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The Citrus Grove of the Future and Its Implications for Huanglongbing Management

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Revolutionary changes face Florida's citrus industry as huanglongbing (greening) becomes widespread. Changing economic realities have encouraged many tree fruit industries to modify planting density, tree architecture, training and production systems. More trees/acre translate into earlier bearing and less yield disruption as trees die, but with greater establishment costs per acre. A model for citrus production, which may permit profitable production in Florida using huanglongbing susceptible material, has been called an Advanced Production System combined with Open Hydroponic System. These practices have been adopted in a number of citrus producing countries, but need to be evaluated and adapted to Florida conditions. Practices that facilitate early cropping and fruit quality are critical to high density orchard profitability. Control of water and nutrients to manage tree development, girdling, use of plant growth regulators, larger planting stock, and tree supports may maximize early yields and help contain canopy volume. In the more distant future, genetic improvement solutions may contribute additional tools. The purpose of this paper is to stimulate discussion, facilitate assembly of diverse useful ideas in facing this challenge, and coordinate efforts within Florida to get a critical mass of production and economic data as quickly as possible.

The Florida and U.S. citrus industries are facing an unprecedented crisis. It is projected that with the current rates of spread and increase, virtually all current citrus plantings in Florida will be affected by huanglongbing (HLB) in 7–12 years (T. Gottwald, personal communication). Total Florida citrus production will decline in this period in the absence of any offsetting options. For the long-term future of Florida citrus, the greatest threat may be that a significant lapse in citrus production could result in the permanent loss of the processing and packing infrastructure, which requires a high level of throughput to remain viable (R. Norberg, personal communication).

Psyllid-control and/or HLB-detection and tree roguing solutions may be found that will protect existing groves (Bove, 2006), but those solutions alone may take too long to sustain the volume of fruit production necessary to maintain a viable industry. Thus, it is critical to develop new procedures that permit economically acceptable production in new plantings until long-term solutions such as pest/disease control measures, HLB-resistant transgenics, or other "sustainable" practices are identified and implemented. The purpose of this paper is not to provide answers obtained through research, because there are no solid answers currently available. Indeed, it appears that the industry needs guidance sooner than the established research verification/extension/industry adoption paradigm can possibly provide it. It is our intent to mobilize the research community and industry to establish a coordinated series of research plots, which will provide reasonable guidance to industry decision makers, so that they can rationally consider establishing extensive new groves which may provide the fruit production necessary to sustain the processing and packing infrastructure.

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How Might Production Remain Economic in the Presence of HLB with Existing Control Measures and Susceptible Varieties?

Citrus growers in some parts of the world have identified short-cycle production as a critical component of living with HLB. For this to be economically viable, it is necessary to establish and manage groves in such a way that production reaches high levels early and that high production is maintained for as much of the orchard life as possible. Many world tree-fruit industries have transitioned to more trees/area (e.g., Jackson, 1989; Robinson et al., 2007; Taylor and Beckman, 2003) because research and commercial experience have shown that these higher density orchards maximize fruit quality and productivity, provide a convenient way to rapidly introduce new scion varieties, and enable new, less costly harvesting options. Early and high production is achieved primarily through moving the production curve up in time by using more trees/area and intensive management.

The 10–12 year economic life we may expect for a Florida citrus grove in the HLB era is something that has been standard reality for northern European apple growers for the last 20 years due to demand for newer varieties and need to maintain orchards which can be harvested without ladders. Similar needs have compelled changes in U.S. apple production more recently. What can we learn from them? In New York apple production systems trials, yield per tree is about the same in the early years after planting whether trees are planted at 239 or 2150 trees/acre (Fig 1; Robinson et al., 2007). However, at the higher densities, the smaller area designated for each tree allows the trees to fill their space more quickly, with the result that they reach "mature" full-bearing size much earlier after planting. At an intermediate age, yield will still be similar across a wide range of trees/area. Later in the orchard life, perhaps at 12+ years, as trees become

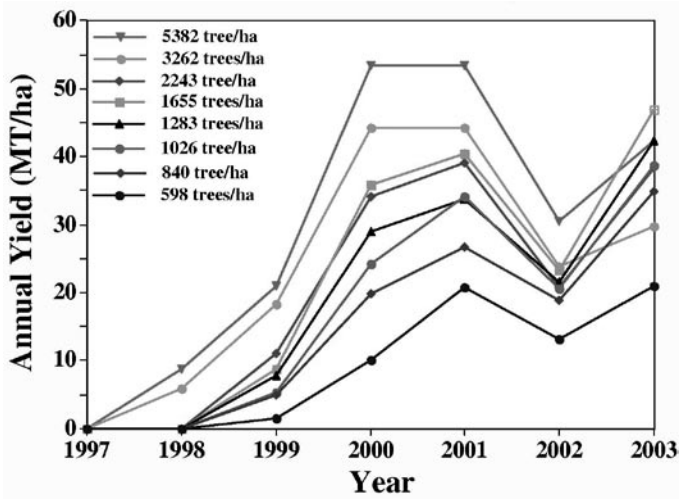

Fig. 1. Yield curves for apple production in New York, demonstrating that early yield is largely a function of trees/area (Robinson et al., 2007).

crowded at the high planting densities and require more pruning, the higher tree/area plantings often display lower productivity and greater management costs than those orchards planted at lower densities. It should be noted, however, that apple growers do not experience the kinds of tree loss rates that may occur with HLB which would alleviate crowding issues as the tree population declines. Yield per area is not the only factor in economic viability; consideration of establishment and management costs frequently reveal an optimum of around 1000 trees/acre in high density modern apple orchards (Fig. 2). Furthermore, the results of the apple system trials typically demonstrate that higher early yields from high planting densities do not necessarily lead to better lifetime economic performance. That concept of lifetime performance was introduced to Florida citrus growers during a 1978 symposium on the subject of high density plantings (Wheaton et al., 1978).

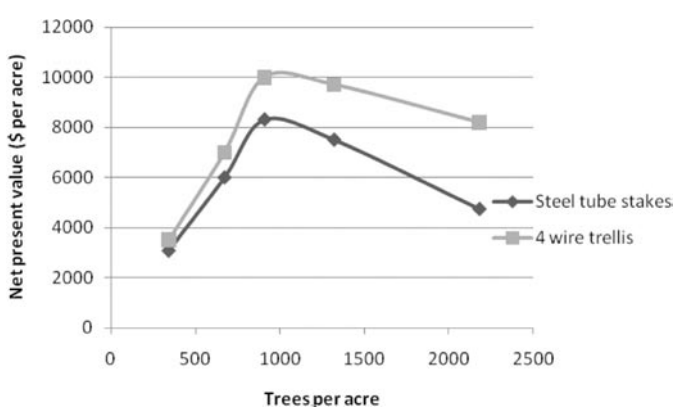

Fig. 2. Profitability curves for two apple production support systems in New York, demonstrating that intermediate trees/area provide the optimal return over the first 12 years of orchard life. (Robinson et al., 2007). Steel tube stakes are individual 8-ft rods vertically supporting individual trees. Four wire trellis support is a system in which four horizontal wires are strung down rows with vertical posts supporting wires every 20 ft, and individual trees fastened to vertical wires attached to trellis wires. All nursery trees used were "feathered," meaning that they had numerous branches.

What does a similar analysis of citrus density show especially in conjunction with tree losses that might occur from HLB? Projections on citrus production at several tree/area plantings are proposed with the assumptions that initial protection from psyllid by imidacloprid results in 2 years with no tree loss. Additional assumptions include yields are 0.2 box/tree in year 2, 0.4 box/tree in year 3, 0.8 box/tree in year 4, 1.2 box/tree in year 5, 2.0 box/tree in year 6 with continued increases of 0.5 box/tree in subsequent years to a maximum yield of 800 boxes/acre, and a 20% fluctuation due to alternate bearing, weather, and pruning perturbations (Figs. 3–5). Boxes are 90 lbs = 41 kg. For reference, note that a conventional Florida grove planted at 15 ft × 25 ft has 116 trees/acres, planting at 10 ft × 20 ft achieves 218 trees/acre, and planting at 6 ft × 20 ft or 8 ft × 15 ft produces 363 trees/acre. Existing grove equipment and bedded grove engineering design will make it difficult to immediately implement tighter row spacings. It is anticipated that 300–400 trees/acre may be a reasonable planting density to consider in the next generation of groves. Therefore, the following discussion focuses on entries for 200 and 400 trees/acre.

In one scenario (Fig. 3), the loss rate is 3% of trees/year, a situation only slightly worse than is historically typical in Florida

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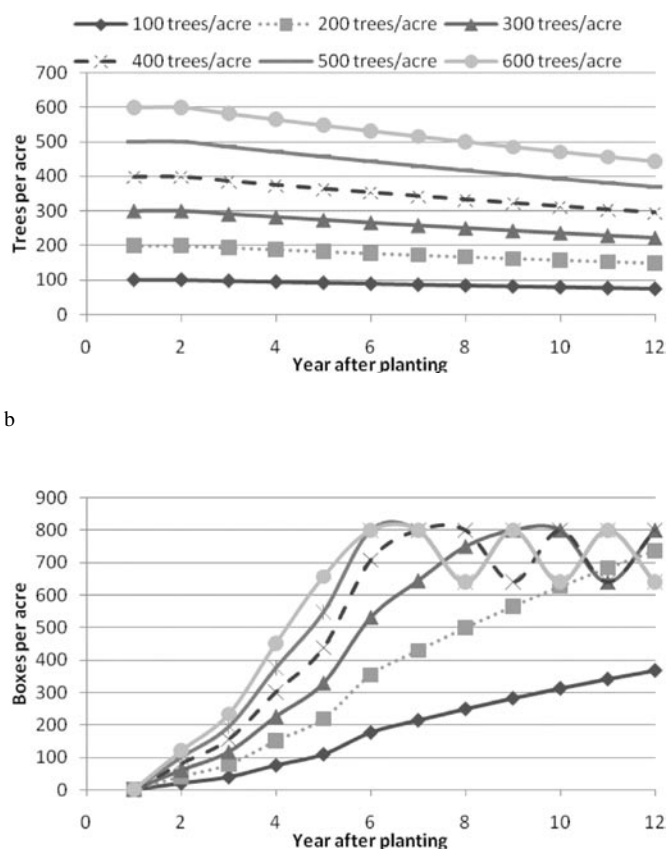

Fig. 3. Projections on annual trees per area (a) and citrus production (b; boxes = 90 lbs, 41 kg) with 3% loss of trees per year at 100 - 600 tree/acre at planting (legend in Fig. 3a also applies to Fig. 3b). Assumptions are that protection from psyllid by imidacloprid results in 2 years with no tree loss, and yields of 0.2 box/tree in year 2, 0.4 box/tree in year 3, 0.8 box/tree in year 4, 1.2 box/tree in year 5, 2.0 box/tree in year 6 with continued increases of 0.5 box/tree in subsequent years, with a maximum yield of 800 boxes/acre, and a 20% fluctuation due to alternate bearing, weather, and pruning perturbations

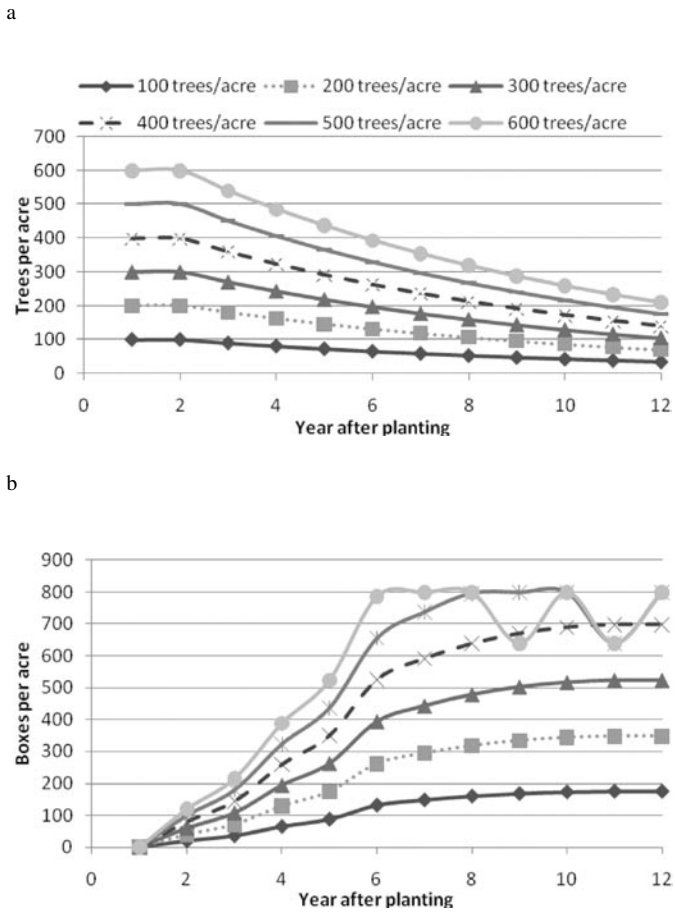

Fig. 4. Projections on annual trees per area (a) and citrus production (b; boxes = 90 lbs, 41 kg) with 10% loss of trees per year at 100–600 trees/acre at planting (legend in Fig. 4a also applies to Fig. 4b). Assumptions are that protection from psyllid by imidacloprid results in 2 years with no tree loss, and yields of 0.2 box/tree in year 2, 0.4 box/tree in year 3, 0.8 box/tree in year 4, 1.2 box/tree in year 5, 2.0 box/tree in year 6 with continued increases of 0.5 box/tree in subsequent years, with a maximum yield of 800 boxes/acre, and a 20% fluctuation due to alternate bearing, weather, and pruning perturbations.

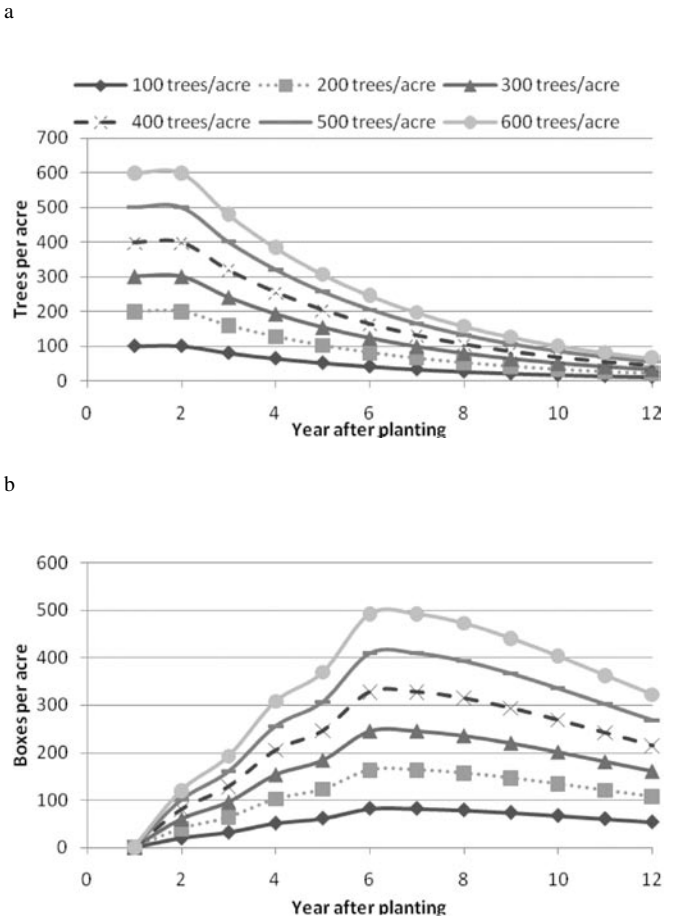

Fig. 5. Projections on annual trees per area (a) and citrus production (b; boxes = 90 lbs, 41 kg) with 30% loss of trees per year at 100–600 trees/acre at planting (legend in Fig. 5a also applies to Fig. 5b). Assumptions are that protection from psyllid by imidacloprid results in 2 years with no tree loss, and yields of 0.2 box/tree in year 2, 0.4 box/tree in year 3, 0.8 box/tree in year 4, 1.2 box/tree in year 5, 2.0 box/tree in year 6 with continued increases of 0.5 box/tree in subsequent years, with a maximum yield of 800 boxes/acre, and a 20% fluctuation due to alternate bearing, weather, and pruning perturbations.

citrus production. At the end of year 12, the grove planted to 400 trees/acre has declined to 300 trees/acre and the grove planted at 200 trees/acre has declined to 150 trees/acre (Fig. 3a), all above the current Florida average trees/acre. Due to more trees/acre, the grove planted to 400 trees/acre reaches 500 boxes/acre in year 5 and remains above this level through year 12, while the grove planted at 200 trees/acre takes an additional 3 years to pass this threshold (Fig. 3b).

At a loss rate of 10% of trees/year, a situation reflecting very serious loss of trees to HLB, at the end of year 12 the grove planted to 400 trees/acre has declined to 150 trees/acre and the grove planted at 200 trees/acre has declined to 75 trees/acre (Fig. 4a). The grove planted to 400 trees/acre is projected to reach 500 boxes/acre in year 6 and remains above this level through years 12, while the grove planted at 200 trees/acre reaches a maximum of 350 boxes/acre (Fig. 4b).

When the loss rate is 30% of trees/year, a situation reflecting catastrophic loss of trees to HLB, at the end of year 12 the grove planted to 400 trees/acre has declined to 50 trees/acre and the grove planted at 200 trees/acre has declined to 25 trees/acre (Fig. 5a). The grove planted to 400 trees/acre approaches 350 boxes/acre in year 6 and declines through year 12, while the grove planted at 200 trees/acre reaches a maximum of 170 boxes/acre (Fig. 4b). This figure shows that even with extreme loss rates, the higher density grove has a greater chance of returning establishment costs, which significantly mitigates the risks associated with HLB for new plantings. In the future, the assumptions regarding yield and the ability to control HLB using novel techniques will certainly be improved based on research and the experience of growers.

Many industry members and researchers will recall that higher-density citrus production has been tested in Florida in the past, and that the results did not compel commercial adoption of these practices (Wheaton et al., 1978, 1991). These trials were conducted within the paradigm of standard production methods and expectations of groves surviving 20–30 years. Furthermore, demonstrating that closely spaced trees could produce high yield has not resulted in broad commercial implementation primarily because of lingering concerns about the availability of appropriate scion/rootstock combinations and culturing and harvesting such orchards with conventional equipment. The constraints of living with HLB will change economics and incentive for change, and information developed in other countries where HLB has been endemic provides direction for responding to the situation in Florida since growers in these countries have developed manage-

ment practices that will achieve high production over a period of years with increased tree densities. Moreover, some practices being considered will be valuable even after a solution to HLB is identified.

A Framework for Testing Higher-density Citrus Production Systems in Florida

One possible new model for Florida citrus production has been called an Advanced Production System (APS) combined with Open Hydroponic System (OHS). The APS component largely reflects grove design factors that once decided are not usually changed following implementation (static variables). These would include such factors as scion–rootstock combination, planting density, and irrigation design. The dynamic factors that are likely to change after planting are aspects of cultural management, becoming more intensive as is routine in modern apple production, but quite different from conventional Florida citrus production. OHS is a group of practices developed initially in Spain, Israel and South Africa, which seeks to provide more rapid tree growth, earlier production, higher yields and better fruit quality by maximizing control over tree water relations and nutrient status. By irrigating daily with drip irrigation to train the root system into a limited area and fertigating with the daily requirement of nutrients, the goal is to provide tight control over water and nutrient-mediated plant growth and development. Details of OHS can be viewed at <http://www.imok.ufl.edu/events/expo/> where the presentations from 2007 Citrus EXPO are maintained.

Growers may be hesitant to adopt APS/OHS because it represents a departure from the grove designs and production practices that have been successful in the past. The reason why we feel that it is important to look to APS/OHS for future success relates to the inevitable tree losses that will occur due to HLB. HLB infection will occur, and tree loss rates will be accelerated by the need to remove infected trees that are otherwise healthy and productive to reduce the subsequent spread of the disease through the grove. Therefore, the successful financial approaches of the past will no longer be relevant, as has been seen in other countries. Both China and South Africa have had HLB for decades, and the citrus industries in both countries were originally decimated by the disease. Currently, however, the citrus industries are expanding even in the areas of the countries where HLB is endemic (China recently passed the US as the second largest citrus producing country in the world, behind Brazil). The approach that has been proven to be financially successful in both countries has been to increase the number of trees per acre to offset the increased tree loss rates caused by HLB, accompanied by necessary shifts in management, fruit removal systems, and other advancements.

Intensive scouting and rapid tree removal are appropriate strategies for reducing the immediate impact of HLB in existing groves. At some point, however, the healthy tree population will be reduced to the point where it is no longer economic to continue with existing groves, or the HLB infection rate will exceed the percentage where tree removal is a viable approach. At the point where existing blocks are no longer capable of producing a net positive economic return, replanting at conventional densities will accentuate risk. Therefore, OHS/APS offer a lower risk alternative. Essentially, risk is transferred from HLB to management and horticultural practices, which are controllable.

Many critical questions relate to understanding of HLB and psyllid spread and control. The likely progression of tree loss is absolutely critical to projecting whether any production system will be viable (Figs. 3–5). How will aggressive psyllid spraying and tree roguing reduce rate of spread and loss? Is the Brazilian model of aggressive removal of HLB-infected trees appropriate for South Florida, or in some groves with advanced HLB are we willing to accept production from trees declining from HLB, despite their being sources of inoculum? If inoculum is too abundant to rogue trees, what management techniques may maintain production in HLB-infected trees?

What components are missing for implementation of higher density Florida citrus production systems? High early production is absolutely essential for sound economics in shorter-cycle citrus production. From initial OHS/APS plantings it appears that grapefruit, but not 'Minneola', will be sufficiently early-bearing to achieve ideal early yields without the need for additional management. How will we encourage earlier and heavier cropping in slower-to-bear cultivars or where rootstock selection delays cropping? Girdling, control of water and nutrients, and gibberellins during flowering have all been used to enhance floral initiation and fruit set in areas where OHS/APS has been implemented. These practices may not all be directly applicable to the very different climate and soils of Florida.

There is no established understanding of how trees in Florida will grow in OHS/APS or other higher-density systems especially when coupled with the differences in scion/rootstock responses to techniques for early cropping, which will influence resulting vegetative growth, and may perturb our understanding of scion and rootstock effects on tree size. To properly design a grove, we need to develop data on growth of different scions/rootstocks grown with OHS/APS in major citrus soil types in order to establish appropriate in-row spacing. It is likely that constraints on equipment and established bed dimensions will limit options for between row spacing until the following generation of groves.

Conventional wisdom is that young citrus trees have poor fruit quality. However, those observations are for fruit on trees which are being pushed hard to develop canopy volume. If the nutritional program is modified in anticipation of bearing in year 3, will fruit quality be acceptable to the market? Experience in other countries and early observations in Florida suggest that this will be true, but experiments need to confirm this or there is no advantage to producing fresh fruit before year 5.

Is it important to have a dense root ball under drip emitters for greater control of drought stress? Many growers may be more comfortable using the microsprinkler emitters with which they are already familiar if similar results can be achieved. What nutrient regimes will work best for Florida conditions and varieties? Is there possibly value in pulsing young trees with plant growth regulators like GA-biosynthesis inhibitors in the winter to enhance floral initiation (e.g., Takahara et al., 2001)?

What other lessons learned in deciduous fruits may be relevant to citrus production? It certainly appears that early heavy cropping will help control vegetative growth, keeping trees in check and reducing cost of pruning while also providing earlier cash flow. The high-density apple producers state that "large branches make large trees," and annually prune out the largest branches. Some synthesis of this practice with OHS/APS by selective removal of upright branches from tree centers to encourage "growth inward rather than outward" may prove effective in Florida citrus production. Apple research has repeatedly shown that use of large, well-branched nursery stock provides earlier yield and that use of tree supports enhances early cropping. These practices are essentially untested for Florida citrus production.

Further into the Future?

Considerable effort is going into developing transgenic citrus resistant to HLB. Transgenic solutions may open the door to previously unimaginable opportunities for controlling plant and fruit development. Inducing earlier flowering through transgenic solutions is likely to be a reality within 20 years using sprayable inducible promoters (e.g., Cao et al., 2006) to shift trees into bearing when adequate tree size is realized. Genes such as AP1 and LFY from *Arabidopsis* (Pena et al., 2001) and FT from *Citrus* (Endo et al., 2005) have already been inserted into *Citrus* or *Poncirus* using less useful constitutive promoters, proving the potential for these tools. AP1 and LFY have now been isolated directly from citrus (Pillitteri et al., 2004). Genes that will control branching and tree height have also been identified (e.g., Koshita et al., 2002), so we need to start thinking about where we want to go now. We propose that any HLB "solutions" produced in the next few years are likely to be transitional, and production systems and plant materials will evolve rapidly over the next 20 years. However, at each step in this rapidly changing citrus production landscape, it will be invaluable to have proven methods for quickly bringing new groves into production to reduce the time necessary to determine the outcome of these new approaches.

How Will We Test Priority Practices in Time to Provide Critical Guidance?

UF/IFAS faculty members have initiated a number of experiments and demonstration trials around the citrus growing region, but more work, coordinated to target diverse regions and priority questions, will be needed. Clearly it will be critical to include economic analyses and provide frequent updates so that early-adopters will be in the best position to choose which planting system makes sense, and if they move ahead, provide positive results which will encourage more wide-spread adoption. Industry needs to get involved by establishing plots in collaboration with researchers and sharing results widely. It is likely additional trials can be accelerated within the context of HLB grants projected to be available through FCPRAC/DOC if planting systems are used that will reduce the pre-productive periods of groves.

There are also positive environmental effects from OHS/APS. The Arapaho trial in Ft. Pierce is using less than one-third of the normal nutrients and water through the second year of the planting while achieving rapid tree growth rates (Spyke, unpublished). This combined with daily rationing of nutrients markedly reduces risk of substantial nutrient efflux, which makes it likely that water management district funds could be leveraged for research.

It certainly seems to make sense to coordinate efforts/proposals within Florida to get a critical mass of production and economic data as quickly as possible. Growers and researchers can readily see the downside of HLB establishment in Florida, so we need to develop interim solutions that will maintain the viability of the industry while long-term solutions are pursued. The OHS/APS approach has proven to be the most viable response in other countries, so we need to tailor the principles to fit Florida conditions as quickly as possible.

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