

Evaluating Variable Rate Fertilizer Technologies In Florida Citrus

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Executive Summary

Optimum application of nitrogen (N) is a major concern in Florida citrus production from an environmental and economic standpoint. Environmentally mitigating nitrate contamination is a principal concern while reduced fertilizer usage would enhance grower returns. Nitrogen rates and yield are generally correlated with a standard recommendation being 0.3 to 0.4 lb/FL field box (3.3 to 4.5 kg/Mt). However, such a recommendation does not take into account varietal and rootstock selection, tree age, missing trees, resets, unhealthy trees or spatial variability due to soil type, water table levels, etc. With Florida citrus grown in the Interior Ridge area, both the number of N applications and their timing within the year are critical. This research reports on evaluation techniques to ascertain the merits of variable rate technologies (VRT) for dry fertilizer application. Techniques to evaluate both real-time sensing and differential global positioning system (DGPS) map-based applications have been developed and initial results are reported. Standard test procedures were developed to evaluate dry fertilizer spreaders with various sensors and hydraulic-mechanical components that influence accuracy and response time. A large field plot test was undertaken to determine problems in actual grove applications and to make mass balance comparisons. Fertilizer target levels were compared to as-applied rates determined from integrated controller values and independent weighing of the fertilizer spreader unit.

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Introduction

Developing precise application technology to apply fertilizer to Florida citrus is essential for optimal economic return and to mitigate groundwater contamination. Nutrient management plans are being

researched that will require spatially variable application rates dependent upon variety and rootstock combinations and the soil type and its properties. Such overall production block information must be coupled with individual tree space allocations consisting of either producing trees, small resets or spaces where unproductive trees recently have been removed. Fertilizer timing throughout the year is important also. At present, tree fruit industries are in the initial stages of adopting VRT (variable-rate technologies) and questions have been raised about the accuracy and economic payback for such systems. The research reported herein has been directed toward developing test protocols to evaluate VRT granular fertilizer applications and to provide data to ascertain the economic potential/environmental impact of such technologies in Florida's Ridge citrus production area.

Some test programs for granular fertilizer applications have been developed and formulated to an ASAE Standard S341.3 "Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcast Spreaders" (ASAE, 1999). However, since the standard is directed toward uniform broadcast applications, spatial variability caused by VRT control is not addressed. An example would be in the total shut-off of fertilizer output when encountering tree skips within a tree row. This expands the required analysis into a two dimensional problem. Also, whether to use real-time control or GIS application map technology or both remains in question. Management-based data generation, engineering constraints and capital costs vary significantly among proposed systems for granular applicators in tree crops. Rund (1997) has proposed that site-specific technologies be based on multiple criteria that include availability, longevity/obsolescence, durability, compatibility, field tested, flexibility, upgradeability, performance, accuracy, cost, user friendliness, training, support, repair service, return on investment. Criteria with direct relationship to fruit yield and environmental concerns are field testing, plus accuracy and precision of the application.

Mechanical performance of broadcast spreaders has been studied by Parish (2002a, 2002b) and Parish and Chaney (1986). They analyzed drop point, PTO speed and impeller/spout height. Real-time control through optical sensing of plant vigor was proposed for agronomic crops by Needham et al. (2002). Clark (1996) proposed VRT fertilizer and lime application as part of a precision agriculture program. Sensor systems, both optical laser and ultrasonic were investigated by Kataoka et al. (2002) to measure cotton crop height. A comprehensive reference listing of VRT applications appears at the end of this report. However, cited GPS/GIS literature, especially VRT pertinent to tree crops, is quite limited.

A general review of potential applications for tree crops was compiled by Righetti (1997). Miller and Whitney (1999) have investigated citrus yield monitoring, both on mass and volume measurements. Tumbo et al. (2002) reported on an automatic triggering system for yield monitoring and picker productivity record-keeping. Scholberg et al. (2000) have pointed out the need on integrating dry fertilizer applications with water management practices. They suggested modified practice such as fertigation, controlled release materials, foliar applications and tensiometer-based irrigation scheduling. With such additional technologies and management practices, the need for optimal dry fertilizer applications is enhanced.

Objectives

This report details initial studies to:

- 1) Develop a test system and protocol for VRT dry fertilizer applications to tree crops, in particular citrus.
- 2) Measure pertinent variables associated with mechanical performance of VRT fertilizer units.
- 3) Describe variability found in initial standard tests and field trials.

Materials and Methods

After a review of standards for granular fertilizer applicators, a modified pan collection system was developed to accommodate features unique to VRT tree crop applications. Two inherent features not addressed in the ASAE standards were the dynamic rate changes in output levels and shifting levels of side-to-side output rates. The ASAE S341.3 standard was developed for broadcast spreaders but is based on a) uniform output with travel speed (nominal 5mph (8 km/h)) and b) collection uniformity about the centerline of the applicator.

A test track (Fig. 1) was laid out at the Citrus Research & Education Center, Lake Alfred, FL. Two sections of a black landscape material, 100% polypropylene with 2% carbon black UV inhibitor, were anchored into the ground and marked to uniformly space collection trays. Square collection trays of 12 in. (30 cm) length were fabricated from galvanized sheet metal. Their height was 2 in. (5.0 cm) with equally spaced dividers of the same height added to form 9 compartments. A rough-top belting was added to the bottom of each tray to minimizing bouncing of any fertilizer granules from the trays. For testing photocells, ultrasonics or other sensor techniques that detect and provide real-time control of fertilizer output, a vertical canvas section was positioned alongside the guide path of the tractor-fertilizer unit.

Initial tests were performed to test the dynamic response of one VRT dry fertilizer unit (M&D Spreaders-DeSota Machine, Arcadia, FL) equipped with split-chain output, photocell canopy sensors, DGPS capability and modulating hydraulic flow control. The control system was provided through a second vendor (Chemical Containers, Lake Wales, FL). The controller was a CAN based unit (Legacy 6000, Midwest Technologies, Springfield, IL) with inputs of radar-based ground speed, gearbox encoder pulses representative of chain belt speeds and digital control through photocell sensing (3 per side). The infrared photoelectric sensors (Model QMT42, Banner Engineering, Minneapolis, MN) had a maximum range of 7.2 m (Table 1). The fertilizer output rate was modulated through servo valves controlling hydraulic fluid flowrates to separate hydraulically driven gearboxes associated with each discharge side. Spinner rotation speeds, checked with an optical tachometer, were adjusted via manual valve control. Only one adjustment was necessary as the spinner hydraulic motors operated in series. The spinner discharge was enclosed in a rectangular stainless steel section to condense the output patterns.

Table 1. Maximum measurable distance for Banner QMT 42 photocell unit (value from manufacturer: 6 m for white target).

Target	Background light level (lux)	Max. distance (m)
Black felt	432	2.39
	388	2.26
	34	2.05
Green baize	449	6.6
	392	6.6
	42	6.6
White paper	422	7.2
	421	7.2
	14	7.2

A nominal ground speed of either 3 or 4 mph (4.8 to 6.4 km/h) was selected for the first set of tests. Generalized data on the output rate was collected based on pulse count of the gearbox with 1 revolution equal to 67 pulses. Additionally, background data were collected regarding spinner speed and aerodynamic enhancement (Table 2). To estimate spinner maximum throw distance, a MathCad computer program was written (Appendix I). A general data sheet was developed for the test track testing and is included as Appendix II.

Table 2. Calculated tangential velocity and measured airflow associated with various operating spinner speeds.

Spinner rot. Speed (rpm)	Tangential velocity, ft/min (m/min)	Measured air output, cfm (m ³ /s)
450	2709 (13.76)	428 (0.20)
600	3612 (18.35)	563 (0.27)
750	4515 (22.94)	678 (0.32)

To pursue the VRT dry fertilizer feasibility, a large trial was conducted at a commercial site. At that location (Gapway Groves, Ft. Meade, FL), a project is being conducted to evaluate nitrogen application levels and frequencies with respect to nitrate leaching. In this situation, the application rate was controlled by DGPS determined location and a prescription map setpoint. Prescription maps were generated in

ArcView (ESRI, Redlands, CA) and downloaded into the MidTech controller (Appendix IV). A conversion to an application rate management (.arm) file was required as an intermediate step using MidTech's Fieldware software. A 10 Hz DGPS system (Trimble 132, Sunnyvale, CA) was added as an additional input into the Legacy 6000 controller. The rates, as determined from the controller, were compared to initial and final weighings of the fertilizer spreader and known quantities of fertilizer provided for application.

Initial Results and Discussion

Distribution

Maximum discharge distances are governed by spinner speed, supplemental air velocity and particle characteristics of the fertilizer. Broadcast spinner speed and the air velocity are related for the enclosed discharge units that direct the fertilizer pattern. The relationship between spinner speed and air velocity for the M&D unit tested was somewhat linear for the range tested, 450 to 750 rev/min (Table 2). Average airflow rate associated with the enclosed spinner was 428 cfm (450 r/min), 563 cfm (600 r/min) and 678 cfm (700 r/min). Using the MathCad program (Appendix I), projected maximum particle distances are 4.5 m at 450 r/min and 7.6 m at 750 r/min.

Time to achieve steady-state conditions in changing the controller from 0 to half-scale was measured in stationary tests. The controller initially was programmed for a 2 sec delay but was reprogrammed for minimal delay which was ~ 0.1 sec. Settling time for the controller was ~ 4 sec. With these inherent time delays, initial plot tests conducted at 3 mph (4.8 km/h) to 4 mph (6.4 km/h) translated to 18 ft (5.5m) at 3 mph and 24 ft (7.3 m) at 4 mph for a 4.1 sec delay.

Initial test results for a typical setpoint changes are plotted in Figs. 3a-d. Preset controller rates were 250 lb/A (280 kg/hectare) for a low rate and 500 lb/A (560 kg/hectare) for a high rate. Transitional results in attaining both low and high rates are shown in Figs. 3a and 3c while responses in turning off the controller are plotted as Figs. 3b and 3d. System response was typically 9 to 12 ft (2.7 to 3.7 m) which corresponded with the initial stationary trials. Actual values were somewhat less but it was noted that the fertilizer pattern projects both behind and ahead of the spinner discharge opening. The falling transition (i.e., to zero output) was quicker than the zero to low or high operating states. This probably occurred as the controller required minimal settling for a zero state operating condition. Another factor may be spillage from the conveyor belts. With any spillage from the rear of the belt discharge, time for full load discharge is extended.

To further validate overall time lags of the system, an additional encoder circuit has been designed to measure pulse rate of the gearbox. With known values of gate height, product density, etc., the material discharge per count can be monitored (Fig. 2). The relationship followed a power law fit, $y = 1413 * x^{-1.24}$ where y represents pulses/cubic ft. and the x -axis is gate height. In future tests the encoder pulses will be recorded separately as well as DGPS information at either 5 or 10 Hz. This encoder data will serve as a direct indicator of overall response of the mechanical-hydraulic system.

Field Application

One extensive field application was undertaken using VRT control based on both position and photocell interrupt information. A prescription map for tree blocks, 6 x 6 with 12 ft (3.6 m) in row spacing and 25 ft (7.6 m) between row spacing was developed. Steps required to transform GIS data to and from the controller are summarized in Appendix IV. Rates varied from 241 to 689 lb-material/acre (270 to 772 kg/hectare). Target and actual output data from the Legacy 6000 control, with color coding for the actual output rates, are plotted in Fig. 4. Programmed rates are denoted numerically for each block with the bottom portion of the grove site receiving a constant rate of 400 lb-material/acre (448 kg/hectare). Open areas in the applied rate mapping would indicate either very small trees or blanks spots within the grove. Taking these areas into account, the applied rate followed closely the prescription rate but was consistently underestimated (Figs. 4 and 6). Figure 4 presents actual rate values and Fig. 6 is a plot of percent differences between target and actual values. Figure 5 includes comparative data for each test block.

Initial calibration of the fertilizer may have caused some of the underestimation. With higher rates, the offset reduction was greater. Therefore, the total applied rate comparisons were significantly less than those predicted by the application map. Comparisons of the prescription rate total with actual values found from scale measurements of the fertilizer spreader and values from the fertilizer company are presented in Table 3.

Table 3. Comparative values of total fertilizer applied in first trial of VRT field plot application.

Metric source	Missing tree correct (Y/N)	Total lb (kg)
Target (controller)	N	18702 (8481)
As applied (controller)	N	17667 (8012)
Target (controller)	Y	15510 (7034)
As applied (controller)	Y	14160 (6422)
Fertilizer unit (field scale)		11006 (4991)
Fertilizer comp (delivered/return)		11660 (5261)

The Legacy 6000 has an offset $\bar{x}$ and $\bar{y}$ positional feature which can be employed advantageously for these field trials. By using an offset with respect to the travel vector, different application rates may be programmed to control the left and right chain drives. With DGPS horizontal accuracy typically 3 ft (1 m) and one-half row spacing, nominally 10 ft to 12 ft (3.0 to 3.7 m) programmed as the offset, the unit can be readily programmed for different left/right application rates at plot boundaries.

Further Research

It is essential to compare various dry fertilizer units. In surveying units typically found in use for Florida citrus (Appendix III), different types of control for hydraulics and fertilizer distribution were encountered. Some units implement discrete level control, normally at 3 states, for instance 20:40:40 or 33:33:33 ratios. Pneumatic dispersal may alter the distribution pattern and the system response times greatly. To date, only preliminary comparisons have been made between real-time sensors system (photoelectric, ultrasonic, laser) versus DGPS- based spatial control. It is anticipated that the distribution pattern can have a significant effect on amount of fertilizer discharged into open areas. Conceptually, it is desirable to have a very tight pattern for tree crops where agronomic crops require a wide broadcast distribution. In Year II, extensive testing of numerous units having different design features will be undertaken. In Appendix III, major manufacturers of dry fertilizer rigs with potential interfacing to VRT control are listed. Each of the companies has been contacted about participating in a test program to be undertaken in 2003-2004.

Table 4. Budgeted Expenditure Summary (Year 1-compiled 15 January 2003)

	Projected	Actual
Salary (OPS)	30000	24750
Operating Expense (OE)	9616	8250
Capital (OCO)	8000	8000
Overhead	2387	--

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Appendix I. MathCad programs written for fertilizer rate calculations; 1-spinner throw calculation and 2-application rate.

Appendix II. Data sheet developed for collection of standard test data of VRT dry fertilizer units.

Appendix III. Dry Fertilizer Manufacturer's with VRT Capabilities.

Chandler Equipment
P.O. Box 2533
Gainesville, GA 30503
1-800-243-3319

Chemical Containers (VRT controls)
P.O. Box 1307
Lake Wales, FL 33859
863-638-1407

Conibear Equipment
P.O. Box 90215
Lakeland, FL 33804
863-858-4414

DeSoto Machine Shop (M&D, Triangle Spreaders)
2692 N.E. National Ave.
Arcadia, FL 34266
800-494-03335

GVM (Best Air Pneumatic)
374 Heidlersburg Rd.
Biglerville, PA 17307
800-345-3546
(Florida)
620 Dundee Road
Dundee, FL 33838
863-287-2201

Newton Crouch
890 E. Solomon St., P.O. Box 17
Griffin, GA 30224
770-227-1234

Appendix IV. Procedural steps to load and download files for GIS compatibility with MidTech Legacy 6000 controller.

Figure 1. Test tract layout located at Citrus Research and Education Center, Lake Alfred, FL.

Figure 2. Pulse calibration chart for VRT spreader with Rawson gearbox, 67 pulse/revolution.

Figure 4. As applied map for Ft. Meade test block, prescription rates (lb/A) are noted numerically in each block.

Figure 5. Actual and target values of field test for each application block.

Figure 6. Percent differences between actual and target values for field test (color codes represent absolute value differences based on target values).