Citrus Nursery Research Report:

Optimization of citrus nursery production in screened houses

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Nov 30 2016

This project focuses on developing information about irrigation and substrate production with and without recirculation.

Earlier in the year we had some difficulties with the project as we encountered aspects about plant nutrition on citrus in protected cultivation. We had a number of issues to solve. We solved some of these but also encountered new problems.

Our research focus in the project has been three-fold:

1. **Plant Growth Trial:** Studying the growth of young citrus trees from post-grafting to marketable size, using various substrates (UC Mix and Coir) with and without recirculation.
2. **Motherblock Productivity Trial**: Testing this scenario for Carrizo rootstock to identify suitability of the recirculation methodology for maximization of cutting production
3. **Screenhouse research:** Growing in screenhouse structures with various degrees of shade. All trials in #1 and #2 above were conducted in two screenhouses, one with 70% shade, the other with no shade.

Prior to 2016 we found that both recirculation and non-recirculation approaches worked well, but we saw some nutrient deficiency symptoms on some plants which we could not explain. So the current trials were designed to develop a more extensive system for recirculating plants.

We also noted that the shade levels and screenhouses significantly benefitted the plants even to the point that 70% shade was better than lesser degrees of shade or no shade at all. Prior to 2016 we had citrus plants in 4 light-level treatments: outdoor full sun (no protection), screenhouse full sun, screenhouse with 35% shade, and screenhouse with 70% shade over the screen. The screening is thrips-level screening. The results from two years of research informed us that the most important treatments to pursue are the screenhouse without any additional shade in contrast with the screenhouse with 70% shade.

Prior to 2016 I had issues with labor, in that two technicians (former MS students) whom I hired for the project left to take industry jobs, leaving me without staffing and thus stalling the project until a new graduate student (Ed Chiurco, MS degree student) was brought on in the fall of 2015. During the Fall of 2015 he received training on the project, so that in early 2016 he could start working on the various facets of the project. The target for getting the research restarted was Spring 2016. Mr Chiurco was charged with building the various systems, getting the screenhouse space configured for the project, setting up the plants into the various research trials, collecting, analyzing and reporting the data. He was also introduced to the

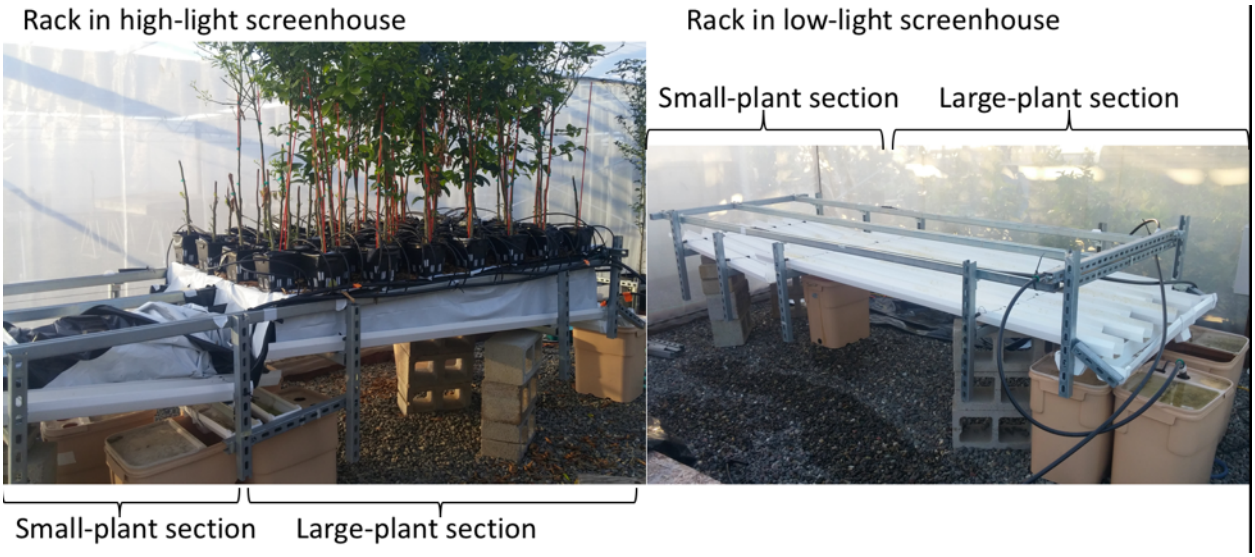
industry and communicated with growers. Unfortunately, and without warning, Mr Chiurco abruptly left the project during the summer 2016, causing various parts of the project to be stalled since then.

Methods and Progress during 2016

During the Spring of 2016 we upgraded the screenhouses and irrigation systems as well as the fertigation system. We visited the Lindcove station to learn specifics on their irrigation and fertigation approaches so as to use those as Control treatment in our research. In consultation with the growers and staff at the Lindcove station we modified our nutrient solution the same that is used at Lindcove.

Plant Growth Trial

Two racks were constructed, one in each screen compartment (these compartments differed by degrees of shade with one compartment shaded 70% with the other had no shade). Each rack is designed to accommodate a large-plant trial as well as a small-plant trial so that two sets of plants can be tested at the same time. The photo below shows how the plants are installed. The core concept is that the rack is designed to hold the Proptek stand in such a way that plants are suspended over plastic rain gutters. The rain gutters connect into to separate sets of tanks so that any one gutter belongs to either the recirculation or the non-recirculation treatment.



The design was specifically to allow randomization of plants growing in Proptek pots. The difficulty is to keep the leachates from the two recirculation treatments from mixing. The system has two reservoirs for the large-plant trails and two for the small-plant trials; in both cases, one for the recirculated treatment, the other for the non-recirculated treatment (see photos).

The drainage gutters were alternated so that the plants could be spaced in such a way that the plants could be randomized on the rack. Tanks were installed with short gutters to direct leachate from either treatment to separate tanks.

The overall plan for the plants in the rack was that young plants would be started pot-tight in the Proptek racks. Once these reach a size where they were so crowded that they need to be moved, these plants would then be moved into the large-plant section of the rack where the spacing would be such that each Proptek frame would hold only 4 pots. Any plants in the Large-plant section would have to be moved at that point to make room for this. Data would be collected at this point on the plants leaving the rack as well as on the plants being moved. Newly propagated plants (grafted plants ready for growth) would be inserted pot-tight into the small-plant sections.

In anticipation of getting this started we obtained some plants from the large-plant section from Wonderful Citrus (Mr Jose Lima). We had planned to obtain small plants as soon as the large plants would be in place. This is the place where this trial abruptly came to a halt when Mr Chiurco left the project. So the current status is that the project is ready for new plants and data collection.

Motherblock Productivity trial

The Carrizo mother block trial was set up to use seedlings which had been grown from seed obtained from the Lindcove station in 2015. The seeds were started in small pots and

transplanted into tall Stuewe pots in the greenhouse during winter conditions. During the spring 2016 these plants were moved into the two screenhouse compartments. In each of the screenhouses, the plants were potted into either: (1) a General Hydroponics Power Grower system (one plant per pot) or (2) a 3-gallon pot filled with UC Mix. The image above shows the configuration in one of the screenhouses on Nov 30 2016.

UC Mix is a substrate mix which is used widely in nursery operations. It consists of redwood sawdust, peat and sand in equal volumes. It has good drainage and adequate bulk density for a large nursery plants. The size of the UCMix pot was selected to provide for roughly equivalent root volumes in both treatments. Timer-activated drip irrigation was used to fertigate the plants growing in UCmix. Parallel strust were installed so that the hexcagonl hydorponics container could be suspended from its lip (see image).

The plants growing in UCmix were simply elevated and positoined within the randomized design. The image shows one each of the containers of each system. The hexagonal container is such that the top 1/3 is filled with hydroton (gravel) which the bottom is a irrigation solution reservoir. A pump is used to lift nutrient solution from the reservoir into the ring that is visible above the hydroton; this disperses it on a continual basis with a slow drip. Note that the container has a sight-tube which allows monitoring the amount of nutrient solution. We calibrate this so that we can easily note how much water is in the system. There is no attempt to catch leachate from the plants growing in UC mix. The hydroponic pots are refilled manually as needed. The data to be collected was water use data as well as estimation of number of cuttings which could be harvested and actual harvested cuttings over time.

Problems (Labor issues)

By early summer both systems were nearly ready to begin testing with the mother block plants installed as above and the plant growth racks nearly completed. We obtained new plants from Paramount nursery and transported these back to Davis to be installed in the system. As the systems were not fully operational we placed all the plants into a greenhouse so that they would have the same conditions.

During the early summer things began to be problematic as Mr Chiurco failed to meet target dates for getting the system operational. Unfortunately this coincided with some of my international travels so that I was not able to personally intervene. Mr Chiurco experienced a number of stresses as part of his academic work and the combined stress of continually failing to meet his goals caused him be become erratic. He walked off the job. I tried various approaches but in the end he simply could not get the work done. I tried to hire additional assistants onto the job but this did not resolve the issue. It became clear that while the quality of Mr Chiurco's work was reasonably good (although too slow) on physical parts of the research

(building the system, working on the screenhouse, etc) he failed to carry out anything that required complex intellectual capacity (writing, design, analysis,…). To make a long story short, this ended up such that he walked off the job permanently during the middle of the summer.

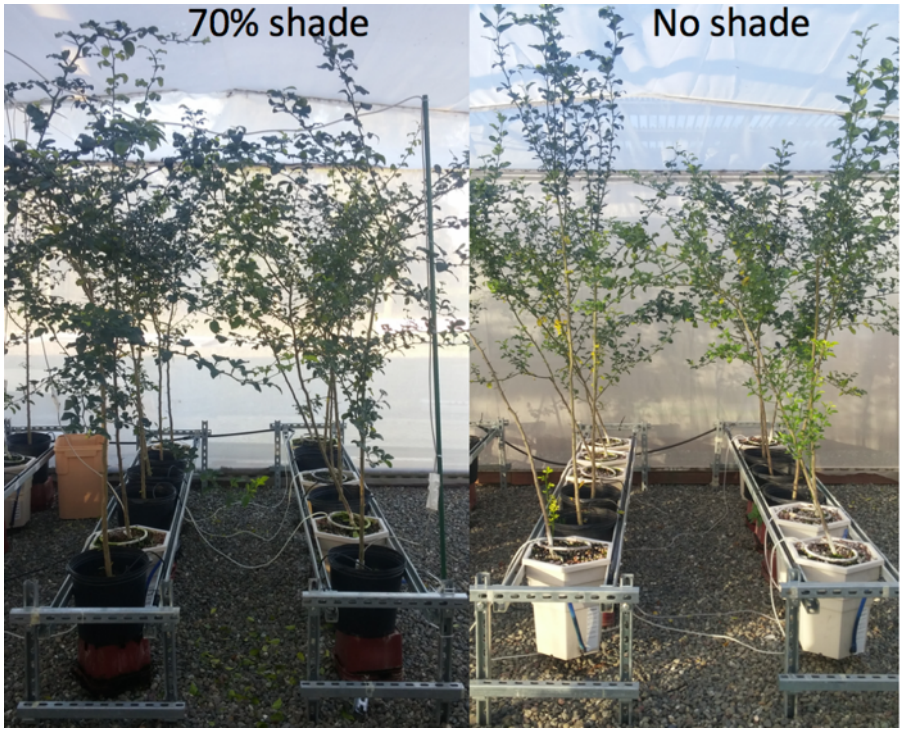
I had no one available to take the project so I tried to hire a non-student by looking for a finishing MS students or advanced recent Bachelors of Science graduate. I initiated a recruitment of Junior Specialist (the only job title we can use for this) through he Plant Sciences Department (this is a long arduous process). Recent changes in hiring policies at UCDavis have made it very difficult and complex to hire any type of assistant other than student assistant (requiring full recruitment procedures). So it took several weeks to get this set up, to advertise and receive applications. I am currently bringing staff on to the project to continue the project where it left off in the summer.

What we have learned

Motherblock trail

The Carrizo plants were to be cut them back to initiate side branch growth and to measure the number of usable cuttings that could be taken off the plants. We have not yet done that and expect to do that as soon as the new staff is ready to start collecting data.

However, we can already see some effects from the conditions since the plants have been in this situation ("waiting") for several months. They started out roughly the same size and it is clear that there are significant differences in growth in the two shadehouse compartments. The plants in the darker condition are growing significantly better than the plant in the screenhouse that has no additional shading. The leaves in the latter are smaller and the plants are shorter. By now all plants are growing against the screen over the top, but the plants growing with more shade touched the screen first. It is not possible to judge whether the number of cutting would be different. This will be explored as soon as we can get a new technician on board. (The foliage color differences in the photo are mostly due to



differences in lighting conditions – darker green is due to less light).

It is also clear that Carrizo grows very well in either UC Mix or the hydroponic system where there is very little organic substrate. As such we have already identified that the General Hydroponics Power Grower is an excellent tool for woody stock plants.

We also noted that we needed to add water to the hydroponics more often than we anticipated. We noted that the water use in the hydroponic system in the summer was greater than the water use in the pot. This was due to the fact that the air pumps used for aeration and recirculation were running constantly. We tried cutting this in half and found that we had less water use without any apparent impact on the plants. This has taught us that it is relevant as part of development of BMPs for this type of production that we identify the optimal duty-cycle of the pumps over the course of the year. The key is to impose only the amount of aeration that is necessary for good root health.

Plant Growth Trial

Although we have not yet had plants growing in the rack system we were able to learn quite a bit to help us get some of the problems worked out. It should be noted that various details had to be modified so as to gain stability of the rack while getting the various systems (irrigation, fertigation, recirculation) working. At this point I need to hire a new technician and this individual would first install the drip irrigation systems into the racks and install plants and then being the short plant trials as well as the large plant trials. For the large plants trials we can use the plants we have on hand. For small plants we need to secure new plants from a commercial nursery. In future work I also plan to install sensors within the hydroponics to track water and nutrient conditions.

Screenhouse research

The screenhouse compartment that were used prior to 2016 (photo) were upgraded and repaired. During the winter the wind had caused some damage and we invested time and effort in getting this repaired. Our protocol also called for installation of more temperature and humidity sensing equipment in addition to the data logging systems that had been installed before.

Our earlier observations suggested that it would be ideal if we could develop screenhouse space with some active cooling for those days during the summer where the heat in an unshaded screenhouse is so hot that humans cannot stay within the space for any amount of time. Citrus seems to tolerate such temperatures, but all our indications were that during periods of high heat, the plants simply shut down resulting in smaller leaves and delayed growth.

I also began to develop new screenhouse space for the purpose of studying new cooling technologies for screenhouse compartments. We have quite a few visitors to the site learning about the research so that many persons get to learn about this research and to experience the core problems of high heat within unshaded screenhouses. The CEO of Koolfog (fog cooling, http://www.koolfog.com) offered to partner with me on a project to test whether one of their cooling systems could be used in screenhouses to mitigate the heat. He donated a fog cooling system. Another firm, Avolved (http://www.avolvedgrow.com), is currently partnering with Koolfog and myself to develop a controller which would be designed specifically for citrus nursery production. Recently the western one-fifth of the UCDavis Photovoltaic Shadehouse was converted in to screen compartments and this is ready to receive plants. We will construct additional Plant Growth Trial racks for these compartments.

This structure will be used in future trials to test whether fog cooling in citrus nursery screenhouse production can be a useful tool.

I am also currently setting up a small greenhouse adjacent to the test area so as to be able to do greenhouse work on the site. To date all our greenhouse work was conducted at the Environmental Horticulture greenhouses. This new house will allow me to study citrus

greenhouse growth in comparison with adjacent screenhouses. This is currently under construction and should be ready during January.

Proposal