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Huanglongbing and the California Citrus Industry: A Cost Comparison of Do Nothing vs. Do Something Management Practices

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ABSTRACT

The disease Huanglongbing (HLB) was first discovered in the United States in Florida in 2005. Since its discovery, HLB has not only decreased citrus production, but has drastically increased production costs. With California contributing over 80% of the nation's fresh oranges, it is important to attempt to keep HLB from becoming endemic in this state. This study examines two alternative management practices and estimates the potential total loss in production value over a 20-year period due to HLB in the California citrus industry. The total loss is estimated to be $2.7 billion under a do-nothing approach and $2.2 billion under an aggressive mitigation approach. This suggests that limiting the spread of HLB is the preferred management approach. It not only results in total damage savings of $2,803 per acre over the do-nothing approach, but also protects the California citrus industry from HLB and promotes economic growth.

KEY WORDS: Huanglongbing, citrus greening, fresh oranges, damage costs, production costs, management practices

INTRODUCTION

The disease Huanglongbing (HLB), also known as citrus greening, was first discovered in the United States in Florida in 2005. Two positive tests were confirmed by the United States Department of Agriculture (USDA) in Miami-Dade County in southern Florida on September 2, 2005 (Animal and Plant Health Inspection Service 2005). These detections initiated changes in traditional management practices and domestic trade policies and regulations, and prompted the allocation of millions of dollars for related research funding.

HLB is a bacterium that affects all citrus cultivars. From the genus *Candidatus* Liberibacter, this phloem-limiting, gram-negative bacterium inhibits the flow of nutrients throughout the tree, decreases fruit production (Bové 2006; Citrus Research Board 2011), and can kill the tree (Citrus Research Board 2011). Oftentimes, isolated limbs of the tree exhibit symptoms and limb dieback diminishes production. Root loss before detecting symptoms can also lead to production losses. In general, as the health of the tree declines, early fruit abscission increases while the fruit also becomes bitter and misshapen, and

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remains green and small (USDA 2011a). Ultimately, the fruit is undesirable and unmarketable.

Within five to eight years of infection, the tree will no longer be economically productive (National Research Council 2010). When attempting to limit the spread of HLB, infected trees are usually removed before they ever reach the point of being considered unproductive. There is no cure for this disease, so prevention is important. Severe symptoms may appear in young trees as early as 6 months post infection and typically from 1-5 years for mature trees (National Research Council 2010, p. 4).[1] This potential for delayed symptom expression adds to the threat of this disease.

HLB generally transfers from tree to tree through three different means: the Asian citrus psyllid (ACP), the African citrus psyllid, and contaminated budwood propagation. Without any of these transmission methods present, the spread of HLB is limited. While the African citrus psyllid is considered a vector pest of HLB, it is not currently found in the United States and therefore is not a current concern in California. The Asian citrus psyllid, on the other hand, is found in the United States and has been a major concern in every citrus growing state; especially in Florida and California, the leading citrus producing states. In Florida where HLB is endemic, regulations have been placed to minimize the transfer of HLB through propagation. For instance, nursery stock may only come from trees that test negative for the bacteria and are grown in screened nursery buildings.

The Asian citrus psyllid (*Diaphorina citri)* is the main vector of HLB transmission. Since its introduction to the United States in 1998, ACP has been found in ten states, including Alabama, Arizona, California, Florida, Georgia, Hawaii, Louisiana, Mississippi, South Carolina, and Texas. Acting in the capacity of a vector of HLB, this species of psyllid has the potential to spread the disease anywhere the psyllid goes.

ACP was first detected in California in 2008 (Blake 2008). California supplies the United States with over 80% of its fresh oranges and is the country's largest exporter of fresh citrus. While Florida has a larger amount of acreage dedicated to citrus than California, in 2009 California contributed 45% of the industry's nearly $2.9 billion value of production (USDA 2011b).

General and Specific Objectives. The main objective of this study is to simulate the potential economic impact of HLB on the California citrus industry. The specific objectives of the study are: (a) to determine and estimate the costs involved with limiting the spread of HLB in California; (b) to estimate and compare the net present value of the total damage costs due to HLB over a period of 20 years for two management practices; and (c) to evaluate and compare the total production loss in oranges in California due to HLB for these the two management practices.

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[1] Bové (2006, p. 14) discusses the appearance of severe symptoms according to various forms of HLB (Asian, African, and American), temperature conditions (hot, warm, and cool), and altitudes (low and high). In Bové (2006, p. 14), severe symptoms were usually obtained after 7.5 months. Bové (2006, p. 29) also explains that the latency period during which recently infected trees do not show symptoms may vary from tree to tree, and is generally assumed to be 6 to 12 months long, if not longer.

MATERIALS AND METHODS

The study analyzes two management approaches to estimate the potential economic impact of reduced yields and increased costs associated with HLB management in California. The first management approach consists of no attempts to limit the spread of the disease when HLB is introduced into California. HLB is projected to spread rapidly throughout the state under this management approach. This management approach is referred to as the pessimistic approach. On the contrary, the second management approach attempts to minimize the HLB spread throughout the state when HLB is introduced into California. Both the pessimistic and optimistic approaches estimate the decline in yields over time and the costs associated with attempting to minimize the spread of HLB.

ACP is currently found in California; and although it may not be too late to eradicate ACP from the entire state, it would be difficult to accomplish since ACP is found in Mexico and Arizona, which makes reintroduction likely to occur. In order to analyze how HLB may impact the orange production in California, this study assumes that ACP spreads through the state, as was seen in Florida, and becomes a naturalized species. ACP naturalization means that once HLB is introduced, it has the potential to spread through the entire state.

If farmers were to make no changes in cultural practices after an introduction of HLB, the disease would ultimately reduce yields as it spreads through the state. It would be difficult to keep production levels high enough to be economically productive. Attempting to replant trees would also be ineffective, as young trees are very susceptible to infection and may never produce any fruit. Therefore, the pessimistic approach assumes no replanting attempts.

Given the California citrus industry's contribution to the state economy and the fact that many growers depend on it to make a living, a do-nothing approach is likely to be rejected by the majority of growers. According to Morris and Muraro (2008) and Roistacher (1996), if effective control practices are followed diligently, it is possible to keep the rate of greening infection below 1%. With ACP populations established throughout the state, the optimistic approach assumes immediate attempts to limit the spread of the disease will take place upon the discovery of HLB. This includes beginning to conduct HLB field surveys and increasing pesticide applications in an attempt to minimize ACP population levels throughout the state. As HLB spreads throughout California, there would be costs associated with diseased tree removal and replacement, and yields would also decrease. While the extent to which control practices will be implemented diligently depends on each grower, the optimistic approach assumes that all growers in the state will take an active role. Expenses incurred by the state of California in monitoring that growers take such active role can be incorporated into the analysis (as in Miranda et al. 2013). However, since there is little (if any) information in the US on state-wide monitoring expenses, our optimistic approach does not take into account such expenses.

The loss in production value under a worst case scenario (a do-nothing approach) can be compared with optimistic scenario (a do-something approach) to assist producers in their decision making process and assess policy implications. For instance, such comparison provides an estimate of the additional damage that could be avoided by adopting modified cultural practices.

Production Loss. The total production loss ($/acre) in year *t* ($TL_t$) is estimated as

$$TL_t = HP_t - HLBP_t, \quad (1)$$

where HP_t and $HLBP_t$ are the production ($) in year *t* without and with the presence of HLB respectively.

The healthy production ($) in year *t* ($HP_t$) without the presence of HLB is estimated as

$$HP_t = \left(HY_t \times k_t \times P_{pt}\right) + (HY_t \times (1 - k_t) \times P_{ft}), \quad (2)$$

where HY_t is the expected yield (75-pound cartons per acre) from healthy trees at year *t*, k_t is the proportion of oranges that will be processed in year *t*, P_{pt} is the price of processed oranges ($ per 75-pound carton) in year *t*, $(1 - k_t)$ is the proportion that will be sold as fresh oranges in year *t*, and P_{ft} is the price of fresh oranges ($ per 75-pound carton) in year *t*.

On the other hand, the production ($) in year *t* under the presence of HLB ($HLBP_t$) is estimated as

$$HLBP_t = P_{ft} \times HLBY_{ft} + P_{pt} \times HLBY_{pt}, \quad (3)$$

where $HLBY_{ft}$ and $HLBY_{pt}$ are the expected yields (75-pound cartons per acre) under the presence of HLB that are sold as fresh oranges and processed in year *t* respectively. These variables are estimated as

$$HLBY_{ft} = HLBTY_t - HLBY_{pt} \quad (4)$$

and

$$HLBY_{pt} = HLBTY_t \times k_t. \quad (5)$$

Total yield (75-pound cartons per acre) under the presence of HLB ($HLBTY_t$) is estimated differently under the pessimistic and optimistic approach.

The present value of the total damage cost ($/acre) ($PV_{Damage}$) from HLB over a 20-year period is simulated 10,000 times using equation (6).[2] That is,

$$PV_{Damage} = \sum_{t=1}^{T}(1 + i)^{-t} \times D_t, \quad (6)$$

where D_t is the total damage costs ($/acre) from HLB in year *t* and is estimated differently under the pessimistic and optimistic approach, as explained in the next two subsections.

[2] According to the National Research Council (National Research Council 2010, p. 121), the lifespan of a citrus tree can reach 100 years. A 20-year scenario is consistent with the remaining lifespan of several orange groves in California. Several studies have used a 20-year time period (Miranda et al. 2012; Bassanezi and Bassanezi 2008). Miranda et al. (2012) explain that they chose a 20-year period because 20 years is the life expectation of citrus orchard in the Sao Paulo, Brazil.

Pessimistic Approach Model. Under pessimistic approach, the total damage costs ($/acre) from HLB ($D_t$) in year *t* equals the total production loss ($/acre) from HLB in year *t* (TL_t). That is,

$$D_t = TL_t, \tag{7}$$

where TL_t is estimated by equation (1).

In addition, total yield (75-pound cartons per acre) under the presence of HLB and is estimated as

$$HLBTY_t = HY_t \times RY_t, \tag{8}$$

where RY_t is the relative yield at year *t.* A negative exponential model is used to estimate RY_t (Miranda et al 2012; Bassanezi et al. 2011; Bassanezi and Bassanezi 2008). That is,

$$RY_t = e^{(-1.8TD_t)}, \tag{9}$$

where TD_t is total disease severity at year *t.* Equation (9) is used to compare HLB yields with yields from healthy trees (Miranda et al. 2012, Bassanezi et al. 2011, Bassanezi and Bassanezi 2008). Producers usually stop harvesting infected trees before relate yield reaches very low levels, as returns to growers will no longer cover the cost of production and/or harvesting.

Total disease severity (*TD*) can be estimated as

$$TD_t = \sum_{j=0}^{j=t} \left(y_j - y_{j-1}\right) s_{t-j}, \tag{10}$$

where *y* is the incidence of symptomatic trees and *s* is the portion of the canopy exhibiting HLB symptoms (Bassanezi and Bassanezi 2008). Equation (10) combines the proportion of HLB severity in individual trees (s_t) and the incidence of symptomatic trees (y_t) and can be used to estimate the overall severity of HLB in a grove for any number of years (*t*) after an HLB introduction.

The incidence of symptomatic trees (*y*) in year *t* is estimated using the Gompertz function (Bassanezi and Bassanezi 2008; Miranda et al. 2012),

$$y_t = e^{-(-\ln(y_o))^{e^{-Rt}}}, \tag{11}$$

where y_o is the portion of symptomatic trees when HLB symptoms first present themselves and *R* is the rate of disease incidence progress through a grove each year. *R* is estimated to range from 1.3 for trees between 0 and 2 years old down to 0.244 for trees older than 10 years (Bassanezi and Bassanezi 2008).

Determining the rate of spread of a pest and or disease is a challenge. Different environmental factors can attribute to how rapidly and how successful an invasive species or pathogen can be, in addition to the number of original pest introduction sites. Management practices play an important role in the dispersion of HLB over time. Aggressive management practices may allow contaminated groves to stay economically viable.

The proportion of HLB severity in an individual tree (*s*) is approximated by

$$s_t = \frac{1}{1+\left(\left(\frac{1}{s_o}-1\right)e^{-rt}\right)}, \tag{12}$$

where s_o is the initial proportion of symptom expression, and r is the rate at which HLB moves through the tree in year t (Bassanezi and Bassanezi 2008; Miranda et al. 2012). The initial disease severity may change how fast HLB progress through a tree. The age of the tree plays a critical role in the rate of disease spread. HLB is estimated to progress through young trees (r = 3.68) at such fast rates that the tree may never become productive. When no control practices are in place, the high rate of spread in young trees makes replanting ineffective. Young trees are highly likely to become infected shortly after planting. The initial proportion of symptom expression (s_o) is estimated to range from 0.2 to 0.025 depending on the age of the tree (Bassanezi and Bassanezi 2008), while the rate at which HLB moves through the tree (r) is estimated to range from 3.68 down to 0.69 depending on the age of the tree (Bassanezi and Bassanezi 2008).

A two-year-old tree is estimated to get infected in less than two years, whereas a 10-year-old tree can take up to 10 years. Once a tree is infected its production will decline. An infected tree can continue producing, but the fruit quality is likely to be degraded.

There are currently around 180,000 bearing acres of oranges in California (USDA 2011b). Of these 180,000 acres, approximately 86% are over 10 years old and 9% fall into the age category of 6 to 10 years old (California Agricultural Statistics Service 1999, 2002; USDA 2006a, 2008a, 2010a, 2011b; Computed by Author). Instead of assuming that that the entire grove is in the same age bracket (Bassanezi and Bassanezi 2008), this study accounts for the variability in the age of trees by using a stochastic simulation model. A stochastic simulation model takes into account different parameters from each age group that determine the rate of spread of HLB and estimates the total expected damage of HLB over time.

The proportion of symptom expression in individual trees (s_o), annual rates of HLB progress in individual trees (r), and the annual rate of HLB incidence progress through a block of oranges (R) are estimated using PERT distributions. With most of trees in California being 10 years or older, the minimum and most likely values of the PERT distribution are appropriately estimated by the parameter values that correspond to the trees greater than 10 years old (Bassanezi and Bassanezi 2008).

Optimistic Approach Model. Under the optimistic approach, the total damage costs ($/acre) from HLB ($D_t$) is the sum of the total loss in production value per acre (TL_t) plus the additional costs associated with limiting HLB spread per acre (AC_t). That is,

$$D_t = TL_t + AC_t, \tag{13}$$

where TL_t is estimated by equation (1), and AC_t is the total additional costs incurred per acre in year t as a result of HLB. The variable AC_t is estimated as

$$AC_t = \Delta FC + RT_t + PT_t, \tag{14}$$

where ΔFC is the immediate per-acre increase in fixed production costs;[3] RT_t is the cost of removing the tree in year *t*, equation (15), which depends on the rate of spread of HLB; and PT_t is the total per acre cost of replanting trees in year *t* that were removed the previous year, equation (16).[4]

The direct cost of removing the tree (RT_t) is estimated as

$$RT_t = CR \times OTL_t, \tag{15}$$

while and the direct cost of replacing it (PT_t) is estimated as

$$PT_t = CP \times OTL_{t-1}, \tag{16}$$

where *CR* is the tree removal cost, *CP* is the cost of a replacement tree, and OTL_t is the number of orange trees that were removed/loss in year *t* and is estimated as $(R_t \times HY_t)/(HY_t/121)$. It is assumed under the optimistic approach that all trees removed in year *t* are replaced with new trees the following year. The variable OTL_t depends on the rate of HLB spread (R_t) in year *t*, which is estimated using a PERT distribution (Cook et al. 2007, Cook and Matheson 2008). The minimum, most likely, and maximum values of the PERT distribution for R_t differ in the optimistic approach and pessimistic approach. The optimistic approach assumes that orange growers attempt to keep the HLB spread rate as small as possible.

The minimum, most likely, and maximum values of the PERT distribution for R_t under the optimistic approach are assumed to be 0.010, 0.023, and 0.032 respectively. According to Morris and Muraro (2008) and Roistacher (1996), the rate of HLB spread can be kept as low as 0.010. According to Morris et al. (2008) and Morris and Muraro (2008), the rate of spread of HLB in Florida averages 0.023 when attempting to limit its spread. The National Research Council (2010) reports a rate of spread as high as 0.040. Given that the 4% reported by the National Research Council (2010) correspond to mixed management practices and no uniform attempt to control the HLB spread, the maximum value for R_t is assumed to be 0.032.

Finally, total yield (75-pound cartons per acre) under the presence of HLB and is estimated as

$$HLBTY_t = HY_t - DY_t - DY_{t-1} - DY_{t-2} - DY_{t-3} - DY_{t-4} - DY_{t-5}, \tag{17}$$

where DY_t is the yield reduction (75-pound cartons/acre) from removing diseased trees in year *t.* It usually takes from four to five years for the replacement tree to produce oranges.

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[3] According to the California Agricultural Statistics Service (1999, 2002) and USDA (2006a, 2008a, 2010a, 2011b), approximately 86% of the orange trees in California are over 10 years old. Given that most of the orange trees in California are already grown up, this study assumes of a fixed increase in fixed production costs (a fixed increase in scouting costs and pesticide applications).

[4] The costs that are taken into account consist of scouting for the disease, removing the diseased trees in year *t* (RT_t), replanting removed trees with replacement trees in year *t* (PT_t), and managing ACP, which mainly consists of applying additional pesticides. Clearly, not all the costs associated with the presence of HLB are included in this assessment. Some additional costs derived from HLB establishment, including managerial and management implementation costs, are not included in the analysis, as there is little (if any) information available about these costs.

In addition, DY_t takes into account the opportunity cost of removing diseased but still productive trees. It is estimated by multiplying the healthy yield in year t (HY_t) by the proportion of trees that are removed in one acre.[5] That is,

$$DY_t = \frac{OTL_t}{121} \times HY_t \ . \tag{18}$$

Estimated ACP Control, Scouting, Tree Removal, and Tree Replacement Costs. The cost of controlling ACP populations depends on the insecticide that is used and the number applications. However, there seems to be disagreement in the number of insecticides applications that are needed to manage greening. For instance, some studies explain that many large growers in Florida have used systemic insecticides such as Temik (whose chemical name is aldicarb and its use on citrus was discontinued effective December 31, 2011 (Bayer Crop Science, 2010)) for mature trees and Admire (whose chemical name is imidacloprid) for young trees; and spraying at least five times a year (three sprays are in addition to the grove's regular spray program) to manage greening (Morris et al. 2008; Rogers et al. 2008). On the contrary, other studies explain that monthly or fortnightly insecticide applications (12 to 24/year) have not been enough to keep the disease under control or at a constant rate, especially in young groves (Gatineau et al. Fruits 2006; Bassanezi et al. 2013; Hall et al. 2013). In addition, it is now suggested to use imidachloprid and thiamethoxam instead of aldicar. The United States Environmental Protection Agency (EPA) and Bayer CropScience, the manufacturer of aldicarb, reached an agreement to end the use of aldicard in the United States. "To address the most significant risks, Bayer has agreed to first end aldicarb use on citrus and potatoes, and will adopt risk mitigation measures for other uses to protect groundwater resources. The company will voluntarily phase out production of aldicarb by December 31, 2014. All remaining aldicarb uses will end no later than August 2018" (US EPA 2010).

A recent study conducted in Sao Paulo state, Brazil (Belasque et al. 2010) reports costs for three HLB-management programs (program I: four inspections, five ground sprays, and one systemic insecticide; program II: six inspections, 10 ground sprays, two systemic insecticide, and one airplane spay; and program III: 12 inspections, 15 ground sprays, three systemic insecticide, and three airplane spays). The total cost of programs I, II, and III in Sao Paulo State, Brazil were estimated to be $96.38/acre, $242.60/acre, and $420.81/acre respectively (Belasque et al. 2010). Other studies estimate controlling for ACP in Florida can range from about $400/acre to $450/acre (Muraro 2010; Roka et al. 2010). Provided that the number of applications can vary significantly, and the fact that the optimum number of spray applications in Florida is unknown (Morris et al. 2008; Morris and Muraro 2008), this study estimates the average cost for pesticide applications and scouting in California to be around $426.47/acre per year.

Since HLB is not currently found in California, there are no values that can be attributed to scouting costs. To estimate scouting costs, this study assumes that the costs are going to be similar as the ones in Florida. In 2011, the minimum wages in Florida and California were $7.25 and $8.00 per hour respectively (US DOL 2012). Florida's

[5] Other factors such as early fruit drop off and reduced initial fruit set can also contribute to reduced yields under the presence of HLB. However, since the optimistic approach assumes that all trees identified with HLB will be immediately removed, these latter forms of yield loss are not considered in the analysis.

scouting costs range from $14.00 to $35.00 per acre (Morris and Muraro 2008). Following the principles of purchasing power parity (PPP), California's scouting costs are estimated to range from $15.45 to $38.62 per acre. If scouting is conducted four times per year as recommended (Morris et al. 2008; Belaque et al. 2010), scouting costs in California are estimated to average $108.88 per acre per year.

The costs associated with tree removal vary depending on the number of trees that are being removed. Tree removal includes uprooting the tree, disposing of the tree, ground preparation for replanting the tree, and the direct cost of the replacement tree. The number of trees planted per acre can vary; however, this study assumes an average of 121 trees per acre. Removed trees will be replaced with new plantings the year after their removal. Removal and ground preparation costs are estimated at an average of $13.34 per removed tree (Irey et al. 2008; Morris and Muraro 2008; O'Connell et al. 2009). The current cost of replacement trees in California is estimated at $10.50 per tree (O'Connell et al. 2009). Since the introduction of HLB in Florida, the cost of replacement trees in Florida has doubled (National Research Council 2010). This study estimates the cost of replacing trees in California at $21.00 per replacement tree. It has been shown that under consistent and stringent management practices for HLB, an average increase in tree removal of 2.3% is possible (Morris et al. 2008).

Estimated Prices, Yields, and Utilization. Under both the optimistic and pessimistic approach, the prices for both fresh and processed oranges for each year are estimated using price ranges from 2001 to 2008 and are incorporated in the simulation. The processed-orange price ranges from $0.23 to $1.52 per 75-pound carton while the fresh-orange price ranges from $9.26 to $18.01 per 75-pound carton (USDA 2003, 2004, 2005, 2006b, 2007, 2008b, 2009, 2010b). Based on the 1992-2011 annual fresh orange prices in California, the fresh orange price is assumed to be normally distributed with a mean of $12.73 and a standard deviation of $1.16 from year 1 to year 20 in the simulation analysis. Similarly, based on the 1992-2011 annual processed orange prices in California, the processed orange price was assumed to be normally distributed with a mean of $0.76 and a standard deviation of $0.25 from year 1 to year 20.

The expected yield is estimated using uniform distribution with a minimum value of 242 75-pound cartons per acre and a maximum value of 354 75-pound cartons per acre. The minimum and maximum yield values for the uniform distribution were determined based on the observed yields during crop years 2000-2011 (USDA 2002-2011).

To account for the variability in what percentage of the harvested crop goes to processing and what remains as fresh fruit under both approaches, a range of values for the percent that are processed is considered. In the last 10 years (period 2000-2011), the average minimum value for the percentage of oranges that are processed is 13.0% and the average maximum value is 29.1% (USDA 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006b, 2007, 2008b, 2009, 2010b, 2011b). Based on the observed values from 1994-2011, the proportion of oranges that will be processed is assumed to be uniformly distributed.

RESULTS

If HLB is allowed to spread throughout California without any attempts to limit it (the pessimistic scenario) for a period of 20 years, today's total loss in production value is on average estimated to be $2.7 billion. However, if California orange growers take aggressive actions attempting to limit its spread (the optimistic scenario), today's total damages over the 20-year period considered are on average estimated to be $2.2 billion. When comparing the loss in production value between the pessimistic and optimistic approaches over a 20-year period, damages under the pessimistic approach are much higher (Table 1). Limiting the spread of HLB is the preferred approach and is consistent with several studies about citrus disease controls (Miranda et al. 2012; Salifu et al. 2012; Fishman et al. 1983). Under the pessimistic approach, it takes longer to see the reduction in yields while under the optimistic approach yield loss and increased production costs are observed sooner. The difference in the yield loss is related to the fact that under the pessimistic approach, infected trees are left to continue to produce, while under the optimistic approach, infected trees are removed immediately upon disease detection.

Compared to the simulated average value of healthy production, the estimated production loss accounts to 33% and 27% under the pessimistic approach and optimistic approach respectively. When compared directly to today's value of the past 20 years of production, this is equivalent to an estimated 19% and 15% reduction in the present value over the next 20 years if HLB were to be detected in 2012 for the pessimistic and optimistic approaches respectively. If total orange bearing acreage in California is held constant at 180,000 acres over the past 20 years, as in the 20-year-simulated projection, an estimated 26% and 21% decrease in production value is estimated under the pessimistic and optimistic approach respectively.

CONCLUSION AND DISCUSSION

With California contributing over 80% of the nation's fresh oranges, it is important to keep HLB from becoming endemic in the state. Quantifying the potential economic impact of HLB under different management approaches provides insight in developing the most appropriate mitigation practices and reinforces the importance of the actions and efforts of Plant Protection Agencies in preventing the introduction and establishment of HLB in California. The citrus industry in California is worth protecting from the spread of diseases. In 2009, California contributed 45% of the United States citrus industry's nearly $2.9 billion production value (USDA 2011b). As California's 15th ranked commodity in terms of production value, orange production is worth an estimated $722 million in 2010 (USDA 2011c) and employs around 26,000 people in the state (Chavez 2010).

This study approximates and compares the loss in orange production value in California due to HLB under a pessimistic and an optimistic scenario. The pessimistic approach estimated the costs associated with a do-nothing management practice while the optimistic approach estimated the costs associated with attempting to limit the spread of HLB (a do-something management practice). Monte Carlo simulations were employed to estimate the total damage of HLB in California under both approaches.

Fig. 1 and Fig. 2 report the average total loss in production value as well as 95% confidence intervals under each management approach over a 20-year period. Damages under the pessimistic approach tend to be higher but they are also more dispersed. On the contrary, damages under the optimistic approach tend to be smaller and have narrower confidence intervals. Average total damage under the pessimistic approach is estimated to be $14,938 per acre (Fig. 1), while under the optimistic approach is estimated to be $12,135 per acre (Fig. 2). This is a difference of $2,803 per acre over the 20 years that are projected. Under the pessimistic approach it takes longer to see the reduction in yields while under the optimistic approach yield loss and increased production costs are observed sooner (Table 1).

The optimistic approach considers an increase in pesticide applications, which leads to an increase in production costs, which could potentially lead to a decrease in orange acreage. Although production costs increase, the total damage caused by HLB is significantly less under the optimistic approach than in the pessimistic approach. About half a billion dollars in in production costs savings is estimated over a period of 20 years if HLB if is detected in California and the optimistic approach is chosen over the pessimistic approach. This suggests the optimistic approach is the preferred approach, which is also consistent with several previous studies about citrus disease controls (Miranda et al. 2012; Salifu et al. 2012; Fishman et al. 1983).

Under the pessimistic approach, production decreases by over 50% after 11 years following an HLB introduction. The production loss would be felt throughout the food distribution channel (chemical companies, growers, farmers, packing houses, distributing companies, marketers, etc.). Under the optimistic approach, the growers are likely to absorb the additional production costs but it is always possible that they could also be partially subsidized by the government as in Brazil (Miranda et al. 2012). If the government or the state of California does not help growers, the optimistic approach could also result in a partial reduction of the number of orange bearing acreage. Among the two management approaches considered (doing nothing vs. doing something), limiting the spread of HLB is the preferred management practice. It results in damage savings, protects the California citrus industry from HLB, and promotes economic growth. Further research could explore additional management practices or combinations of them.

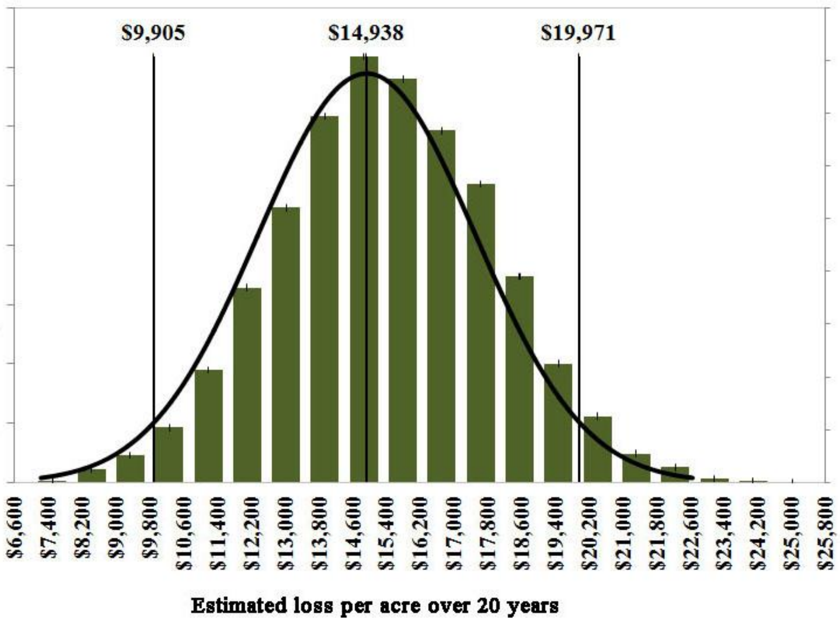

Figure 1. Distribution of the per acre loss in production value under the pessimistic approach.

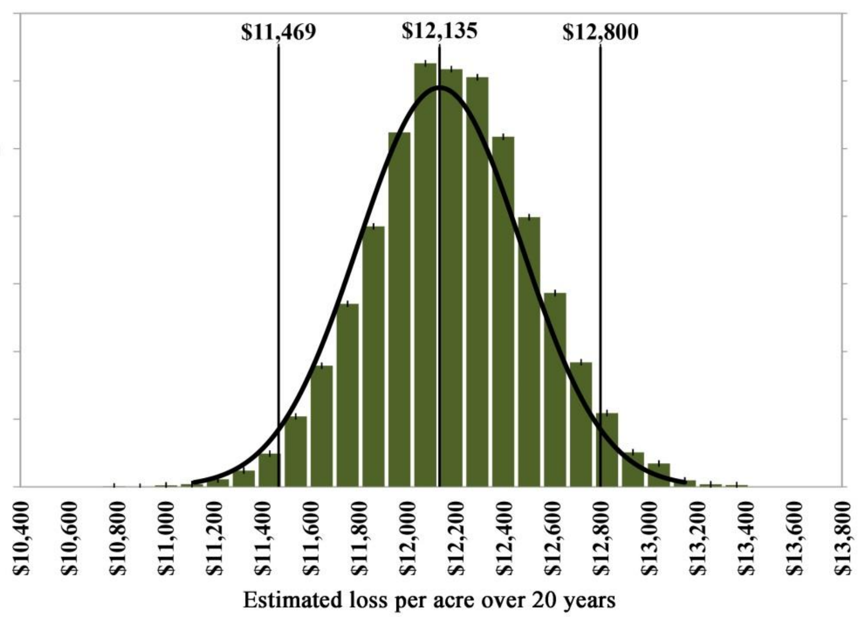

Figure 2. Distribution of the per acre total damage under the optimistic approach.

Table 1. Comparison of the average total damages and differences in average production losses per acre under the optimistic and pessimistic approaches.

	Optimistic Approach			Pessimistic Approach	Difference	
Year	Average Total Damage	Average Increased Production Costs	Average Production Loss	Average Total Damage	Production Loss	Total Damage
1	$504.94	$445.57	$59.37	$0.32	$59.05	$504.62
2	$596.53	$480.78	$115.75	$2.18	$113.57	$594.35
3	$635.02	$466.77	$168.24	$9.27	$158.98	$625.75
4	$670.27	$452.99	$217.28	$28.76	$188.52	$641.51
5	$703.70	$439.75	$263.95	$70.95	$193.00	$632.75
6	$734.44	$427.11	$307.33	$146.65	$160.68	$587.79
7	$713.65	$414.61	$299.04	$262.88	$36.16	$450.77
8	$692.04	$402.59	$289.45	$415.54	$126.09	$276.50
9	$671.50	$390.78	$280.72	$592.61	$311.89	$78.89
10	$651.28	$379.24	$272.04	$772.69	$500.66	$121.41
11	$632.52	$368.14	$264.38	$942.97	$678.59	$310.45
12	$614.73	$357.62	$257.11	$1,086.17	$829.06	$471.44
13	$596.98	$347.23	$249.75	$1,195.64	$945.89	$598.66
14	$579.34	$337.06	$242.28	$1,280.16	$1,037.88	$700.82
15	$562.44	$327.24	$235.19	$1,329.09	$1,093.89	$766.65
16	$546.02	$317.64	$228.38	$1,361.71	$1,133.33	$815.69
17	$530.05	$308.40	$221.65	$1,371.76	$1,150.12	$841.71
18	$515.09	$299.53	$215.56	$1,368.53	$1,152.97	$853.44
19	$499.39	$290.73	$208.66	$1,358.45	$1,149.79	$859.05
20	$484.72	$282.27	$202.45	$1,341.59	$1,139.13	$856.86
Total	$12,134.64	$7,536.07	$4,598.57	$14,937.91	$12,159.24	$11,589.13

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