Special Report

Developing a Management Strategy for Little Cherry Disease: The Case of Washington State

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Abstract

Little cherry disease (LCD) threatens the long-term economic sustainability of the Pacific Northwest sweet cherry (*Prunus avium*) industry. Results from a series of partial budget analyses indicate that additional investments in monitoring, testing, spraying to control for insect vectors, and removing infected trees are lower than the reduced profit losses compared with the do-nothing scenario. Also, management can prevent or lessen the negative impacts of higher little cherry virus (Velarivirus little cherry virus 1,

Ampelovirus little cherry virus 2) spread rates. Our findings illustrate the importance of prevention, correct identification, and controlling for insect vectors in preventing the dissemination of LCD, for which the only known treatment is tree removal.

Keywords: partial budgets, disease management, sweet cherry, decision making

Little cherry disease (LCD) is a viral disease that threatens the long-term economic sustainability of the sweet cherry (*Prunus avium*) industry in the Pacific Northwest. It was first reported in Washington State in 1946 (Reeves et al. 1946). However, LCD was not considered a statewide problem until 2010 (K. Eastwell, *unpublished observation*). Fruits from trees expressing LCD symptoms are unmarketable because they are small and lack flavor, sweetness, and color (Eastwell 1997; Lee and Looney 1978; Yorston et al. 1981). Once a tree is infected with LCD, no treatment exists other than tree removal. When disease incidence is severe, entire orchards are removed. Although the exact amount of infected cultivated surface in Washington is unknown, LCD has been verified in Grant, Chelan, Douglas, Yakima, Benton, and Okanogan Counties (K. Eastwell and A. J. Bixby-Brosi, *unpublished observation*).

LCD is caused by one or more of three pathogens, all of which are known to occur in Washington State: little cherry virus 1 (LChV1), little cherry virus 2 (LChV2) (Bajet et al. 2008), and western X phytoplasma (WX) (Blodgett et al. 1950). In Washington State, LChV2 is currently the most widespread of the three pathogens mentioned; hence, this paper will focus on this virus (LChV2). Currently, the apple mealybug (*Phenacoccus aceris* [Signoret]; Raine et al. 1986) and the grape mealybug (*Pseudococcus maritimus* [Ehrhorn]; Mekuria et al. 2013) are the only two known vectors for LChV2, but it is possible that other vector species exist. Both mealybug species can be found in sweet cherry orchards in Washington, and their presence has been verified in LChV2-infected orchards (A. J. Bixby-Brosi

and E. H. Beers, *unpublished observation*). However, the natural rate of mealybug movement between trees—and hence their role in the epidemiology of this disease—is poorly understood. The virus is also readily transmitted by all types of budding or grafting (Foster and Lott 1947). WX is also found in Washington orchards, is vectored by several leafhopper species (Wolfe and Anthon 1953), and can be transmitted through grafting (Wadley 1952). Aside from root grafting and budding, little is known about the spread of LChV1 (Jelkmann et al. 2010). In Washington cherries, LChV1 is typically found in combination with one of the other two pathogens (LChV2 or WX). When this occurs, visual symptoms of the disease are more severe (K. Eastwell and A. J. Bixby-Brosi, *unpublished observation*).

Prompt removal of infected trees is a highly recommended management strategy (O'Reilly et al. 1970). Unidentified infected trees remaining in orchards serve as disease reservoirs. Correctly diagnosing LCD is challenging because visual symptoms may take years to appear, can vary depending on the weather and cherry variety, and can be confused with other disease or nutrient deficiencies (O'Reilly et al. 1970). Therefore, molecular analysis is the recommended and most reliable diagnostic method. Because symptoms are only visible in the cherries themselves—that is, the rest of the tree is asymptomatic—the best time to observe symptoms is at or 2 weeks before harvest (Foster and Lott 1947). Owing to the expense of molecular analysis (Clean Plant Center of the Northwest, WSU Prosser, WA), growers typically test only a small subset of trees but remove all other trees showing similar visual disease symptoms. Currently, there are no recommendations for identifying or locating symptomless carriers of LChV2.

Controlling mealybug vectors is another strategy for stopping or slowing the spread of LChV2 (Petruschke et al. 2011). Before the recent concern about LChV2 transmission, mealybugs had not been considered a pest of sweet cherries because consequential direct damage to the fruit is rare. Therefore, there are no control recommendations for mealybugs for Washington sweet cherry orchards (WSU Crop Protection Guide for Tree Fruits in Washington 2019, <http://cpg.treefruit.wsu.edu/>). Mealybugs are notoriously difficult to manage because they stay protected in crevices in bark or leaf axils for a portion of the year, and when exposed on leaves and twigs, the eggs, nymphs, and adults are protected by waxy filaments (McKenzie 1967). These life-cycle strategies make them extremely difficult

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to reach with foliar insecticides (McKenzie 1967). A recent study of various insecticidal compounds and spray timings for the control of apple mealybug in Washington apples showed that organophosphate insecticides with delayed-dormant application, targeting emerged females, and applied at midsummer, targeting newly hatched crawlers, provide some suppression (Bixby-Brosi and Beers 2017). What is known about grape mealybug control is adopted from WSU Crop Protection Guide (2016, <http://tfrec.cahnrs.wsu.edu/>) recommendations for pears.

Considering that tree removal once the disease is detected and/or intense monitoring and control for insect vectors are the current alternatives to manage LCD caused by LChV2, the industry urgently needs information on the likely economic outcomes of management alternatives for LCD caused by LChV2. This study assesses the economic impact of LChV2 given its effects on crop yield and quality of two sweet cherry varieties grown in Washington State: ‘Bing’ and ‘Sweetheart’. Bing has historically been the dominant sweet cherry variety produced in the state, comprising 43% of the total bearing cultivated surface in 2011; Sweetheart was second to Bing, with 2,658 ha representing 17% of the total bearing cultivated surface of sweet cherries in the state in the same year (USDA NASS 2011). The information provided in this study will help growers make decisions for managing LChV2-infected orchards, resulting in better financial outcomes.

Why Washington State? From 2006 to 2016, Washington State was the largest producer of sweet cherries by volume in the United States, generating 56% of total production in the country. Over that time, the bearing cultivated surface in Washington State increased by 22%, from 12,950 ha in 2006 to 15,783 ha in 2016, and production volume increased by 24% from 168,000 tons in 2006 to 209,000 tons in 2016. On average, during the same period, 78% of all sweet cherry produced in Washington State was sold in the fresh market, and the remaining was sold to processors. Washington absorbs 61% of all fresh market sweet cherries commercialized in the United States (USDA NASS 2017). In 2016, the gross value of sweet cherries was \$503 million, ranking it sixth in terms of overall value of agricultural commodities produced in the state (Washington State Department of Agriculture 2018, <https://agr.wa.gov/>).

In this study, we performed a partial budget analysis for two strategies to be taken in the presence of LCD. The first strategy assumes that LChV2 is present in the orchard but undetectable to the grower; hence, she does not take remedial measures. The analyses apply only to situations in which LChV2 is the cause of the disease symptoms.

The second strategy assumes the grower constantly monitors for symptomatic fruit, conducts a spray program to control the insect vectors, and removes infected trees. Because no published studies have assessed the rates of spread of LChV2 in an infected orchard, we assumed three spread rates based on experts’ projections: 1, 3, and 5% in the absence of management and 0.5, 1, and 2% under management. We calculated profit losses under the six resulting scenarios (two strategies × three spread rates).

Materials and Methods

Baseline scenario. We developed enterprise budgets for Bing and Sweetheart to serve as baselines for the estimated costs and returns of producing sweet cherries not affected by LChV2. We gathered data from five sweet cherry producers—representatives of North Central Washington, Yakima, and the lower Columbia River Basin of Washington—between December 2014 and January 2015. The enterprise budgets reflected industry practices and average costs to produce the two varieties of sweet cherries. For both Bing and Sweetheart orchard blocks, we assumed the area of the total farm operation to be 121.4 ha. The bearing cultivated surface in the farm includes 91.05 ha of apples (75% of total area), 19.42 ha of sweet cherries (16%), and 10.93 ha of pears (9%).

This budget was based on two separate 4.45-ha blocks in the 121.4-ha orchard, one for Bing and the other for Sweetheart sweet cherries. We assumed that 0.4 ha of each block was dedicated to roads, pond, loading area, buildings, and so on, rather than to fruit production. Therefore, the total productive area for both blocks was 4.05 ha. The irrigation system consisted of dual system drip irrigation and micro under-tree sprinkler system. Water was provided

through a public irrigation district. The cultural practices and harvest activities were done by hand and using ladders (no mechanical aids). Table 1 lists block specifications for both varieties.

Alternative scenarios for orchard blocks affected with LChV2. We used a partial budget approach to estimate the costs associated with LChV2. This method calculates the net change in profit that can be expected from a specific change in production. This change can generate one or more of the following effects: (i) incur new or additional costs, (ii) reduce or eliminate current costs, (iii) receive new or additional revenue, and/or (iv) lose or reduce current revenue (Kay et al. 2012).

As explained in the previous section, this study considered two scenarios. The first scenario is “do-nothing.” The grower is unaware of LCD in their orchard; therefore, there are no added costs for controlling the disease. For the purposes of this study, we make the assumption that each infected tree will be 100% symptomatic the year it is infected, but because the grower is unaware, the picking crew will not be warned about LCD and will pick all cherries in the trees. All of the fruits will be sent to the packinghouse. All cherries from infected trees will be sorted as culls. The rate of infection increases linearly in production years 1 to 10, with a maximum rate in production years 11 to 25. In the first 2 years, there will be one tree infected each year. We assumed three rates of spread for LChV2: 1, 3, and 5%.

In the second scenario, all possible measures to control LCD are taken, including monitoring for disease symptoms, testing symptomatic trees, removing infected trees, and spraying for mealybugs. Monitoring costs are incurred beginning the third year through full production. A trained field man examines each tree for symptoms. We assumed it takes 1 h to inspect 0.54 ha (1.3 acres) if the field man uses a four-wheeler in the walkthrough. Given 672 trees/ha, monitoring would take 114 min/ha (46.2 min/acre). We considered that monitoring younger trees would take 75% of the stated time for full production (i.e., 85.5 min/ha) during establishment years (years 3 to 5). For testing LChV2, at least 12 trees/ha need to be tested (i.e., 12 samples/ha). The test kit costs \$30/tree. After monitoring trees in year 3, infected trees will be detected and subsequently removed, implying fewer trees in production starting year 3. For simplicity of the analysis, we assumed that removed trees are not replaced or replanted. Yield is directly proportional to the number of infected trees. For example, if 20% of trees are removed, there is a 20% reduction in gross yield relative to the baseline. Starting in year 4 through full production, input costs (pruning and training, thinning, chemicals, and fertilizer) were reduced owing to fewer trees being managed relative to the baseline. To control for the insect vectors, we assumed that two additional sprays for mealybugs were needed. The chemicals used are Lorsban (9.8 pt/ha) plus Supreme oil (4.9 gal/ha) for delayed dormant, Admire Pro (6.9 fl oz/ha) for crawlers before harvest, and Diazinon (10.98 kg/ha) for cleanup after harvest. The additional costs are only for the materials, assuming growers mix the mealybug control material with another material being sprayed for something else. Similar to previous scenarios, we held all other costs constant.

The rate of spread for this second scenario is 0.5% in the first 2 years of production (no fruit to assess symptoms) and constant. This rate rounds to 1 tree infected in those years, so lowering it further does not change things much. In production years 3 to 25, the rate

Table 1. ‘Bing’ and ‘Sweetheart’ sweet cherry assumed specifications for a productive block in Washington State as of 2015

Item	Description
Tree architecture	Central leader, three-dimensional
In-row spacing	3.05 m
Between-row spacing	4.88 m
Rootstock	‘Bing’ on Gisela G12 rootstock or ‘Sweetheart’ on Mazzard rootstock
Block size (productive)	4.05 ha
Life of planting	25 years
Tree density	672 trees/ha (5% of total number of trees are Lapins as pollinizers)
Trellis system	No support/trellis

of spread is constant with three possible values: 0.5, 1, and 2% per year. Infected trees are detected in June of a given year and removed in October of that year.

Results

Baseline economic analysis. The baseline studies considered the production scenarios when the sweet cherry orchard was not infected by LChV2. Production costs were classified into variable and fixed costs. Variable costs comprised orchard operations, harvest activities, materials, maintenance and repairs, and packing costs. Fixed costs were incurred regardless of whether sweet cherries were produced. The fixed costs included depreciation on capital, interest, taxes, insurance, management, and amortized establishment costs. Management was treated as a fixed cost rather than a variable cost because, like land, management has been committed to the production cycle of the crop. Tables 2 and 3 summarize the enterprise budget results for Bing and Sweetheart sweet cherries, respectively. We assumed that a Bing or a Sweetheart orchard started bearing fruit in

the third year and achieved full production in the sixth year. Given these assumptions, the total production costs in a full production year were estimated to be \$56,128/ha for Bing and \$82,390/ha for Sweetheart. Total returns in a full production year were \$76,504/ha for Bing and \$99,633/ha for Sweetheart. Estimated net returns in a full production year were \$8,021/ha for Bing and \$17,243/ha for Sweetheart. The breakeven prices were estimated to be \$4.12/kg for Bing and \$3.73/kg for Sweetheart.

Partial budget results. Tables 4 (Bing) and 5 (Sweetheart) present detailed partial budget results for the two LCD management scenarios assumed in this study. These tables include the additional returns, reduced costs, additional costs, and reduced returns from both scenarios.

The do-nothing scenario for both Bing (Table 4) and Sweetheart (Table 5) led to reduced returns owing to less fruit that could be sold at fresh market prices. This scenario also led to additional amortized establishment costs, which represented the costs incurred during establishment years (minus revenues during those years) that must be recaptured during full production years. The resulting net changes

Table 2. Summary of costs and returns for establishing and producing 'Bing' sweet cherries in Washington State as of 2015

Item	Units	Establishment years					Full production ^a
		1	2	3	4	5	
Returns							
Estimated net production, fresh ^b	kg/ha	—	—	2,690	9,863	13,450	16,140
Estimated FOB price, fresh ^c	\$/ha	—	—	5.2	5.2	5.2	5.2
Estimated net production, cull	kg/ha	—	—	673	2,466	3,363	4,035
Estimated FOB price, cull	\$/ha	—	—	0.5	0.5	0.5	0.5
Total returns	\$/ha	—	—	12,751	46,752	63,753	76,504
Costs							
Establishment costs	\$/ha	146,261	—	—	—	—	—
Orchard activities	\$/ha	2,525	5,431	7,744	6,590	6,689	6,936
Harvest	\$/ha	—	—	2,150	7,883	10,749	12,899
Packing costs	\$/ha	—	—	3,707	13,591	18,533	22,239
Other variable costs	\$/ha	15,985	1,394	2,763	4,327	5,286	5,340
Total variable costs	\$/ha	164,775	6,825	16,361	32,391	41,257	47,415
Fixed costs	\$/ha	4,500	12,963	14,404	15,303	15,350	21,068
Total costs	\$/ha	169,274	19,788	30,765	47,694	56,607	68,483
Estimated net returns ^d	\$/ha	−169,274	−19,788	−18,014	−941	7,146	8,021

^a The full production year is representative of all the remaining years the orchard is in full production (year 6 to year 25).

^b Estimated net production considers an average packout of 80%.

^c These prices reflect gross freight on board (FOB) prices (price before packing charges).

^d Estimated net returns is equal to total returns minus total costs.

Table 3. Summary of costs and returns for establishing and producing 'Sweetheart' sweet cherries in Washington State as of 2015

Item	Units	Establishment years					Full production ^a
		1	2	3	4	5	
Returns							
Estimated net production, fresh ^b	kg/ha	—	—	1,793	8,967	16,140	21,520
Estimated FOB price, fresh ^c	\$/ha	—	—	5.1	5.1	5.1	5.1
Estimated net production, cull	kg/ha	—	—	448	2,242	4,035	5,380
Estimated FOB price, cull	\$/ha	—	—	0.5	0.5	0.5	0.5
Total returns	\$/ha	—	—	8,303	41,514	74,725	99,633
Costs							
Establishment costs	\$/ha	145,120	—	—	—	—	—
Orchard activities	\$/ha	2,439	4,193	5,735	7,025	7,702	8,196
Harvest	\$/ha	—	—	1,433	7,166	12,899	17,199
Packing cost	\$/ha	—	—	2,471	12,355	22,239	29,653
Other variable costs	\$/ha	15,859	1,265	2,355	4,171	5,990	6,499
Total variable costs	\$/ha	163,418	5,459	11,994	30,715	48,830	61,546
Fixed costs	\$/ha	4,500	12,894	14,263	15,162	15,380	20,843
Total costs	\$/ha	167,918	18,355	26,257	45,878	64,210	82,390
Estimated net returns ^d	\$/ha	−167,918	−18,355	−17,955	4,364	10,514	17,243

^a The full production year is representative of all the remaining years the orchard is in full production (year 6 to year 25).

^b Estimated net production considers an average packout of 80%.

^c These prices reflect gross freight on board (FOB) prices (price before packing charges).

^d Estimated net returns is equal to total returns minus total cost.

Table 4. Results from the partial budget of the two management scenarios assumed in this study for ‘Bing’ sweet cherries grown in Washington State as of 2015

Item	Scenario 1: do nothing ^a (maximum rate of infection, years 10 to 25) (\$/ha)			Scenario 2: with management ^b (rate of infection, years 3 to 25) (\$/ha)		
	1%	3%	5%	0.5%	1%	2%
Additional returns						
Bing sales, fresh	–	–	–	–	–	–
Bing sales, culls	\$858	\$2,312	\$3,931	–	–	–
Reduced costs						
Pruning and training	–	–	–	\$65	\$150	\$272
Green fruit thinning	–	–	–	\$24	\$55	\$100
Chemicals	–	–	–	\$165	\$381	\$689
Fertilizer	–	–	–	\$10	\$22	\$40
Harvest labor	–	–	–	\$735	\$1,693	\$3,078
Warehouse packing charges	–	–	–	\$1,267	\$2,919	\$5,306
Other ^c	–	–	–	\$106	\$350	\$695
Additional costs						
Monitoring ^d	–	–	–	\$113	\$217	\$398
Tree removal	–	–	–	\$106	\$234	\$457
Chemicals	–	–	–	\$856	\$856	\$856
Amortized establishment cost ^e	\$145	\$287	\$462	\$237	\$422	\$608
Reduced returns ^f						
Bing sales, fresh	\$9,011	\$24,271	\$41,276	\$4,258	\$9,807	\$17,829
Bing sales, culls	\$0	\$0	\$0	\$101	\$234	\$424
Net change in profit ^g	–\$8,298	–\$22,246	–\$37,807	–\$3,300	–\$6,199	–\$10,393

^a Do-nothing scenario: Grower is unaware of the little cherry disease (LCD). All fruits are picked regardless of whether they are picked from infected trees, and all are sent to the packinghouse for sorting. All fruits from infected trees are sorted as culls.

^b With-management scenario: Grower monitors and tests trees, removes infected trees, and applies additional chemical sprays for mealybug control.

^c Overhead and interest costs on operating capital, calculated as a percentage of the variable costs.

^d Monitoring costs include the walkthrough (labor) to examine trees. Samples are sent to the testing center.

^e Amortized establishment costs represent the costs incurred during the establishment years (minus revenues during those years) that must be recaptured during the full production years.

^f Owing to yield loss, leading to forgone sales of fresh and culls.

^g Relative to the baseline (no LCD); net change in profit = additional returns + reduced costs – additional costs – reduced returns.

Table 5. Results from the partial budget of the two management scenarios assumed in this study for ‘Sweetheart’ sweet cherries grown in Washington State as of 2015 (\$/ha)

Item	Scenario 1: do nothing ^a (maximum rate of infection, years 10 to 25) (\$/ha)			Scenario 2: with management ^b (rate of infection, years 3 to 25) (\$/ha)		
	1%	3%	5%	0.5%	1%	2%
Additional returns						
Sweetheart sales, fresh	–	–	–	–	–	–
Sweetheart sales, culls	\$1,144	\$3,082	\$5,241	–	–	–
Reduced costs						
Pruning and training	–	–	–	\$96	\$222	\$401
Green fruit thinning	–	–	–	\$34	\$79	\$143
Chemicals	–	–	–	\$165	\$381	\$689
Fertilizer	–	–	–	\$42	\$96	\$174
Harvest labor	–	–	–	\$980	\$2,257	\$4,103
Warehouse packing charges	–	–	–	\$1,690	\$3,892	\$7,075
Other ^c	–	–	–	\$173	\$530	\$1,000
Additional costs						
Monitoring ^d	–	–	–	\$113	\$217	\$398
Tree removal	–	–	–	\$106	\$234	\$457
Chemicals	–	–	–	\$856	\$856	\$856
Amortized establishment cost ^e	\$150	\$302	\$488	\$405	\$592	\$780
Reduced returns ^f						
Sweetheart sales, fresh	\$11,728	\$31,591	\$53,724	\$5,542	\$12,765	\$23,206
Sweetheart sales, culls	\$0	\$0	\$0	\$135	\$311	\$566
Net change in profit ^g	–\$10,733	–\$28,811	–\$48,971	–\$3,979	–\$7,518	–\$12,678

^a Do-nothing scenario: Grower is unaware of the little cherry disease (LCD). All fruits are picked regardless of whether they are picked from infected trees, and all are sent to the packinghouse for sorting. All fruits from infected trees are sorted as culls.

^b With-management scenario: Grower monitors and tests trees, removes infected trees, and applies additional chemical sprays for mealybug control.

^c Overhead and interest costs on operating capital, calculated as a percentage of the variable costs.

^d Monitoring costs include the walkthrough (labor) to examine trees. Samples are sent to the testing center.

^e Amortized establishment costs represent the costs incurred during the establishment years (minus revenues during those years) that must be recaptured during the full production years.

^f Owing to yield loss, leading to forgone sales of fresh and culls.

^g Relative to the baseline (no LCD); net change in profit = additional returns + reduced costs – additional costs – reduced returns.

in profit, relative to the baseline, were negative because the reduced returns and additional costs were larger than additional returns. The net changes in profits for Bing cherries considering LChV2 spread rates of 1, 3, and 5% were $-\$8,298/\text{ha}$, $-\$22,247/\text{ha}$, and $-\$37,807/\text{ha}$, respectively. The net profit changes for Sweetheart under the same spread rates were $-\$10,733/\text{ha}$, $-\$28,811/\text{ha}$, and $-\$48,971/\text{ha}$, respectively. A higher LChV2 spread rate implies a larger profit loss. The difference in profit losses between the two varieties is owing to the higher market prices commanded by Sweetheart compared with Bing.

The with-management scenario for both Bing (Table 4) and Sweetheart (Table 5) also resulted in profit losses, but the magnitude of the losses was smaller compared with the do-nothing scenario. In this scenario, reduced returns were observed owing to less fruit being sold to the fresh market. We also estimated additional costs for monitoring, tree removal, and chemical application to control for insect vectors and additional amortized costs. Reduced costs are experienced owing to fewer trees in the orchard block and include pruning and training, green fruit thinning, chemical application, fertilizer, harvest labor, warehouse packing charges, and other costs (including overhead and interest costs on operating capital). The LChV2 spread rates considered were 0.5, 1, and 2%. Resulting changes in net profits for Bing under each spread rate were $-\$3,300/\text{ha}$, $-\$6,199/\text{ha}$, and $-\$10,393/\text{ha}$, respectively. For Sweetheart under the same spread rates, the changes in net profits amounted to $-\$3,979/\text{ha}$, $-\$7,518/\text{ha}$, and

$-\$12,678/\text{ha}$, respectively. Similar to the do-nothing scenario, a higher spread rate implies a higher loss in net profits.

Figures 1 and 2 compare net profits for the two varieties under the two scenarios, given three LChV2 spread rates, and during the years of production when there is crop load (i.e., years 3 to 25). The one similarity between Bing and Sweetheart is that the best possible scenario is the baseline, with no LChV2. Then, differences in the profits realized after LChV2 management strategies and spread rates between the two varieties are observed.

For Bing, years 3 to 5, most of the six scenarios overlap (two strategies $\times$ three spread rates). This is probably because trees are not yet in full production, so the losses from not selling larger percentages of sweet cherries in the fresh market are not fully realized. For the Bing variety the strategy that minimizes profit losses is with management at 0.5% LChV2 spread rate, followed by with management at 1% LChV2 spread rate. The strategies with management at 1% spread rate, with management at 2% spread rate, and do-noting 1% spread rate overlap at different production years. Clearly, the least favorable strategy is the do-nothing at 5% spread rate followed by do-nothing at 3% spread rate.

For Sweetheart, the most favorable strategy is with management at 0.5% LChV2 spread rate, followed by with management at 1% spread rate. The do-nothing at 1% spread rate overlaps with management at 2% spread rate and with management at 1% spread rate, at different production years. Similar to Bing, the least favorable

Fig. 1. Comparison of profits for the two management scenarios for 'Bing' cherries infected with little cherry virus 2 (LChV2).

Fig. 2. Comparison of profits for the two management scenarios for 'Sweetheart' cherries infected with little cherry virus 2 (LChV2).

strategy is the do-nothing at 5% LChV2 spread rate, followed by do-nothing at 3% spread rate.

In sum, results from this analysis suggest that adopting a management strategy in the presence of LChV2 could offset increases in the LChV2 spread rate. Despite the additional costs of monitoring, tree removal, chemical application, and amortized establishment cost, the lower reductions in net returns justify the additional investment. Management could also lessen the negative impact of a disease that is difficult to control, especially when it can spread and infect other trees in the orchard.

Discussion

LChV2 is becoming a severe threat to sweet cherry production in the state of Washington. We conducted a partial budget analysis to measure the potential additional revenues, reduced costs, additional costs, and reduced revenues after the presence of LChV2 is detected in a sweet cherry orchard block. Two strategies are considered. First, the do-nothing strategy, in which the grower is unaware of the presence of LChV2, does nothing to control mealybugs (the insect vector) and assumes the losses of the fruit sent to the packinghouse that does not meet the quality standards for the fresh market. The with-management strategy considers that the grower invests in constant monitoring, sends symptomatic tree samples to be analyzed, implements a pest management program to control mealybugs, and removes the affected trees to prevent further disseminating the disease. Because there is no a priori study of LChV2 spread rates, we assumed spread rates of 1, 3, and

5% under the do-nothing scenario and 0.5, 1, and 2% under the with-management scenario.

Results from the partial budget scenarios indicate that the additional investment in a management strategy is justified. The additional costs incurred in monitoring, testing, spraying to control for mealybugs, and removing infected trees are lower than the reduced profit losses compared with the do-nothing scenario. Even when comparing different LChV2 spread rates, management can prevent or lessen the negative economic impacts of higher spread rates. The results from this study illustrate the importance of prevention—particularly monitoring, correct identification, and controlling for insect vectors—in preventing the dissemination of a disease, such as LCD, for which tree removal is the only known treatment.

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Literature Cited

- Bajet, N. B., Unruh, T. R., Druffel, K. L., and Eastwell, K. C. 2008. Occurrence of two little cherry viruses in sweet cherry in Washington State. *Plant Dis.* 92: 234-238.
- Bixby-Brosi, A. J., and Beers, E. H. 2017. Chemical control of grape mealybug, 2016. *Arthropod Manage. Tests* 42:tsx031.
- Blodgett, E. C., Williams, H. E., Reeves, E. L., and Wright, C. M. 1950. Survey of Western X Little Cherry and Western X Disease for 1949. Washington State Department of Agriculture, Olympia, WA.

- Eastwell, K. C. 1997. Little cherry disease in perspective. Pages 143-151 in: Filamentous Viruses of Woody Plants. P. L. Monette, ed. Research Signpost, Triandrum, India.
- Foster, W. R., and Lott, T. B. 1947. "Little cherry," a virus disease. *Sci. Agric.* 27: 1-6.
- Jelkmann, W., Herenhahn, F., and Berwarth, C. 2010. Transmission of little cherry virus-1 by *Cuscuta europea* to herbaceous host plants. *Julius-Kühn-Arch.* 428: 407-408.
- Kay, R. D., Edwards, W. M., and Duffy, P. A. 2012. *Farm Management*, 7th Ed. McGraw Hill, New York, NY.
- Lee, J. M., and Looney, N. E. 1978. A physical and morphological assessment of little cherry disease of *Prunus avium* in British Columbia. *Can. J. Plant Sci.* 58: 371-378.
- McKenzie, H. 1967. *Mealybugs of California*. University of California Press, Berkeley, CA.
- Mekuria, A., Smith, T. J., Beers, E., Watson, G. W., and Eastwell, K. C. 2013. First report of transmission of little cherry virus 2 to sweet cherry by *Pseudococcus maritimus* (Ehrhorn) (Hemiptera: Pseudococcidae). *Plant Dis.* 97:851.
- O'Reilly, H. J., Welsh, M. F., and Jansen, A. J. 1970. Little Cherry Disease, a Renewed Threat to British Columbia Fruit Districts? Publication 70-10. British Columbia Department of Agriculture, Victoria, BC.
- Petruschke, M., Rissler, D., and Schneller, H. 2011. Apple mealybug *Phenacoccus aceris* proved as a vector of the little cherry virus 2 on sweet cherry in Baden-Württemberg. *Erwerbs-Obstbau* 53:11-13.
- Raine, J., McMullen, R. D., and Forbes, A. R. 1986. Transmission of the agent causing little cherry disease by the apple mealybug *Phenacoccus aceris* and the dodder *Cuscuta lupuliformis*. *Can. J. Plant Pathol.* 8:6-11.
- Reeves, E. L., Blodgett, E. C., and Fischer, G. W. 1946. The problem of the little cherry disease in Washington. *Proc. Wash. State Hortic. Assoc.* 42:1-4.
- USDA NASS. 2011. Washington Tree Fruit Acreage Report 2011. U.S. Department of Agriculture, National Agricultural Statistics Service, Washington Field Office, Washington, DC.
- USDA NASS. 2017. Noncitrus Fruits and Nuts 2016 Summary. U.S. Department of Agriculture, National Agricultural Statistics Service, Washington, DC.
- Wadley, B. N. 1952. Symptoms in sweet cherry produced by western X disease virus from peach. *Phytopathology* 42:519-520.
- Wolfe, H. R., and Anthon, E. W. 1953. Transmission of the western-X disease from sweet and sour cherry to peach by two species of leafhoppers. *J. Econ. Entomol.* 46:1090-1092.
- Yorston, J. M., McMullen, R. D., Slykhuis, J. T., and Welsh, M. F. 1981. Little Cherry Disease in British Columbia. Province of British Columbia, Ministry of Agriculture and Food, Victoria, BC.