Left, good psyllid control is an essential part of any HLB management strategy.

Right, removing infected trees is one HLB management strategy.

IFAS guidance for huanglongbing (greening) management

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This document has been developed in an effort to provide guidance to the Florida citrus industry in making management decisions regarding huanglongbing (HLB, citrus greening). Note that the information contained in this document reflects the best thinking of IFAS citrus researchers, based on current scientific evidence and observations under Florida conditions as of spring 2010. However, it is subject to change and the document will be updated as necessary based on new research findings. Users of the document are encouraged to consult with their IFAS citrus Extension agents to make sure they are referencing the most recent version.

This document is presented in four sections.

1. HLB in Florida.
2. Management strategies: a) inoculum reduction via removal of HLB-infected trees, and b) use of foliar nutritional sprays to maintain the productivity of HLB-infected trees.
3. Deciding which management strategy to use.
4. HLB infection scenarios and management guidance.

1. HLB IN FLORIDA

HLB, also known as citrus greening, is the most devastating disease of citrus, affecting all citrus species and varieties. This disease has severely limited production in many citrus-growing areas around the world. In Florida, the disease is believed to be caused by the bacterium *Candidatus* Liberibacter asiaticus (Las) and is spread by the Asian citrus psyllid (*Diaphorina citri* Kuwayama). This insect was first found in Florida in 1998, and at that time was considered to be a pest of minor importance since the HLB pathogen was not known to be present.

The 2005 discovery of HLB in Florida changed the status of this insect to a pest of great importance.

Since 2005, HLB has spread to all citrus-producing counties in Florida. Las is a phloem-limited bacterium that appears to cause phloem plugging and likely has other undetermined effects on infected trees. Phloem plugging disrupts the transport of carbohydrates, leading to root and subsequent tree decline. Symptomatic trees display visual symptoms of blotchy mottle leaf chlorosis and produce small, lopsided fruit that fail to ripen and drop prematurely. Juice from fruit displaying these symptoms is similar in quality to juice from less mature fruit.

2. MANAGEMENT STRATEGIES

a) Inoculum reduction via removal of HLB-infected trees

At the time of its discovery in Florida, growers attempted to follow the guidelines used for HLB management in other countries, including rigorous psyllid control and inoculum (i.e. infected tree) removal. In reality, the urgency with which these guidelines needed to be followed for them to be most effective was not fully appreciated initially.

Inoculum removal is a sound epidemiological principle that has been practiced for decades in many crop/disease systems, including other citrus-producing areas where HLB is present. The principle behind tree removal for HLB control is simple: By removing diseased trees, the percentage of the tree population that is infected is reduced. A lower percentage of infected trees should result in reduced spread of the disease.

Even under the best circumstances, HLB will likely never be eradicated. The goal of this strategy is to keep the number of infected trees low — ideally under 2 percent. This requires a rigorous management effort of psyllid control, scouting for and removing infected trees, followed by resetting with clean nursery stock to recover productivity in the long term. Since psyllid control and scouting are not 100 percent effective, psyllid control, scouting, tree removal and resetting must be repeated judiciously.

Several factors may prevent tree removal from being as effective in practice as it is in principle. Perhaps most important is HLB disease detection. Our current methods for detecting HLB-infected trees rely on visual detection of symptoms. Currently, our best estimate places visual detection by scouting at about 50 percent to 60 percent effective in finding all the symptomatic trees in a single survey. In addition, there is a latency period between infection and symptom development (estimated between six months and two years, or longer, depending on tree size and other factors). During this latency period, psyllids can acquire the pathogen from asymptomatic trees; however, the rate of acquisition may be lower than from symptomatic trees containing higher levels of the pathogen. Anecdotal evidence suggests that there is usually at least one asymptomatic tree for every symptomatic

tree found, although some estimates put this number much higher. Despite this limitation, removal of infected trees does reduce inoculum.

The second factor that impacts the effectiveness of tree removal is timeliness. Even growers with the most aggressive tree removal program find it difficult to keep pace with new finds, and many growers may delay tree removal until the current crop is harvested. Thus, inoculum-source trees may remain in the grove longer than desired. Because of these inherent limitations, HLB inoculum reduction must be done in combination with stringent psyllid control to maximize the management of inoculum spread.

The importance of keeping accurate records of the numbers and locations of infected trees and psyllid control efforts cannot be overemphasized. Growers should track their finds of infected trees over time to see what impact their efforts are having. It is important to remember that because of the latency period of this disease, it is very likely that the number of infected trees will continue to increase for some time after tree removal is initiated. However, if the program is effective and good psyllid control is maintained without lapses, the number of finds should decline and can be maintained at a relatively low level.

One factor that we have only begun to realize is the necessity for HLB inoculum management to be regional. On many occasions, an inoculum control strategy in a grove is not as successful as desired because of deficiencies in management practices in neighboring groves. If psyllid control is inadequate or not coordinated and infected trees not removed, inoculum builds up in the immediate area.

The experiences in Florida are similar to those in Brazil. In Brazil, where there are large acreages of citrus with aggressive psyllid and inoculum management, infection rates decrease from the outside edge to the center of a grove. Conversely, small blocks, even with aggressive programs, are unable to reduce the rate of infection when surrounded by other blocks with minimal or no HLB management programs. In Brazil, there are many very large farms that are able to implement aggressive management programs over a wide area, thereby creating an HLB management buffer around them. Large farms are fewer in number in Florida, which may prove to be a disadvantage to the citrus industry here unless growers can begin to coordinate their efforts collectively to control inoculum as they have begun to do with psyllid control.

b) Use of foliar nutritional sprays to maintain the productivity of HLB-infected trees

An alternative HLB management strategy being adopted by many Florida citrus growers uses various foliar nutritional products, primarily micronutrients, to maintain tree health and productivity. There is substantial scientific evidence about the positive effects of improved, balanced mineral nutrition on plant disease, particularly with annual crops and foliar fungal and bacterial diseases. However, the data regarding the interaction of plant nutrition and systemic vascular diseases, like HLB, are less conclusive. The beneficial effects of nutrition do not extend to situations of excessive or luxuriant fertilization, which can in fact increase disease severity.

The theory behind the use of mineral nutrition for management of HLB-infected trees is fairly straightforward. It is well documented that citrus trees respond to Las infection with the production of callose and p-protein, natural wound/defense compounds that block the damaged or infected phloem vessels. This plugging of phloem likely results in disruption of carbohydrate movement from leaves to roots, leading to root system decline. The disruption of carbohydrate transport from the leaves leads to starch accumulation and chloroplast disruption, expressed as the blotchy mottle symptom in leaves. The declining root system likely reduces water and nutrient uptake contributing to the nutrient deficiencies and twig dieback that are general HLB symptoms.

By supplying nutrients to the tree by foliar application, the declining root system may be circumvented, and the tree may tolerate the effects of the disease on disruption of carbohydrate, water and nutrient supply, thereby sustaining the tree for some period of time depending on tree size, vigor and other factors. This potentially could result in new phloem production and supply of carbohydrates to the roots, and eventually new root production and a restoration of root function. Thus, the production of new vascular tissue may enable the tree to "live with" the infection. That is, the tree may sustain an economic yield for some period of time in spite of the infection.

Nutrient supplementation may also affect trees by inducing naturally occurring plant resistance mechanisms that are reported to protect against infection. Such mechanisms, including those known as SAR, SIR and ISR, are thought to be preventative and not curative. If nutrient supplementation can induce these mechanisms, the maximum benefit should be achieved when nutrients are applied to uninfected trees. At this point, there is little evidence that these resistance mechanisms can protect against systemic diseases like HLB at any stage of infection.

Some users and/or manufacturers of nutrient supplement products add compounds to the mixture, outside of traditional macro and micronutrients that have been postulated to induce plant resistance, such as salicylic acid. These compounds should not be applied to commercial citrus if they are not registered for this purpose. The maximum benefit from applications of properly dosed and balanced nutrients may lie in their well-known effect on maintaining productive trees through balanced plant metabolism.

Although the potential exists for enhanced nutrition to increase tolerance to HLB, many unknowns exist. First, what nutrients are important and at what rates? It is unlikely that one single nutrient will be the key; rather it will likely be a combination of nutrients and possibly other compounds. Furthermore, it will be important to maintain the balance between nutrients because having one nutrient drastically out of balance with the others is just as damaging as a deficiency.

How long can enhanced nutrition sustain the health of HLB-affected trees? Anecdotally, mature tree productivity has been maintained for at least four years on such a program when combined with aggressive psyllid management. However, replicated scientific experiments to test these observations are only in their second year. We also do not know if there is a point at which such a management strategy will not work.

It is likely that a nutritional program has a greater chance of success when implemented early (at first disease detection or before) rather than after a grove has reached a state of significant decline from infection. In addition, it is unknown if trees in the pre-bearing or early-bearing stages will respond similarly to mature trees. Good horticultural practices that promote healthy, productive trees make sense for all groves, regardless of HLB infection.

In addition, significant questions remain about the buildup and spread of inoculum under a nutrient-management program. As with tree removal, good psyllid control remains critical for two reasons. First, it is likely that a tree will

succumb to HLB infection more quickly if it is repeatedly inoculated with the pathogen. Moreover, since tree removal is not practiced under a nutrient-management program, coupled with the fact that psyllids reared on infected trees are more likely to spread the pathogen as adults, the risk for disease spread increases. This raises the question of whether new plantings or resets can be brought into production where the regional decision has been made to adopt the nutrient-management strategy. Regardless of how long a nutrient-management program can sustain tree productivity, there will come a time when those trees die.

If the grove or block is within a large area under nutrient management where high levels of inoculum have been allowed to accumulate, can a new grove be planted and brought into production in such a situation? Experiences have been that even in areas where inoculum control is aggressively practiced, it has not been possible to keep 100 percent of new trees HLB-free from the time of planting to bearing age. Thus, if inoculum is allowed to build in an area, it is likely that it will be even more difficult, if not impossible, to bring new trees into production.

To summarize, broadly accepted, sound scientific data to support which management strategy — tree removal or nutrient-management strategy, or a combination of the two — can sustain a grove or a commercial citrus industry do not exist, although a significant amount of research is currently under way to gather such data. At this point, a recent study from Brazil has been published, and this, together with our experiences in Florida, forms the basis of management under the infection scenarios presented below.

Decisions about HLB management are very difficult to make because of the continued uncertainty of how best to control inoculum or whether inoculum control is even possible. Many factors other than biology are involved, including economics, sociology and regional HLB incidence that further complicate an individual grower's decisions on HLB management. The decision of which strategy to pursue must be made by each grower based upon his or her particular situation and objectives as discussed below.

3. DECIDING WHICH MANAGEMENT STRATEGY TO USE

The decision to remove infected trees to control HLB or pursue a nutritional supplementation program is a difficult and complex one. The following series of questions and discussion are designed to aid you in making the best decisions possible given your circumstances. The underlying presumption for these questions is that you are reassessing whether to continue tree removal for HLB management or pursue a nutritional program instead. It is our current opinion that a decision to abandon inoculum removal for a program of nutritional supplementation is a one-way path that cannot be reversed for that grove, and the productivity of that grove and possibly surrounding groves will be restricted to the life of the trees in the ground.

What percentage of trees in your grove is infected with HLB?

To accurately assess your situation and make an educated management decision, you must have accurate data about HLB incidence and spread within your grove over time, as well as information about the incidence of HLB in surrounding groves. Your data should include the number of infected trees per block and their location recorded by GPS or on a physical map. This mapping allows you to track success or failure of your management efforts, and make changes to your program in a timely manner.

What has your psyllid control program been?

This is one of the first questions you must ask yourself before making any further HLB management decisions, because the vector of the disease, the Asian citrus psyllid, is the sole natural means by which HLB spreads. As pointed out above, the efficacy of either management strategy relies on a sound psyllid control program.

Have all reasonable efforts been made to successfully control psyllids?

You must answer this question honestly. Have you invested the maximum and sufficient resources available to control psyllids in your grove? If not, could this be why tree removal has not been successful for you? If you have made the maximum investment in psyllid control, it is important to consider the local situation. Are your groves adjacent to other groves (large or small acreage) where psyllid control is poor or not practiced? Can you work with your neighbors to develop an area-wide psyllid control program? Can you use aerial or low-volume applications in your grove to improve the economics and efficacy of psyllid control? Aerial and low-volume applications of pesticides are known to be highly effective for psyllid control, especially when used over large areas. These actions may increase your level of psyllid control, allowing tree removal to be effective.

Has the grove been routinely scouted (three to four times per year) followed by immediate tree removal up to this point?

As described above, identification of infected trees is perhaps the weakest link in the tree-removal strategy. Since not every symptomatic tree is found at each scouting, it is critical that scouting be repeated at least three to four times annually. This will ensure that trees missed during one scouting event are detected and that newly symptomatic trees are found as soon as possible.

Additionally, a major reason why a tree removal strategy can fail is the lack of timely tree removal. Once a tree is positively identified, it should be treated with pesticide and removed as quickly as possible to stop psyllids from feeding on it and transmitting the disease to healthy trees. This must be done regardless of the desire to harvest the tree's crop or because of interference with other grove operations.

You must ask yourself and honestly answer the question whether you have been dedicating all possible resources to scouting and tree removal. Importantly, the HLB management practices of the immediate surrounding groves must be taken into account in making this assessment. If possible, scouting and tree removal should be coordinated in cooperation with your neighbors to develop a regional management program.

What is your long-term plan as a citrus grower?

If you are in the business for the "long-haul," then you must consider the future and your long-term investment. In such a case, you may decide the goal of keeping inoculum levels low, despite current yield losses from tree removal, is the best long-term strategy for yourself or the future of the Florida citrus industry.

Perhaps you're interested in staying in the business long-term, but surrounding citrus acreage doesn't indicate this will be feasible because of encroaching development or other circumstances. Since tree removal demands a substantial financial outlay, the economic realities of your citrus enterprise may also force a change in strategy. In this case, you may decide that preserving your current investment in mature trees and maintaining their productivity for as long as possible is the best strategy to maximize your current returns for future investment elsewhere. Psyllid control must

still be practiced in this situation. This is a serious question that everyone will need to answer before making major management decisions.

4. HLB INFECTION SCENARIOS AND MANAGEMENT GUIDANCE

After assessing your situation, it is likely that you will find yourself in one of the three situations below. While we would like to state the three scenarios below in more detail, our current knowledge does not allow us to define these categories concretely. However, research is currently under way to help us better define these categories and develop management thresholds. Growers, based on their unique set of circumstances, will have to determine which category best describes their HLB situation.

Groves with low infection

If your grove has a low infection incidence and is located in a region of low infection, now is the time to begin managing the disease. Psyllid suppression and scouting for and removing infected trees are the first and second steps to keep HLB incidence low in your grove.

Do not wait until you begin finding HLB-infected trees in a grove to begin controlling psyllids. HLB is in many ways a silent disease in its early stages because it is invisible to the naked eye. HLB can be present in the tree for as long as two years or more before symptoms are evident. Such infected trees still harbor the HLB pathogen that can be picked up by a psyllid and spread to neighboring trees. Thus, it is important to implement a psyllid control program prior to the discovery of HLB in a grove that will maintain psyllid populations as low as possible at all times of the year to minimize pathogen spread from asymptomatic trees.

Growers should not wait to remove an HLB-infected tree, even if it has fruit nearing harvest, as these trees will serve as an inoculum source for continued pathogen spread.

If your grove is close to other groves that are not being managed by aggressive infected tree removal and psyllid control, it is just a matter of time before HLB begins spreading through your grove. Collaboration with neighboring grove owners to ensure that infected trees and psyllids are managed effectively is the third step to keep HLB incidence low in your grove.

Recent research and experiences from Florida and Brazil indicate that chances for keeping HLB incidence low in your grove are much greater if you 1) aggressively suppress the psyllid population, 2) remove HLB-infected trees immediately, and 3) are located in an area of low HLB incidence.

How large must this HLB-management area be? We are not precisely sure at this writing, but evidence from Brazil indicates that at least a one-mile distance between a managed grove and an unmanaged grove is necessary to keep HLB incidence low. The larger the area of aggressive HLB management, the larger the area will be with low HLB incidence. Keep in mind that infected psyllid incursions will likely occur on the margins of a managed grove, creating higher HLB incidences along the grove edges. Additional scouting and psyllid control measures may be needed in these border areas.

The chances of bringing a reset tree, from clean nursery stock, into production and keeping HLB infection rates low are much greater if the first, second and third steps are fully implemented. Good horticultural practices involving the application of optimal nutrition and irrigation must be followed to reduce tree stress.

Groves with moderate infection

If you determine that you are at a moderate infection level, it will be imperative that you make an honest assessment of your HLB management efforts up to this point. Have gaps in your program (e.g. inadequate psyllid control, untimely tree removal) played a role in the rise of your infection level? Could an improvement in your psyllid control and/or tree removal program be accomplished while maintaining the economic viability of the grove? Would an increased level of psyllid control be sufficient for dealing with psyllid migrations from surrounding unmanaged groves? Has an attempt been made to coordinate psyllid control and tree removal efforts with your neighbors?

Excellent psyllid control will be essential to reduce the spread of HLB. Tree removal may still be an option in this situation, especially if you are located in a region of low HLB incidence, but your answers to the above questions and your economic situation must be considered in the decision to maintain your management strategy. Grove care practices should be evaluated and you should consider steps to improve overall tree health and minimize tree stress, including the addition of foliar nutrition sprays, emphasizing micronutrients, even if deficiency symptoms are not present.

Groves with high infection

In a high-infection situation, economics is likely to be the primary factor influencing your management decisions. That is, you will likely conclude that you can no longer survive economically with a reduced tree population, scouting costs, tree removal costs, etc., and decide to pursue a nutrient management strategy. However, rigorous psyllid control must continue in order to reduce infection of newly planted trees, the re-inoculation of infected trees, and to minimize spread to nearby groves.

Resources previously allocated to scouting for infected trees should be shifted to scouting for psyllid populations to aid in control efforts. There is currently no IFAS recommendation for a nutrient management strategy; however, information on formulations currently being used in IFAS trials can be found on the IFAS greening Web site (http://greening.ifas.ufl.edu). The goal of this strategy is to maintain the productivity of HLB infected trees by increasing the levels of nutrients, particularly micronutrients, within the tree by providing nutrients at remedial (corrective) levels. This strategy should be implemented before trees have severely declined from HLB. It will likely be at least one year before improvements are seen, depending on the severity of disease symptoms in infected trees when the program was started.

At what point you decide to completely push a grove, rather than continuing either management program, and replant with clean nursery stock will depend on your economic ability to manage a young grove given the HLB and psyllid situation in your region.

SUMMARY

IFAS realizes that the Florida citrus industry faces unprecedented challenges to its continued economic viability, productivity and existence. Making management decisions for HLB control have been greatly complicated by the rapid buildup of HLB inoculum in the citrus industry, particularly in areas first affected by the epidemic. The industry's muted response to the initial HLB challenge, followed by a failure to realize the importance of rigorous implementation of psyllid control and scouting coupled with immediate tree removal, has resulted in a dangerous buildup of HLB inoculum statewide.

Grove owners who find HLB infection rates too high in their groves to remove trees and remain economically viable

are looking to other management strategies that will keep their existing trees in the ground. The nutrient-management strategy can, at least for a short term, maintain infected grove productivity. However, most dangerously for the citrus industry, a grove solely on nutrient supplementation allows HLB inoculum to remain; eventually every tree will become infected, as psyllid control is not perfect even in the best case. Under such conditions, clean resets or newly planted groves will become infected with HLB and may decline before they become productive, in essence throwing the investment in those young trees away. Surrounding groves will find it difficult, if not impossible, to maintain low infection rates.

Thus, with current knowledge and technology, groves managed under a nutrient program without infected tree removal are restricted to the life of the trees in the ground. The management strategy that should ensure the continued economic viability and productivity for the citrus industry is rigorous psyllid control, scouting for infected trees, removing infected trees immediately, and establishing area-wide regions of such management, coupled with good nutrient management practices that will keep HLB infection rates low over large areas and maintain optimal health and productivity of uninfected trees. We hope that this is achievable, given the current statewide inoculum levels and psyllid populations. Until a long-term solution emerges in the form of a resistant citrus variety, managing HLB successfully will remain one of the largest historic challenges to the Florida citrus industry.

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