An Economic Evaluation of Alternative Methods to Manage Fire Blight in Apple Production

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Our research examined the economic implications of managing fire blight in apple production by using susceptible rootstocks or resistant rootstocks with and without protective sprays. Our results indicate that use Geneva® rootstocks across all incidence levels of fire blight considered gave superior economic outcomes compared to susceptible rootstocks or tree insurance for fire blight.

Fire blight outbreaks have become more common and more severe in apple orchards in New York in recent years (Milkovich, 2022; Robbins 2019). The pathogen has created significant economic distress for apple producers in 2012 in the Hudson Valley, in 2016 in the Champlain Lake Valley and Western New York (Aćimović et al., 2019; Aćimović et al., 2021), and then again in 2020 in Western New York. Damage estimates to producers from the 2016 epidemic exceed $16 million in Champlain Lake Valley. These sudden fire blight outbreaks can cause over 50% apple tree losses in young, recently planted orchards (Breth 2008). The most severe symptom behind tree death is the girdling effect of a fire blight canker on susceptible rootstock (Fig. 1). Scientists and growers are considering a range of strategies to manage the pathogen, and the purpose of this research was to outline the economic implications of adopting a few alternative strategies.

We evaluated five scenarios to manage fire blight where each scenario is based on the adoption of a different strategy. Scenarios model the outcomes of using individual tools (e.g., Geneva® rootstocks (G) alone) and combinations of tools (e.g., Geneva® rootstocks plus post-infection spray programs). The first scenario is a baseline scenario that does not employ a management strategy for fire blight (specifically, the baseline case assumes the use of Malling rootstocks (M) without the use of tree insurance or the use of pre- or post-infection spray applications). The Malling rootstocks M.26 and M.9 and its subclones (Nic29, T337, Pajam 2) are very susceptible to fire blight, M.7, and the Budagovskij series B.9 and B.118 are tolerant or moderately resistant to fire blight. The Geneva® rootstocks G.11, G.41, G.202, G.214 , G. 890, G.935, G.969 and others are fire blight resistant (Wertheim, 1998; Aldwinckle et al., 2001, 2004; WSU, 2022).

The other four scenarios that we modeled included the adoption of 1) Geneva® rootstocks, 2) pre- and post-infection spray programs coupled with Malling rootstocks, 3) pre- and post-infection spray programs coupled with Geneva® rootstocks, and 4) the use of tree insurance products offered by the USDA - Risk Management Agency (RMA) coupled with the Malling rootstocks. We do not consider scenarios that adopt Geneva rootstocks with tree insurance as this combination is unlikely to be adopted by a commercial orchard owner. Our analysis also considers the adoption of these scenarios across a range of fire blight incidence levels (ranging from 0% incidence to 40% incidence). Incidence refers to the intensity rate of infection on the tree crown; the incidence rate describes the estimated share of infected flowers/shoots in the tree canopy on average. The exact nature of the link between the incidence rate and the percent of overall rootstock infection is unknown.

A Description of Fire Blight Management Tools

The baseline scenario was based on the use of Malling rootstocks and absent any pre- or post-infection spray programs and tree insurance. The Malling rootstocks are susceptible to fire blight and exposure to fire blight necessitates tree removal and replacement. There are no surcharges associated with planting the Malling rootstock (tree plus rootstock costs=$8/each) and trees must be replaced (also at $8 per tree and rootstock, and with the assumption that replanted trees will restart the standard production progression that reaches full production in the sixth year after planting). This replant also requires soil preparation, a cost that is scaled to the level of damage. A scenario with greater than 30% incidence of fire blight (i.e., average intensity rate of infection in the tree canopy) is assumed to require a full replant and will also require the costs associated with orchard soil preparation.

The Geneva® rootstocks, developed by a partnership between Cornell University and the United States Department of Agriculture-Agricultural Research Service, were created to increase resistance to disease (particularly fire blight) for fruit trees (Fazio, et al., 2013). Geneva® apple rootstocks were developed to overcome the limitations present in commercial dwarfing and precocious rootstocks which are sensitive to fire blight (M.9 clones, M.26, O.3, etc.) resulting in the death of the whole tree once infected. Genetic resistance to *E. amylovora* was observed in wild apple species, and this natural resistance was utilized by conventional breeding to develop apple rootstocks genetically resistant to fire blight (G.65, G.11, G.16, G.30, G.202, G.41, G.935, G.213, G.214, G.969, G.890, G.222 and G.210). The use of fire blight resistant rootstocks has been shown to decrease the severity of the disease in susceptible scions (Jensen et al., 2012; Jensen et al., 2011) possibly by changing the expression of genes during the infection (Baldo et al., 2010; Norelli et al., 2009; Norelli et al., 2008). We assume that G rootstocks cost 25% more than comparable M rootstocks (a supplemental $2), which is included as a one-time cost that is paid when the trees are planted (in Year 1). The most notable assumption built into this model is that these rootstocks protect trees from requiring a full replant when exposed to fire blight; trees planted on G rootstocks can simply be pruned back (resulting in a 1-year slowdown in productivity).

Fire blight spray programs have been developed to protect apple trees against climatic conditions associated with the blossom blight infections. The programs typically include a combination of streptomycin and prohexadione calcium spray applications (among others) after specific weather triggers (Aćimović, Higgins, and Meredith, 2019). In this model there are no annual costs associated with this treatment—the only costs are in years where fire blight prediction models recommend application [Maryblyt7.1.1 (Steiner 1990; Turechek and Biggs 2015), CougarBlight (Smith and Pusey 2011), and RIMpro-Erwinia (Philion and Trapman 2011)]. There is a one-time cost for materials and labor in years when the spray program is required. We used prices of protective spray materials available to authors in 2020 and 2021; results could be impacted with changes in material costs related to preferential customer pricing by distributors and market inflation. In our model we considered the impact for an inexperienced grower using the spray program; in this worst-case scenario that employs a non-optimal and untimely spray application results in a 50% reduction in blight severity (e.g., for a 40% blight incidence we would observe only a 20% actual fire blight impact). A more skilled grower with greater familiarity with the fire blight prediction models could achieve reductions in blight by up to 90%. This spray program can be used with either M or G rootstocks, and the rootstocks were assumed to maintain their original properties (so G rootstocks would require pruning but not require a replant, but M rootstocks would require a replant).

Our scenarios that consider the adoption of tree insurance are based on a new risk management product provided through the USDA-RMA and was developed in partnership with AgriLogic Consulting (USDA, Federal Crop Insurance Corporation. 2021). Tree insurance is designed to protect apple farmers from making big up-front investments in their orchards and is modeled, in part, after a similar product that is available to U.S. pecan producers. (USDA-RMA 2020). Tree insurance is different from traditional crop insurance in that it aims to place value on the trees themselves (particularly as plantings become denser and more vulnerable to communicable infections). Within this model there are annual costs associated with tree insurance and premiums are tied to tree age (Stages I, II, & III) and are paid every year. The current rates for tree insurance for the Honeycrisp cultivar are $1,513 (Stage I), $1,299 (Stage II), and $1,699 (Stage III). Our model assumed that the Occurrence Loss Option (OLO) and the Fire Blight Endorsement (FBE) had both been purchased by the orchard owner, the latter of which is mandatory in the Northeast Region of the U.S. With these endorsements an indemnity would be paid any time the damage *exceeds* 10%. Indemnity payments were calculated based on a model provided by New York State crop insurance agents.

Materials and Methods

Our analysis identified the costs and benefits for an orchard owner producing one acre of Honeycrisp over a 15-year period. The costs and benefits were incorporated into a net present value (NPV) model to calculate the net economic benefits associated with the adoption of the various fire blight management strategies over the life of the orchard. This is a widely used tool by agricultural economists to compare the economic outcomes for the adoption of technologies across a range of time horizons. The economic analysis was based on a set of representative costs, yields, and prices that are reflective of those in the industry in New York State. The values we used in our analysis may not always align with those for all growers in all regions. However, the purpose of our analysis was to shed new light on the relative merit of the different strategies to manage fire blight, and our results using representative data are able to provide useful information for orchard owners to address business decisions concerning strategies to manage fire blight.

The NPV framework requires estimates for establishment costs (in the first year), on-going costs that occur each year of production, per acre yields, and prices. Table 1 outlines the main categories of costs that are required to establish an orchard in New York State. Many of these cost items included expenses for materials plus expenses for labor to conduct the work. The top establishment expenses are for land, trees (plus rootstocks), trellising materials, and irrigation equipment. The establishment costs shown in Table 1 are similar in magnitude to those in a recent report outlining establishment costs for Honeycrisp production in Washington State (Gallardo and Galinato 2020). We made several assumptions in our economic

Table 1. Establishment costs for 1 acre of Honeycrisp (on Geneva® rootstocks)

Item	Material/Unit	Quantity	Labor Hours	Labor Rate	Total Cost
Land	$6,000.00	1			$6,000.00
Property Taxes	$150.00	1			$150.00
H2A Housing	$1,000.00	1			$1,000.00
Equipment Depreciation	$250.00	1			$250.00
Soil preparation	$1,242.00	1	1.5	19.99	$1,271.99
Trees	$8.00	1320	1320	0.30	$10,956.00
G Rootstock surcharge	$2.00	1320			$2,640.00
Trellising	$5,000.00	1			$5,000.00
Irrigation Install	$3,200.00	1	53	18.74	$4,193.22
Irrigation Operation	$180.00	1	10	19.99	$379.90
Pruning and Training	$0.00		29	$18.74	$543.46
Hand Thinning			15	18.74	$281.10
Fuel	$3.30	45			$148.50
H2A Transportation	$200.00	1			$200.00
Management	$700.00	1			$700.00
Herbicide	$73.00	1	0.75	19.99	$87.99
Insecticide	$0.00	0	0	19.99	$0.00
Other Fungicide	$300.00	1	2.5	19.99	$349.98
Rodenticide	$29.60	1	0.5	19.99	$39.60
Total					**$34,191.73**

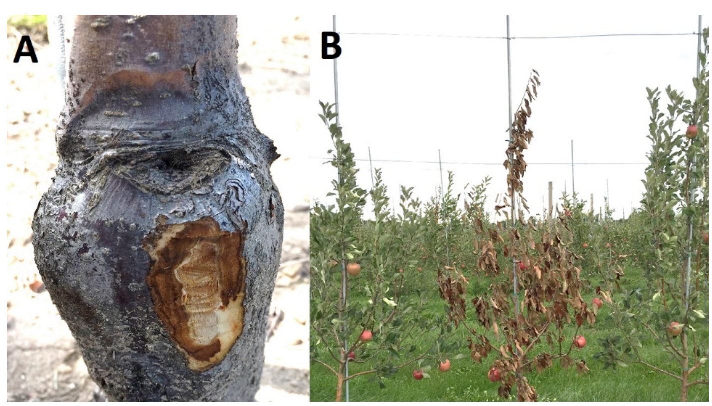

Figure 1. Figure 1. (A) Fire blight canker on apple rootstock with an exposed canker margin. (B) Dead apple tree from rootstock girdling by a fire blight canker (Photo by Wallis A. E. 2016, Cornell Cooperative Extension; re-printed by permission from Aćimović et al. 2023).

analysis, and we outline some of the important assumptions below.

The adverse labor rate in New York State was $14.99 in 2022; given 25% benefits we assumed the hourly wage rate is $18.74. For some technical activities (e.g., spraying and irrigation labor) we included a $1/hour supplement and set the hourly wage at $19.99 per hour for these activities. We assumed that land used for apple orchards is valued at $6,000 per acre and that property taxes are assessed at 2.5% per acre per year. In all our scenarios we assumed that the trees were planted in a tall spindle orchard system, and that the trellising cost were $5,000 per acre including labor.

On the revenue side, we assumed that a bin of apples weighs 800 pounds, and we used an average price per bin of $543.71 based on 2018-2020 prices for Honeycrisp apples sold in New York State. We assumed that apples are sold through a wholesaler and that growers are not responsible for additional marketing costs. In the scenarios that modeled a fire blight incident, we assumed this happened in the fourth year of production. For the scenarios that included Geneva® rootstocks, we assumed that fire blight can be managed via pruning and that yields are delayed by one year. Labor costs for tree pruning (and tree removal in scenarios that include tree removal) were assumed to be twice the original amount that it costs to plant tree. The spray programs were assumed to save 50% of the affected trees. In the scenarios that employed tree insurance, we assumed it is purchased at a 75% coverage level with both the Fire Blight Endorsement and the Occurrence Loss Option (and no Comprehensive Tree Value Insurance).

Table 2. Costs and Revenues in Year 4 (with Geneva® rootstocks and 10% fire blight incidence)

Item	Material/Unit	Quantity	Labor Hours	Labor Rate	Total Cost
Property Taxes	$150.00	1			$150.00
Equipment Depreciation	$250.00	1			$250.00
Trellising	$0.00	0		$19.99	$0.00
Irrigation Operation	$180.00	1	10	$18.74	$367.40
Pruning and Training	$0.00	0	25	$18.74	$468.50
Hand thinning	$0.00	0	35	$19.99	$699.65
Chemical thinning	$250.00	1	5	$18.74	$343.70
Growth regulator	$330.00	1	1	$0.00	$330.00
Fuel	$3.30	45	0	$0.00	$148.50
H2A Transportation	$200.00	1	0	$0.00	$200.00
Management	$700.00	1	0	$0.00	$700.00
Beehive	$50.00	1.2	0	$19.99	$60.00
Herbicide	$200.00	1	2.5	$19.99	$249.98
Insecticide	680	1	7.5	$19.99	$829.93
Fungicide	$300.00	1	10	$19.99	$499.90
Rodenticide	$30.00	1	1		$30.00
Ethylene inhibitor	$500.00	1			$500.00
Crop Insurance	$2,000.00	1		$18.74	$2,000.00
Harvesting			105.84	$18.74	$1,983.44
Packing			162	$18.74	$3,035.88
Potential costs to manage fire blight[a]					
Blight Pruning			132	$0.60	$79.20
Fire blight spray	278.25	0	0	$19.99	$0.00
Tree Removal			132	$0.60	$0.00
Tree Insurance	$0.00	1			$0.00
Total Costs					**$12,926.07**
Apple Sales	**$543.71**	**37.8**			**$20,552.28**
Net Annual Return					**$7,626.21**

[a] The potential costs depend on the scenario being considered. In this example, the Geneva rootstocks were used and therefore the added costs to manage the fire blight incident related only to the tree pruning activities.

Table 2 outlines the annual costs and revenues in Year 4 which is the year when we assumed fire blight occurred and by modeling that year, we could illustrate the impact of the management strategies we considered. Full production is modeled to begin in the sixth year of production at which point many of the cost items increase (relative to those shown in Table 4), crop insurance costs become $3,500 per acre, total costs are approximately $19,300, and yields reach their maximum of 70 bins per acre. The bottom section of Table 2, labeled "Potential costs to manage fire blight" lists four cost items that could be activated depending on the scenario. Table 2 represents the scenario with a 10% incidence of fire blight and the use of G rootstocks. In this scenario the strategy is to prune the infected trees for a cost of $79.20 per acre and yields are delayed by one year for the infected trees.

Table 3 is included to showcase the effect of the fire blight management strategies (and the associated scenarios) on yields, and hence revenues. The first column in Table 3 shows the yields that are modeled in the absence of fire blight; in this case a maximum yield of 70 bins per acre is reached in Year 6. The other columns highlight the effects of either a 10% or 40% fire blight incidence, and the associated management strategy, on yields. The use of the M rootstock with replanting (column 2) or with the spray program (column 5) in Year 4 delay reaching maximum yields by 4 years

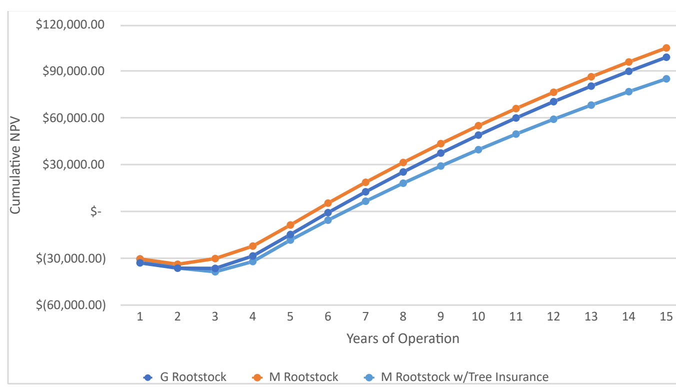

Figure 2. NPV results assuming no fire blight incidence

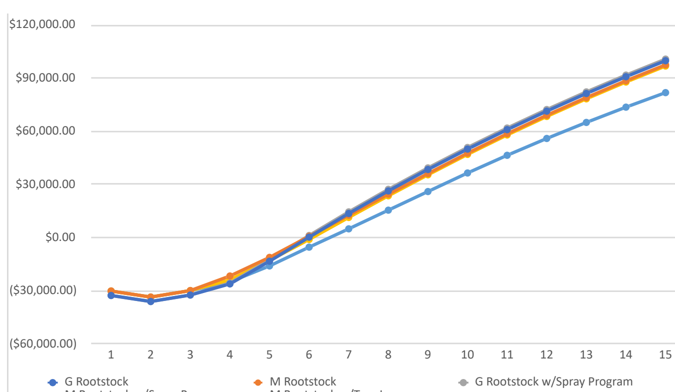

Figure 3. NPV results assuming 10% fire blight incidence in Year 4

(until Year 10). Other strategies with the G rootstocks (with or without the spray program) allow the maximum yield to be delayed by only one year. The final four columns in Table 3 show that as the incidence of fire blight increases, the yields are slower to rebound back to their maximum, and this is most notable for the scenarios with M rootstocks.

Results

The NPV results are presented in a series of figures as a way to parsimoniously show their cumulative values over time. The figures also allow for an illustrative comparison of the net economic returns across the five scenarios. Each figure shows the cumulative NPVs for the relevant scenarios, and the progression of the figures highlights how the NPVs are affected with greater rates of incidence of fire blight in Year 4.

Figure 2 shows the NPVs with three management scenarios for the case with no fire blight incidence in Year 4. Here we do not model scenarios involving the spray programs as these are only triggered with the fire blight prediction models recommending application. In this case we see that the NPV is greatest for the scenario that uses the M rootstock; this makes economic sense as the G rootstocks cost more than the M rootstocks and without fire blight incident(s) the yields are unaffected in Year 4 and thereafter. The result in this case with the M rootstocks also represents the maximum NPV of $105,204.73. The strategy with the lowest NPV (in Figure 2) was the scenario with M rootstocks and the tree insurance (given that there are non-trivial costs to purchase the tree insurance each year).

Figures 3, 4, and 5 consider all five management strategies under various levels of fire blight incidence in Year 4. Figure 3 shows the results for 10% fire blight incidence in Year 4, and in this case, we see that the highest NPV was achieved in the scenarios that implement the pre- and post-infection spray program; the NPV for the case with G rootstocks and the spray program slightly outperforms that with M rootstocks and the spray program, however, the differences were not significant. The NPV for the scenario with M rootstock and tree insurance continued to result in the lowest NPV. In Figure 4 we find qualitatively similar results as those in Figure 3, yet in this case with 25% fire blight incidence in Year 4, the NPVs for the strategies that include G rootstocks (with or without the spray programs) and the strategy with M rootstocks and the spray program are noticeably higher compared to the management strategy with only M rootstocks. With 25% fire blight incidence in Year 4, the strategy that employs tree insurance (with the M rootstocks) yields the lowest NPV again.

In Figure 5 we show the NPV results for the case with a significant fire blight incident in Year 4 (40% incidence). Now we see greater differences in the calculated NPVs across the five strategies. A NPV of approximately $100,000 is found for the scenario employing G rootstocks and the spray program; this is in line with the maximum NPV achieved with various strategies when the fire blight incidence was 0%, 10%, and 25%. However, with the 40% incidence level, the other strategies (G rootstocks alone and M rootstocks with the spray program) begin to generate less NPV compared to the strategy employing the G rootstocks and

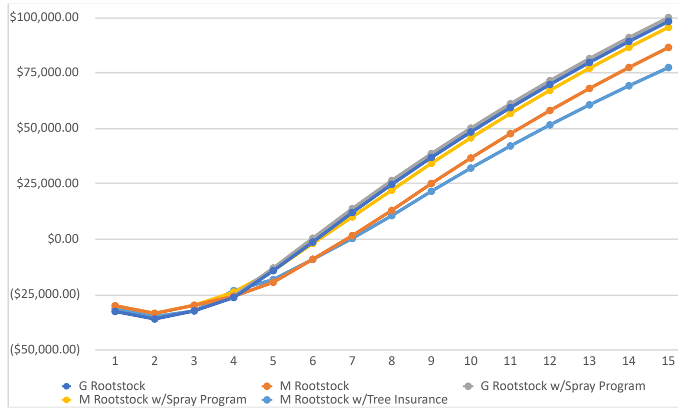

Figure 4. NPV results assuming 25% fire blight incidence in Year 4

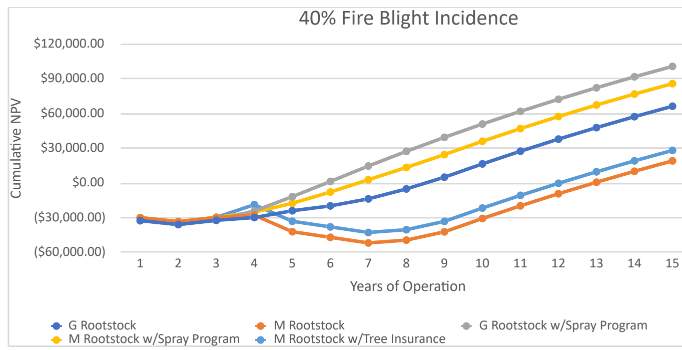

Figure 5. NPV results assuming 40% fire blight incidence in Year 4

Table 3. Assumptions on the effect of fire blight on yields (10% and 40% fire blight incidence scenarios shown)

Year	M rootstock, no fire blight	M rootstock with 10% fire blight, spot replant	Geneva rootstock with 10% fire blight, spot pruning	Geneva rootstock with 10% fire blight, spray program	M rootstock with 10% fire blight, spray program	Geneva rootstock with 40% fire blight, spot pruning	M rootstock with 40% fire blight, full replant	Geneva rootstock with 40% fire blight, spray program	M rootstock with 40% fire blight, spray program and replant
Bins per acre									
1	0	0	0.0	0.0	0.0	0	0	0	0
2	0	0	0.0	0.0	0.0	0	0	0	0
3	23	23	23.0	23.1	23.1	23	23	23	23
4	42	37.8	37.8	39.9	37.8	25.2	25.2	38.22	33.6
5	56	50.4	54.6	55.3	50.4	33.6	0	53.2	44.8
6	70	63	68.6	69.3	63.0	42	0	67.2	56
7	70	65.31	70.0	70.0	67.7	51.24	23	70	60.62
8	70	67.2	70.0	70.0	68.6	58.8	42	70	64.4
9	70	68.6	70.0	70.0	69.3	64.4	56	70	67.2
10	70	70	70.0	70.0	70.0	70	70	70	70
11	70	70	70.0	70.0	70.0	70	70	70	70
12	70	70	70.0	70.0	70.0	70	70	70	70
13	70	70	70.0	70.0	70.0	70	70	70	70
14	70	70	70.0	70.0	70.0	70	70	70	70
15	70	70	70.0	70.0	70.0	70	70	70	70

the spray programs. Finally, the NPV drops considerably for the strategies that use only M rootstocks and M rootstocks with tree insurance when there is a 40% incidence of fire blight. Interestingly, in this case we see that the strategy using tree insurance no longer generated the lowest NPV.

Discussion

Fire blight is a significant issue facing apple growers in the Northeast. Our research examines the economic implications associated with different strategies to manage and/or control the pathogen. The analysis also considers the efficacy of the strategies across different levels of incidence of fire blight (i.e., average intensity rate of infection in the tree canopy). Results show that even with low levels of fire blight incidence, there are clear economic benefits from adopting G rootstocks relative to M rootstocks. For the case with 10% fire blight incidence, the adoption of G rootstocks leads to a NPV of $99.830.85 compared to $97,530.85 with M rootstocks; this is equivalent to an additional $2300 per acre over the 15-year period. Furthermore, coupling the spray program with the G rootstocks increases the NPV to $100,738.48 (an increase of $3207.63 per acre compared to the M rootstocks) with 10% fire blight incidence. Additional results that model the effects with 25% and 40% incidence of fire blight showcase even stronger evidence on the economic case to adopt G rootstocks (coupled with the spray applications based on the fire blight prediction models).

M rootstocks are still widely planted in the United States and elsewhere and we expect this trend is likely to continue until we experience a greater number of fire blight epidemics in the future. In the last 20 years there has been a strong dependence of apple industry on M.9 rootstock in high density apple orchards (Russo et al. 2007). M.9 rootstock is widely available because in nursery stool beds, M.9 rootstock “mother plants” are more productive in growing rootstock liners when compared to G rootstock mother plants. However, M.9 is extremely susceptible to fire blight and in years with devastating fire blight epidemics, more than 50% to 60% apple tree mortality is often recorded in orchards on M.9 rootstock (Breth 2008; Ferree et al. 2002; Norelli et al. 2003a; Robinson et al. 2007). Therefore, the fire blight resistant G rootstocks are a key integral part of growers’ long-term economic insurance against violent fire blight epidemics protecting trees and trellis systems.

Tree insurance products made available by the USDA-RMA show some promise in certain situations (high incidence of fire blight and relative to M rootstocks). However, our results indicate that tree insurance is economically inferior to the adoption of G rootstocks across all incidence levels of fire blight considered. This finding is driven largely by the non-trivial annual cost of premiums required to adopt tree insurance in apple production.

The economic results presented here are for a representative acre producing Honeycrisp apples in New York State. Extensions to our work should consider the effects of fire blight management strategies for other cultivars, in other regions, and across a range of tree density/orchard designs. Lastly, although the focus of this research is to examine the economic implications of managing fire blight in apple production, our modeling framework could be augmented to consider the economic consequences of pathogens that impact production of other perennial fruit crops, and strategies that could be employed to manage such pathogens.

Acknowledgments

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