2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation
DOI: 10.13031/aim.20162455891
Paper Number: 162455891

Commercial-Scale Thermotherapy for Combating Citrus Greening (Huanglongbing)

Joseph Trotochaud and Reza Ehsani

University of Florida
Institute of Food and Agricultural Sciences
Citrus Research and Education Center
Lake Alfred, FL, United States

Written for presentation at the
2016 ASABE Annual International Meeting
Sponsored by ASABE
Orlando, Florida
July 17-20, 2016

ABSTRACT. Citrus greening disease (Huanglongbing, HLB) is a destructive bacterial infection of citrus which clogs vascular tissues and results in the death of the tree. Lacking any clear biological cure, citrus growers have begun to explore the use of thermotherapy as a method of impeding the spread and diminishing the effects of citrus greening in commercial groves. Thermotherapy, also called heat treatment, is the use of heat to eliminate disease from plants and produce and has been used at smaller scales for pathogen elimination since the early 20th century. The goal of the thermotherapy process for treating HLB is to heat a citrus tree to a temperature at which the citrus greening bacteria is killed, but the tree itself is left unharmed. However, the practical and technological challenges of using thermotherapy on mature citrus trees are unique and unperfected, especially considering that to-date only a handful of commercial-scale citrus thermotherapy machines exist, all of which are located in Florida. Using practical experiences from researchers and citrus growers in Florida, current thermotherapy methods and technologies are detailed, and initial lessons learned from application of thermotherapy to over 5000 trees in Central Florida are discussed.

Keywords. *Citrus, huanglongbing, pathogen, thermotherapy*

Introduction

Until recently, applications of thermotherapy for the elimination of HLB were limited to laboratory settings and primarily focused on reducing disease in new plantings or for scientific study on a small scale (Hoffman et al., 2013; Lin and Lo, 1965; Schwarz and Green, 1972). New challenges of scale, mobility, and feasibility of laboratory methods exist when applying thermotherapy to production-scale trees in groves with hundreds or thousands of trees. Two methods of field-scale thermotherapy which apply heat to the canopy of the tree are described. The first method involves covering trees in plastic to heat the tree up using energy from the sun and is referred to as solarization or tenting. The second method involves introducing heat from a supplemental source, such as hot water or steam. A prototype mobile field thermotherapy system of the second method was demonstrated by the University of Florida Citrus Research and Education Center (UF-CREC) in 2012. Since then, several thermotherapy systems have been developed by several growers and companies based upon the UF prototype. The objectives of this paper are to present how these two methods of thermotherapy are applied to production-scale trees, to discuss the applicability of thermotherapy for combating HLB in a production setting, and to discuss the current frontiers of in-field thermotherapy technologies.

Thermotherapy using Solarization

Solar tenting, often referred to as solarization, has become a popular form of thermotherapy in Florida due to its low cost and ease of use. Solar tenting is accomplished by placing plastic over an infected citrus tree and allowing the energy of the sun to heat the inside of the plastic for several hours (Figure 1). Once the inside of the plastic reaches the desired temperature, the plastic is removed and thermotherapy is complete.

Figure 1: Small tree covered in solarization plastic. Image courtesy of Daniel Skousen and Mikiele Luce, Deseret Farms of Ruskin

Daniel Skousen and Mikiele Luce from Deseret Farm of Ruskin provide a specific procedure for solarization:

1. Select a tree that has been infected with HLB.
2. Cover the tree completely with a green opaque plastic bag.
3. Insert a thermometer 12 inches from the top of the bag.
4. Check temperatures every hour until the thermometer reaches 130°F degrees.
5. Start a timer for one hour and 15 minutes.
6. Remove the bag from the tree.
7. Trim all burned leaves and branches back to live wood.

Some damage (Figure 2) to the topmost portion of trees treated with solarization is to be expected, since heat will accumulate at the highest point and there is no circulation within the plastic. Using this procedure, it is estimated that a team of two people should be able to treat roughly 60 trees per day if the trees are all on the same row. If the trees being treated are scattered throughout a block, less trees will be treated per day because of travel time. If treating multiple trees at once with solarization, it is critical to remove all plastic covers quickly to prevent temperatures from getting too high and damaging the trees. Even if the trees are covered with plastic over several hours in the morning, they will all reach 130°F at about the same time, so the plastic will need to be removed quickly from all trees. Using this procedure, canopy foliage was noticeably fuller and new flush appeared free of HLB symptoms (Figure 3).

Figure 2: Tree showing signs of burning following thermotherapy. Image courtesy of Daniel Skousen

Figure 3: Tree from Figure 2, five weeks after application of thermotherapy. Image courtesy of Daniel Skousen

Growers using solarization are overall pleased with the results when tenting trees less than six feet tall, but the plastic tents required to treat trees taller than six feet become increasingly difficult to move with increasing size and are more susceptible to damage from wind and transportation. Additionally, while the cost of equipment is low, the labor cost for two or more workers for days at a time for a single block can be high.

Thermotherapy using Supplementary Heat

The remainder of the paper will focus on thermotherapy using supplementary heat. Supplementary heat involves the use of a heat source other than the sun to provide the high temperature required for thermotherapy. In practice, there are two primary heat sources used for this purpose: steam and hot water. Other heat sources, such as dry heat and heat lamps, have also been tested but either required too much time to reach the desired temperature or proved impractical for commercial scale application. While the equipment needed for steam and hot water are very different, the process of thermotherapy and treatment times are very similar. The following procedures have been used by UF researchers for steam and also applies for hot water:

1. Select a tree that has been infected with HLB.
2. Position the tree enclosure over the tree.
3. Open the steam or hot water valve to deliver heat to the tree, and bring the temperature in the tree enclosure to 131°F.
4. Start a timer for 30 seconds once 131°F has been reached.
5. Monitor the temperature within the tree enclosure and regulate the valve to maintain 131°F.
6. At the end of 30 seconds, close the valve and raise the enclosure.

Using this procedure, researchers at the UF CREC treated over 5,000 trees during five months in 2015. Trees treated using this procedure showed similar results as those treated with solarization. While some defoliation can be expected with steam or hot water, the addition of fans for circulation of hot air around the tree canopy can eliminate damage to the bark and the subsequent need to trim dead branches back to live wood as with solarization. The temperature and time duration of 131°F for 30 seconds was determined through research conducted at the UF-CREC.

Further research is currently being conducted at the UF-CREC to determine the ideal time/temperature duration as well as examine the ideal time of year to apply thermotherapy for treatment of HLB. However, small research trials and field trials of several thousand citrus trees using these methods have been conducted thus far which have produced visually favorable results in the form of new flush that is free of HLB symptoms and with minimal damage to the citrus trees, i.e. fewer burned tops compared to the solarization method.

The Technology of Thermotherapy

The technology of thermotherapy is relatively simple compared to other agricultural implements. There are very few moving parts and most of the components can be purchased off the shelf without any modification. However, the practice of using thermotherapy in commercial-scale applications is only a few years old. In 2014, researchers at the UF-CREC demonstrated the first prototype commercial-scale thermotherapy system (Figure 4) which used a steam generator and curtain-style tree enclosure mounted to a converted citrus hauler. Using lessons learned from that system, a second improved system (Figure 5) was built in June of 2015 with a goal of treating 10,000 trees by the end of 2016. While the prototype system was only meant as a research platform, the idea became popular and many similar machines have been built by growers and companies in 2015 and 2016 (Figure 6).

Figure 4: The CREC prototype steaming system mounted to a converted citrus hauler (goat)

Figure 5: The CREC improved steaming system mounted to a surplus military M1078 cargo truck showing interior of tree enclosure (top) and while applying thermotherapy to a tree (bottom).

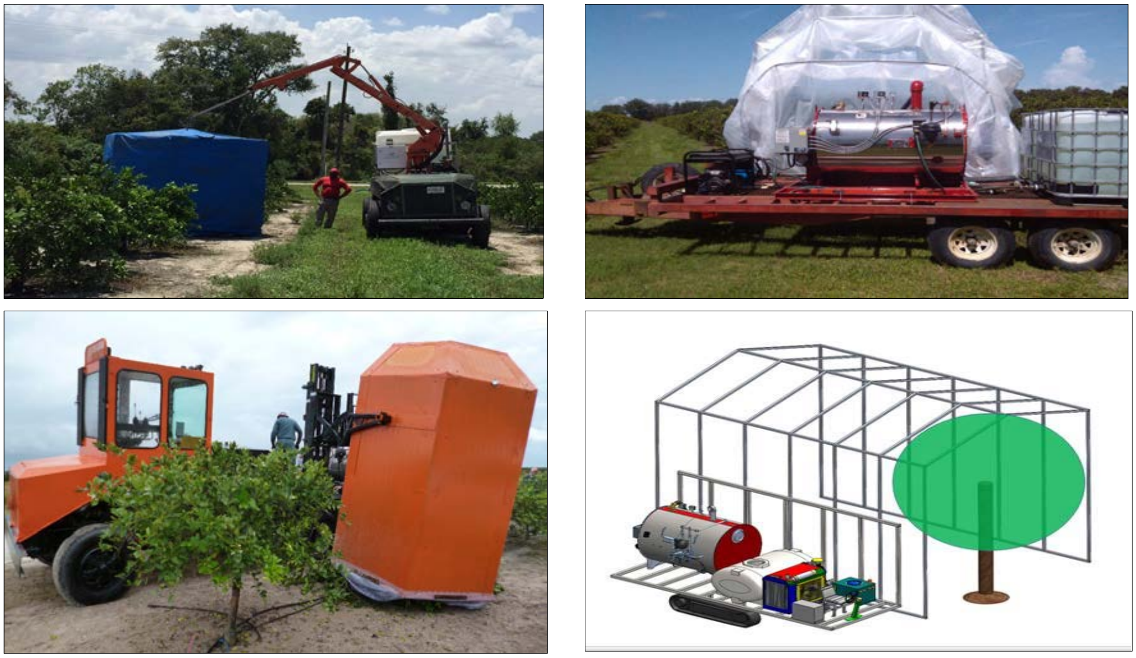

Figure 6: Examples of field scale thermotherapy systems built by (clockwise from top left) Premier Energy, Larry Davis, AgHarvester, and Lykes Brothers.

All field-scale thermotherapy machines share the same basic components mounted to a self-propelled or pull-behind platform: a water tank, water filters, a heat source, a power source, and a tree enclosure (Figure 6c). Water from the water tank is fed through a sediment filter and softener to remove any debris and hard water deposits which would reduce the life of the heat source. The heat source heats the water to a high temperature before a series of hoses and nozzles delivers the water to the tree enclosure. A valve controls the delivery of heat to the tree enclosure, which sits over and around a tree to ensure the heat is evenly distributed in a controlled manner. The tree enclosure itself may be a cage hung from a hydraulic arm and lowered on top of the tree (Figure 6, left two images) or a curtain-style enclosure which folds over a tree (Figure 6, right two images). All field-scale thermotherapy machines built to-date are operated as a batch process, steaming a single tree at a time, or two trees at a time if they are close enough together. A few companies are working on continuous process thermotherapy machines, but the machines are not yet ready for field trials (Figure 6, bottom right).

Components of a Field-Scale Thermotherapy Machine

Construction and operation of a thermotherapy machine is relatively simple, and can be completed without advance automotive, machine tools, or technical background. However, there are several considerations which must be made during the construction and planning phase which will affect the cost of thermotherapy, as well as the complexity and size of the equipment used.

Tree Sizing and Spacing

Larger trees will require larger tree enclosures and also a larger capacity heat source to generate the heat required to heat a larger volume. Additionally, if the spacing in a grove is close enough, or double resets are common, then it may be possible to treat two trees at a time.

Heat Sources and Delivery

Steam heats the canopy faster than hot water and requires less water. However, the equipment costs much more

Water Demand, Capacity, and Quality

Clean and soft water is necessary for steam and hot water systems to prevent clogging or shortened life of equipment. Steam requires much less water than a hot water system. Smaller steam systems can operate for half of a day with just 200 gallons of water.

Vehicle

The vehicle which carries the thermotherapy machine must be able to handle the weight of the equipment and the water, as well as travel within very sandy groves. A self-propelled machine is easier to maneuver in a grove than a pull-behind system. Moreover, self-propelled machines can be transported easily from one grove to another when necessary. If traveling between groves on roadways, a street-legal vehicle should also be considered.

Tree Enclosure

The tree enclosure should match the size of the trees being heated. An oversized enclosure will require more heat and time to get up to temperature, while an undersized enclosure can be damaged by larger trees.

Power Source

A power source will be required to operate the oil burners on steam or hot water systems, as well as power fans and water pumps. Power can come from a small generator or from the vehicle directly if it is powerful enough. As much as 3,000W to 5,000W will likely be enough to handle all but the largest thermotherapy systems.

Heat Distribution

Hot air rises, so circulation must be added to prevent burning the tops of trees. For steam, this can be accomplished with the placement of fans at the ceiling of the enclosure. For hot water the placement and angle of spray nozzles will need to be considered.

Number and Placement of Thermometers

The temperature in the tree enclosure must be monitored to prevent over- or under-treatment. A single thermometer may not give a representative picture of the temperature distribution, so a series of four or more thermometers should be placed within the tree enclosure and monitored in real-time by the operator.

Operator Vision and Equipment Placement

Most thermotherapy machines require two people to operate them: one driving the machine, and one person on the ground helping the driver line the machine up with the tree. Installing side-facing cameras or positioning equipment to create good sightlines for the driver can eliminate this second person.

Operating Costs

The cost of constructing a thermotherapy machine depends on the factors listed in the previous section. As an example, the cost for construction of the improved steaming system used by the UF-CREC is shown in Table 1. This machine was designed to accommodate the following requirements: (1) treat a single tree up to eight feet tall in under three minutes, (2) hold enough water for four hours of steaming, (3) have filtration and water softening capabilities on-board, (4) be operable by a single person, and (5) be street-legal for transportation to and from field sites across Central Florida. The size of the tree to be treated will be the most influential cost driver, since larger trees require larger heat generators, vehicles, water tanks, pumps, and tree enclosures. Larger trees also take longer to reach treatment temperature because there is more tree to be heated. Cost savings can be found by recycling spare equipment such as water tanks, pumps, electricity generators, and hydraulic components. The steam or hot water generators will be the most expensive single component, but can be purchased readily off-the-shelf. The tree enclosure will be the second most expensive component, since this is a custom item. A large cost saving- can be found if a vehicle does not need to be purchased or can be purchased second hand. Having only a single operator by using simple side-facing cameras can reduce daily operating costs by as much as a third.

Table 1: Cost estimate for the CREC improved steaming system

Component	Item	Capacity	Cost
Mobile Platform	Military Surplus M1078	2-1/2 ton, 4x4, 8 ft-wide	$15,000.00
Steam Generator	Sioux Steam-Flo® SF-20	690lb/hr steam	$20,000.00
Water Storage	IBC Tote Tank	275 gal	$285.00
Water Pump	Flowjet Sprayer Pump	3.8 gpm @ 45psi	$1,000.00
Water Filter	4-1/2” X 20” Sediment Filter	20 micron, 10 gal/min	$60.00
Water Softener	Kinetico Signature Series®	300 gal/recharge	$2,300.00
Electricity Generator	Military Surplus M802A	5kW	$600.00
Tree Enclosure	Custom Hydraulic Frame with Cloth Cover	10 ft L x 8 ft W x 9 ft H	$15,000.00
Electronics	Cameras, Controls, Thermometers	Single Operator Required	$600.00
Total Estimated[12]:			$54,845.00

[1]The cost of salvaged or second hand items was estimated for this cost analysis.
[2]Does not include labor for final assembly (<10 hours)

Since steam and hot water generators typically operate continuously, the daily cost of thermotherapy then becomes dependent on how many trees can be done per hour. If only a few trees are treated per acre, costs will rise because more time is spent moving from tree to tree than actually applying thermotherapy. This means that block with higher rates of HLB infection will actually have a lower cost per tree for thermotherapy. Combining tree size and infection rate, the operational cost of thermotherapy can be estimated (Figure 7). The highest costs of fuel and labor, upwards of $4.00 per tree and 75 trees treated per day, have been found to occur in blocks with trees over eight feet tall at low infection rates. The lowest costs for fuel and labor, under $1.50 per tree and 150 trees treated per day, were found in groves where trees were less than six feet tall at higher infection rates. If renting equipment, or contracting out a company to do the work, the costs are much higher due to transportation, mobilization, and worker housing and food costs. Premier Energy, a company which provides thermotherapy services, has indicated that the absolute lowest cost for thermotherapy at the moment is around $6.50 per tree. That figure is dependent on several factors, including assumptions such as favorable, at least 10,000 trees are to be treated, and he grower supplies one worker per thermotherapy machine to assist in operations. A more typical cost is about $6.50-$7.50 dollars per tree when using a machine which treats one tree at a time.

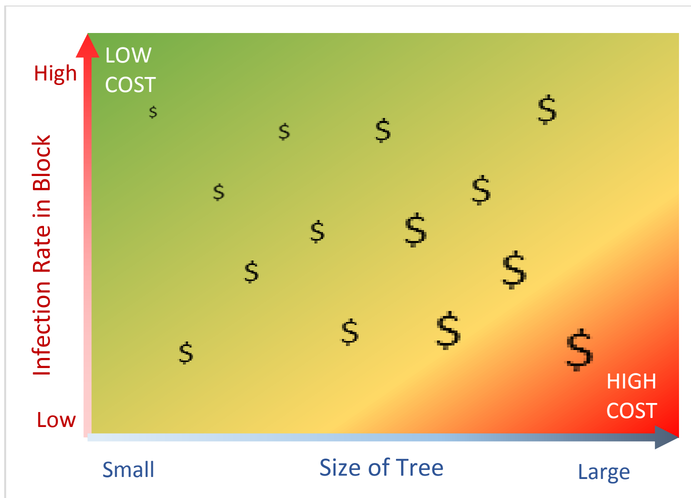

Figure 7: The cost per tree of thermotherapy increases with increasing tree size and decreasing infection rate

Some growers have chosen to use machines which treat three trees at a time. This reduces the cost per tree but requires more advanced temperature control systems to provide uniform heating.

Limitations and other Factors

Several lessons regarding the operation of thermotherapy equipment have been learned regarding standard operating procedure and equipment that are commercially available. Primarily, the off-the-shelf equipment used to assemble a thermotherapy machines are not intended for use in mobile, rapid-batch, outdoor applications in humid environments. Circulation fans only last for a few thousand trees before the moisture shorts out the motors. Currently, steam generators and hot water heaters are not designed for use on moving platforms, and water sloshing in the heating vessels can trip safety sensors which shut the burners off, resulting in a loss of heat. This has been found to be of particular concern in groves with slight elevation inclines or very uneven ground because safety sensors are constantly being tripped, making it difficult or even impossible to apply thermotherapy.

Weather also can have a substantial impact on operation of thermotherapy machines. Thermotherapy takes less time when it is hot and sunny because higher ambient temperature reduces the time to reach treatment temperature and a small amount of solarization still occurs inside the tree enclosure. Alternately, cold and cloudy days will result in longer times to reach treatment temperature. It will also take longer to reach treatment temperature if there is moisture present on the leaves from dew or rain. Wind is the most important aspect of the weather, since small gaps between the tree enclosure and the ground will result in wind pushing cold air into and hot air out of the tree enclosure. With high enough winds, the large surface areas of the fabric used for tree enclosure walls can act as sails and cause damage to metal frames or tearing of the fabric itself.

Since the cost of operating a thermotherapy machine is very dependent on how many trees can be treated per day, saving small amounts of time at different stages of the process can add up to an overall reduction in costs. Holding enough water for half of a day’s work can reduce the number of trips to fill up on water, saving as much as an hour of time each day. Developing a tree enclosure which retains heat from one tree to another can also reduce the amount of time it takes to reach treatment temperature. Losing heat between trees is problematic more so in curtain-style tree enclosures than cage-style ones; curtain style enclosures must be folded up completely before moving to the next tree, while cage-style enclosures can be lifted strait up and retain their heat. Tree enclosures which have more contact with the ground will retain heat better when wind is present, reducing the time to reach treatment temperature. Automating time and temperature controls can also improve productivity by reducing human error and eliminating the possibility of under- or over-treatment, which can save money in the long-term.

There are still gaps in the knowledge on thermotherapy use in the field and for HLB treatment in specific. Thermotherapy as a field-scale treatment for HLB has existed for just over one year and most groves treated using thermotherapy have yet to be harvested for fruit analysis. This problem with time is two-fold. First, the true effects of thermotherapy on fruit quality may not be apparent until the second harvest after thermotherapy application. Second, it is unknown if or how frequently thermotherapy will need to be reapplied, and it may be several years before the answer to this is known. Laboratory methods for detection of the bacteria which causes HLB must also be improved before it can be said with certainty that thermotherapy is an effective long-term treatment for Citrus Greening Disease. Additionally, a thermotherapy method for treating the roots of trees must be developed, since current thermotherapy machines only treat what is above the ground.

References

Hoffman, M.T., M.S. Doud, L. Williams, M.Q. Zhang, F. Ding, E. Stover, D. Hall, S. Zhang, L. Jones, M. Gooch, L. Fleites, W. Dixon, D. Gabriel, and Y.P. Duan. 2013. Heat treatment eliminates ‘Candidatus Liberibacter asiaticus' from infected citrus trees under controlled conditions. Phytopathology 103(1):15-22.

Lin, K. H. and H. H. Lo. 1965. A preliminary study on thermotherapy of yellow shoot disease of citrus. Acta Phytopathol. Sinica 4(2):169-175.

Schwarz, R.E. and G.C. Green. 1972, October. Heat requirements for symptom suppression and inactivation of the greening pathogen. In Proceedings of the fifth Conference of the International Organisation of Citrus Virologists pp. 44-51.Acknowledgments

We would like to thank Sherrie Buchanon, Roy Sweeb, Ahmed Al-Jumaili, and Hesam Zaeri for technical support with the CREC steaming platforms, Skip Noll of Premier Energy for information of operational costs, and Cininta Pertiwi and Ariel Singerman for their input.