



Implementing Advanced Citrus Production Systems in Florida—Early Results

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The advanced citrus production system (ACPS) is a short- to medium-term approach to citrus water and nutrient management now being evaluated in Florida citrus groves for sustainable, profitable citrus production in the presence of greening and canker diseases. The goal of ACPS is to compress and enhance the citrus production cycle so economic payback can be reached in fewer years to offset some of the disease losses. Early economic fruit production (producing annual net profits) should be reached in as little as 3 years, thus achieving early return on investment with its associated economic advantages. The early high yields will be achieved primarily with high-density planting and optimum nutrition and water management using computerized daily fertigation, commonly referred to as “open hydroponics.” Additionally, the production of an ACPS grove could be sustained by higher tree density (built-in redundancy) since removed diseased trees will simply be compensated for by additional growth of adjacent trees in the high density planting. Two field experiments evaluating ACPS using newly planted and mature trees are described. Descriptions include field plot layouts, automated fertigation system design, equipment selection, irrigation scheduling, monitoring, remote control, fertilizer formulations, and preliminary results from tree measurement and fruit yield. The information will be useful for growers wanting to convert citrus blocks to ACPS, and will update the research and grower community on the latest Florida-specific research results for this intensively managed production system.

The rapid spread of the citrus greening disease or huanglongbing (HLB), thought to be caused by the bacterium *Candidatus Liberibacter asiaticus*, to all Florida citrus producing counties has prompted researchers and growers to evaluate an Advanced Citrus Production System (ACPS) in order to survive the disease and remain competitive until a long-term solution is developed. Citrus canker disease caused by the bacterium *Xanthomonas axonopodis* pv. *citri* (Hasse) is also spreading rapidly in Florida. Canker causes fruit drop and results in unsalable fruit; HLB reduces fruit quantity and quality and may kill the citrus trees over a few years. Current recommendations for HLB management in Florida require the infected trees to be removed as soon as possible after detection, in order to reduce the disease inoculum which can be spread via Asian citrus psyllid insects (*Diaphorina citri*) (Brlansky et al., 2009). Therefore, the productive life time of Florida citrus groves infected with HLB and canker is being severely constrained to perhaps as short as 10 years. Thus, the economic payback period of about 12 years required with conventional management practices will be increasingly difficult to achieve. The ACPS is based on the Open Hydroponics System (OHS) already being used for intensive production of citrus and

other fruit crops in arid or winter rainfall climates, but is untested in Florida. A sustainable, profitable Florida citrus grove of the future should produce high, early yields in order to rapidly reach economic payback goals and improve disease and pest management efficiency. The ACPS could enhance citrus production and reduce abiotic stress and disease pressure by optimizing daily water and nutrient levels for trees growing on sandy soils. This system also promotes rapid canopy development by incorporating high planting densities.

The ACPS merges three main approaches for achieving early high fruit production in a short- to medium-term strategy for survival. Intensive fertigation, and balanced complete plant nutrition will be used to accelerate plant growth rates along with higher density plantings with built-in redundancy. Removed diseased trees will simply be compensated for by additional growth of adjacent trees in the high density planting and will compress and enhance the citrus production cycle so that economic payback can be reached in eight years or less. Moreover, the aim for early economic fruit production (producing annual net profits) to be reached in as little as three years, will achieve early return on investment with its associated economic advantages. Eventually when enough diseased trees have been removed to make the grove unprofitable, the whole grove will simply be replanted with new disease-free trees.

The term “open hydroponics system” was developed from the culture of large perennial crops in ordinary field soil where nutrient solution cannot be re-used as in standard hydroponics, but is still carefully controlled and monitored, while root systems are constrained by targeted fertigation in a limited soil volume. More background and details of the OHS and ACPS concepts are discussed by Stover et al. (2008) and Morgan et al. (2009). Possible limitations of using OHS successfully in Florida include the

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unique combination of sandy soils (>95% sand) and the distribution of more than half the high (~1200 mm) annual rainfall in the summer months of June to September. Root growth beyond the limited fertigation zones is a concern. In those parts of the world where OHS has been successfully deployed, the annual rainfall is usually less and predominantly occurs in winter (Mediterranean climate) so root growth can be constrained in summer.

Hydroponics advocates using balanced fertilizer formulae containing all the essential plant nutrients to optimize plant growth. Unfortunately, OHS nutrient technology has become part of the trade secrets of consultants, and publicly available research on OHS is almost non-existent. Current Florida citrus fertilizer recommendations do not advocate the routine application of most micronutrients to the soil and roots (Obreza et al., 2008b) except when warranted by deficiency symptoms in leaves. The recommended foliar sprays of micronutrients offer a temporary solution but are often too infrequent or too inefficient to completely correct micronutrient deficiencies throughout the year. In this research, the application of daily water and fertilizer requirements as a complete mixture of balanced nutrients to the root zone will be compared against the standard fertilizer practices in order to fulfill the main research objective of proof of concept for the ACPS in Florida conditions. This paper will update scientists and growers on the early results of implementing the ACPS in new field experiments.

Materials and Methods

There are currently three field experiments for evaluating the ACPS in Florida's Ridge and Flatwoods growing regions. Selected early results from the two Ridge experiments are the focus of this paper.

SOIL WETTING MEASUREMENTS. Soil volumetric water content was measured around drip emitters during a typical day of irrigation in the absence of rainfall to assess the horizontal movement of water in the Candler fine sand (hyperthermic, coated Typic Quartzipsamments) found in both experiments. A Time Domain Reflectometry (TDR) Field Scout Soil Moisture Meter (Spectrum Technologies, Plainfield, IL) with 20 cm probe rods was used for this purpose, taking measurements in a semi-grid pattern at 2-inch spacing.

RIDGE REPLANT EXPERIMENT. A 15-acre citrus block near Auburndale, FL was replaced in Dec. 2008 with 'Hamlin' orange [*Citrus sinensis* (L.) Osb.] trees, three planting densities, two rootstocks, two irrigation methods and two fertilization methods (Table 1). Statistical analysis was based on a randomized blocks design with plots of 20 measured trees and four replications. Drip irrigation (treatments 1–2, 5–7) was provided to each tree with two 0.53 gph pressure-compensating external plug emitters

(Netafim, Fresno, CA) spaced 15 inches apart on the distribution pipe at the soil surface (Fig. 1). The irrigation system capacity was designed to allow doubling the number of drip emitters per tree as the trees develop. Microsprinkler irrigation was provided with either a single 10.5 gph Max-14 (Maxijet, Dundee, FL) fill-in blue emitter (treatment 3) or a 7.7 gph Max-14 fill-in orange emitter (treatment 4) at each tree. A 2-ft-diameter Tree T-Pee® plastic tree guard (GSI Inc., Arcadia FL; Fig. 1) was placed around each tree trunk. The tree guards protect the trees from herbicide sprays and enhance freeze protection with irrigation. Irrigation time requirements with microsprinklers are also reduced by the tree guards due to the reduced wetted soil surface area. Soil water sensors (VG400, Vegetronix, Sandy, UT), using the capacitance method of estimating volumetric water content were used to measure moisture in the 0 to 4 inch and 18-inch soil depths to assist with irrigation scheduling.

Nutrients were supplied to all fertigation treatments on a nearly daily basis through the irrigation system, which was operated to maintain the soil water content of the 0- to 4-inch depth interval near field capacity (~10 %). For fertigation treatments 1–2 and 4–7, liquid fertilizer was bulk-injected into the irrigation water in order to achieve a nitrogen (N) concentration of approximately 100 ppm after dilution with the total water supplied during each event. The complete nutrient solution added to the plant root zone was (ppm) N: 100, P: 44.2, K: 71.1, Ca: 81.9, Mg: 10.9, S: 15.6, Fe: 1.91, Mn: 0.46, Zn: 0.24, B: 0.26, Cu: 0.06, Mo: 0.04. Treatment 2 also received 2 lb of composted cow manure per tree (Black Kow, Oxford, FL) placed on the drippers once in the spring. Treatment 3 received only dry blended granular fertilizer (%): N: 8.0, P: 0.87, K: 6.64, Mg: 1.8, S: 3.87, B: 0.03, Fe: 0.032, Mn: 0.2. Granular fertilizer was applied around each tree six times during the year at approximately 6-week intervals starting in March (0.25, 0.5, 0.5, 0.5, 0.5, 0.5 lb/tree, respectively) according to UF/IFAS recommendations for Florida citrus (Obreza et al., 2008b).

All fertigation events were scheduled, controlled and monitored with a NMC-Jr irrigation computer (Netafim) linked to the office with a wireless Zigbee network (Digi International, Minnetonka, MN). Treatment 3 was irrigated by the grower cooperater according to the normal grove schedule and all irrigation events were recorded with the flow meter and data logger features of the NMC-Jr computer controller. Weed control, rootstock sprout removal, pest management and freeze protection were conducted by the grower cooperater as needed. Tree canopy heights and the average leaf chlorophyll greenness index of each plot were measured every month. Chlorophyll indices were determined on 20 fresh leaves in the 20 measured trees using the SPAD-502 meter (Konica Minolta, Ramsey, NJ; Jifon et al. 2005). Leaf samples were collected quarterly and leaf nutrient concentrations analyzed

Table 1. Treatments in the young-tree 'Hamlin' orange experiment on the Ridge.

Treatment	Spacing (ft)	Rootstock	Irrigation	Fertilization	Comments
1	10 × 20	Swingle	Drip	OHS ^a	Daily irrigation
2	10 × 20	Swingle	Drip	OHS+OM ^b	Daily irrigation
3	10 × 20	Swingle	Microsprinkler	Dry granular ^c	Grower irrigation
4	10 × 20	Swingle	Microsprinkler	OHS	Daily irrigation
5	8 × 18	Swingle	Drip	OHS	Daily irrigation
6	8 × 18	C-35	Drip	OHS	Daily irrigation
7	8 × 15	C-35	Drip	OHS	Daily irrigation

^aOHS = "open hydroponics system" (intensive, frequent liquid fertigation to supply all nutrients).

^bOrganic matter as 2 lb of composted cow manure per tree placed at the drippers.

^cConventional dry granular fertilizer applied under the canopy six times a year.

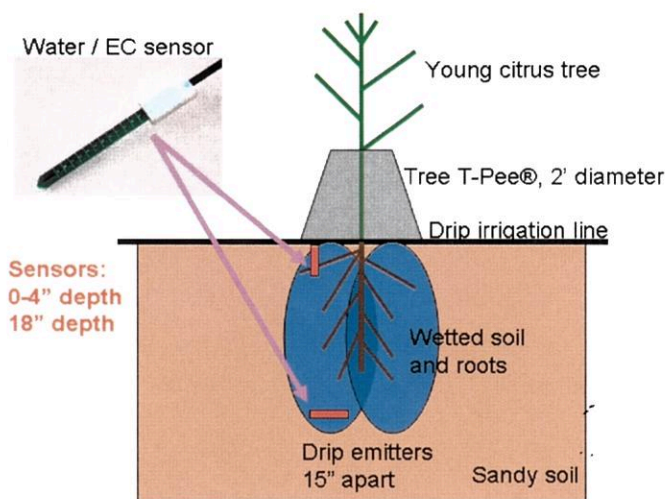


Fig. 1. Tested configuration for planting Florida Ridge citrus in an ACPS (The tree T-pee tree guard is optional).

(Obreza et al., 2008a). Twenty leaves from the 20 measured trees per plot were dried to constant weight at 70 °C and ground to a powder with a Cyclotec mill (FOSS NIRSystems, Inc., Laurel, MD) before analysis of mineral nutrient concentrations (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B) using standard methods (Waters Agricultural Laboratories, Camilla, GA).

RIDGE MATURE TREE EXPERIMENT. Fertigation treatments (Table 2) were imposed on a 2.2-acre block of mature ‘Hamlin’ orange trees on Swingle citrumelo [*Citrus paradisi* Macf. × *Poncirus trifoliata* (L.) Raf.] rootstock near Lake Alfred, FL. The trees were planted in 1991 at a 13 × 20 ft spacing and historically had produced low fruit yields [~25 Mg/ha (~250 boxes/acre)] in the previous 2 years. The treatments were designed to compare different fertigation delivery methods (microsprinkler versus drip) and frequencies (multiple pulses per day, daily, or weekly; Table 2). Drip irrigation (treatments 5, 6) was provided with integral Uniram (Netafim) pressure-compensating drip emitters (0.5 gph) spaced at 12 inches down the tree row. Microsprinkler irrigation (treatments 2–4) was provided with Supernet (Netafim) purple emitters delivering 5.3 gph (treatment 1) and Supernet gray emitters delivering 15.3 gph.

Statistical analysis was based on a randomized blocks design with plots of 16 trees (10 measured) and four replications. Equal total amounts of water and nutrients were delivered to each treatment in the experiment during the first year for which results are reported in this paper. The liquid fertilizer was bulk-injected into the irrigation water in order to achieve a nitrogen (N) concentration of approximately 100 ppm after dilution with the water supplied during each event. The complete nutrient solution added to the plant root zone in the spring was (ppm) N: 100, P: 14, K: 57, Ca: 100, Mg: 14.3, S: 20.6, Fe: 1.71, Mn: 0.86, Zn: 0.86, B: 0.86, Cu: 0.03, Mo: 0.02. The ratio of N:K was changed from 1.75 in the spring to 1.00 in the summer and fall seasons. The water requirement of the mature trees on daily irrigation treatments was based on soil water measurements in the root zone and the infrequently irrigated treatment 3 was allocated the same total amount of water, applied twice per week. All fertigation events were computer scheduled and monitored as above. Weed control, pest management and freeze protection were conducted as needed according to CREC grove management policy. The average leaf

Table 2. Fertigation treatments^a in the mature-tree ‘Hamlin’ orange experiment on the Ridge.

Treatment	Description
1	Microsprinkler 5.3 gph, two times per day ^b
2	Microsprinkler 15.3 gph once per day ^b
3	Microsprinkler 15.3 gph, 1–2 times per week (low intensity “standard grove practice”) ^b
4	Same as 2, with reduced irrigation from November to February ^b
5	1 dripper line per tree row at 12-inch spacing; short pulse irrigation every hour during daylight hours; 10× pulse irrigation ^b
6	1 dripper line per tree row at 12-inch spacing; irrigation once per day ^b

^aAll treatments were fertigated as needed through a separate flow meter and injection valve. Irrigation water volumes were metered separately for each treatment (totals of four replications).

^bActual scheduling depended on rainfall probabilities, ET_o, soil water probes.

^cNo special irrigation scheduling methods used.

chlorophyll index of each plot was determined as above on 20 fresh leaves among the 10 measured trees. The leaves were then processed and analyzed for nutrient elements described for the replant experiment above. Tree canopy heights and volumes in the plots were measured annually using an automated ultrasonic array (Schumann and Zaman, 2005). Fruit yield was estimated from a photographic method (Schumann et al., 2007) and fruit quality was expressed as fruit size, percentage juice, brix, acid, and ratio, using standard processing plant analytical procedures.

DATA ANALYSIS. Plant growth, fruit yield and nutrient status data were analyzed using analysis of variance (ANOVA) and the F-test to determine statistical significance of treatment differences (Genstat 5.0, Lawes Agricultural Trust, Rothamsted, UK). Separation of significantly different treatment means was achieved with least significant differences (LSDs) at $P < 0.05$.

Results and Discussion

SOIL WETTING MEASUREMENTS. The volumetric soil water contents were mapped in color to visualize the extent of water movement horizontally around drip emitters (red=dry, yellow=intermediate, blue=wet; Fig. 2). Soil was wetted to a horizontal distance of no more than 6 to 8 inches from the drip emitters, but pulse irrigation 10 times per day caused a slightly wider wetting pattern than a single large pulse per day. These results are useful for determining correct dripper spacing, the approximate volume of soil which is wetted by drippers, and can be used for predicting leaching potential and for developing suitable irrigation schedules.

RIDGE REPLANT EXPERIMENT. The NMC-Jr fertigation controllers and monitoring system were able to automatically manage the various ACPS treatments in these experiments on a daily basis and wireless remote control and monitoring with the NMCnet software (Fig. 3) was invaluable for detecting problems and changing run-time parameters remotely. The NMC-Jr computer controller appears to be a good choice for small to medium-sized ACPS installations in Florida. Irrigation water supplied per tree during the first 21 weeks to the three main ACPS irrigation management treatments was lower for the sensor-based drip fertigation (51%), and sensor-based microsprinkler fertigation

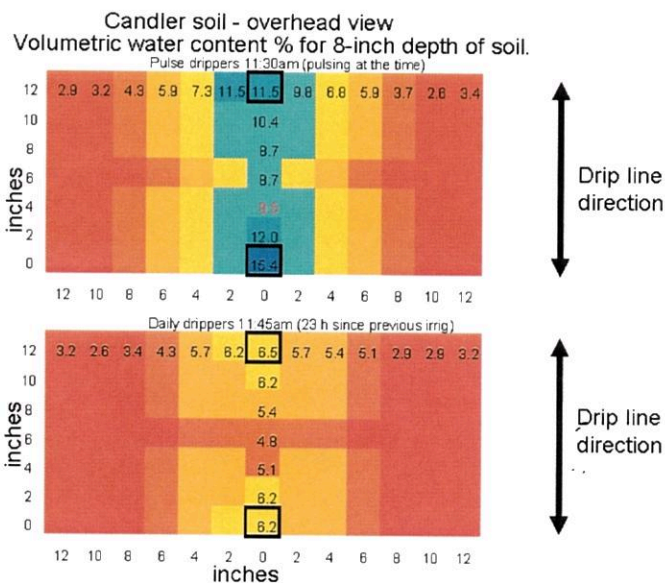


Fig. 2. Overhead view of wetted soil surrounding four drip emitters (black squares at position 0) on a Ridge soil. Volumetric water content was measured in the 0–8 inch soil depth interval. The moisture scale is colored red (dry), yellow (intermediate), and blue (wet).

(72%) than for the conventional grower microsprinkler (100%) treatment (Fig. 4). These early results represent only the dry spring period of the first year. After visible leaf tip burn and yellowing appeared from mild salinity damage in the drip treatments during rain-free spring weather, a 14-d leaching cycle was introduced whereby the drip irrigation system was run once for a prolonged time to deliver water equivalent to 70% to 90% of the soil pore volume. The leaching schedule was only necessary in rain-free periods and will probably only be needed during the first year of growth. Despite the additional leaching water required for drip irrigation, this method still used substantially less water per tree than the microsprinkler method.

Leaf nutrient concentrations sampled in Apr. 2009 were non-significant among treatments as all leaves had a high, non-limiting nitrogen (N) concentration of >3% (Obreza et al., 2008a). Nitrogen applications per tree relative to the benchmark N fertilizer applied were however, lower for drip (13%) and microsprinkler (20%) fertigation treatments than the conventional grower treatment (100%; Fig. 5). The linear and logistic lines in Fig. 5 are representations of two possible suggested fertilization strategies during the first season of growth. The horizontal target line is the anticipated end-of-season N requirement for the efficient fertigation treatments. At this early stage it appears that the logistic curve is most realistic because it accommodates seasonal differences in nutrient requirement. The chlorophyll index of leaves after

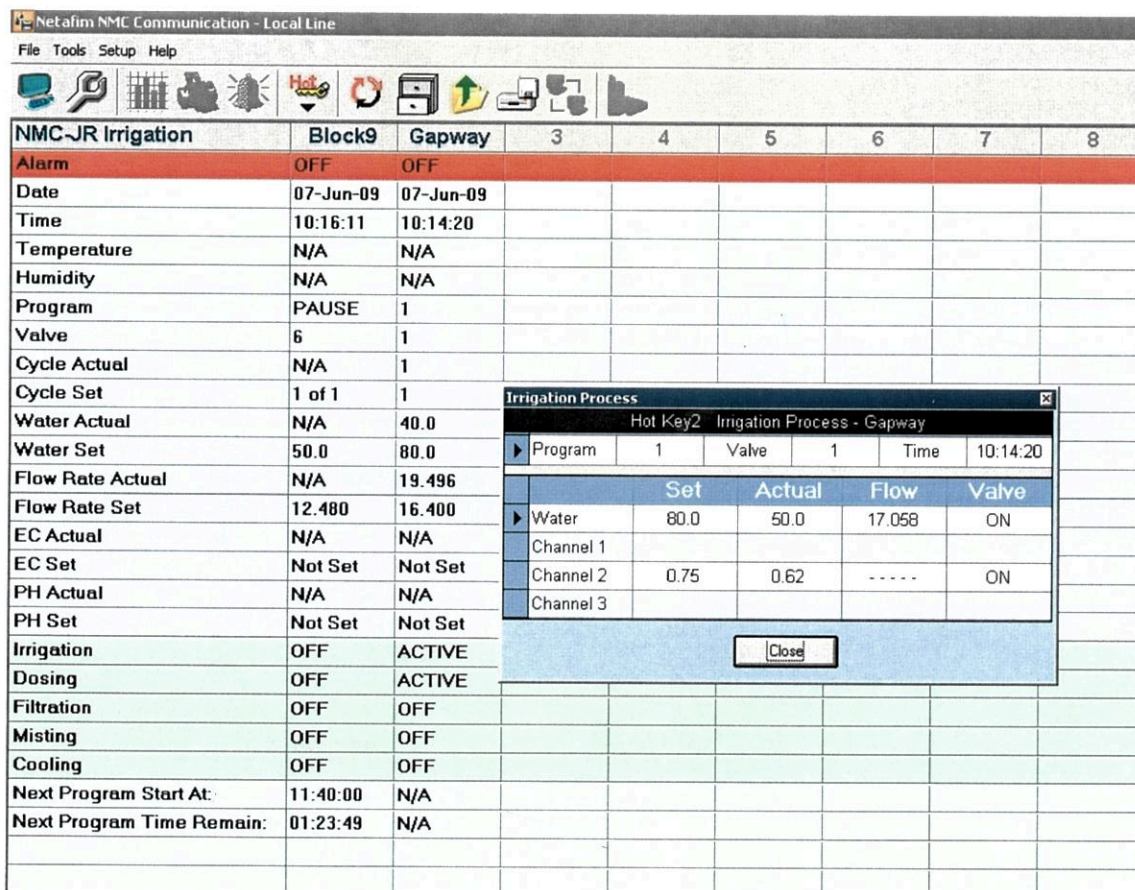


Fig. 3. Status screen of a typical irrigation computer controller showing the irrigation and fertilizer injection progress for two blocks of citrus.

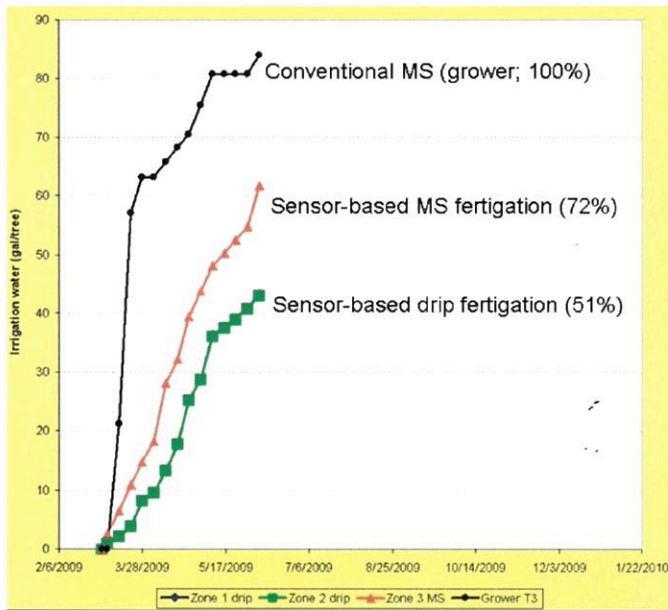


Fig. 4. Irrigation water applied to young 'Hamlin' orange trees during the first 21 weeks of growth on the Ridge using three different management systems. Conventional MS = grower practice microsprinkler emitters under tree guards, irrigation scheduled by grower, granular fertilizer. Sensor-based MS fertigation = nearly daily fertigation with microsprinkler emitters under tree guards, targeting a soil water content near field capacity. Sensor-based drip fertigation = nearly daily fertigation with drip emitters under tree guards, targeting a soil water content near field capacity. Percentages of water applied relative to conventional practices are in parentheses.

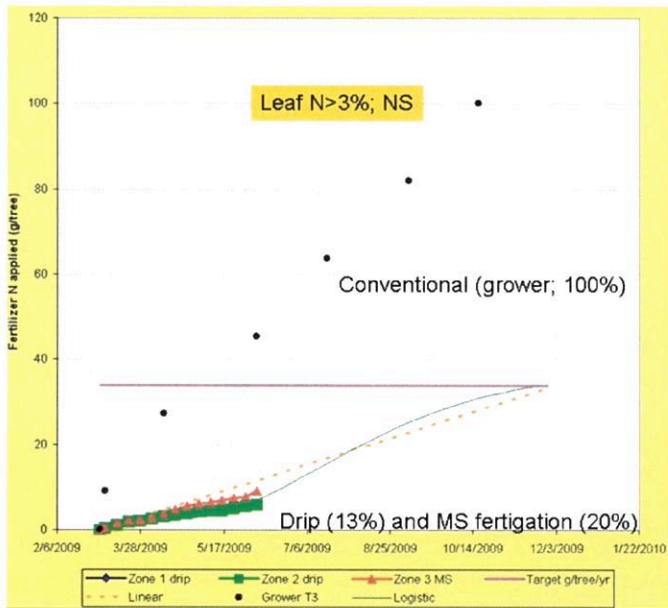


Fig. 5. Nitrogen fertilizer applied to young 'Hamlin' orange trees during the first 21 weeks of growth on the Ridge using three different management systems. Conventional grower practice = granular fertilizer applied six times per year at 6-week intervals. Drip and MS fertigation = nearly daily fertigation with drip or microsprinkler emitters, respectively. The horizontal target line represents the initially estimated 33% of conventional N required by fertigation for the year, and the linear and logistic curves represent two approaches for achieving the annual quota.

21 weeks was significantly lower for the larger trees on C-35 rootstocks compared with those on Swingle rootstocks (Fig. 6). All other comparisons within the Swingle rootstock group were non-significant.

The 'Hamlin' trees on C-35 rootstocks were already visibly larger than those on Swingle rootstocks at the time of planting in Dec. 2008, but the Swingle rootstocks are expected to catch up to the C-35 rootstocks in the first year. Separation of the heights for the Swingle rootstock treatments after 21 weeks showed a nearly significant difference between the conventional grower treatment (3) which was shorter than the best drip treatment (5). These differences are expected to increase with time, but the substantial benefits of drip fertigation for establishing new citrus blocks with the ACPS in Florida are already apparent when compared with conventional dry granular fertilization and microsprinkler irrigation. These growth benefits of ACPS are even more significant when assessed against the much lower requirements for water (~50%) and fertilizer (~13%) in a young citrus block and will be assessed as nutrient and water use efficiencies in future reports. The greater efficiency of fertilizer uptake for ACPS drip fertigation than for microsprinkler and conventional treatments is supported by the comparable growth, leaf N levels and even transient salinity problems using ACPS drip that received only 13% of the fertilizer applied in conventional treatment.

RIDGE MATURE TREE EXPERIMENT. Fruit yield after 9 months of ACPS treatments in the mature 'Hamlin' block was substantially improved (about doubled) from the previous years, and the most intensive pulsed drip fertigation treatment (5) had the highest yields [over 50 Mg/ha (~500 boxes/acre)] which were significantly different from two less intensive microsprinkler fertigation treatments (2 and 4; Fig. 7). The soluble solids yield showed a similar trend, with the pulsed drip fertigation treatment yielding a profitable ~3500 kg/ha (~3125 lb/acre) (Fig. 7). Fruit numbers as a result of better fruit set, rather than fruit size appeared to be the reason for yield differences among treatments (Fig. 8). Fruit quality parameters like percentage juice yield were non-significant, but the 'ratio' measurement was significantly different across

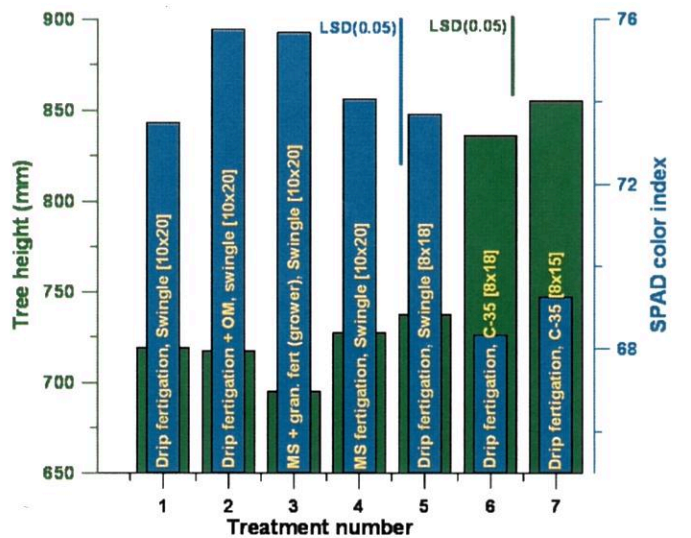


Fig. 6. Tree height and leaf chlorophyll index (Minolta SPAD) of young 'Hamlin' orange trees after 21 weeks of growth on the Ridge. Treatment numbers correspond to the detailed treatment descriptions in Table 1.

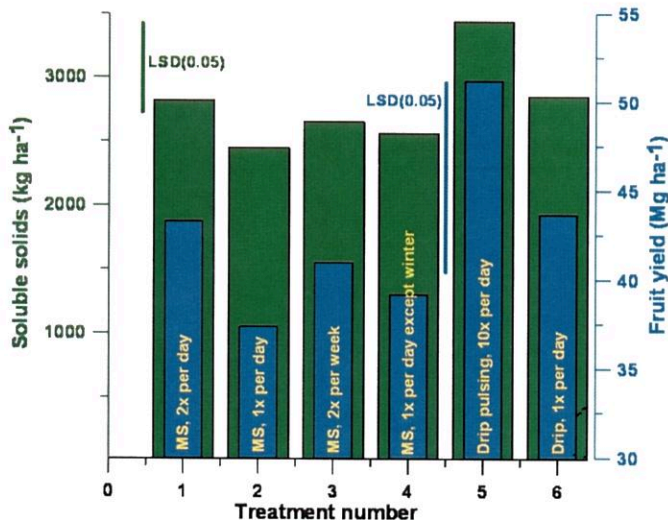


Fig. 7. Fruit and soluble solids yield of mature 'Hamlin' orange trees after 9 months of fertigation treatment. MS, Drip = microsprinkler or drip emitters, respectively. Treatment numbers correspond to descriptions in Table 2.

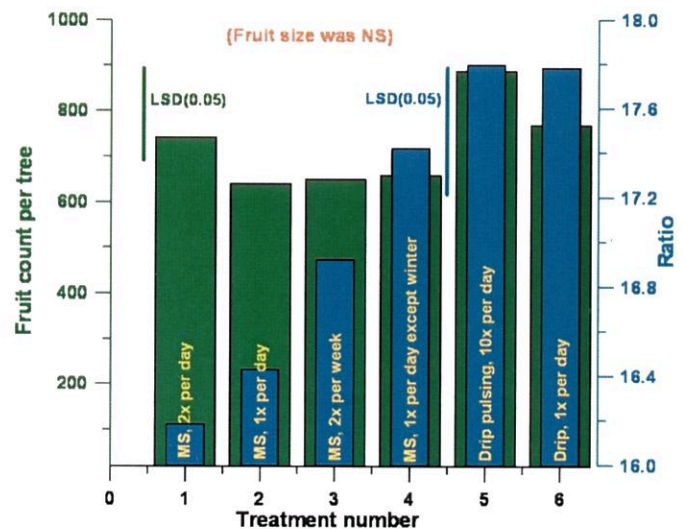


Fig. 8. Fruit numbers per tree and soluble solids : acid content ratio of mature 'Hamlin' orange trees after 9 months of fertigation treatment. MS, Drip = microsprinkler or drip emitters, respectively. Treatment numbers correspond to descriptions in Table 2.

treatments, with drip treatments having the highest ratio (Fig. 8). The ratios among the microsprinkler treatments appeared to follow an inverse relationship to the frequency of fertigation applications (Fig. 8) and may be due to the cumulative affects of partial root zone drying (PRD). Trees growing with drip fertigation treatments 5 and 6 would be subjected to the most PRD because the horizontal wetting pattern from a drip emitter on this soil is limited to only 6–8 inches (Fig. 2). Treatments 5 and 6 coincidentally also produced the highest ratios (Fig. 8). It remains to be seen if these positive trends attributed to ACPS and PRD can be sustained in subsequent years.

Conclusions and Future Work

Early results after 21 weeks for the young replant block ACPS experiment and after 9 months for the mature tree ACPS experiment, both on the Florida Ridge, are positive. The expected biological benefits of increased tree growth rates, higher yields, and better fruit quality were all demonstrated. Additional benefits, especially the higher fertilizer and water use efficiencies possible with an ACPS in a young replanted citrus block could improve overall profitability by reducing production costs and would certainly benefit the environment. These are long-term experiments and therefore the final outcomes after 5 to 10 years may be different from these early results, especially after the different tree densities start to become effective. The economics of the ACPS in Florida will obviously determine its ultimate success or failure. A companion paper by Roka et al. (2009) discusses some of the economic constraints and required break-even points for the ACPS.

Initial problems associated with growing Florida citrus with ACPS were identified as salt accumulation during the dry spring season, and high incidences of insect pests attracted to the rapidly flushing foliage. Periodic leaching of salts during dry periods and additional insecticide sprays can solve these problems. ACPS will likely rely substantially on Integrated Pest Management (IPM)

to succeed. If root growth occurred beyond the limited fertigated zones due to the high rainfall incidence in Florida summers, it apparently did not negate the benefits of ACPS. The biological benefits of the ACPS seem to be as achievable in Florida's summer rainfall subtropical climate as in a Mediterranean climate.

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