CUPS Quick Start Guide

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Introduction and goals

Huanglongbing (HLB), an incurable, persistent, systemic disease of all citrus varieties in Florida since 2005, has spawned unprecedented research efforts to develop solutions over the past 11 years. Although many valuable pieces of the HLB puzzle have been discovered through the ongoing research, there are still many elusive unsolved components, like the ability to culture the *Candidatus* Liberibacter asiaticus bacteria in-vitro and developing reliable genetic resistance of commercial citrus varieties and rootstocks to the disease. Meanwhile by 2016, the Florida citrus industry has declined to historically low fruit production levels, mainly due to HLB. Interim, sustainable and profitable solutions for the continuation of citrus cultivation in Florida are urgently needed until a research breakthrough with long-term solutions is developed. Growing citrus for fresh fruit production under protective structures to eliminate the Asian Citrus Psyllid [ACP] (*Diaphorina citri*) vector of HLB, was selected as one such interim solution.

Protected horticulture is an increasingly popular option for growing high-value fresh fruit and vegetable crops profitably in greenhouses and screen houses. Most often the reasons for growing crops in protected environments are to escape adverse weather conditions, diseases or pests. In greenhouses with controlled environments (temperature, humidity, photoperiod, atmosphere [e.g. carbon dioxide enrichment]), the growth rates, yields, and quality of the crops can often be greatly increased, compared with conventional outdoor production methods. Typically an additional layer of enhancement to the controlled environment is to use soilless hydroponic fertigation on an intensive daily or hourly frequency.

The Florida citrus nursery industry adopted a similar greenhouse or screen house production practice about 10 years ago in order to protect budwood sources and commercial citrus nursery tree production from citrus canker and ACP. The Citrus Undercover Production System (CUPS) described in this guide is very similar to the screen house citrus nursery system, but with a different goal: ***the sustainable and profitable production of HLB-free, premium quality fresh fruit in psyllid-free enclosed screen house environments***.

In order to achieve the overall goal, it is necessary to establish additional objectives in order to make CUPS viable, primarily due to the high cost of protective screen houses. Objectives include 1) maximizing early yields to achieve early returns on the investment, 2) ensure that citrus varieties with the highest quality and market value can produce fruit successfully in CUPS (self pollination is essential), 3) develop modern, automated production methods and best management practices to minimize the annual citrus caretaking costs, and 4) develop effective remedies for “greenhouse” pests and diseases (notably thrips, mites, and fungal pathogens) that are more prevalent in the protected environment of a CUPS. In summary, CUPS uses conventional methods and off-the-shelf components in uniquely effective, unconventional combinations. Information in this quick guide was derived mainly from ongoing UF/IFAS research at the CREC and IRREC since 2014, and from frequently asked questions by growers and contractors that are interested in using CUPS. A more comprehensive guide with expanded authorship is being planned.

1) CUPS

i) The screened insect-proof enclosure

A psyllid-excluding screen house for growing HLB-free citrus is the fundamental requirement for CUPS. The structure should be extensive enough to accommodate the planned acres of citrus grove, and tall enough to allow the trees to grow for a profitable multi-year production cycle without the need for excessive canopy topping. Additionally, the roof height of the structure should be designed to leave a few feet of open headspace between the tree canopy and the ceiling. This ensures better air convection in the house and minimizes the impacts of re-radiated heat from the sunlit roof surface. A satisfactory roof height in our experience has been 14 to 20 feet, but taller structures are more expensive. The construction method of most screen houses in Florida consists of the pole-and-cable type, using either treated wood or steel for the poles. The screen covering material must be 50-mesh (0.3 mm openings) or higher. The 50-mesh is a good balance between insect exclusion (psyllids and larger) and adequate air flow through the structure. However, smaller pests like thrips and mites are not completely excluded by 50-mesh screen.

Poles must be anchored to the ground with poured concrete bases, or with soil anchors. The aerodynamics of an enclosed structure, specifically the flow of strong winds across the roof, generates an upward force on the structure, which can lift supporting poles out of the ground unless they are anchored down securely.

A 50-mesh high density polyethylene (HDPE) screen roof blocks about 20 to 25% of the incident solar radiation, and about 66 to 75% of the ultraviolet radiation. The partial shading provided by the 50-mesh screen does not harm citrus tree growth or fruit production. In a passively ventilated screen house (no fans), average wind speeds are reduced by about 70%, and the average screen house air temperatures are usually 2 to 3 degrees Fahrenheit higher than the outside temperatures during sunny winter days, and 6 to 8 degrees Fahrenheit higher than outside air temperatures during the summer. Air temperatures inside and outside the screen house are not different at night. Air dewpoint temperatures are slightly higher in the screen house than outside.

Due to the higher risk of hurricane or tropical storm force wind speeds in coastal Florida than in the interior, an inland location for a CUPS is often preferred. For example, Hardee, Polk or Highlands counties are popular locations for new CUPS. A CUPS screen house is also best constructed on level, well-drained land (not bedded flatwood citrus) more commonly found in those counties on the Lake Wales Ridge region of Florida.

One of the most expensive components of a screen house is the HDPE screen material. The amount of screen required and therefore the cost of the screen house per acre is influenced to some extent by the choice of screen house shape and size. The amount of screen covering the roof is directly correlated with the area of citrus grove being protected. However the amount of screen used to cover the walls per acre of protected grove is influenced by the screen house shape and size. Consider the illustration in Fig. 1, where the perimeter:area ratio of a given hypothetical screen house shape is lowest for a circle, a bit higher for a square, and increasingly higher for more rectangular shapes. A circular enclosed area would be difficult to manage for citrus groves, so a CUPS that is as square as possible will represent the lowest-cost shape for practical purposes.

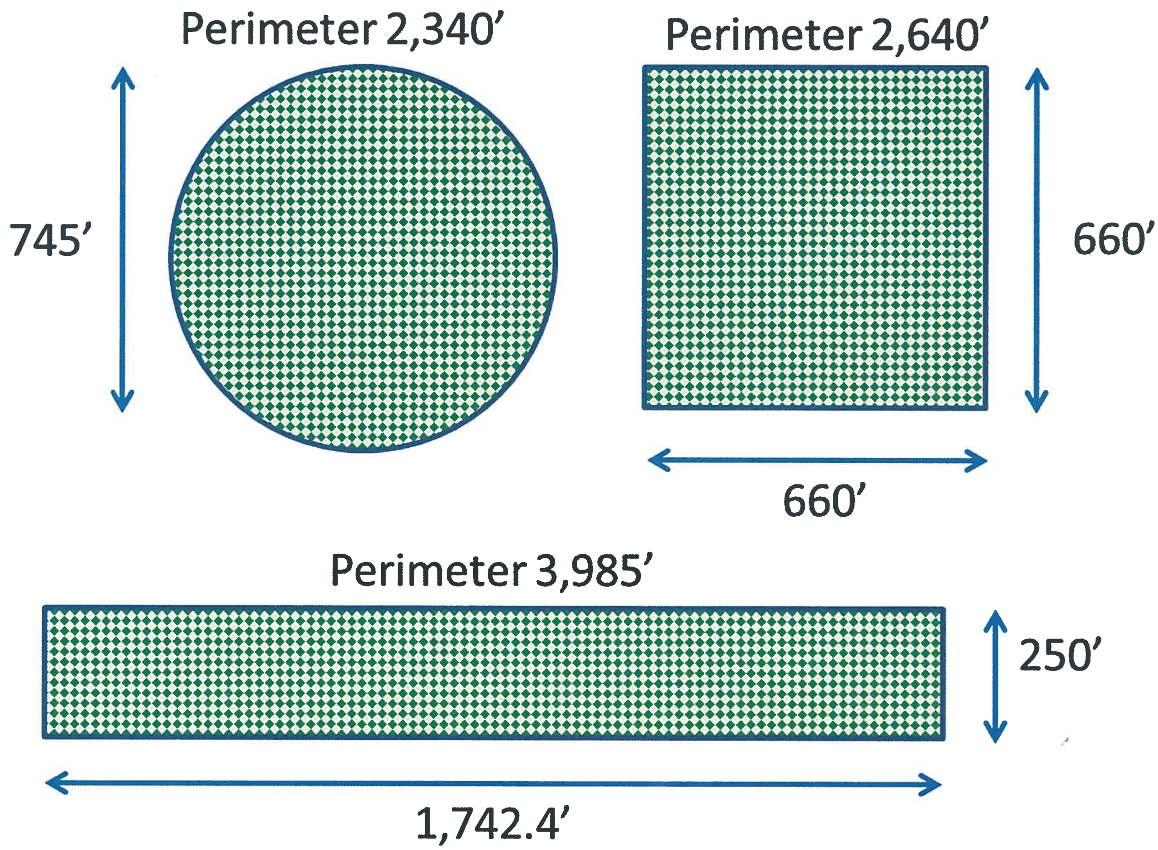

Figure 1. Overhead view of three screen house shapes, each representing 10 acres of protected grove area.

A larger screen house (area protected) for a given shape and design, will require less wall materials per protected acre than a smaller version (Fig. 2). The costs of building the walls of a screen house include the screen material, support poles, cables, anchors, labor, and entrances. The costs of all those components as well as the cost of internal structural support poles will increase as the roof height is increased.

Consider a square screen house and using only the cost of the screen material for illustrative purposes ($0.25 per square foot), a wall height of 14 feet, and a series of hypothetical sizes (Table 1). As expected, the price drop with increasing grove area protected decreases rapidly from the smallest 0.1 acre size to the moderate 10-acre size. Screen house sizes larger than the tens of acres don't show very substantial discounts for size (Table 1). The screen material costs per acre for a 10-acre screen house will be only 59% of the screen costs for a 0.1-acre screen house. The cost structure is reflected in the percentage of total screen material used for the wall construction, which drops exponentially from 46% at 0.1 acres, to 1% at 1,000 acres (Table 1). Other wall component costs such as for the poles, cables, and anchors will be similarly affected. These size and shape considerations will help the prospective CUPS grower

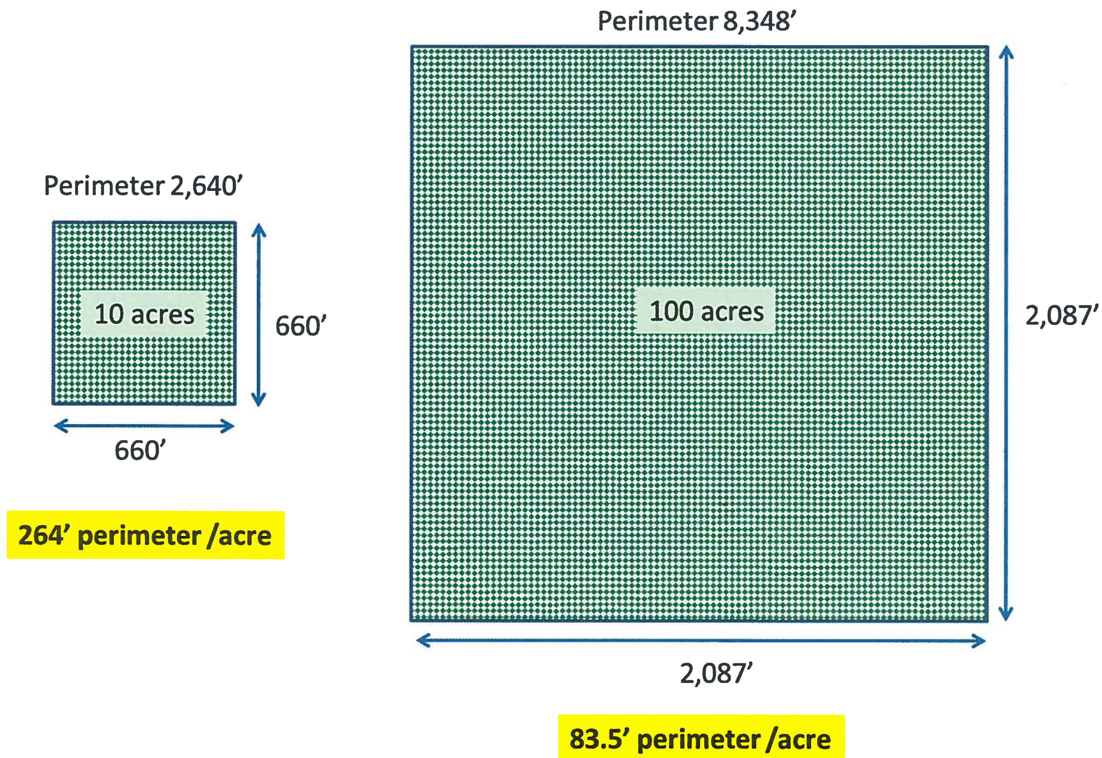

Figure 2. Overhead view of two square screen houses, illustrating the effect of screen house size on the perimeter length to grove area ratio.

decide whether to build less, larger structures, or more, smaller structures for a given protected acreage. Other very important considerations are 1) the number and cost of doorways for accessing the screen houses, which will increase with smaller sizes, and 2) the ability to comprehensively spray and quarantine a screen house if needed, which will be more difficult with larger sizes. Aerial spraying is impractical or impossible for screen houses, even with permeable roof screen material, and therefore procedures must be in place for rapid turnaround spraying with ground equipment for both routine maintenance and in the case of a pest or disease outbreak.

Table 1. The effect of screen house size on the per acre cost of screen material required.

Screen house size	Total, $/acre	Total%	Wall%
0.1 ac, 66x66'	$20,130	100	46
1 ac, 209x209'	$13,808	69	21
10 ac, 660x660'	$11,814	59	8
100 ac, 2087x2087'	$11,182	56	3
1,000 ac, 6600x6600'	$10,982	55	1

The feasibility of rapid, responsive spraying diminishes with the larger screen houses, and additionally certain pests and diseases may more easily find refuges and be more difficult to eliminate in larger screen houses than in smaller ones. In summary, to achieve the lowest cost per acre, and at the same time keeping things practical, the best choices for CUPS screen houses appear to be medium-sized (tens of acres), square-ish structures, probably not too different from the shape of many existing geometrically simple Florida citrus groves. The rectangularity of the screen house shape affects the cost per acre less when the structure is larger because the wall cost as a percentage of the total drops with increasing size. There may be additional economies of scale like quantity discounts for bulk purchasing of construction materials that are not included in this discussion.

The CREC CUPS is shown in Fig. 3, and was constructed using pole-and-cable methods with a 14-foot high roof. There is a large 10'x12' roll-up door for farm machinery and a separate control room is attached to the screen house wall to double as an entrance foyer for personnel. The large equipment entrance has a second layer of protection in the form of a plastic strip "cold room door", attached to the inside of the doorway. An even more effective double door entrance consists of a foyer or small entrance tunnel between the doors, which have interlocking mechanisms to prevent both being opened simultaneously. Fans placed at the doors to blow air out of the screen house help to prevent any airborne pests or diseases from entering the main structure. The 50-mesh screen has a warranty of five years, and we are optimistic to get seven or more years of use before it will need replacement.

Figure 3. The CREC CUPS screen house encloses 1.3 acres of ground, and accommodates 1.0 acre of citrus trees.

ii) Grove layout in a CUPS

In order to attain high fruit yields very early in the CUPS production cycle, the planting density needs to be high. High density groves require tree size controlling techniques so that the inter-plant competition from close-spaced neighbors does not interfere with fruit production. A negative effect of improperly implemented high density planting is excessive vegetative growth and subsequent low fruit yields. Excessive shading and inefficient light utilization by overlapping tree canopies can be a problem in high densities, but root competition can also be a factor. The best and most economically sound method for tree size control is by promoting heavy fruit set and high yields. A second preferred approach is to utilize dwarfing rootstocks that limit the growth of the trees without harming yields. Flying dragon rootstock is one of the most effective dwarfing rootstocks. A last resort for tree size control is mechanical or hand pruning, hedging and topping of the tree canopies. Tree size control by canopy removal is the most damaging to fruit yields, and can also spread certain pests and diseases through wounding.

Our research at the CREC testing high planting densities in CUPS is still ongoing, but it appears that 300 to 500 high-yielding tangerine trees per acre on dwarfing or semi-dwarfing rootstocks planted in the ground will work well. Vigorous varieties that usually grow larger trees like grapefruit, will definitely require dwarfing rootstocks when grown in the ground inside a screen house. We are also experimenting with growing trees hydroponically with soilless media in pots, at much higher densities of 871 to 1,361 trees per acre. In that case the pots function to restrict root growth and limit tree canopy size without harming yields. Whatever density is chosen, the ground space allocated for each tree should be approximately square in shape, to best accommodate the roots underground and the canopies above-ground while minimizing competition. Regardless of the planting method (soil or soilless) chosen, at the high tree densities required for a CUPS, narrow four-foot wide tractors and implements as used in vineyards and blueberry farms would improve maneuverability and maximize the space for growing fruit-bearing canopy. In the CREC CUPS, we exclusively use narrow equipment, not exceeding a width of four feet.

Growing trees in the ground

The method of planting and growing citrus trees in the ground inside a screen house should follow most of the existing conventional grove setup and caretaking guidelines for Florida fresh citrus production. Careful alignment of the interior structural support poles with the tree rows is necessary in order to allow normal vehicle traffic down the drive middles. For example, if poles are 30 feet apart, then a tree row spacing of 15 feet is appropriate. Special precautions must be taken during tree topping and hedging operations. A sicklebar hedging and topping machine would be the best choice, since the circular saw type of hedging machine tends to fling projectiles of wood, which could puncture the screen. Special care must be taken when topping and hedging the tree rows superimposed on the pole rows. Similarly if a ground cover of grass is maintained and periodically mowed in the screen house, then the mowers should not operate close to the screen walls both inside and outside due to the risk of flying debris. Instead, herbicide sprays should be used to control vegetation around the screen house walls. Under-tree microjet irrigation is a good choice for trees growing in the soil, since the irrigation water can also serve as freeze protection in the winter. Standard herbicide booms can be used for in-row weed management. Fertilization methods can include dry soluble granular fertilizer, controlled release fertilizer, diluted soluble fertilizer applied by fertigation, or a combination of the three. Usually fertigation will produce the fastest tree growth and early yields, essential for a CUPS.

Growing trees in containers

In the CREC CUPS, trees are grown in plastic pots mainly to benefit from soilless hydroponics nutrition, and to induce the necessary dwarfing or tree size restriction needed for very high planting densities (871 and 1,361 trees per acre). Using this production method, early (2nd year) yields of 416 boxes/acre for 'Ray Ruby' grapefruit and 525 boxes/acre for 'Honey' murcott trees were achieved. The grapefruit trees also yielded 110 boxes/acre in the first year.

In addition to the plastic pots, a suitable potting media (e.g. 50% Canadian peat, 50% perlite), a ceramic tile under each pot, a drip fertigation system, and a supporting trellis for the trees are required (Fig. 4). In the CREC CUPS, adjustable plastic straps and steel clips were used for securing tree trunks and branches to the trellis wires (Fig. 5). These accessories are sold in horticultural supply shops such as A.M Leonard (amleo.com) and Dubois Agrinovation (duboisag.com). The life expectancy of the potted trees is about 10 years, at which time the expected return on the investment should be realized and the grove can be replanted.

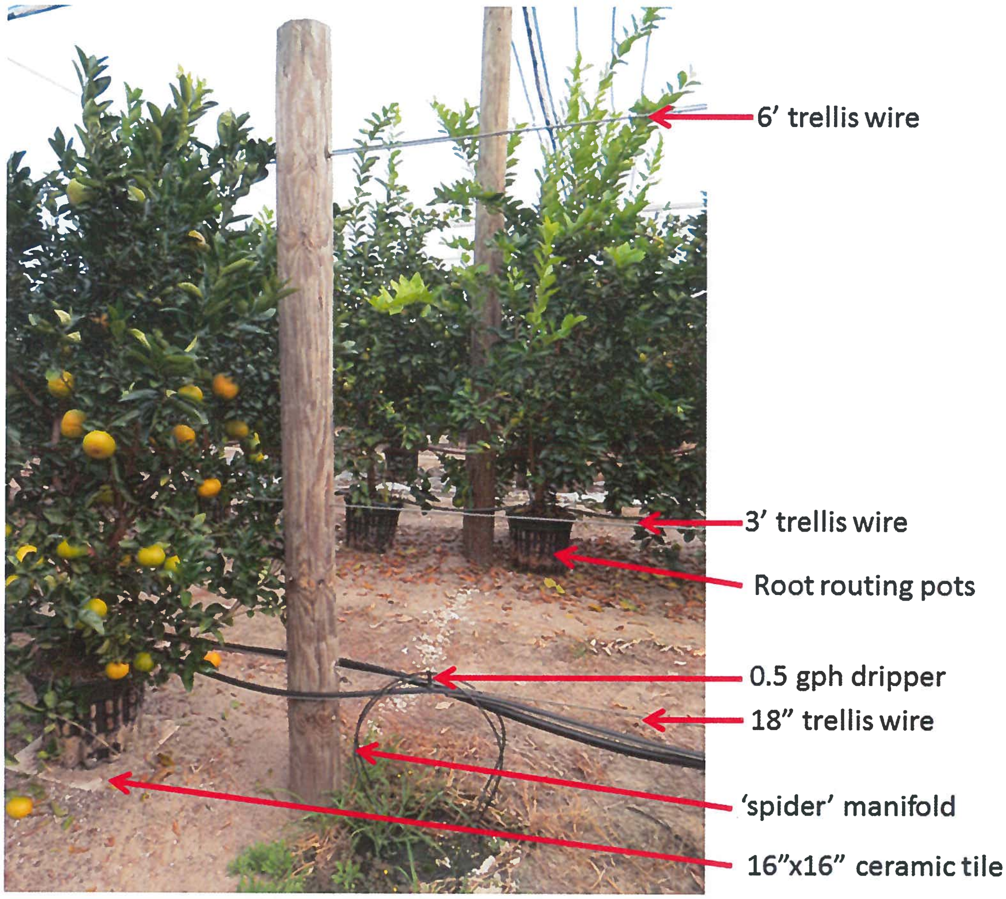

Figure 4. The trellised, pot-grown citrus tree configuration used in the CREC CUPS

Citrus trees grown hydroponically in pots have more exacting requirements for quantities and frequencies of irrigation and nutrition than trees grown in the ground. Potted trees are best cared for by a computerized fertigation system with comprehensive remote monitoring and control capabilities. A minimum of two hydroponic fertilizer stock solutions (tanks A and B) are required for balanced nutrient supply to the trees and to keep incompatible chemicals apart. For example tank A could consist of a stock solution of all essential nutrients except sulfur and magnesium, and tank B would then contain magnesium sulfate. The two stock solutions used together after dilution in the irrigation stream then provide a comprehensive balanced nutrient supply to the trees. Some pre-mixed fertilizers are already formulated to lower the pH of the diluted fertigation stream, which is often necessary since many Florida irrigation sources are in the alkaline range. If separate acidification is required, then a tank of acid (e.g. sulfuric acid) may be needed to adjust the final fertigation pH to 5.5 – 6.5, with 5.8 being optimal for hydroponics. The mixed media pH should first be tested before deciding how much limestone, if any, should be added. An excessive amount of limestone added to a peat – perlite potting mix can result in alkaline pHs that can be very difficult to correct over a long time.

There are many choices of pots to use for citrus trees, which vary in size, construction materials and design. Ongoing research at the CREC confirmed that pots designed with lateral corrugations and openings can reduce root circling by encouraging air pruning of main roots, thus causing more lateral root branches and a healthy fibrous root ball. There are various brands of pots designed to reduce root circling, including "air pots" and "root routing" pots. A rule of thumb for pot sizing is to reduce the size for increasing planting densities; at the CREC CUPS the Murcott trees use 7-gallon pots at 1,361 trees/acre and 10-gallon pots at 871 trees/acre. The pots should be sturdy and able to last the full expected 10-year production cycle (Fig. 6).

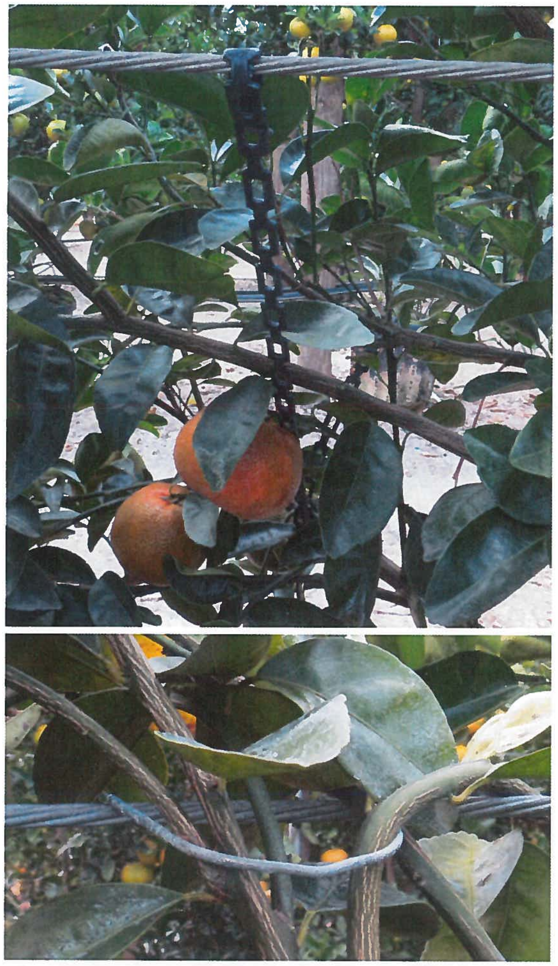

Figure 5. Adjustable plastic straps and steel clips used to attach trees to the trellis

Weed control is problematic when growing trees in containers because conventional citrus herbicide booms don't suit the task. Weeds germinate from the top of the pots, from the side wall holes of pots, and on the ground between and around pots. So far the best remedy has been spot spraying the weeds with a contact herbicide like paraquat or glufosinate-ammonium. Do not use glyphosate or other systemic herbicides which can be absorbed by exposed citrus roots and may systemically damage the trees.

iii) Citrus varieties

Citrus varieties with high consumer preference and price on the fresh fruit market should be grown in CUPS. Also, due to the absence of insect pollinators in CUPS, the citrus varieties must be self-pollinating. In the CREC CUPS, we successfully demonstrated self-pollination and fruit set of Ray Ruby and Flame grapefruit, Meyer and Eureka lemon, Persian Lime, Hamlin and Valencia orange, Honey and W Murcott varieties. Other known self-pollinating varieties are Dancy, Ponkan, Satsuma, Temple, Fallglo, and Early Pride. Examples of self-incompatible varieties unsuitable for CUPS are Minneola, Nova, Orlando, Robinson, and Sunburst.

iv) Weather stations and soil water sensors

An automatic weather station mounted inside the screen house is useful to monitor the modified meteorological variables inside, especially air temperature, relative humidity, wind speed, solar radiation, ultraviolet radiation, and rainfall. Derived variables such as heat index, dewpoint air temperature, and potential evapotranspiration are also available on the higher-end weather station models. Wireless links make it relatively straightforward to transmit the weather station data in real time to display on a web site that is accessible from any internet connection and is useful for remote monitoring of the CUPS. The water content in the root zones of both the in-ground plantings as well as the container-grown plantings can be similarly measured with volumetric water sensors and transmitted to the internet for remotely monitoring the water status of the tree roots and soil in the CUPS. Soil water data together with potential evapotranspiration are most useful for fine tuning the irrigation schedules of intensively managed citrus groves in order to maximize tree growth and fruit production.

v) Pest and disease management

The main need for pest and disease control in the CREC CUPS environment has been timely management of thrips to prevent flower, fruit and leaf damage, rust mite and spider mite control on developing fruits and leaves, and greasy spot fungus control, mainly on grapefruit leaves. Due to the exclusion of psyllids by the 50-mesh screen, no special insecticide sprays are routinely used to target psyllids, although it is good practice to apply preventive sprays occasionally, especially if the main screen house doors have been opened frequently and workers and vehicles have been entering the structure. Frequent scouting on a weekly or fortnightly basis is recommended to detect any new or changed pest and disease conditions, so that remedial actions can be taken immediately. Yellow sticky insect traps are also valuable.

Figure 6. Trellised, pot-grown 'Honey' murcott trees after 26 months in the CREC CUPS

Due to the greatly reduced wind speeds in the CUPS screen house, an ultra-low volume (ULV) sprayer with cold fogging capabilities is very effective, as used in greenhouses (Fig. 7). The smaller droplets of an ULV sprayer tend to more effectively target the very small pests (mites, thrips) that pose significant problems in CUPS. Many citrus varieties form dense canopies, and therefore an ULV sprayer with air assist is recommended in order to blow the pesticide spray into and through the canopies for proper coverage. Citrus pesticides and labeled rates must be used, and the prescribed re-entry and pre-harvest intervals must be observed as in conventional outdoor production systems.

Figure 7. ULV greenhouse sprayer applying pesticide at 2 mph, 25 gpa in the CREC CUPS screen house.

vi) Suggested checklist for CUPS management

Daily duties

- Review the daily irrigation and fertigation logs and verify that the system performs optimally with respect to amounts of water and fertilizer dispensed, and the application run times. These logs may be generated by the irrigation controller.

- Measure and record the stable flow rates and pressures of each zone and compare with previous values. A sudden change of pressure and /or flow rate from previous days' values will usually indicate a leak or burst pipe. An open poly pipe can easily be detected in this way. A more gradual change can often indicate that filters or drip or microjet emitters are dirty and getting clogged. A daily check of the pressure on each side of the main filters during operation will determine whether they are clean or need cleaning. Pressure differential should typically not exceed 5 psi.
- Record and review the soil water and weather data from the previous 24 hours. Modify the irrigation/fertigation schedule accordingly if needed.
- Scan the 3-5 day weather forecasts to estimate the best day(s) for pesticide and herbicide applications.

Weekly / semi-weekly duties

- Inspect the roof and walls from the inside for signs of damage to the screen.
- Walk (or drive with ATV) every row while the irrigation is running to verify microjets are performing as they should. Partially or fully blocked jets can be removed and cleaned or replaced. An electric vehicle is ideal for this because the sound of the microjets can be heard easily when the canopies become too dense for easy visual inspection.
- Record any abnormal visual symptoms of nutritional disorders, salinity damage, and presence of pests or diseases. Look out for major damaging pests like thrips during bloom and rust mites during summer and fall. Early corrective treatments are essential.
- Spray protectant pesticides as needed; the highest spray frequency may be with crop oils and insecticidal soaps (sometimes weekly). Other pesticides, fungicides and miticides generally fall into the monthly or less frequent category.
- Apply fertigation nutrients manually, if weekly instead of daily automated doses are scheduled.
- Inspect the fertigation system, including fertilizer stocks, acid injection (if used) in preparation for the next week.
- During the dry growing season, run a special leaching irrigation event every 2 weeks to leach accumulated fertilizer and irrigation water salts out of the root zone if it has not rained more than 0.5 inches during that time. This is essential when using drippers, but is less necessary for microjets.
- Mow the middles – weekly or semi-weekly depending on the season.

Monthly duties

- Sample leaves for nutrient analysis (monthly when grown in containers; quarterly if grown in ground)
- Apply herbicides to control in-row weeds as required according to the growing season. In summer, the frequency of application may be monthly if no residual herbicide is used. Spray appropriate insecticides, fungicides and miticides as needed.

- Spray supplementary or corrective nutrients according to the leaf sample results.
- Flush the irrigation system – mainlines, submains, and poly lines. Use a chemical cleaner as needed according to your conditions. In our system we need only an oxidizer – either hydrogen peroxide or sodium hypochlorite – to clean out bacterial, fungal or algae residues in the irrigation system.
- Make corrections to the fertigation schedule based on the leaf sample results and according to the season progression.

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