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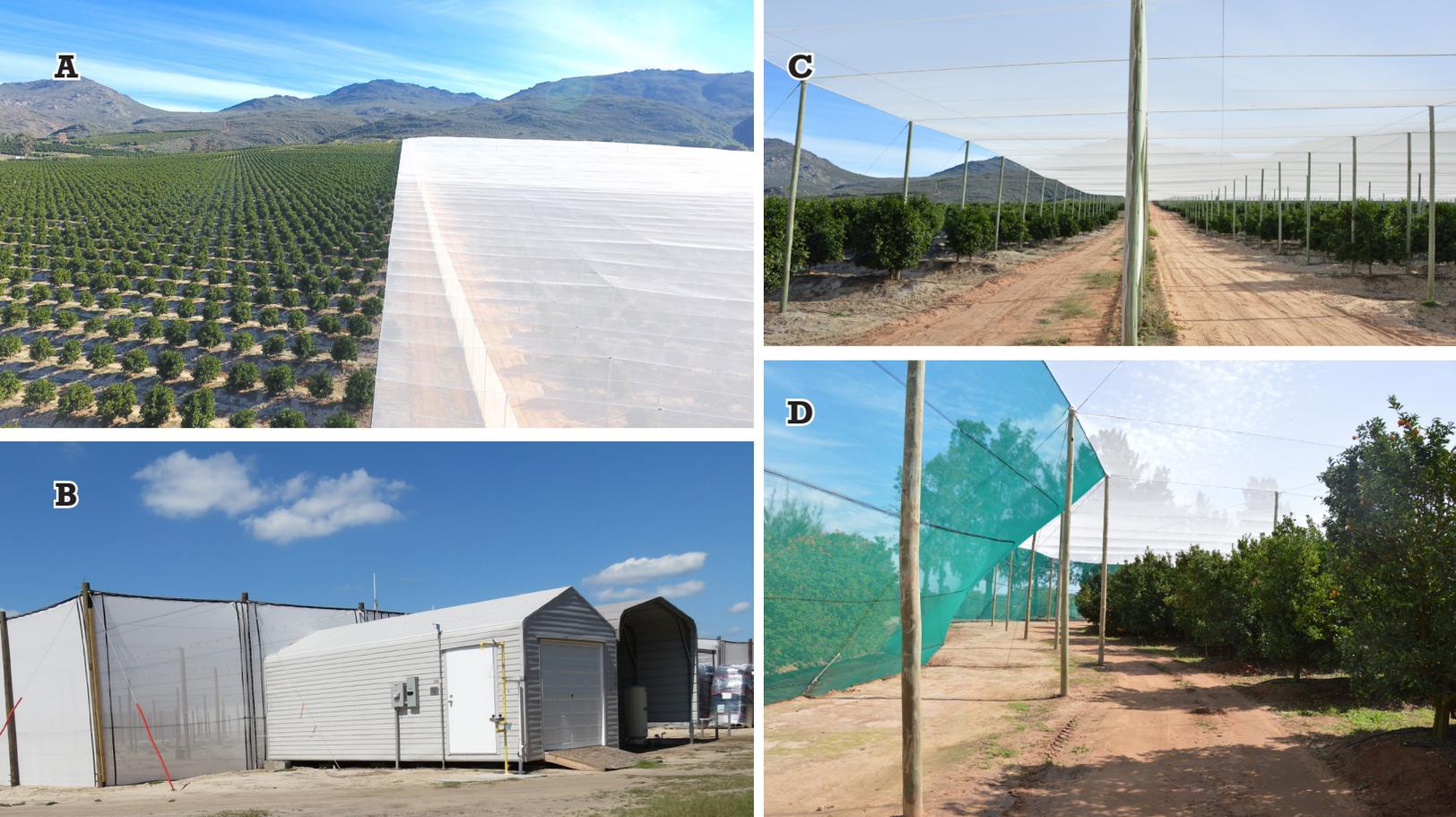


Figure 1: Netting structures in South Africa (A) and Florida (B) erected for cross-pollination, wind breaks, sunburn protection (for South Africa) and huanglongbing management (for Florida) respectively. Note the difference between the 90° (C) and 45° (D) angle of the side walls.

Growing Citrus Under Nets

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Project Summary

This article provides an overview about growing citrus under nets. It mostly reflects the body of the knowledge acquired from citrus production in Florida and South Africa. In the former, insect-excluding screenhouses have been erected to manage huanglongbing (HLB), whereas in the latter, netting has been used for protection against cross-pollination, sunburn, frost, hail and wind damage. Here we review some of the benefits and limitations of these systems for citrus production.

Net houses have been used in agriculture since the middle of the 20th century and have become a standard cultural practice in the U.S. and around the world, particularly for annual crops and plant nurseries. In light of their sustainability and effectiveness to exclude insect pests, but also against environmental challenges, undercover production systems have gained interest for perennial cropping systems. Permanent netting structures for commercial citrus production have been used since the beginning of the 21st century in countries including South Africa, Israel, Australia and Spain to protect against cross-pollination, sunburn, frost, hail and wind damage. In HLB-affected areas, completely sealed structures have been used to exclude the Asian citrus psyllid (ACP) and produce HLB-free trees. This approach has proven to be very effective

for citrus nurseries in Brazil (Salvador et al. 2016) and Florida (Rouse et al. 2007; Solis et al. 2016) and is now being implemented for commercial citrus production.

The South African citrus industry focuses on fresh fruit production like California, and displays similar winter rainfall conditions. There are 185,000 acres of citrus in South Africa, and the majority of its fresh fruit production is exported to international markets such as Europe and China (USDA Foreign Agricultural Service 2017). In the southern coastal provinces of South Africa, nets are set up to provide shading and windbreaks, whereas in the northern inland provinces, nets are built mainly to protect against hail. In both areas, they are also effective at excluding bees and minimizing cross-pollination. Fifteen years ago, only a few growers

used netting, and these were often built over an already existing orchard. Nowadays, in light of the many advantages of netting, they are set up before orchard establishment. At \$8,000 USD per acre, the upfront establishment costs are three times higher than the standard for South Africa. However, it only takes two to four years to pay back those investments, depending on the market values of the planted varieties. The netting structure can cover several tens of acres and the design is fairly standard with a 20-foot (six-meter) tall structure to accommodate tree height and machinery (**Figures 1A and B**). Most netting material used is white or pearl in color and provides 20 percent shading. Sidewalls may be green to blend into the environment. Sidewalls were initially at a 90° angle to the ground, but recent designs feature a 45° angle to sustain higher wind speeds (up to 80 miles per hour – **Figures 1C and D**). In-row tree spacing ranges from six to ten feet (two to three meters) with 16 to 20 feet (five to six meters) between rows and at least 300 trees per acre. Support poles are spaced four or five trees apart within the structure, depending on planting density (about 26-30 feet), and poles are offset between each row (**Figure 2A and B**).

In South Africa, research demonstrated the many benefits of growing citrus under 20 percent shade (Botes 2018; Brown 2018; Prins 2018). First of all, significantly fewer fruit were blemished, and growers experienced much higher pack-outs, sometimes up to 99 percent, and with a much higher number of premium-grade fruit. Netting provided

80 percent wind speed reduction, a 17 percent decrease in solar radiation and protected against wind scar, fruit splitting and sunburn in sensitive varieties such as ‘Cambria,’ ‘Autumn Gold,’ and ‘W. Murcott,’ respectively. Environmental conditions under netting were vastly different than in the open air, but trees responded positively to those changes at many levels. Temperatures were buffered, which was critical during the flowering period. Overall, there was less heat stress and freeze damage, and more heat units were accumulated than in open air. Air temperature effects also translated into moderated soil temperatures with decreased maximum daily soil temperatures and increased minimum soil temperature. As a result, root growth and flower set were stimulated. In addition, a higher relative humidity was measured under netting, especially in the summer months, which favored stomatal conductance¹ and gas exchange and increased photosynthesis by up to 20 percent. Overall, tree water demand was less and reduced water consumption in the range of 25-35 percent. Vegetative growth also was stimulated, but not at the expense of flowering, fruit set, fruit size or yield. Trees went into production earlier (two years under netting vs. four years in open air), with a yield increase of 10-30 percent in both on and off years, a shift toward bigger fruit size and no negative impact on fruit quality parameters or post-harvest characteristics. Trees were over-all larger with earlier canopy development, longer shoots in summer flush, more nodes and more leaves with increased surface area. High vigor sometimes can become an issue under netting, especially for varieties like lemons, so

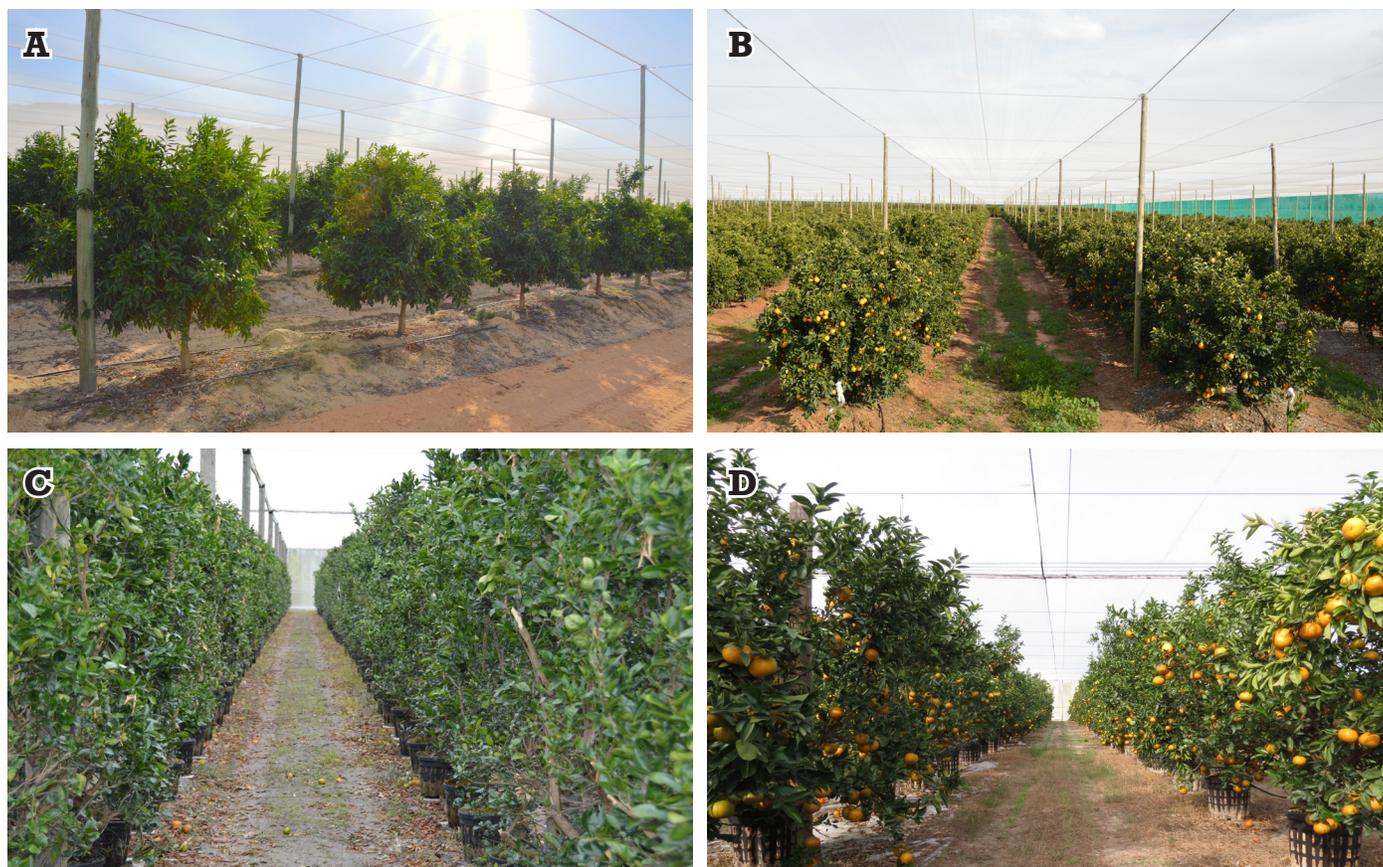


Figure 2: Trees grown under nets in South Africa (A, B) and Florida (C, D). Note the pole spacing in South Africa (A, B) and how poles are offset from one row to the next. Note the very high density obtained by planting trees in pots in Florida. Also, note the difference in structure height between Florida (14 feet) and South Africa (20 feet) with a lot more room between tree canopy and roof-top in South Africa.



Figure 3: Fruit set in trees grown under nets in South Africa (A) *W. Murcott*, 200 lbs. per tree, and Florida (B) *Ray Ruby*, 346 boxes per acre. Note the high yields and quality of the fruit.

pruning management and plant growth regulator treatments are necessary, as growers in South Africa have not commonly used dwarfing or semi-dwarfing rootstocks.

In Florida, the purpose for growing citrus under netting is different than in South Africa. CUPS (also known as Citrus Under Protective Screen or Citrus Undercover Production System) started in 2014 with the goal to exclude ACP, the vector of the HLB-associated bacterium, from citrus production areas. To that end, screen mesh apertures are smaller than the shading nets used in South Africa, and the production area is sealed from the outdoors on all sides. Thus, the structure is more costly.

Environmental conditions underneath the structure also are different from those of the shade nets. The initial structure design that was built at the University of Florida's Lake Alfred and Indian River Research and Extension Centers resembled the ones in South Africa with sidewalls perpendicular to the ground, net buried one foot in the soil and pressure-treated wooden utility poles anchored to the ground for use as support posts (**Figure 1**). The major differences were the height of the structure (14 feet vs. 20 feet) and the hermetic anti-ACP screen design. Construction cost is about one dollar per square foot; therefore, a one-acre structure costs about \$43,000 to build. The initial experimental design under the covered structures at the Florida Research and Extension

Center included in-ground and potted trees (**Figure 2**). Fruit yields harvested in the second year from 'Honey Murcott' trees planted in pots or in the ground were not statistically different, but trees in pots set fruit more uniformly than those growing in the ground. Both in-ground and potted 'Honey Murcott' trees became strongly alternate-bearing after year two. This year (year four), the trees again set excessive fruit. A fruit thinning experiment was initiated to better regulate alternate bearing, preserve tree health and improve fruit size and quality without reducing yields.

The benefits of using trees in pots are that tree density can be very high (871 trees per acre for 'Ray Ruby' grapefruit in ten-gallon pots to 1,361 trees per acre for 'Honey Murcott' in seven-gallon pots). Tree canopy size is well controlled, which is an advantage when dealing with a relatively low ceiling (**Figure 2**). Potted trees set fruit after one year; and after 2.5 years, 'Honey Murcott' yield was 680 boxes per acre, and 'Ray Ruby' was 346 boxes per acre with 99 percent pack-out for both varieties (**Figure 3**). Fruit quality parameters (fruit size, color, brix and acid) were significantly better for the CUPS fruit in comparison to outdoor fruit, primarily due to HLB impacts on unprotected trees. Research showed that the overall environmental conditions and tree response were similar to those observed in South Africa. Wind gusts, evapotranspiration and cumulative solar radiation were all reduced by 75 percent, 23 percent and 21 percent,

respectively (Ferrarezi et al. 2017b). Trees grown inside the enclosed greenhouse had higher canopy surface area, leaf area index and water use efficiency (Ferrarezi et al. 2017a). The major difference found between the Florida and South African trials was the maximum daytime temperature, which increased in Florida, perhaps due to a lower roof structure and/or smaller mesh size.

The main disadvantage to using nets was higher pest incidence (thrips, mites, white flies, mealybugs) (G. Barry, *personal communication*). Growers had to remain on the top of their pest and disease management and tree nutrition programs.

Large-scale commercial citrus production under netting or anti-insect screens has not been widely adopted within California. However, evidence suggests that trees responded positively to the shift in environmental conditions set by the nets in other citriculture areas with different climates. The major benefits of growing citrus under nets were a quick fruit set following tree planting, higher yield with higher pack-outs and premium marketable fruit. Those benefits offset the upfront investment costs of the netting structure, especially for high value varieties, although cost benefit analyses would have to address the economic value of CUPS for California markets. As HLB looms as a potential threat to California citrus production, CUPS provides an additional choice for HLB management, but also offers new possibilities to grow citrus that alleviate some of the environmental risks and challenges. 🌱

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Glossary

Stomatal conductance: The rate of water vapor and carbon dioxide movement through stomata (pores on the surface of a leaf).

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