40	132.1-175	235.8	330.2	269.5	377.2	47.1
0.28	>175	269.5	75.5	269.5	75.5	0.00
Total			1416.4		2287.6	871.2

powerful assets for enhancing the performance of the Ridge Citrus N-BMPs in Florida, both economically and environmentally by avoiding over-fertilization on each tree rather than on an entire averaged grove.

Future Research

This study is continuing and we will be collecting harvest data, and soil leachate samples are being collected from 36 vacuum lysimeters from 18 paired plots (six trees in each of small, medium, and large size classes of VRT and uniform side). Nitrate analysis of these samples will allow a comparison of potential impacts that VRT or uniform fertilization have on the ground water. Leaf samples are being collected in July and before every fertilization from selected trees to analyze the leaf nutrient status under VRT and uniform fertilization. Tree canopy growth will be estimated by an ultrasonic system. Fruit yield will be mapped and fruit samples from selected trees can be analyzed for N content and standard juice quality parameters. The tree canopy volume will be measured real-time and mapped every year using the ultrasonic system to generate prescription maps for VRT fertilization.

Similar studies in other commercial groves are needed to develop general recommendations for optimal N rates per tree size basis, not only by tree age. In addition, a range of measured and calculated tree size variables (canopy height, maximum diameter, canopy volume, bearing canopy volume, canopy ground area, and cross-sectional canopy area) will be established and their ability to predict the correct fertilizer rate will be tested by regression.

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