Estimating Citrus Production Loss due to Citrus Huanglongbing in Florida

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Abstract

Huanglongbing (HLB) or citrus greening disease has jeopardized the Florida's signature citrus industry that makes a valuable contribution towards state's economy. Despite the rigorous efforts to control the disease impact, efficient management measures do not exist. There is limited information on the extent of the impact of the disease. This study provides the measure of the impact of the disease in terms of production loss. Using the regional level data on citrus yield and the tree population we quantified the loss and estimated the probability of loss due to the HLB. The findings demonstrate a substantial production loss in major counties in the Florida. The result further reveals a high probability of loss due to the disease. Higher likelihood of the production loss indicates the ineffectiveness on controlling the impact of the disease.

Key words: citrus greening, production loss, probability loss
JEL Classification: Q10

Introduction

Over the years, Florida's citrus industry has been under considerable abiotic and biotic stress resulting in a substantial economic and environmental loss. More recently, HLB has jeopardized the Florida citrus industry. Despite the citrus industry's acknowledgment of the disease impact, only a few studies have estimated the economic cost of HLB outbreak in Florida (Spreen et al., 2006; Hodges and Spreen, 2012; Moss et al., 2014). A proper estimation of the economic cost of a disease outbreak requires identification and quantification of the losses. These losses incurred from different sources such as the cost of disease management, loss in production, income and employment and loss of international trade (Alam and Rolfe, 2006). While theoretical relationships between disease severity and citrus yield are developed using experimental studies, information on the extent of production loss due to HLB is still unknown. Although recent research has shown encouraging progress towards disease control, the "Silver Bullet" cure and the preventions of the disease are still unknown (Wang and Trivedi, 2013). Moreover, information that provides the effectiveness of such progress is limited. Therefore, this paper presents the first study that estimates the magnitude of production loss in different counties in Florida. Similarly, based on simulation results, the study also computes the probability of the loss due to HLB. The result from the probability loss estimation is critical since it reveals the information about the effectiveness of current disease management procedures.

Background

Agricultural commodities are vulnerable to different abiotic and biotic factors. These factors have considerable effects on crop yield. Abiotic factors such as climatic conditions are critical factors that determine the crop yield (Lobell and Field, 2007). In the meantime, biotic factors such as pest and pathogens are known to have a substantial impact on crop yield and the value of production (Pimentel et al., 2005). These effects result in noticeable yield gaps that have significant implications while considering the increasing demand for food and energy (Lobell et al., 2009; Ittersum et al., 2013) and the global food security (Strange and Scott, 2005). Citrus production in Florida is also limited by the impact of different biotic and abiotic stress (Farnsworth et al., 2014).

Of all the citrus limiting factors, Huanglongbing (HLB) or citrus greening is the most prominent one. Although Florida's favorable condition is best suitable for citrus production, a recent study by Narouei-Khandan et al. (2015) has shown that Florida has a very high probability of HLB and its vector[1] incidence. The impact of abiotic and biotic stresses has created a gap in citrus production, and HLB has been shown to have further widened the gap. Figure 1 and 2 present the box and whisker plots of age-specific and regionally aggregated yield per tree for Valencia and non-Valencia oranges in Florida. Orange color boxes with the horizontal lines illustrate the age-

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[1] Asian Citrus Psyllid (ACP) is the major vector of HLB.

specific univariate yield information for the period before the HLB. Similarly, green boxes with horizontal lines exhibit the age-specific yield information after the onset of the disease. Both plots clearly show that there has been a tremendous difference in the crop yield before and after the HLB epidemics in Florida.

The USA is one of the major orange exporters and exports around 500,000 metric tons of fresh oranges to international markets (FAS/USDA, 2015). However, recent data suggests a decreasing trend in orange export duly credited to the yield and bearing acreage lowering impact of the greening disease (FAS/USDA, 2015). This decline further results in annual loss of revenue to the citrus producers and the national economy. Florida is the largest citrus producer in the USA and accounts for fifty-six percent of the total US citrus production (NASS/USDA, 2015). The citrus industry in Florida makes valuable contributions to the state's economy and generates a large scale employment opportunities (Spreen et al., 2006). However, recent HLB epidemic has been a major constraint to the citrus industry in Florida, resulting in an immense economic loss.

Undoubtedly, crop losses due to pest and pathogens have a direct impact on producers, consumers, and national economy. Using economic welfare approach, Moss et al. (2014) estimate more than a billion-dollar welfare loss due to HLB. The loss was estimated by considering the HLB impact on the tree stocks and increasing orange supply elasticity. Similarly, using IMPLAN model, Hodges and Spreen (2012) estimate a total economic impact of the disease over a five-year period under the two hypothetical scenarios of with and without HLB[2]. Their findings suggest a $4.5 billion total output impact of HLB during five years.

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[2] Both Moss et al. (2014) and Hodges and Spreen (2012) assume no yield from the infected trees. Both of the studies consider the tree mortality as an impact of the disease. However, other studies (Bassanezi et al., 2011; Stansly et al., 2014) have concluded a significantly reduced but positive yield from the symptomatic trees.

The outbreak of any epidemic diseases such as HLB has a potential economic, social and environmental impact. Hence, designing and implementing policies for disease research and management strategies have substantial importance to reduce the economic loss due to the HLB. Studies have also shown the potential of the micronutrients in improving the yield (Spann et al., 2014) and chemicals in controlling the ACP. Nevertheless, the costs of such input usage are high. Therefore, developing policies relating to input subsidies also have a significant role in maintaining citrus productivity. To address such policy issues, information relating to the extent of crop losses is crucial. Hence, proper identification and quantification of the crop losses are necessary (Alam and Rolfe, 2006). However, studies that quantify the extent of citrus production loss due to disease are very limited, and the study by Moss et al. (2014) and Hodges and Spreen (2012) solely assume tree mortality as the only impact of the disease.

Although Figure 1 and 2 depict the differences in yield, studies that examine the production loss potential in Florida due to the greening are scarce. Singerman and Useche (2015) present the first growers' survey report on HLB impact. Using the survey response from citrus growers in different citrus growing regions in Florida, Singerman and Useche publish the estimates on the level of HLB infection and the impact of the diseases on yield. However, understanding the effects of HLB on citrus production is essential to measure the actual impacts of disease on Florida's citrus industry. While, Narouei-Khandan et al. (2015) provide the likelihood for HLB and ACP incidence in Florida, this study seeks to estimate the probability of the loss due to the disease. The likelihood of the production loss at the lower tail of the distribution indicates the effectiveness of the HLB management strategies adopted by the growers whereas, high probability of the loss indicates the ineffectiveness in managing the disease. Overall, the findings from this study are helpful in updating the status of the disease as it quantifies the loss and provides the probability of the loss due to HLB.

The general approach to quantify the yield impact of the HLB is to estimate a statistical relationship between the citrus yield and disease severity and incidence. A symptom diagnostic procedure is used to develop such relationship. First, disease severity is calculated based on the symptoms that are observed in the diseased plants (Gottwald et al., 2007; Bassanezi and Bassanezi, 2008; Bassanezi et al., 2011). Subsequently, yield data are collected from both infected trees and non-infected trees. Finally, relative yield loss is calculated by comparing the yield from the healthy trees and the infected trees. However, application of such procedure in large scale (county and regional level) is difficult due to unavailability of the regional level information on disease severity and incidence.

In this paper, we propose to estimate the production loss due to HLB by using a method that estimates boundary line parameters from the available regional level data. We first estimate boundary line parameters for the yield by using the available information before the HLB epidemics in Florida. With the estimated boundary line parameters, we forecast the yield and then production during HLB years. Finally, the gap between the forecasted production and the observed production provides the estimation of the production loss. The frequency of the positive value of the loss from the total simulated sample provides the measure of the probability of crop loss.

Theoretical Consideration

A conceptual framework to measure the citrus loss due to the disease is presented in the figure 3. This study uses concepts from yield gap models to estimate the loss in citrus production. The literature on yield gap study defines potential production as the level of production without any stress from limiting factors such as water and nutrients (Lobell et al., 2009, Ittursum et al., 2013). Similarly, a yield gap exists whenever crops react to water stress and/or nutrient stress, which results in lower yield as compared to the potential yield and is termed as water limited yield or water- nutrient limited yield. During the event of pests and diseases, farmers observe reduced yield due to pests and disease impact. Such reduced yield is farmers' actual realization of crop yield that is termed as actual yield. The difference in the potential yield and the actual yield is defined as the yield gap due to the impact of both yield limiting and yield reducing factors.

However, estimating a yield gap is always a difficult task (Ittursum et al., 2013). The estimation of yield potential is affected by several factors such as data quality (Bussel et al., 2015; Wart et al., 2013) and estimation techniques (Wart et al., 2013). Lobell et al. (2009) suggest several methods such as field experiments, yield contests, maximum farmers' yields and crop model simulations to estimate the yield gaps.

Although a yield gap is defined by both the yield limiting and reducing factors, this study emphasizes on estimating the total production loss due to HLB. For the purpose of measuring the loss due to HLB, a production gap between the periods before and after the HLB incidence is sufficient[3]. Therefore, we define pre-HLB production Q_{preHLB} as the production level limited by the impact of yield-limiting factors other than HLB. Q_{preHLB} is the actual production level under the stress of water nutrients, weeds, and other important pests and diseases of the citrus. However, the production after the HLB incidence depicts the actual citrus production that is expressed as Q_{HLB}. Conceptually, the difference between Q_{preHLB} and Q_{HLB} is the estimate of the citrus loss due to HLB.

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[3] This study assumes that there are no new significant infestations other than HLB since 2005.

Methodology and Data

Various techniques have been used and suggested to quantify the yield gap at research plot level and a regional and national level. These techniques use surveys, experimental data and crop modeling (Lobell et al., 2009). This paper uses boundary line parameters of the yield components to estimate the crop loss due to the HLB. Webb (1972) states that the boundary line parameters are those that provide the maximum output, which can be expressed as,

$$Y_{\max} = f(X;\beta) \qquad (1)$$

where $f(X;\beta)$ is the functional form depicting output from the some variable(s) X. Similarly, Y is the observed yield.

The notion of a boundary line is briefly discussed in Brancourt-Hulmel et al. (1999) and Makowski et al. (2007). Following the discussion from Brancourt-Hulmel et al. (1999) and Makowski et al. (2007), in the absence of measurement errors,

$$f(X;\beta) \geq Y \qquad (2)$$

The difference between $f(X;\beta)$ and Y, if exists, is due to one or many yield limiting and reducing factors. Whereas, in the presence of measurement errors,

$$f(X;\beta) < Y \; \exists Y \qquad (3)$$

However, the small value of Y compared to that of $f(X;\beta)$ indicates that one or many yield limiting and reducing factors probably affect the yield. So the technique to estimate a loss due to

HLB is to determine the boundary line yield parameters using the information before the HLB period[4] at first, which can be estimated by the function,

$$f(X;\beta) \qquad (4)$$

Given the growth and production nature of perennial trees, we specify age- yield relationship for citrus trees in Florida. Similar to other perennial trees, the production from individual trees changes as the tree matures. There is no economic yield for the initial few years after the new tree plantings. Citrus, in general, is assumed to have no economic yield for the first three years. As the tree matures, the yield increases at increasing rate until it reaches its full maturity stage. However, the increasing yield rate starts to decrease once the tree reaches the full maturity. Different specifications are used to model the age-yield growth pattern. Zanzig et al. (1998) use a hyperbolic tangent yield function to estimate the age-yield relationship while other such as Grogan and Mosquera (2014) use yield as a quadratic function of tree age. In this study, we specify yield as a polynomial function of tree age, which is one of the most common specifications while analyzing the production relationship.

Therefore, $f(X;\beta)$ is defined as a yield function for some yield component X, where X represents tree age. With age into consideration, the age-specific yield function can be further expressed as,

$$f_i(X_i;\beta)$$

Then the total production from different aged trees in the year t is,

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[4] Although, the boundary line parameters can be estimated using the information during the HLB infestation period, there is an issue with segregating the HLB effect. The issue persists because the gap between estimated and the observed yield is due to joint effect of HLB and other yield limiting and reducing factors.

$$\widehat{Q}_t = \sum_i N_{it}\, f(X_i;\beta) \qquad (5)$$

where N is the total numbers of trees for age group i. $\widehat{Q}$ is the estimated total production that is expressed as the sum total of individual tree production. Given the number of trees, we assume the productions before and after the HLB infestation as Q_{preHLB} and Q_{HLB} respectively. Then, the loss due to yield limiting and reducing factors in the year t before the HLB period is,

$$\widehat{\delta}_t = \widehat{Q}_{t\ preHLB} - Q_{t\ preHLB} \qquad (6)$$

We finally quantify the crop loss due to HLB in year t as,

$$\widehat{\tau}_t = \widehat{Q}_{t\ preHLB} - Q_{t\ HLB} - \overline{\widehat{\delta}} \qquad (7)$$

where $\overline{\widehat{\delta}}$ is the average loss due to limiting factors over the years before the HLB incidence.

Equation (4) can be estimated using ordinary least squares. Using field experimental data, Makowski et al. (2007) estimate boundary line parameters for the field crop yield components by applying quantile regression method. However, selection of right quantile to define the boundary line is critical in such estimation. Therefore, identification of true quantile for the boundary line is a major problem with the quantile regressions. An overestimation and underestimation from quantile regression can have serious biases and efficiency issue in the estimation (Makowski et al., 2007).

Econometric Estimation

As discussed in the previous section, the yield is defined as a function of tree age, which can be estimated using the following regression model.

$$\mathrm{Y}_{ijt} = \beta_0 + \beta_1 a_{ijt} + \beta_2 a_{ijt}^2 + \beta_3 a_{ijt}^3 + \sum_{j=1}^{3} \gamma_j \mathrm{Region}_j + \varepsilon_{jt} \quad (8)$$

where Y is the citrus yield for age group i, in the region j in year t. a is the median age for the tree age group i. a^2 and a^3 represent polynomial specification of the age. Region accounts for regional fixed effects. βs are the boundary line parameters to be estimated. ε is the random error which is assumed to be normally distributed.

Equation (8) is estimated using the data from the years 1995-2005. The bootstrap method is used to generate the sampling distribution and to estimate confidence interval of the parameters. We bootstrapped the regression model i.e. equation (8) by treating the regressors as fixed while resampling error from the fitted regression model. As such a k^{th} bootstrapped sample is constructed as,

$$Y_{ki}^* = \widehat{Y} + \varepsilon_{ki}^* \qquad (9)$$

where $\widehat{Y}$ is obtained as a fitted value from the equation (8) and ε_{ki}^* is the resampled residuals for the k^{th} bootstrap sample. However, covariates for each bootstrap sample in the regression are fixed. This procedure generates distributions of bootstrapped regression coefficients for each covariate. For each k^{th} set of the coefficients, total production is estimated by using equation (5), thereby generating a distribution of total production before and after the HLB infestation. Subsequently, $\widehat{\delta}_t$ and $\widehat{\tau}_t$ were computed from the estimated and the observed production value. Finally, the probability of the loss due to diseases is calculated as;

$$P_{loss} = \frac{Count(\widehat{\tau}_k)}{K} \forall(\widehat{\tau}_k > 0) \qquad (10)$$

where K is the total number of bootstrapped sample.

Data

The dataset used in this study was extracted from two different publications. Tree population data was taken from Commercial Citrus Inventory publications (NASS/USDA). Tree population dataset has information on both non-bearing trees and bearing trees. Until 2006, the Commercial Citrus Inventory data set was published every two years with tree number data by individual age. However, since 2008, Commercial Citrus Inventory started reporting tree number data every year by the age group. Yield data is obtained from Citrus Summary and Citrus Statistics publications (NASS/USDA). Age-group yield data is published for four different citrus producing regions in Florida. These four regions are Indian River, Northern and Central, Southern, and Western. However, the total crop production and the number of trees for different citrus varieties are published at the county level. Therefore, we assign counties to their respective region using the Florida citrus production map so as to estimate total production and perform subsequent analysis.

Several considerations were made with regard to the available age group yield and tree population data. Since the yield data are grouped together for all the trees aged 24 and over, this study considers all the trees of age 24 and over as of age 24. The median for each age group was used in the regression. Since yield data for oranges was reported under the headings Valencia and non-Valencia, an average of both Valencia and non-Valencia oranges was considered as the yield for all-Round orange.

Results

Production value was predicted using the generated coefficient from bootstrap regression to compute the production loss. Loss from the greening was calculated using the equation (7). Table

4 presents the results from production loss estimates during the years 2008-2013. The result from the estimation suggests that most of the counties incurred tremendous production loss due to the HLB. The result directly implies a high annual loss of revenue to the citrus producers. Another interpretation of the loss value is the value of additional production obtained under the scenario of no HLB[5]. Additionally, the magnitude of the loss has been consistently on the rise in the last few years suggesting increasing impact of the disease. There are two possible explanations for such increase in the production loss. Decrease in the new citrus plantings (Spreen et al., 2014) and a high percentage of HLB-infected citrus trees in major citrus producing regions (Singerman and Useche, 2015) jointly impact the total citrus production.

Table 3 presents the estimated probability of loss for both Valencia and all-Round oranges in selected counties during HLB periods. Except for the few counties and some years, all counties have a high probability of production loss, around 90-100 percent, for both Valencia and all-Round oranges. This result is consistent with our expectation since there is a high likelihood of the disease and its vector incidence in Florida (Narouei-Khandan et al., 2015).

To demonstrate the impact of HLB on production loss, we present Figure 4 and 5. Figure 4 illustrates the distribution of production loss due to HLB and other yield limiting and reducing factor in the Collier County in 2013. Figure 4 clearly shows that HLB accounts for the majority of loss compared to the loss caused by all the factors. Figure 5 compares the distribution of the percentage of production loss in all-Round oranges for different years in Highlands County during HLB period. Both Figures 4 and 5 depict production loss due to citrus greening.

The boundary line results for estimated coefficients are presented in Table 1. The result from the estimation is consistent with our expectation. Tree age is highly significant and is a major factor

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[5] However, there is a cost associated with removing the impact of the disease.

in the yield determination. Positive age coefficient suggests that, as the age of the tree increase, there is an increment in the yield until the maturity. However, as the tree grows older and reaches the maturity stage, the yield starts to decreases. The third polynomial of the tree age suggests that there is a negligible change in the yield once the tree matures. The result also shows that, compared to the citrus orange producing counties in the Indian River region, other regions have higher citrus yield. Table 2 presents the results from bootstrapped regression that was used to generate the distribution for the yield defining parameters and to construct the confidence interval. Results suggest negligible bias from the bootstrapped regression.

Conclusions

HLB is currently jeopardizing the Florida's citrus industry. One of the many implications of the diseases is its impact on yield and production. This study analyzed and computed different aspects of production loss inflicted by the disease. We found that there is a substantial difference in the citrus yield between pre-HLB and post-HLB period. The study found that most of the counties in Florida have very high probability (90-100 %) of production loss due to the HLB. The high likelihood of the loss explains the inability of the growers to control the damage once the disease starts spreading in the orchard. The study also reveals a considerable magnitude of the production loss that is increasing over the years. Besides updating the current status of the disease impact to all the relevant growers, researchers, governmental agents and other stakeholders, the finding supports in the favor of more practical and immediate result oriented disease intervention.

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Table 1: Estimates of Boundary line Parameters

Estimates	Valencia Oranges	all-Round Oranges
Constant	-0.927*	-1.261**
	(-0.396)	(0.396)
age	0.377***	0.424***
	(0.107)	(0.108)
age2	-0.017*	-0.016.
	(0.008)	(0.008)
age3	0.0003.	0.0002
	(0.0002)	(0.0002)
Region 2	1.336***	1.546***
	(0.135)	(0.135)
Region 3	0.596***	0.774***
	(0.135)	(0.135)
Region4	1.192***	1.354***
	(0.135)	(0.135)
R-Squared	0.71	0.76

Significance level: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
Std. error in parenthesis

Table 2: Results From Bootstrapped Regression

all-Round Oranges

Estimates	Mean	Std. Error	Bias	CI_lower	CI_upper
Constant	-1.259	0.387	0.339	-2.059	-0.516
age	0.423	0.106	-0.048	0.216	0.635
age2	-0.016	0.008	-0.001	-0.031	0.001
age3	0.0002	0.0001	0.000	0.0001	0.001
Region 2	1.542	0.129	-0.213	1.287	1.776
Region 3	0.768	0.132	-0.183	0.505	1.013
Region 4	1.356	0.135	-0.159	1.096	1.609

Valencia Oranges

Estimates	Mean	Std. Error	Bias	CI_lower	CI_upper
Constant	-0.923	0.388	0.005	-1.703	-0.153
age	0.376	0.106	-0.001	0.16	0.588
age2	-0.017	0.008	0.000	-0.033	0.000
age3	0.0003	0.0003	0.0002	0.000	0.0006
Region 2	1.333	0.130	-0.003	1.074	1.562
Region 3	0.591	0.134	-0.006	0.334	0.847
Region 4	1.194	0.136	0.002	0.929	1.469

Table 3: Probability of Loss (1000 Samples)

all-Round Orange

County	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Collier	0.90	0.94	1.00	0.99	0.98	0.96
Desoto	0.78	0.92	0.99	1.00	1.00	1.00
Hardy	0.91	0.90	1.00	1.00	1.00	1.00
Hendry	0.76	0.84	1.00	0.96	0.93	0.91
Highlands	0.73	0.87	0.98	0.93	0.89	1.00
Indian River	0.17	0.24	0.88	0.48	0.33	0.42
Manatee	0.83	0.91	1.00	1.00	1.00	1.00
Polk	0.80	0.89	0.99	0.97	0.95	1.00
St. Lucie	0.00	0.00	0.00	0.00	0.00	0.00

Valencia Orange

County	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Collier	0.75	0.83	1.00	0.98	0.97	0.83
Desoto	0.38	0.88	0.98	0.99	0.98	1.00
Hardy	0.37	0.87	0.98	0.98	0.97	1.00
Hendry	0.62	0.72	1.00	0.94	0.92	0.82
Highlands	0.65	0.90	0.93	0.84	0.80	1.00
Indian River	0.35	0.66	0.99	0.94	0.88	0.86
Manatee	0.36	0.89	1.00	0.99	0.97	1.00
Polk	0.66	0.92	0.94	0.85	0.81	1.00
St. Lucie	0.62	0.75	0.93	0.97	0.95	0.95

Table 4: Estimated Average Production Loss (1000 Boxes)

all-Round Orange						
County	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Collier	1901	2255	4736	3210	2652	2170
Desoto	1936	3557	6534	7422	6619	8256
Hardy	2169	2128	4610	5418	4921	5312
Hendry	2370	3003	8674	4874	4117	3754
Highlands	1467	2646	4733	3705	2886	7174
Indian River	-614	-450	656	-22	-224	-92
Manatee	691	1038	2264	2306	1988	2327
Polk	2346	3372	6705	5258	4432	10078
St. Lucie	-5675	-5406	-4089	-3997	-4097	-3798

Valencia Orange

County	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Collier	606	844	2394	1589	1391	737
Desoto	-410	1837	3328	3415	3024	5035
Hardy	-191	667	1232	1279	1214	2087
Hendry	682	1197	5009	2900	2633	1647
Highlands	663	2109	2445	1602	1319	3725
Indian River	-123	139	648	461	295	262
Manatee	-121	448	884	793	635	1229
Polk	622	2154	2306	1542	1324	3716
St. Lucie	292	552	1095	1308	1068	1038

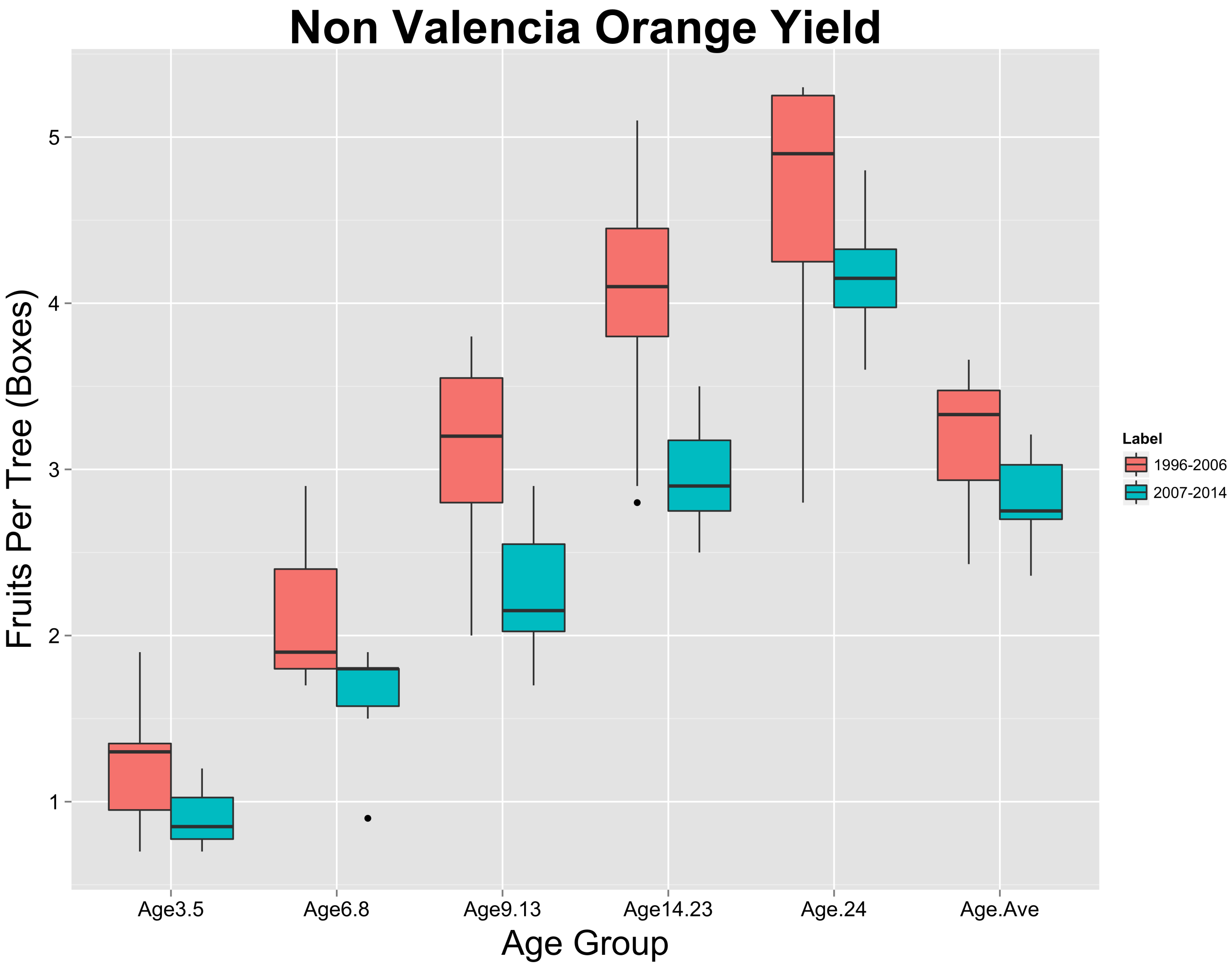

Figure 1: Box Plot and Whisker Plot for non-Valencia orange yield before and after HLB

Source: Florida Agriculture Statistics Service. Citrus Summary (1996-2014). Author Computed

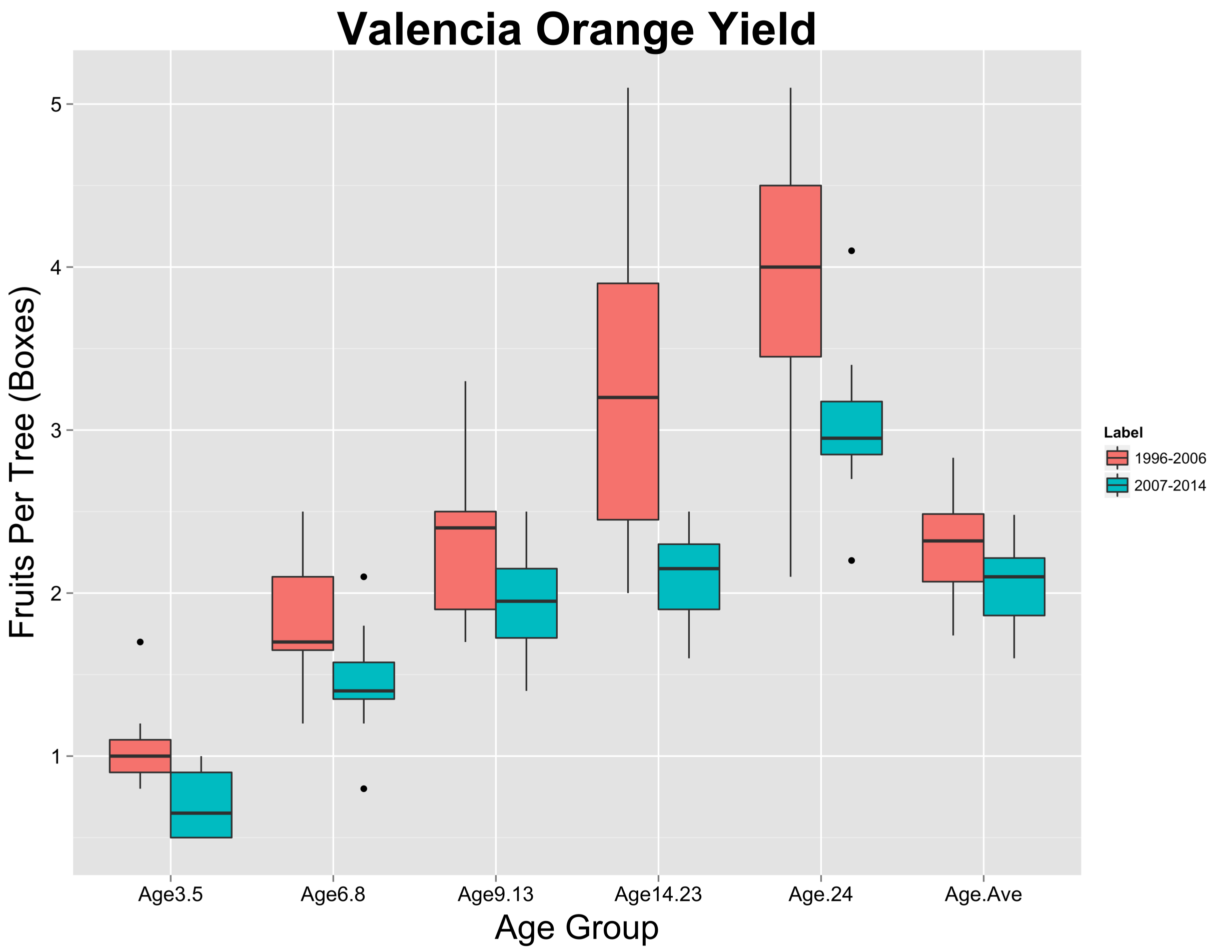

Figure 2: Box and Whisker Plot for Valencia orange yield before and after HLB incidence.

Source: Florida Agriculture Statistics Service. Citrus Summary (1996-2014). Author Computed

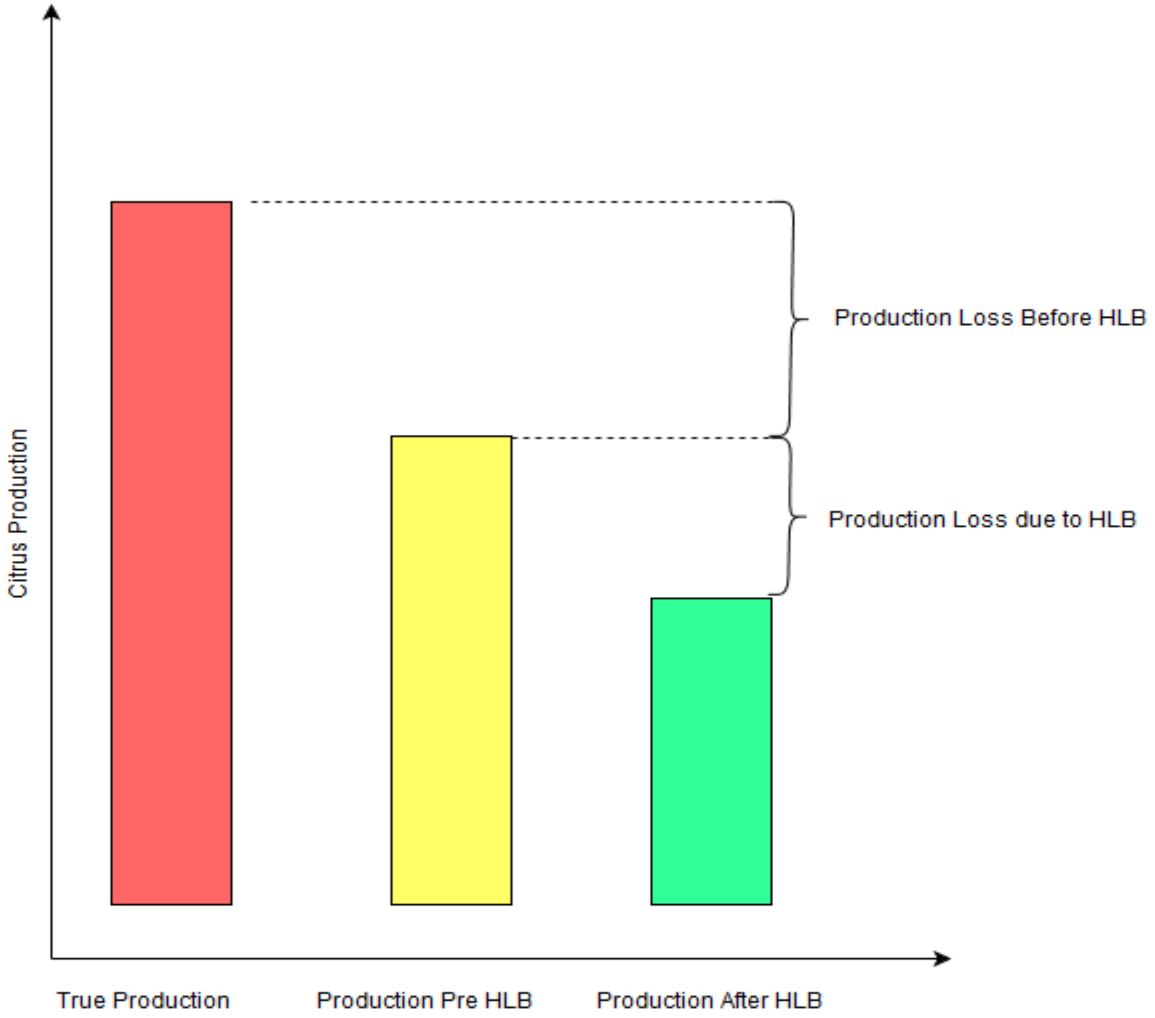

Figure 3: A conceptual framework depicting the difference in production and production loss due to HLB.

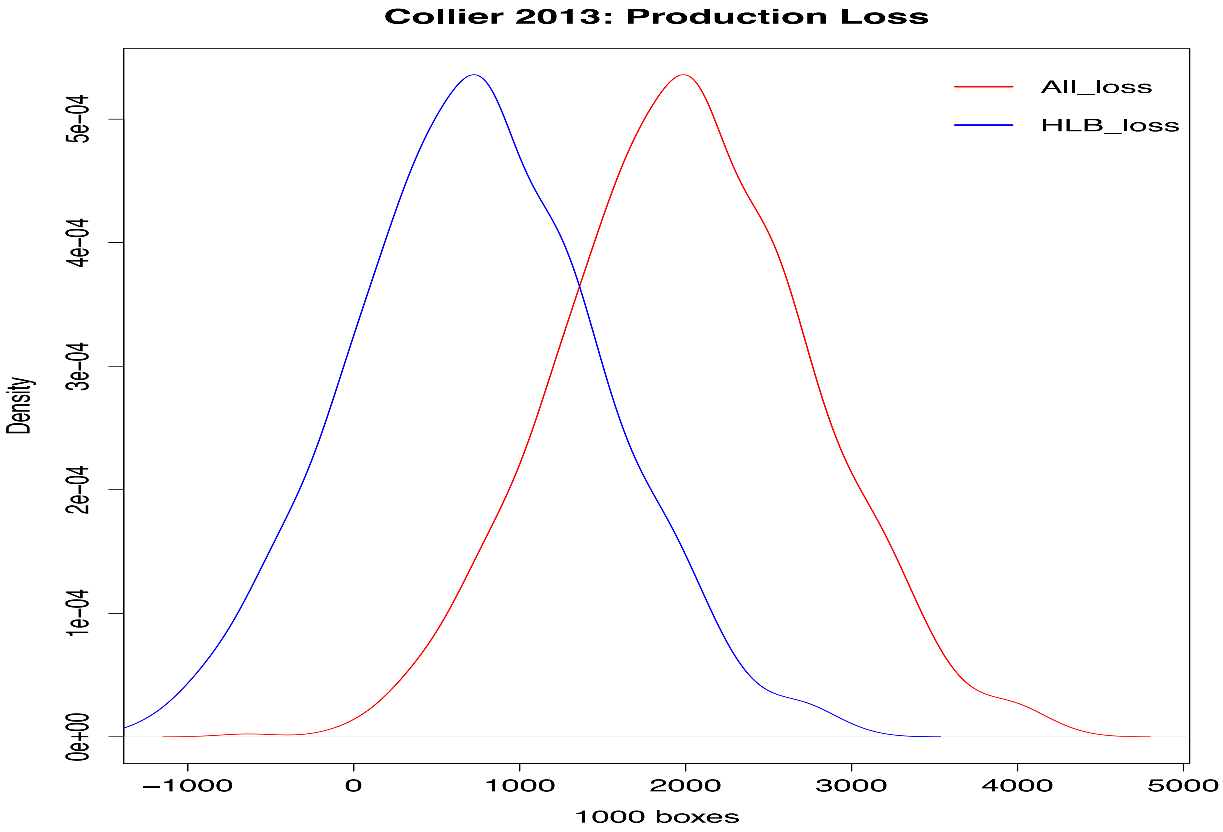

Figure 4: Estimated production loss in Valencia orange in Collier County in the Year 2013

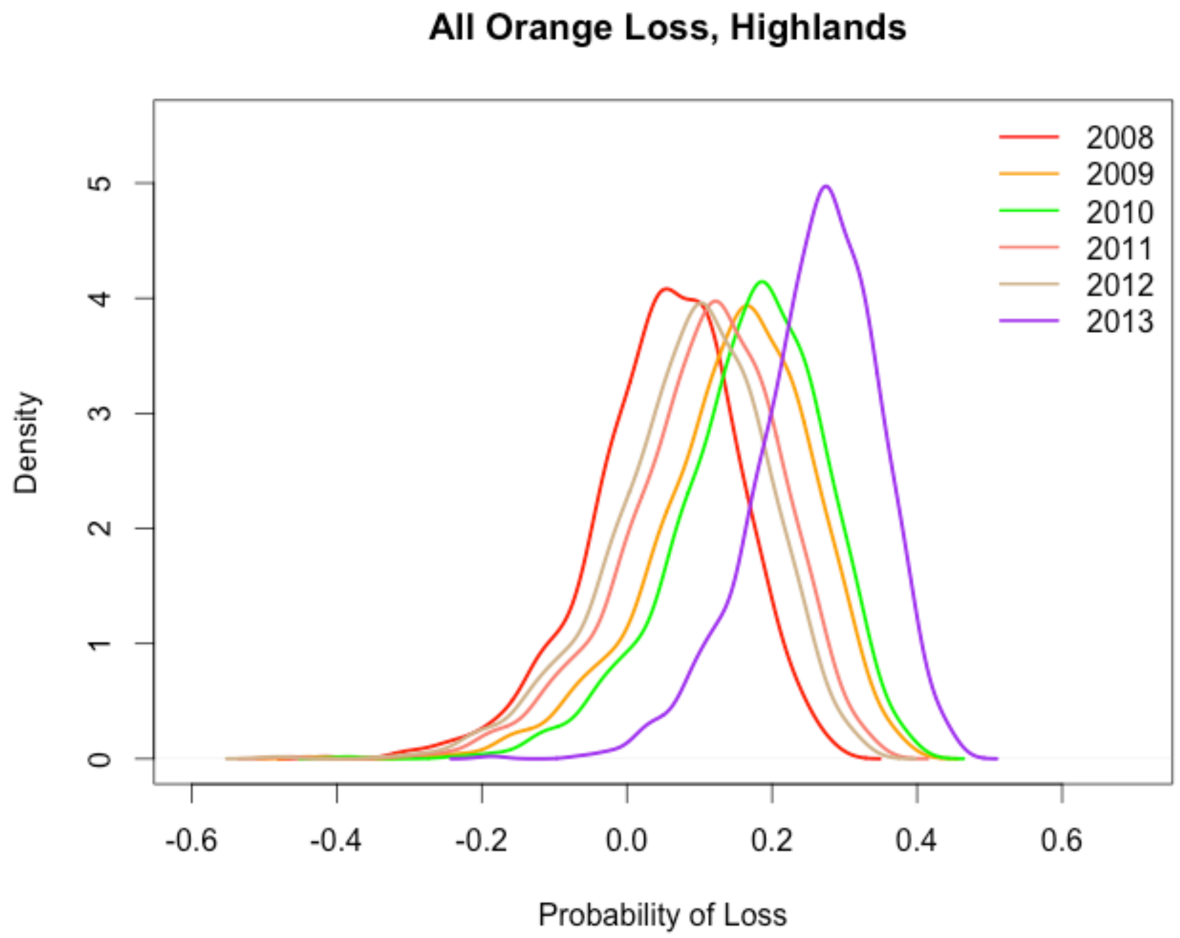

Figure 5: Estimated percentage loss in all-Round oranges due to HLB in Highlands County.