

Preliminary Evaluation of Water Needs in Citrus Nurseries Using Four Different Irrigation Systems

Deliverable 2 – Final report

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This report is a summary of the experimental setup and final data collected for the irrigation demonstration systems installed at the Mid-Florida Research and Education Center - Apopka during October 2012. The objectives of this project were to inform and demonstrate to the citrus nursery industry the options available for irrigation, and to begin to quantify the volumes of water and tree growth rates associated with each system. Since none of these plots are replicated, volumes of water applied and actual evapotranspiration (ET_A) are not definitive. This acknowledged, the results presented provide realistic, though not optimum, irrigation volumes applied to the four demonstration systems for a 9 month period of bud shoot growth. Nine months was the median duration before budded trees were first removed for sale, based on the grower survey conducted in March 2013.

Materials and Methods

Four small irrigation demonstration systems were established on October 26, 2012. These consisted of a truncated overhead irrigation system, an individual container drip irrigation system, and two different sub-irrigation systems. Sub-irrigation systems were a benchtop flood irrigation system and a commercially available self-contained capillary mat system (Aquamats[®], Soleno Inc., Quebec, Canada). Each system was irrigated nightly between midnight and 1 a.m. Mechanical water meters (C700, Elster AMCO Water, Ocala, FL) and 20 psi regulators (Senniger, Irrigation, Inc., Clermont, FL) were installed for each system to quantify irrigation input.

The overhead system consisted of four greenhouse irrigation nozzles (Dramm Nifty Nozzy assemblies). These were suspended 42 inches above the citrus containers. A manual quarter-turn valve was installed and adjusted to limit the area covered to about 12 inches beyond the dimensions of the bench area containing the trees. This was necessary to prevent overspray onto the other irrigation systems. This also substantially reduced pressure and flow. However time was adjusted such that the containers received adequate irrigation. The actual percentage of water applied relative to the metered amount was 42%

The individual drip system consisted of an individual emitter (SXB Xeri-bubbler, Rain Bird Corp., Azusa, CA) being placed in each container. Each emitter was adjusted to a common flow rate ~ 1 gph. These emitters are not the industry standard, but function identically. Issues with emitters loaned from the Ft Pierce REC and time constraints forced the use of these readily available emitters. Irrigation duration was set to a maximum of 4 min., or when the weight gain over 10 sec of irrigation was less than 0.7 oz per tree. Estimated irrigation rate was about 8 oz. per tree.

The flood system was constructed on top of a fiberglass bench using $\frac{1}{2}$ inch plywood and 1x8 inch planks to form the basin. This was lined with 6 mil plastic sheet. Approximately 1 inch of rubber tire mulch was placed in the bottom of the bench to aid drainage from the containers. A wooded frame was constructed above the basin to support a lift mechanism which raised containers out of the wire mesh to measure ET_A each hour. Flood irrigation depth was controlled by a float valve and water was removed using a 12 VDC sump pump.

The Aquamat system was manufactured by Soleno Inc. in Quebec, Canada, and consists of four layers. The bottom is a thick polyethylene sheet hermetically sealed to an upper surface of reinforced polyethylene, thorough which small pin holes allow water passage from the interior while blocking roots. The interior consist of two layers of polyethylene. The bottom polyethylene layer is a thick mat that serves as the water reservoir, while the upper polyethylene layer is spongy. This spongy layer holds the top layer above the water. Water is conveyed into the mat by two polyethylene tubes with drip holes. When compressed by the weight of a pot, the spongy layer compresses and allows water movement into the substrate of the container. Because of the thin water layer, lifting a container during the day can break the water flow until the mat is re-saturated. Additionally, since water can continuously flow from the mat into a container, it is impossible to directly determine ET_A from trees on the Aquamat.

Citrus nursery standard 4-inch square support wire was stretched about 12 inches above the bottom of each system. Both the drip and overhead systems had smaller diameter wire mesh to support the pots. The Aquamat was laid on top of a wire mess bench covered with a flat polycarbonate sheet.

All trees (Valencia budded onto Kuharski rootstock) were purchased from the same nursery (Flood Clinch Lake Nursery, Frostproof, FL) having been budded in mid-August. Mean bud growth was around four inches when the project was started. All trees were in nursery standard 14-inch tall x 4-inch wide citrus pots in a common 60% peat moss: 40% perlite substrate. Trees were delivered on October 12, 2012. They were placed in the irrigation benches on October 19. Computer programing and final assembly of the weighing systems were finalized on October 23. Trees were watered by hand daily from arrival until the system was operational on October 26. Thereafter all irrigation and measurement of ET_A were computer controlled. Trees were staked and tied using 30-inch steel rods inserted into each container as needed. When a shoot tip reached the top of a stake, the terminal was pinched. Similarly as new buds elongated, they were pinched at two to three inches in length.

Controlled released fertilizer had been incorporated into the substrate at potting at the nursery. Trees were drenched with imidacloprid (Mallet; NuFarm Americas, Burr Ridge, IL) to stop an infestation of leaf miners on October 26. Trees were sprayed with a foliar nutrient solution (RTR Plus, Diamond R Fertilizer Co, Ft. Pierce, FL) and each given ¼ tsp of iron (Sequestrene 138, NuFarm America) on November 7.

Each irrigation system was filled completely with trees, with no spacing between trees. The final bench area filled with trees was 3.3 ft wide and varied from 5 to 7 ft long, depending on the irrigation system. Five containers in each system, except the Aquamat, were weighed hourly to determine the daily water use rate per tree. Trees weighed were in the fourth row inward from the outer edge. For the overhead and drip systems, containers were elevated about 2 inches by suspending them from calibrated (50 lbs.) load cells held up by a minimum support frame extending 5 ft above the plants. Trees were weighed on the flood bench using a robotic system that raised trees to be weighed each hour and set them back down afterwards.

Tree height was measured from the bud insertion to the tip of the shoot. Trunk caliper measured one inch above the bud union. Both were recorded weekly on weighed trees. On May 8, after 9 months of growth, caliper of budded shoots one inch above the bud was measured for all successful budded trees within each irrigation systems. Gallons of water applied to each system were recorded weekly and summed for the experimental period. Evapotranspiration of weighed trees was determined daily.

After data collection was complete, ET_A of the flood, drip and overhead irrigated trees on days tree measurements were recorded was compiled by irrigation regime. For each irrigation system, average tree ET_A and branch caliper were calculated. Caliper was measured for each of the 5 weighed trees. However ET_A was based on the average water loss of the five trees measured concurrently. Mean ET_A was plotted against mean trunk caliper for each irrigation regime, and linear regressions were calculated.

Results

Actual Evapotranspiration. Irrigation occurred nightly between midnight and 1 a.m. Containers were allowed to drain for a minimum of 2.5 hours before the first measurement of mass was recorded at 3 a.m. For trees in the flood system, this was found to be sufficient for drainage of nearly all the unbound water in a container.

ET_A of the five flood trees generally ran between 0.5 to 2.5 oz./tree/day (Fig. 1). Most of the time, ET_A was between 1.5 and 2 oz./tree/day, with a slight depression of perhaps 0.5 oz./tree/day from early November to January. Surprisingly, there wasn't much variation in ET_A over time, even though tree height, and therefore the number of leaves increased with time. This may be because the measured trees were 3 rows in from the outside and trees were set pot-tight. With generally even growth rates, 100% canopy closure would have been maintained, which would have suppressed transpiration rates. The upper substrate surface of these containers was dry throughout the data collection phase except for 4 days that foliar sprays were applied to runoff for insecticide or pots were drenched for root disease control.

ET_A of micro-irrigated trees (Drip) was similar to that of flood irrigated trees generally through the middle of January (Fig. 1). ET_A of these trees then increased through early March to nearly 4.5 oz./tree/day. The second weekend in March there was an equipment malfunction over the weekend that prevented irrigation of both the drip and overhead irrigated trees. This resulted in tree wilt and the low ET_A recorded during this period. After irrigation was restored, it took nearly 2 weeks for ET_A of drip and overhead irrigated trees to regain the pre-malfunction transpiration rates. Toward the end of the data collection period, trees were generally transpiring 4 to 4.5 oz./tree/day. The higher ET_A rates of drip trees, compared to the flood irrigated trees may be because these trees were suspended a bit above the surrounding trees to achieve accurate weight measurements. Additionally drip irrigated trees were irrigated from the top down, so there would be evaporation from the substrate that did not occur from flood irrigated trees.

The highest ET_A was recorded for overhead irrigated trees (Fig. 1). Most of these higher values are due to the retention of overhead irrigated water by the canopy throughout the night and its evaporation generally by noon the following day. This surface-held water would have been counted as ET_A . Like the trees measured in the drip system, overhead irrigated trees were also suspended about 2 inches higher than surrounding trees. ET_A of overhead irrigated trees was generally in the 3 to 5 oz./tree/day range until early March and the malfunction. Towards the end of data collection, ET_A ranged between 5.5 to 7 oz./day/tree.

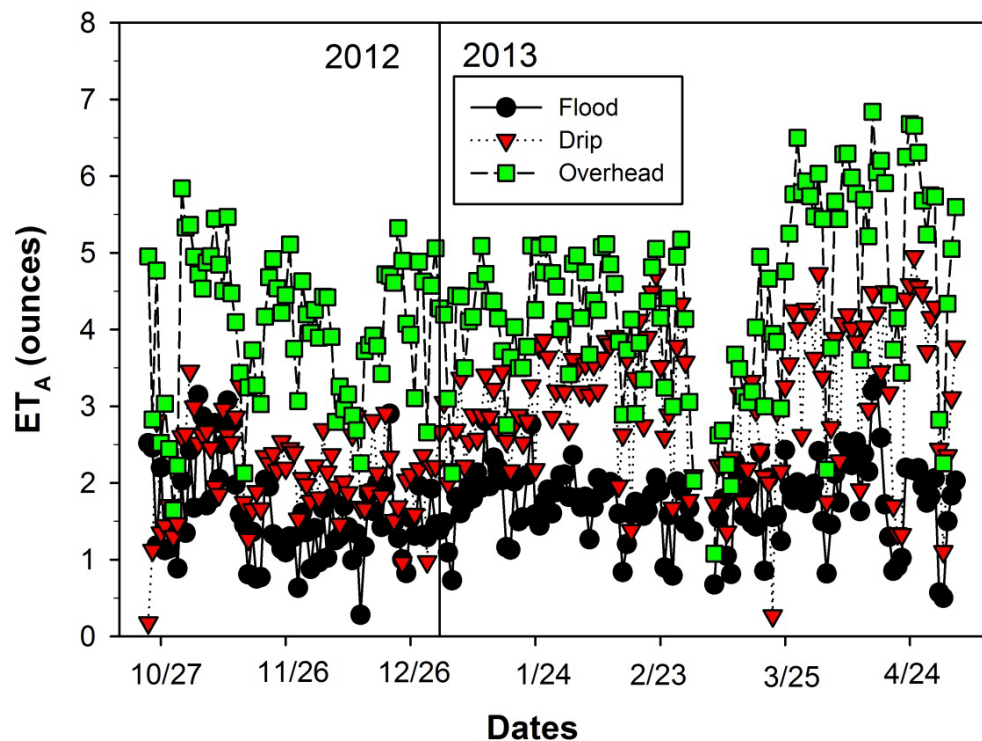


Figure 1. Actual evapotranspiration (ET_A) measured for the 3 irrigation systems beginning about 2.5 months after budding. Each point represents the average ET_A of five trees located in the fourth row within a bench of trees set pot-to-pot.

Cumulative irrigation volume. Cumulative ET_A per tree from initiation when bud shoots averaged around 4 inches in length until final measurements in mid-May were tallied. Flood irrigated trees averaged 2.53 gal per tree. Drip irrigated trees averaged 4.07 gal per tree, while overhead irrigated trees averaged 6.35 gal per tree.

Irrigation volumes applied varied over 21-fold among irrigation systems (Fig. 2). Cumulative irrigation for the Aquamat was 400 gal, whereas cumulative irrigation for the flood system was 8,374 gal. Drip irrigation (1,567 gal) required nearly 4 times as much as the Aquamat, whereas overhead irrigation (7,064 gal) as applied was 84% percent of the flood system volume and 4.5 times more than the drip system. Overhead irrigation was increased in late March to counter wilting of trees by late afternoon. The overhead irrigated area was severely truncated to limit the wetted pattern to prevent overspray on to other demonstration plots. Even then, only 42% the overhead irrigated water actually fell within the area inhabited by the trees.

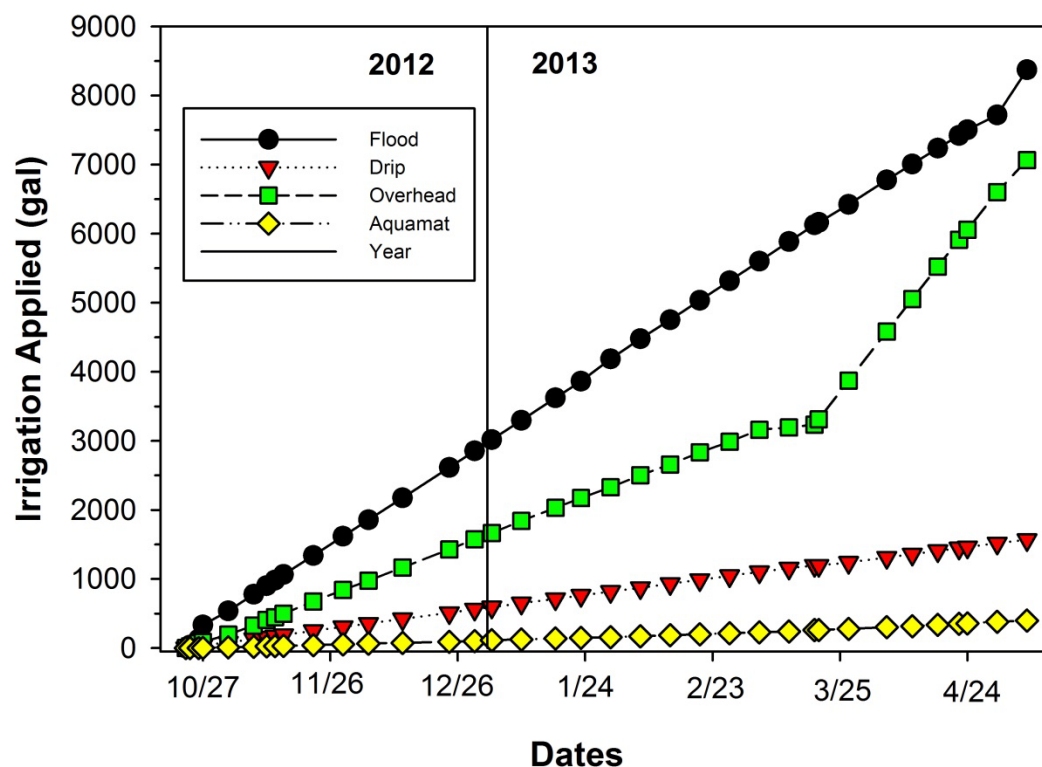


Figure 2. Cumulative irrigation volumes applied to each of the single replication demonstration irrigation systems. Tabulation of irrigation volumes applied was begun about 2.5 months after trees were budded when median shoot growth was around four inches.

Shoot height. Initially, budded shoots of the measured trees randomly assigned to the Aquamat treatment were taller than trees in the other irrigation system (Fig. 3). By early January 2013, mean bud shoot height was similar among irrigation systems, ranging from 17.5 to 22.75

inches. The greatest growth increase in the fall was from trees irrigated with the micro-irrigation, while the least growth increase in the fall occurred from trees on the Aquamat. Through the winter months, tree height remained similar among irrigation regimes until April 2013. While shoot height of flood irrigated trees remained constant, shoot growth of drip and Aquamat trees surged the last 4 weeks before final measurements were recorded.

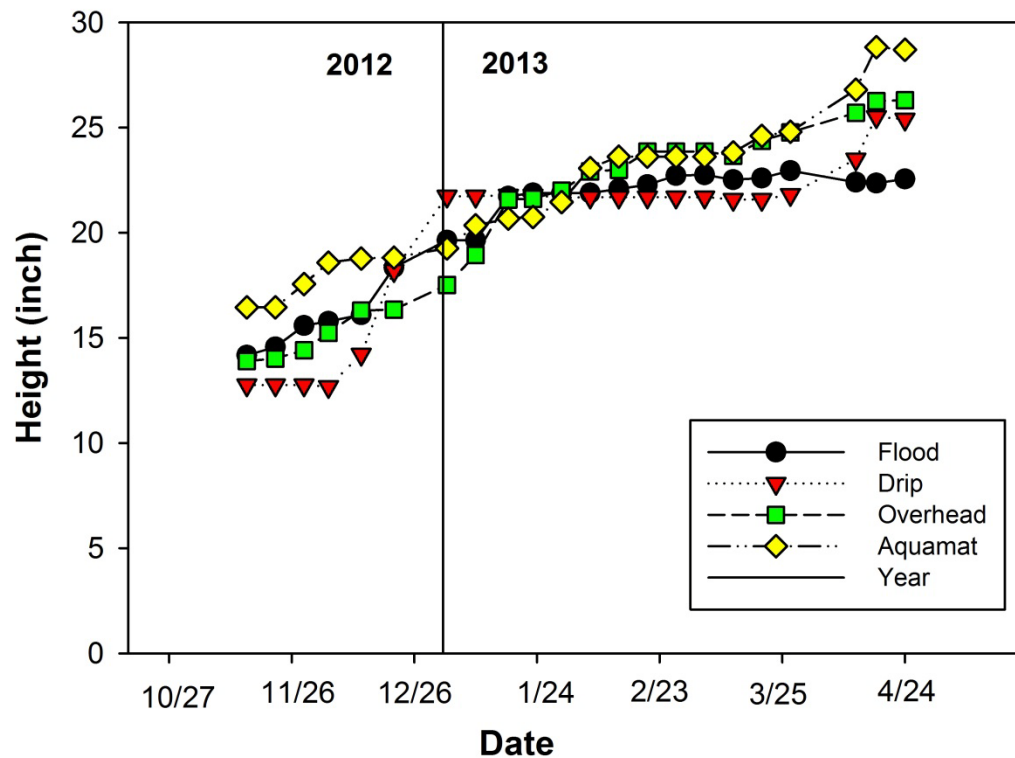


Figure 3. Bud shoot height above the bud measured for the four irrigation systems beginning about three months after budding. Each point represents the mean shoot growth of five trees located in the fourth row in within a bench of trees set pot-to-pot.

Trunk caliper. Initial measurement of trunk caliper measured one inch above the bud was greatest for trees placed on the Aquamat and least for trees placed on the flood table (Fig. 4). Throughout the growth period, this generally maintained until early March, when trunk caliper of trees on the Aquamat initiated caliper growth earlier than those of the other irrigation systems. Caliper growth of drip and overhead irrigated trees also increased during the last 2 months but at a slower rate than trees on the Aquamat. By the final measurement, the average of the 5 shoots repeatedly measured on the Aquamat trees was 0.25 inches, the industry standard for marketable size trees. Trees on the flood table averaged about 0.22 inches in caliper. Final mean caliper for drip and overhead irrigated trees was around 0.23 inches.

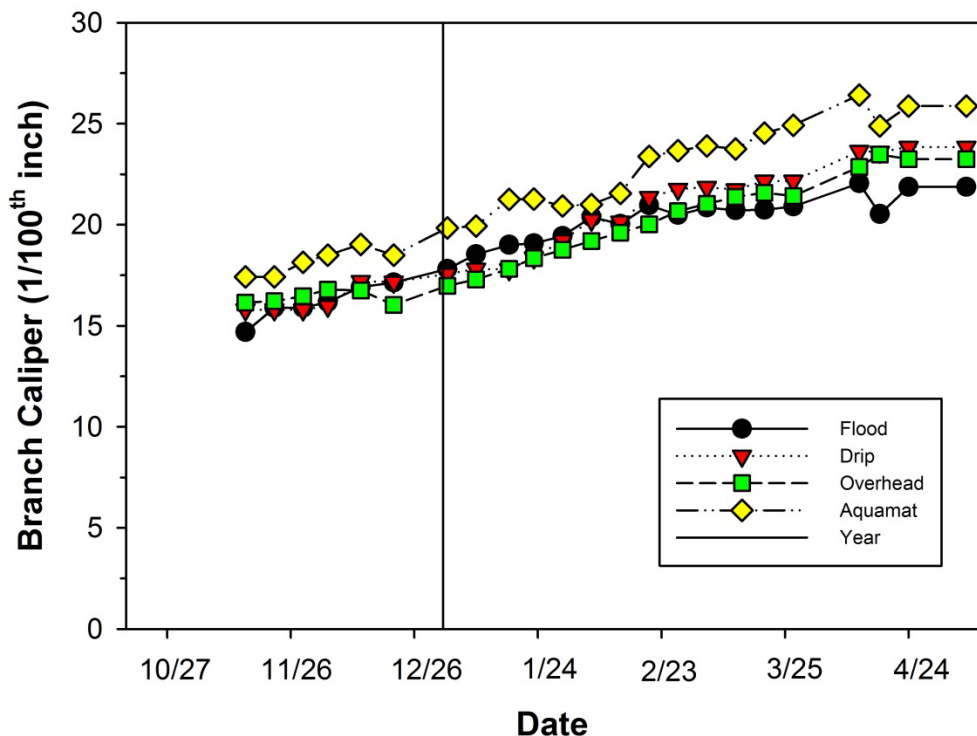


Figure 4. Bud shoot caliper at one inch above the bud measured for the four irrigation systems beginning about 3 months after budding. Each point represents the mean shoot growth of five trees located the fourth row in within a bench of trees set pot-to-pot.

Market size tree count.

Nine months after trees were budded, the middle of May 2013, the caliper of all successfully budded shoots were measured 1 inch above the bud union with a digital caliper. The number of budded shoots that were of marketable size ($\frac{1}{4}$ inch or larger) were counted, and the percent calculated based on number of successful buds. None of the irrigations achieve 50% or more marketable trees after 9 months (Table 1). Trees grown with either drip irrigation or on the Aquamat had the highest percentage of marketable trees at 45%. The least amount of marketable trees after 10 months was produced under overhead irrigation. Although this system had 25% more trees than the next largest demonstration system, flood, the narrowest widths were nearly same, 10 trees wide (about 3.7 ft) compared to 9 trees wide (3.3 ft).

Table 1. Final count of successfully budded trees that bud branch was a minimum of ¼ inch in caliper 10 months after budding. All trees were set pot tight on the bench and not moved after initial placement.

	Flood	Drip	Overhead	Aquamat
% of marketable trees at harvest	37	44	32	45
Total number of successful bud shoots	140	133	178	111
ET _A /tree/day (oz.)	1.65	2.56	4.15	2.35

Relationship of tree water use relative to tree size

For flood irrigated trees, mean caliper increased from 0.147 inch to 21.87 inch over the 185 days. Tree height increased from 14.2 to 22.6 inches over the same time period. Linear regression analysis found no correlation between stem caliper ($r^2 = 0.044$) or stem height ($r^2 = 0.040$) on tree water use.

For trees that were irrigated using drippers, correlations between stem caliper and ET_A or stem height and ET_A were also poorly correlated ($r^2 = 0.165$ and $r^2 = 0.084$ for caliper and height, respectively). Mean trunk caliper for drip irrigated trees increased from 0.158 inch to 0.238 inch, while tree height increased from 12.76 inches to 25.39 inches.

Correlations for overhead irrigated trees were stronger, but still not statistically significant. Correlations were better with stem caliper ($r^2 = 0.248$; range 0.161 to 0.232 inch) than stem height ($r^2 = 0.156$; range 13.9 to 26.3 inches). However neither was strong enough to develop guidelines.

Correlations of ET_A with stem caliper or stem height combining the data from all three irrigation regimes also failed to derive a model to predict daily tree water use ($r^2 = 0.078$ for caliper and $r^2 = 0.066$ for height).

Discussion

Nine months after budding, 45% of successfully budded trees obtained marketable size when either drip-irrigated or grown on the Aquamat (Table 1). Average ET_A for drip-irrigated trees was 2.56 oz./tree/day. This is very close to the average of 2.35 oz./tree/day applied to trees on the Aquamat. This suggests that irrigation of the Aquamat was close to optimum at the pot-tight spacing. In contrast, only 37% of the trees on the flood table reached marketable size during this time frame. Average ET_A of flood-irrigated trees was 1.65 oz./tree/day. The lowest percentage for marketable trees was from overhead irrigated trees (32%), which had the highest daily average ET_A of 4.15 oz./tree/day. But as discussed above, much of this ET_A was due to evaporation from leaf surfaces.

Among irrigation systems, Aquamat was the most water conserving, averaging 2.35 oz./tree of applied water per day. While similar ET_A was calculated for drip irrigated trees, the application volume per tree was 3x higher, at 7.69 oz./tree/day. Overhead irrigation was also seems excessive at an average of 10.9 oz./tree/day, even after accounting that only 42% of the water applied actually fell within area occupied by the trees. This was also over twice as much water applied as was accounted for by evapotranspiration. Yet even then, likely canopy shedding resulted in some wilted trees the last 6 weeks. Previous research has shown tight correlations between canopy closure and amounts of overhead irrigated water reaching a container surface (Beeson and Yeager, 2003). The most water intensive of the irrigation systems evaluated was flood irrigation, averaging almost 1/3 gal/tree/day (39 oz./tree/day). However, based on more recent information, these volumes can be greatly reduced. Post-experiment investigations into substrate properties revealed the wicking of water by the peat moss:perlite substrate from an 1-inch depth of water was nearly the same as water retained by the substrate when it was irrigated to saturation from the top, then allowed it to drain to container capacity (data not shown). Thus flood irrigation volumes would be reduced substantially by eliminating the 1-inch thick mulch layer underneath the pots and lowering the water level in the basin from 5 inches to less than inch. Recycling of leftover flood water could further in reduce irrigation volumes and nutrient loss.

Frequency of irrigation could likely be reduced from daily to some less-frequent interval. Based on woody shrub data and some preliminary citrus data, irrigation events based on the loss of 20% to 30% of plant available water within the container may be sufficient, but will need to be tested.

Overhead irrigation volumes presented here are likely under-represented relative commercial rates since irrigation pressure was lowered to confine the spread to an area slightly larger than the bench area occupied by the trees. Other than caliper growth, overall growth and quality of trees in the four irrigation systems are visually consistent. Yet within each system, there was a wide range of bud shoot growth.

The lack of any correlations between bud branch size and daily ET_A can be explained the by the effects of canopy closure (Beeson 2010) and pot tight spacing. In brief, plant transpiration is constant from a completely isolated plant to a minimum 67% canopy closure. Percent canopy closure means that of a given horizontal area, the combined horizontal projected area of plant canopies as seen from above shades a percentage that is the sum of the individual canopies. Below 67% canopy closure, plants are considered “coupled” to the atmosphere above and around them. Water is loss from all sunlit leaves and at a lesser extend from interior shaded leaves, due to differences in relative humidity between inside the leaf and the air around it. At some undetermined point above 67%, the combined plant canopies become “uncoupled” from the atmosphere above. Shaded leaves, which now comprise most of a canopy, lose little water because the humidity outside the leaf is much higher due to thicker air boundary layers resulting from much lower wind speeds. Additionally, photosynthesis of these lower leaves declines to near zero due to limited solar radiation and thicker air boundary layers. At some percentage,

likely between 75 to 100% canopy closure, whole plant transpiration declines by 40%. Most transpiration is confined to the upper 30 to 40% of the canopy. Photosynthesis also declines due to solar radiation absorption by upper leaves. For most plants, 4 layers of leaves reduce solar radiation of full sunlight to below the light compensation point for photosynthesis. A single sheet of 6 mil clear polyethylene film reduces photosynthetically active radiation (PAR) by 8%, and the effect is additive. Thus less than 4 layers of leaves would prevent photosynthesis in a double polyethylene greenhouse, as was used in this demonstration project and is common commercially. PAR measurements made in double poly commercial greenhouse within a pot tight citrus canopy found insufficient PAR radiation for photosynthesis just 11 inches below the tops of the budded shoots. Thus since only the upper 10 to 12 inches of pot tight citrus canopies receive enough solar radiation for photosynthesis, and transpiration is buffered at this depth and below, correlations of tree size above 12 inch tall canopies and irrigation need do not occur for pot tight spacing.

As a result of this, irrigation demand of trees in common 4 inch square citrus pots set pot-tight becomes a near constant for tree heights above 12 inches. Daily water use will vary mainly due to day length and to a lesser extent by cloud cover. With larger diameter pots, and/or spaced pots, canopy closure would occur more slowly. Correlations between tree size and irrigation demand would be stronger and a tabular guideline for citrus greenhouse irrigation may be possible. However, as outlined above, such a tabular guideline based on tree size cannot be developed from the data collected here. Instead, the average ET_A 's described previously and shown graphically in Figure 1 could be used.

Recommendation

For 14 inch citrus pots which are sub-irrigated or drip irrigated - 3 oz./tree/day.

For overhead, 3 oz./tree/day until canopy are 10 inches tall, then 7 to 10 oz./tree/day to overcome canopy shedding.

References

Beeson, Jr. R. C., and T. H. Yeager. 2003. Plant canopy affects sprinkler application efficiency of container-grown ornamentals. HortScience. 38: 1373-1377.

Beeson, Jr., R.C. 2010. Response of Evapotranspiration of *Viburnum odoratissimum* to Canopy Closure and the Implications for Water Conservation During Production and in Landscapes. HortScience. 45(3): 359-364.

Appendix

Below are photographs of the irrigation systems taken in mid-November 2012.



Flood irrigation

Overhead irrigation



Micro-irrigation (bubblers)



Aquamat