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Assessing the Profitability of Avocado Production in South Florida in the Presence of Laurel Wilt

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Abstract

Laurel wilt (LW) is a lethal disease of trees in the Lauraceae plant family, including the economic significant commercial crop avocado, *Persea americana*. To date, an estimated one-half billion native trees have been destroyed by the disease in the southeastern United States, including the loss of significant and diverse taxa in the Everglades. In the US state of Florida, laurel wilt has spread rapidly throughout the South Florida commercial avocado production area. Since its arrival in 2011, LW has been responsible for the death of about 7000 trees or 1% of the production area. Given the destructive nature of this disease, there are major concerns over the future of the Florida avocado industry. Cost-effective management of LW remains an elusive goal, and current recommendations rely heavily on the early detection and destruction of affected trees (sanitation) in an effort to slow the spread of the disease. An empirical economic model is used to determine when all trees in an orchard affected by LW would need to be destroyed due to negative net returns.

Keywords

Avocado Production, Laurel Wilt, Profitability

1. Introduction

Laurel wilt (LW) has emerged as a lethal threat to plants in the Lauraceae plant family in the southeastern Unit-

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ed States (US Southeast), including important native trees and the commercial avocado crop, *Persea americana* [1] [2]. LW is caused by the fungus *Raffaelea lauricola*, which has an invasive ambrosia beetle vector, *Xyleborus glabratus*. Since 2002, an estimated one-half billion native trees have been destroyed by LW in the US Southeast. Significant environmental, ecological, and economic impacts have been documented throughout this region, as well as the loss of culturally significant and diverse taxa in the Everglades. Since its appearance in Florida commercial avocado production area in 2011, more than 7000 trees, representing approximately 1% of production area, have had to be removed. Commercial production has ceased in severely impacted orchards in Florida, and valuable avocado production in unaffected orchards and in other states (especially California) and the Western Hemisphere is jeopardized.

Although initial infections in a given grove are presumed to involve beetle dispersion of the pathogen, secondary spread within a planting apparently occurs via root grafts between infected and healthy trees. Effective management of root graft transmission is a primary concern in LW-affected groves. Current recommendations for LW control involve the prompt diagnosis of affected trees, rapid removal and destruction of these trees (sanitation), and the treatment of adjacent trees with fungicide and insecticide.

The loss of native members of the Lauraceae family is of ecological significance [1], but LW could also have a considerable economic impact [3] [4]. Since LW could cause a permanent reduction in the long-term profitability of the Florida avocado industry, growers, policy makers, and other stakeholders are concerned about the disease's future impact on the industry, how limited resources should be allocated to mitigate its threat, and how long-term survival of the industry might be ensured. The damage that LW could cause to the industry has been estimated [3] [5], but profitability scenarios have not been examined for the industry. With the disease affecting commercial production, guidelines are needed to assess net revenues using different LW management scenarios. Moreover, a framework is required to evaluate the cost-effectiveness of different LW management strategies which could affect the spread rates. Preliminary work in the latter area indicates that considerable progress is needed before efficacious measures become economically viable [6].

Within this context, the present research was undertaken to assess the potential economic impact of LW and provide producers with a decision tool with which returns could be maximized in the presence of this disease. The approach of Salifu *et al*. [7] was used to address how LW impacts profitability by considering different disease spread rates and incidences, the age of plantings when they were first affected by the disease, and treatment costs. In general, simulation techniques were used to determine when a grove affected by LW would cease to be profitable with and without management.

2. Potential Economic Impact of LW on Commercial Avocado

Avocado is planted on about 3400 hectares in Florida, and represents 60% of the total area planted in tropical fruits in the state. Most commercial avocado orchards are in Miami-Dade County in South Florida, and 93% of the plantings are smaller than 7 hectares [3]. Farm-gate value for Florida avocados is in excess of US $24 million·yr^{-1}, with a wholesale market value upwards of US $35 million. The Florida avocado industry has an overall economic impact of US $100 million and generates about 550 full-time jobs [8]. The property on which mature avocado trees are grown in Florida is valued at US $326 million [3].

Evans and Crane [5] estimated unit replacement costs for commercial avocado trees in South Florida as US $330, based on the Tree Value Analysis internet tool developed at the University of Florida [9]. Trees were calculated as assets whose value was determined using the income method. The approach used by Evans and Crane [5] accounted for lost income from the sale of fruits (a farm gate price for fruit of $1.21 kg^{-1}), and considered the expense of tree removal ($150 tree^{-1}), land preparation, replacement trees, planting, maintenance during a seven-year replacement period (fertilizer, pruning, weeding, and pest control), and a discount rate of 5%.

To assess the economic impact of LW on Florida avocado, Evans *et al*. [3] considered direct and indirect losses resulting from a hypothetical outbreak of the disease. Direct losses were due to lost income, lower property values, and increased management costs, which included disease monitoring, plant protection products, dead tree disposal, and replanting costs (**Table 1**). Indirect losses referred to secondary or spillover effects in associated businesses, such as those that sell trees, fertilizer, fungicide, and packaging materials, as well as packing houses, transportation services, and retailers (**Table 2**). An input-output model (I-O), known as Impact

Table 1. Direct monetary impact on Florida commercial avocado production under different LW scenarios.

Expense/loss category	Relative loss in production		
	100%	75%	50%
Potential losses in fruit sales	$30,000,000	$22,500,000	$15,000,000
Decline in property value*	$326,250,000	$244,688,000	$163,125,000
Disease management costs**	$0	$4,525,000	$4,525,000
Total direct loss	$356,250,000	$271,713,000	$182,650,000

*Based on the value of a mature avocado tree. **Monitoring, fungicide, and labor costs, as indicated by Evans *et al*. [3].

Table 2. Potential indirect impact of LW outbreak on Florida's economy.

Considered impact	100% loss	75% loss	50% loss
Industry sales	30,000,000	22,500,000	15,000,000
Output impacts	54,266,259	40,699,694	27,133,129
Employment impacts	546	409	273
Labor income impacts	19,674,272	14,755,704	9,837,136
Indirect business tax	1,862,415	1,396,811	931,207

Source: Excerpted from Evans *et al*. [3].

Analysis for Planning (IMPLAN), was used to quantify indirect losses [3].

Given the uncertain impact of this disease on avocado production, Evans *et al*. [3] evaluated three different scenarios: 1) total loss, 2) 75% loss, and 3) 50% loss. They obtained a unit value of US $500 for mature avocado trees by using the Tree Value Analysis internet tool [9], which is very sensitive to analysis parameters.

The following input parameters were used in the analysis by Evans *et al*. [3]: the average price received by growers in 2012 (US $1 kg^{-1} fruit); cost for tree removal (US $150); and increases in management costs (included US $733 $ha^{-1}\cdot yr^{-1}$ for vector control through labor and insecticide). Considering these parameters and a total (100%) loss scenario, it was estimated that industry sales would decline US $30 million, and about US $54.3 million would be lost to Florida's GDP (**Table 1**). In terms of employment, it was estimated that 546 jobs would be lost, representing worker earnings of US $19.7 million and tax revenue of US $1.9 million that would not circulate in Florida's economy. It was also estimated that indirect losses would total about US $77 million·$yr^{-1}$ (**Table 2**).

3. Model Parameters

Economic and biological data were utilized to develop the described profitability model. To parameterize the model, a production function was created for avocado in Florida. Yearly avocado production was estimated with linear regressions in which the economic life of an orchard was assumed to be 40 years and production decreased after year 30 at an annual rate of 5% [10]. The derived model was statistically significant and explained up to 70% of the variation in avocado production (**Appendix Table A1**).

Most of the economic data were obtained from the Florida Cooperative Extension Service. They reflected South Florida avocado cultivation costs, which included plant nutrition, pest control, weed control and pruning, and represented 40% of the total costs for production. Fixed costs were 30% of the total costs and included land rent, supervision, and overhead. Ancillary activities, which included from harvesting to marketing, accounted for the remaining 30% (**Appendix Table A2**). Establishment/replanting costs for a hectare of avocado were calculated to be US $5742 (around US$30 per tree), and the cost to produce a kilogram (kg) of fruit was calculated to be US $0.77, which included the cost of picking, packing, and marketing (US $0.37 k^{-1}) [10]. Based on the average farm gate price received by Florida producers over the last 10 years (US $1.1 kg^{-1}), a net return of US $0.33 kg^{-1} of avocado fruit was obtained (**Appendix Table A3**) [11].

4. Model Development

With one of the goals of the present research being to develop a model with which profitability could be assessed in the presence of LW, the model assumes that an avocado orchard is an asset with a useful lifetime and a stream of net benefits during that time. The model estimates the economic impact of LW by applying the income method developed by Spreen *et al*. [12]. Future costs and revenues are estimated to obtain net revenue per annum, and net future revenue is discounted such that the net present value (NPV) is obtained using the formula

$$\text{NPV} = \sum_{t=1}^{T} \frac{\left(pQ_t - c_t Q_t - F\right)}{\left(1+r\right)^{t-1}} \tag{1}$$

where t indexes the corresponding time period; p is the price paid per kilogram of fruit after packing and marketing; Q_t is the marketable yield per hectare of avocado in time period t; c_t represents the variable costs per hectare (harvesting, packing, and marketing) at time period t; F represents production costs (sanitary, irrigation, weed control, and nutrition expenses) and fixed costs (land, supervision, and overhead) per hectare; and r is the discount rate.

It should be noted that LW affects net revenue by both decreasing fruit production (causing the death of trees in the orchard) and increasing management costs (scouting, sanitation, and any prophylactic treatments). The anticipated increase in management costs can therefore be accommodated in the model through an adjustment (reduction) of the net price received for fruit by producers. In this application, net price is adjusted downward by assuming a 10% increase in total costs due to LW management. Higher percent adjustments are also considered but cause the operation to become unprofitable due to slim profit margin growers currently realize.

The effect of LW on avocado production is obtained as indicated by Salifu *et al*. [7]. To calculate the value of disease incidence at time t, Salifu *et al*. [7] considers the effective contact rate of disease spread (β), the age of the grove at first detection (a_0), and the incidence of the disease at first detection (D_0). A unique solution of when to destroy all trees in the orchard or to replant can be determined with these variables. The profit maximizing objective implies that producers will stay in the avocado business until operating costs become greater than returns, at which time they will either exit the business or replant the orchard if resistant varieties are available.

For the model with LW, a Gompertz-type disease incidence function is used, which drives the epidemic to 100% incidence, similar to Salifu *et al*. [7]. The disease spread model describes disease incidence D_t over time as

$$D_t = \mathrm{e}^{\ln(D_0)\mathrm{e}^{-\beta t}} \tag{2}$$

Equation (2) contains two important parameters. The first is the rate of disease spread (β), which is also known as the effective contact rate. β values of 0.1%, 120%, 230%, and 350%, which are considered below, indicate the speed of disease transmission over a period of one year. Preliminary data gathered in South Florida avocado orchards during 2012 indicate that LW incidence increases from 1% to 90% within a year if no action is taken against LW. The latter means that if disease incidence starts with one case $(D_0 = 1\%)$, a beta value (spread rate) equal to 350% will be required for depicting the "do nothing" strategy, leading to 90% incidence after a year of initial infection (**Figure 1**).

5. Model Scenarios

The lifespan of each model scenario is defined as the time between planting and destruction or replacement of the avocado orchard. In this regard, two criteria can be used to assess the economic viability of the orchard. The first criterion centers on estimating the time when the increased management costs associated with the spread of the disease and the reduction in yields due to tree removal (sanitation) results in net returns becoming negative (*i.e.*, costs exceed revenues). The second criterion is based on the calculation of the NPV based on a discount rate of 10%. A positive NPV indicates that an operation is profitable, and a negative NPV indicates that it is not profitable. Using these two criteria, a grower can assess the relative profitability of various management strategies, assuming various rates of spread and incidence of disease when first detected.

Four scenarios are considered based on the management strategy that is adopted and its relative efficacy. The first scenario (Do Nothing) assumes that no action is taken to limit the spread of the disease, hence a spread rate of 350% per annum. The second scenario (Fully Effective) assumes that action is taken with a fully effective control treatment; under this scenario, the value of the parameter beta from Equation (2) decreases to 0.1%. The remaining scenarios consider intermediate levels of control effectiveness: scenario three (Low Effectiveness) assumes that the control strategy reduces beta to 230%, and scenario four (Intermediate Effectiveness) reduces

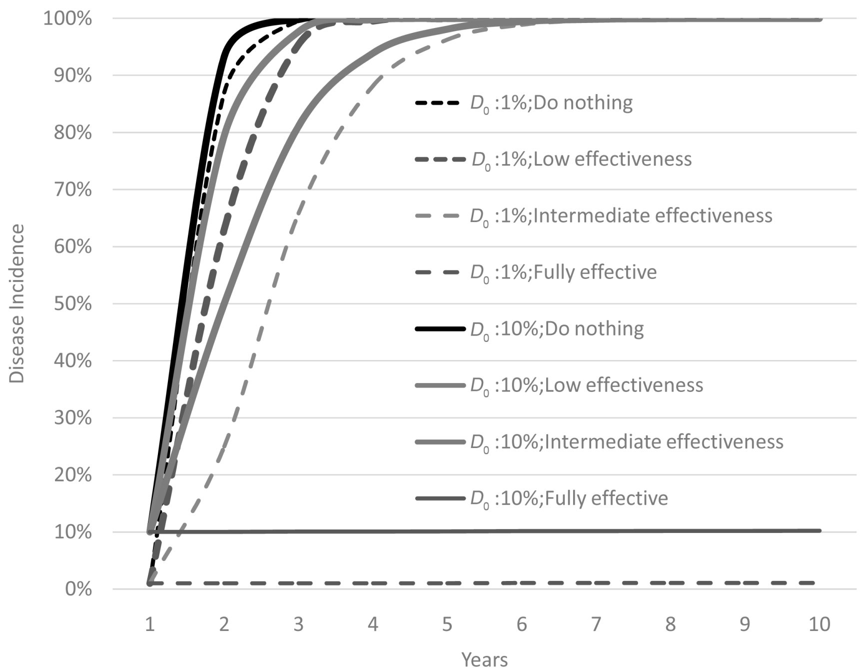

Figure 1. Disease incidence along time according to the considered laurel wilt possible spread rates (Gompertz).

beta to 120%. For each scenario, the two levels of disease incidence at first detection (D_0) considered are 1% and 10% (*i.e.*, respectively, 2 and 20 affected trees out of 192 trees, which corresponds to plant density in avocado groves).

The 10% increase in production costs due to LW management considers the narrow profit margins evident in a previous analysis [8], and translates to a net price, p, of US $0.25 kg^{-1}. Avocado production in the presence of LW is simulated with the previously mentioned spread rates, β, of 0.1%, 120%, 230%, 350%, and initial incidences, D_0, of 1% and 10% after LW is detected on a yearly basis. It is assumed that LW may affect an avocado orchard at any age. Thus, for 1% initial disease incidences, the optimal period at which net returns becomes negative is determined for each scenario, relating to the effectiveness of control measures and the investment value when total tree removal would be advisable (**Table 3** and **Table 4**, respectively). Similar analyses estimate the 10% initial disease incidence (**Table 5** and **Table 6**, respectively).

6. Results and Discussions

LW is a disease that threatens Florida avocado orchards. Given its lethal nature and how fast it kills avocado trees, major concerns for the future of the Florida avocado industry have arisen. Unfortunately, many questions about the epidemiology of LW are unresolved, which has prevented scientists from devising a cost-efficient means of controlling the disease.

An empirical economic model is used to determine when all trees in an orchard affected by LW would need to be destroyed due to negative net returns. Large differences in profitability are determined for avocado orchards affected by hypothetical outbreaks of laurel wilt, depending on whether control measures are utilized and the extent to which these measures are effective.

Table 3 shows the optimal period at which a net return becomes negative for a 1% initial disease incidence under four different scenarios (see also **Figure 2**). For example, in column 1 of **Table 3**, if a seven-year-old orchard (row 3) were to become infected with the disease in a situation using no control measures (Do Nothing, scenario 1), LW would spread so rapidly that the orchard would need to be destroyed within two years (by year 9) of detection of the disease in the orchard. Similar results are obtained for both the low effectiveness $(\beta = 230\%)$ and intermediate effectiveness $(\beta = 120\%)$ scenarios (*i.e.*, scenarios 3 and 4, respectively). In contrast, a fully effective control strategy (scenario 2) that decreases the LW spread rate to 0.1% yr^{-1} would

Table 3. Period at which a net return becomes negative according to age at initial LW infection, assuming 10% cost increase, and $D_0 = 1\%$ *.

Orchard age in years a_0	Do nothing $\beta = 350\%$	Fully effective $\beta = 0.1\%$	Low effectiveness $\beta = 230\%$	Intermediate effectiveness $\beta = 120\%$
5	7	39	7	7
6	8	39	8	8
7	9	39	9	9
8	10	39	10	10
9	11	39	11	11
10	12	39	12	12
11	13	39	13	13
12	14	39	14	14
13	15	39	15	15
14	16	39	16	16
15	17	39	17	17
16	18	39	18	18
17	19	39	19	19
18	20	39	20	20
19	21	39	21	21
20	22	39	22	22
21	23	39	23	23
22	24	39	24	24
23	25	39	25	25
24	26	39	26	26
25	27	39	27	27
26	28	39	28	28
27	29	39	29	29
28	30	39	30	30
29	31	39	31	31
30	32	39	32	32
31	33	39	33	33
32	34	39	34	34
33	35	39	35	35
34	36	39	36	36
35	37	39	37	37
36	38	39	38	38
37	39	39	39	39

* $\beta =$ the rate of LW spread, $a_0 =$ the age of the grove at first detection, $D_0 =$ the incidence of laurel wilt at first detection. Total costs increase due to treatment.

Table 4. NPV according to age of initial infection and control strategy scenarios, assuming control strategy increases costs 10%, and $D_0 = 1\%$ *.

Orchard age in years a_0	Do nothing $\beta = 350\%$	Fully effective $\beta = 0.1\%$	Low effectiveness $\beta = 230\%$	Intermediate effectiveness $\beta = 120\%$
5	–5545	12,236	–8571	–8490
6	–2696	12,388	–6394	–6311
7	–89	12,541	–4399	–4315
8	2308	12,680	–2568	–2491
9	4487	12,806	–903	–833
10	6467	12,921	611	674
11	8268	13,025	1987	2044
12	9905	13,120	3238	3290
13	11,393	13,206	4375	4422
14	12,746	13,284	5409	5452
15	13,976	13,355	6348	6388
16	15,094	13,419	7203	7238
17	16,111	13,478	7980	8012
18	17,035	13,531	8686	8715
19	17,875	13,580	9327	9354
20	18,638	13,624	9911	9935
21	19,333	13,664	10,442	10,464
22	19,964	13,700	10,924	10,944
23	20,538	13,733	11,362	11,380
24	21,059	13,763	11,761	11,777
25	21,533	13,790	12,123	12,138
26	21,964	13,814	12,452	12,466
27	22,356	13,837	12,752	12,764
28	22,713	13,857	13,024	13,035
29	23,036	13,875	13,272	13,282
30	23,299	13,892	13,467	13,476
31	23,512	13,906	13,619	13,627
32	23,681	13,919	13,734	13,741
33	23,814	13,930	13,819	13,825
34	23,916	13,939	13,879	13,884
35	23,994	13,947	13,919	13,923
36	24,051	13,953	13,942	13,946
37	24,091	13,959	13,952	13,956

* $\beta =$ the rate of LW spread, $a_0 =$ the age of the grove at first detection, $D_0 =$ the incidence of laurel wilt at first detection. Total costs increase due to treatment. NPV is calculated from planting to the period in which net returns become negative.

Table 5. Period at which net returns become negative according to age at LW initial infection, assuming 10% cost increase, and $D_0 = 10\%$ *.

Orchard age in years a_0	Do nothing $\beta = 350\%$	Fully effective $\beta = 0.1\%$	Low effectiveness $\beta = 230\%$	Intermediate effectiveness $\beta = 120\%$
5	7	33	7	7
6	8	33	8	8
7	9	33	9	9
8	10	34	10	10
9	11	34	11	11
10	12	34	12	12
11	13	34	13	13
12	14	34	14	14
13	15	34	15	15
14	16	34	16	16
15	17	34	17	17
16	18	34	18	18
17	19	34	19	19
18	20	34	20	20
19	21	34	21	21
20	22	34	22	22
21	23	34	23	23
22	24	34	24	24
23	25	34	25	25
24	26	34	26	26
25	27	34	27	27
26	28	34	28	28
27	29	34	29	29
28	30	34	30	30
29	31	34	31	31
30	32	34	32	32
31	33	34	33	33
32	34	34	34	34
33	35	34	34	34
34	36	35	35	35
35	37	36	36	36
36	37	37	37	37
37	38	38	38	38

* $\beta =$ the rate of LW spread, $a_0 =$ the age of the grove at first detection, $D_0 =$ the incidence of laurel wilt at first detection. Total costs increase due to treatment.

Table 6. NPV according to age of initial infection and control strategy scenarios, assuming control strategy increases costs 10%, and $D_0 = 10\%$ *.

Orchard age in years a_0	Do nothing $\beta = 350\%$	Fully effective $\beta = 0.1\%$	Low effectiveness $\beta = 230\%$	Intermediate effectiveness $\beta = 120\%$
5	–6848	–2819	–9875	–9794
6	–4013	–1336	–7711	–7628
7	–1286	158	–5596	–5512
8	1219	1516	–3656	–3580
9	3497	2751	–1892	–1823
10	5568	3873	–289	–226
11	7450	4892	1169	1226
12	9162	5819	2494	2546
13	10,718	6661	3699	3746
14	12,132	7426	4794	4837
15	13,418	8122	5790	5829
16	14,586	8754	6695	6731
17	15,649	9328	7518	7550
18	16,615	9850	8266	8295
19	17,493	10,324	8946	8973
20	18,292	10,755	9564	9589
21	19,017	11,146	10,126	10,148
22	19,677	11,502	10,637	10,657
23	20,277	11,824	11,102	11,120
24	20,822	12,118	11,524	11,541
25	21,318	12,384	11,908	11,923
26	21,769	12,626	12,257	12,270
27	22,178	12,845	12,574	12,586
28	22,551	13,045	12,862	12,874
29	22,889	13,226	13,125	13,135
30	23,172	13,390	13,340	13,349
31	23,402	13,532	13,509	13,517
32	23,586	13,654	13,639	13,646
33	23,732	13,759	13,746	13,753
34	23,846	13,841	13,830	13,835
35	23,933	13,898	13,888	13,893
36	24,003	13,935	13,927	13,931
37	24,059	13,956	13,949	13,952

* $\beta =$ the rate of LW spread, $a_0 =$ the age of the grove at first detection, $D_0 =$ the incidence of laurel wilt at first detection. Total costs increase due to treatment. NPV is calculated from planting to the period in which net returns become negative.

enable the orchard to remain profitable over the economic life of the crop. Under this scenario, when $D_0 = 1\%$, net returns would become negative in year 39 (**Table 3**, **Figure 2**).

Table 4 presents the value of the orchard at the time when total replanting would be recommended. Thus using the earlier example in which a seven-year-old orchard becomes infected with the disease, the orchard would need to be destroyed immediately using the strategies in scenarios 1, 3, and 4 (the relative values of the investments can be obtained from **Table 4**). In particular, the values of the investment would be –US $89 (do nothing, scenario 1), –US $4399 (low effectiveness, scenario 3), and –US $4315 (intermediate effectiveness, scenario 4), respectively. The larger negative values associated with the latter two strategies are due to the additional management costs assumed. However, in the situation where the management strategy was fully effective to lower the spread rate below 0.1% (scenario 2), the relative value of the investment at the time of the suggested replantation would be approximately US $12,541. In general, the information provided in **Table 4** suggests that, orchards younger than eight-year-old would not be economically viable (negative NPV values) after an LW attack, if the control strategy is not fully effective; these orchards would need to be destroyed immediately and would only be replanted if aresistant variety were available or if a fully effective control measure were employed thereafter. The information presented in **Table 5** and **Table 6**, see also **Figure 3**, where $D_0 = 10\%$, can be interpreted in a similar fashion to that present in **Table 3** and **Table 4**.

In general, the model suggests that minimal impacts by marginally effective control measures (low effectiveness and intermediate effectiveness) result from a less than fully effective strategy. When one considers the NPV for these marginally effective scenarios, the model yields that groves younger than ten-year-old should be destroyed immediately after a LW attack if $D_0 = 1\%$ (**Table 4**), or if $D_0 = 10\%$ (**Table 6**, **Figure 2**) due to negative NPV values. The latter highlights the importance of treating LW opportunely.

In summary, a control strategy that lowers the spread rate to either 230% (scenario 3) or 120% (scenario 4) would have no effect on the time period in which negative net revenue is obtained and immediate destruction of the orchard is indicated, compared to the "Do Nothing" strategy (scenario 1). Encouraging results were found only if a completely effective control strategy (scenario 2) were available. Consequently, a control strategy that is fully effective in controlling the spread of LW at a maximum 10% of the current production costs is required to keep avocado growers in Florida in business. LW incidence when first detected impacts the optimal period of destruction of all orchard trees due to negative net returns and is negatively related to NPV. In addition, there is a negative relationship between costs and the time of tree destruction since increased costs due to control measures become greater than the returns. The only exception to this outcome is when the spread rate is reduced to 0.1%. It should be noted that this model will still be useful as the understanding of the disease, pathogen, vector, and host improves.

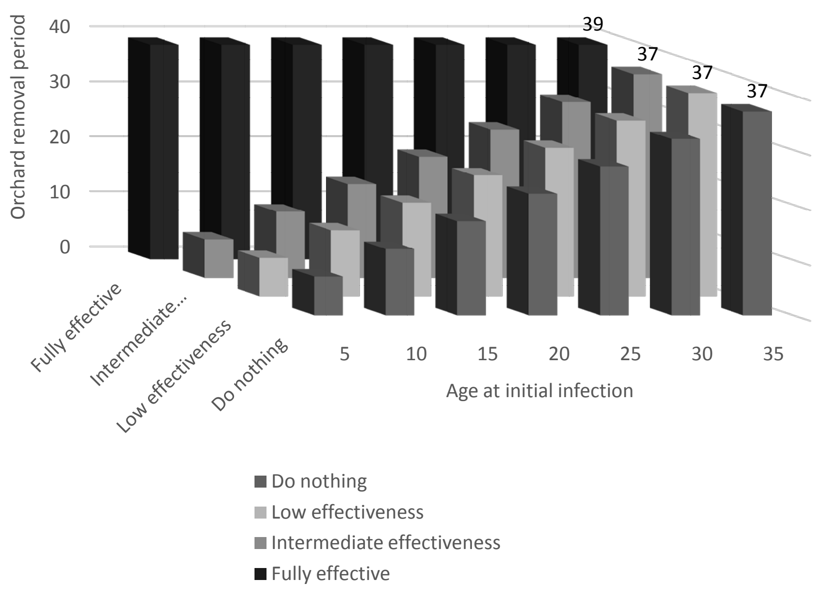

Figure 2. Period at which net returns become negative according to age at LW initial infection, assuming 10% cost increase, and $D_0 = 1\%$.

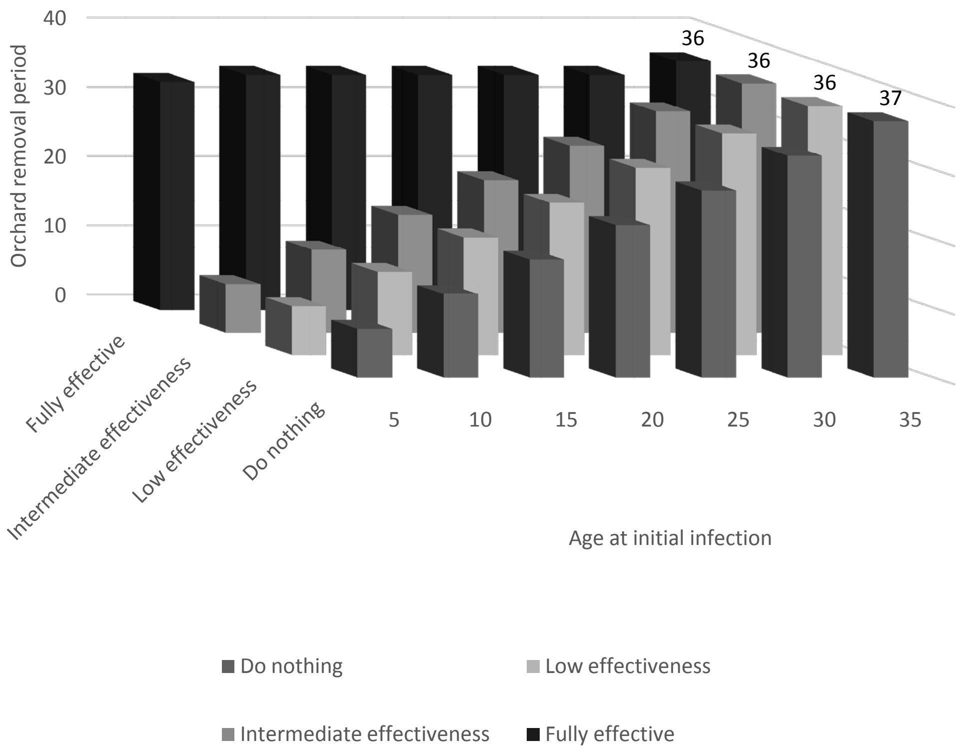

Figure 3. Period at which net returns become negative according to age at LW initial infection, assuming 10% cost increase, and $D_0 = 10\%$.

This paper contributes to the literature by providing a decision framework for completely destroying/replanting an orchard in the presence of disease. The framework integrates an epidemiological model and an economic model into a bio-economic model that allows for ex-ante evaluation of various management strategies. The results of our investigation indicate that due to the aggressive nature of the LW disease, nothing less than an effective management strategy that slows the spread of the disease to less than 0.1% per annum would be effective. Early detection (permanent scouting) and elimination of diseased tissues and vectors are therefore of paramount importance. However, given the slim profit margin, such a strategy cannot exceed more than about 10% of the cost of production, under the current assumptions. The insights given in this paper are widely applicable to other diseases affecting perennial tree crops. The approach for cost quantification is generic and thus suitable for application to other diseases affecting perennial crops. A major limitation of the model is that it requires that the behavior of the disease and the effectiveness of the proposed control measures be reasonably well known. In cases where this information is not well known, the model could be strengthened by using stochastic distributions for key parameters such as spread rate.

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Appendix: Model Used to Parameterize the Model on Laurel Wilt (No Disease Scenario)

Potential Yield (kg/ha/Month)

Estimated model: $Y_t = \left(\alpha_1 + \alpha_2 * a_t + \alpha_3 * a_t^2\right)$, where Y_t represents the expected yield and a_t is the orchard age expressed in terms of years.

Table A1. OLS estimates of the effect of age and age squared on yield.

Parameter	Estimator
Intercept (α_1)	1636.3419^{***} (570.1165)
α_2	616.1789^{***} (64.1302)
α_3	-13.8150^{***} (1.5168)
N	40
F test (p value)	46.53
R squared	0.7155

* = $p < 0.10$, ** = $p < 0.05$, and *** = $p < 0.001$, where p is the p-value. Standard error is in parentheses.

Table A2. Costs per hectare of producing avocado in South Florida.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7–Year 30	Year 35	Year 40
Cultivation Costs									
Fertilizer	431	538	646	754	861	1400	1723	1723	1723
Fungicide	108	108	323	323	323	543	646	646	646
Herbicide	431	431	431	370	370	370	370	370	370
Insecticide	26	54	108	162	215	269	323	323	323
Pruning	108	108	151	431	431	431	732	732	732
Irrigation	86	86	86	86	123	123	123	123	123
Moving	1271	1271	775	711	495	495	495	495	495
Total cultivation cost per hectare (I)	**2459**	**2595**	**2520**	**2836**	**2819**	**3631**	**4412**	**4412**	**4412**
Fixed Costs									
Landrent	1238	1238	1238	1238	1238	1238	1238	1238	1238
Supervision	384	384	384	384	384	384	384	384	384
Overhead	743	743	743	743	743	743	743	743	743
Total fixed cost per hectare (II)	**2364**	**2364**	**2364**	**2364**	**2364**	**2364**	**2364**	**2364**	**2364**
Preharvestcosts (I) + (II)	**4823**	**4959**	**4883**	**5200**	**5183**	**5995**	**6776**	**6776**	**6776**
Harvest and Marketing Costs Per Hectar									
Sales charge (III)	0	0	281	748	1496	1683	1870	1447	1120
Pick, haul, and pack (IV)	0	0	673	1795	3590	4039	4488	3473	2687
Total Costs (I) + (II) + (III) + (IV)	**4823**	**4959**	**5837**	**7743**	**10,269**	**11,717**	**13,134**	**11,696**	**10,583**

Source: http://agecon.centers.ufl.edu.

Table A3. Parameters used for the model.

Planting density per hectare (number of trees)	192
Discount rate (percentage)	10%
Sales charge (per kilogram)	0.11
Pick, haul and pack (per kilogram)*	0.37
Production costs (per kilogram)	0.77
Price received by grower at farm gate (per kilogram)	US $1.1
Stump removal cost (per tree)	150
Cost of a new tree	20
Cost to plant a new tree	10

*Included in the production costs. Source: http://agecon.centers.ufl.edu.