FINAL PROJECT REPORT

Project Title: Integrated Fire Blight Management

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INTEGRATED FIRE BLIGHT MANAGEMENT

OBJECTIVES

1. Test materials to prevent bloom infections including biologicals, tank mixes, and mixes with bioregulators.
2. Demonstrate management strategies for young trees including coppers, plant defense elicitors, and Prohexodine Calcium (PhCa).
3. Test strategies to manage blocks once they are infected. Treatments will address how far back to cut, the utility of stub cuts, timeliness of cutting and the use of plant defense elicitors.
4. Provide outreach on fire blight prevention and management.

SIGNIFICANT FINDINGS

- Alum performed well in 7 of 8 blossom blight prevention trials in WA, NY, PA and OR.
- Thyme and cinnamon oil products provided intermediate control.
- Thyme oil products performed well as part of an organic program with Blossom Protect and soluble copper when applied at petal fall.
- Prohexadione calcium (Apogee/Kudos) performed best when applied 2 weeks before inoculation. 6 oz or higher rates may be important in WA/OR compared to success at the 3 oz rate in NY.
- The 40 oz rate of Serenade Opti performed no better than the 20 oz standard for blossom blight control.
- For protection of young non-bearing trees flower removal was best followed by 3 weekly applications of soluble copper (Previsto/Cueva) at 3-4 qt/ A or basic copper 1.5 lb/100 gal.
- In a replacement tree trial in OR only 42% of trees treated 3 days before infection with Actigard (vs 88% untreated, 79% preplant) developed trunk cankers.
- Timely summer cutting of fire blight infections significantly reduced the number of trees which developed rootstock blight and died from fire blight infections.
- The standard best management fire blight cutting practice where cuts are made 12 inches from the edge of the noticeably infected tissue into 2-year or older wood with sanitized loppers significantly reduced the number of new systemically caused infections compared to no-treatment controls in 8 of 9 case study trials.
- While Breaking provides a fast fire blight removal method it can leave many cankers in the orchard which provide a source for infection in subsequent years.
- In 2 of 4 case studies cutting which left a 5-inch Long Stub from structural wood significantly reduced the number of cankers on structural wood compared to flush cut or 1-inch stub.

RESULTS AND DISCUSSION

Objective 1. Test materials to prevent bloom infections including biologicals, tank mixes, and mixes with bioregulators. A number of biopesticides were tested in order to determine the efficacy of new products and try to improve the use of existing products for the control of fire blight of apple. It was hypothesized that increasing the rate for Serenade Opti might improve control. Serenade Opti provided variable control: intermediate control at low pressure Oregon 2019, 42% relative control (relative to water treated check); good New York 2019 72% relative control, low-moderate Washington 2019 24% control, 29% control Pennsylvania 2019 (Table 1). Considering timings Serenade Opti did better in trials where it was applied closer to the timing of inoculation (day of vs day before inoculation). Overall best timing for Serenade Opti was early or late bloom when the risk due to number of blooms open is less. Doubling the rate provided no additional control (Table 1). The test material Alum (aluminum potassium sulfate) has been tested for multiple years in Oregon and Washington showing significant potential but had not been tested in the eastern United States.

Relative control of fire blight by Alum with 2 to 3 applications was good in seven of eight trials (2019: WA 80%, NY 77%, PA 57%; 2020: WA 29%, OR 86%, NY 65%; 2021: WA 50%, NY 87%) (Tables 1-3). Several new essential oils have recently been marketed for fire blight control. It was critical to test these new products in order to avoid potential control failures and identify appropriate timings and rates. A 23% thyme oil product (Thymegard) with multiple post petal fall applications had provided good control but resulted in marking in WA in 2019. Application timing was adjusted to three applications with the latest application at petal fall and products were applied under fast drying conditions in 2020-21 and applied in multiple states, and it provided intermediate to moderate relative control (WA 2020 45%, WA 2021 45%, NY 2021 81%) (Table 2-3). *Note:* Frost and a freeze occurred during bloom in the 2020 Pennsylvania trial and as such due to very few surviving blooms PA 2020 data is not included in the analysis. Thyme oil was also applied as part of an organic program where Blossom Protect + Buffer Protect was applied 2x pre bloom followed by a soluble copper at full bloom just prior to Erwinia inoculation and thyme oil was applied at petal fall. This alternative organic program provided good control, comparable to the organic standard program in three of three trials (relative control organic alternative:organic standard 59:64% Washington 2021, 100:100% New York 2021, 91:93% Oregon 2021) (Tables 2-3). A new 60% cinnamon oil product (Cinnerate) was tested in four trials with 3-4 applications and provided control relative to the water treated check of 38% WA 2020, 70% NY 2020, 46% WA 2021, and 85% NY 2021 (Tables 2-3).

Objective 2. Demonstrate management strategies for young trees including coppers, plant defense elicitors, and prohexodine calcium (PhCa). Young non-bearing trees are particularly susceptible to fire blight infections and in high-risk areas growers apply preventative programs regardless of seasonal fire blight risk. Trials specific to management of non-bearing trees are important to improve efficacy and potentially reduce costs. In 2019-2020 seven trials were conducted to evaluate the use of plant defense elicitors, prohexodine calcium, coppers and flower removal for the suppression of fire blight bloom and shoot infections.

In 2019 prohexodine calcium (Kudos or Apogee) applied once at pink (10% bloom) at 6 oz/100 gal reduced infections per 100 clusters compared to the water treated check from 27 to 10 in OR, from 88 to 15 in NY, and from 94 to 65 in PA but was no different than the water treated check in WA (Table 4). In 2020 prohexodine calcium at 6 oz per 100 gal applied once at pink provided no significant reduction in infections compared to the water treated check in Oregon and two applications at 12 oz per 100 gal at tight cluster and petal fall reduced infections per 100 clusters from 77 to 11 in NY and 71 to 22 in PA (Table 5). Low rates of prohexodine calcium appear to be most useful for fire blight suppression in young or vigorously growing trees. The time between treatment and infection may also be important. For example, in 2019 the PA application at pink was 9 days before full bloom inoculation, and in Oregon application at pink was 3 days before full bloom and 9 days before when infection likely occurred at petal fall versus in New York pink was 14 days before full bloom inoculation. Further study in OR and WA conditions are necessary. A young tree planting was planted in 2021 to be used for further testing in WA in 2022.

For protection of young non-bearing trees flower removal was best followed by weekly applications of soluble copper 3-4 qt/A or basic copper at 1.5 lb/A. Flower removal at pink for young non-bearing trees reduced infections to the lowest level with 0 infections per 100 clusters in PA and 0 per 100 in NY in the 2020 trial (Table 5). Three applications of soluble copper (Previsto 3 qt, Cueva 4 qt) reduced infections per 100 clusters from 77 to 5.5 NY, and 71 to 17 PA and three applications of basic copper (1.5 lb) reduced infections per 100 clusters from 77 to 27 NY and 71 to 8.3 PA.

In Oregon in 2019 application timing of concentrated Actigard 50WG (acibenzolar-S-methyl (ASM), Syngenta Crop Protection, Greensboro, NC) treatments was evaluated on 1st-leaf Fuji apple trees as either a pre-plant or post-plant trunk spray for protection from fire blight infection. Overall, 99 of 100

(99%) of inoculated trees developed fire blight symptoms on at least one shoot. Number of infected shoots per tree was highest for untreated and pre-plant Actigard (4.1 of 5) and lowest for post-plant Actigard (3.1 of 5). By 18 September, trunk cankers developed and advanced on 88% of untreated trees and on 79% of trees treated with Actigard pre-plant. In contrast, trunk cankers developed on only 42% of trees treated with Actigard near post-plant (near inoculation). For those trees with trunk infection, by September, the average canker on a post-plant Actigard-treated trees was 78% smaller than the average canker on an untreated tree.

Objective 3. Test strategies to manage blocks once they are infected. Nine case studies were conducted to evaluate the success of fire blight cutting strategies in orchards with different scion, rootstocks, age, vigor and training system combinations.

The most important goal of timely aggressive cutting of fire blight infected material during the summer soon after infection occurs is to save the trees. If infections are not cut out and removed the fire blight bacteria can move through the tree killing large limbs, the entire scion or create rootstock blight killing the tree. Seven cutting treatments were compared to identify which would reduce the percentage of trees killed by fire blight infections. In 4 of 7 case studies where rootstock blight or tree death occurred all cutting treatments reduced the number of trees which died or acquired rootstock blight from fire blight compared to the no-treatment control (Table 10). In case studies 'New York 2019 Ever Crisp' and 'New York 2019 Idared' in 100% of no-treatment control (NTC) trees the scion died down to the resistant rootstock compared to 0 trees in cutting treatments. In case study 'Washington 2021 Pink Lady' 38% of NTC trees developed rootstock blight (which will lead to tree death) compared to 0-16% in cutting treatments. This data demonstrates that timely summer cutting of fire blight infections is critical in young or vigorous trees to avoid losing trees and orchards.

The fire blight pathogen *Erwinia amylovora* moves systemically through the tree from the point of infection. Bacterial cells in the plant's vascular system move down the branch and through the tree much more quickly than canker symptoms become visible on limbs and trunks. The recommended best management practice is to cut 12-18 inches below the visible symptoms in the tree to remove the majority of bacterial cells so that insufficient cells remain to move through the tree to new limbs where they can create new infections in young tender shoot tips. The treatment best management practice (BMP) where cuts were made 12-inches from the edge of the noticeably infected tissue into 2-year or older wood with sanitized loppers significantly reduced the number of new infections/ new cuts compared to the no-treatment control (NTC) in eight of nine case studies (Table 7). The only exception was site 'Washington 2020 Pink Lady' where trees were 14-years old, very low vigor and initial cutting was performed more than 2 weeks after symptoms first became noticeable. We hypothesized that aggressive cutting may reduce the number of new infections by removing more bacterial cells from the tree and consequently reducing the chances that sufficient cells are left to cause new infections. In treatment Aggressive branches were cut back approximately 76 cm (30 inches) from the edge of the noticeably infected tissue with sanitized loppers. Treatment Aggressive had fewer new infections than BMP at 'Washington 2019 Yarlington Mill' and 'Washington 2020 Pink Lady' but the number of new infections was no different than BMP at other sites. In site 'Oregon 2020 Gala' no new infections occurred in either BMP or Aggressive. Similarly in site "New York 2021 Gala' the number of new infections was low in both BMP and Aggressive cutting treatments. Site 'New York 2019 Evercrisp' were highly vigorous young trees where both BMP and Aggressive had three times fewer new infections than the no treatment control (NTC) but still resulted in 4-5 new infections per tree. Importantly, in site 'Washington 2021 Pink Lady' aggressive cutting resulted in excessive new growth and provided abundant susceptible tissues for bacterial infection.

When cankers caused by fire blight infections reach central leaders and main structural branches (structural wood) growers face the decision to either cut out the canker removing large parts of the tree resulting in a lost productive capacity for several years or leave cankers which are the source of new fire blight infections the following spring. It was hypothesized that by leaving a stub of 4-5" from the central leader or structural branch when cutting blight any new infections that re-ignite would be on the stub which could then be removed during winter pruning and reduce the number of cankers on structural wood. A Long Stub treatment where noticeable infections were cut back leaving a 5-inch stub of branch from the central leader or main structural branch using sanitized loppers was compared to a Short Stub where branches were cut flush or a 1-2-inch stub left. In two of four case studies where these treatments were compared 'Washington 2020 Pink Lady' and 'Washington 2021 Pink Lady' a Long Stub significantly reduced the number of cankers on structural wood. In the remaining two case studies 'Pennsylvania 2019 Gala' no cankers progressed to structural wood and in 'Washington 2019 Yarlington Mill' trees were grafts where the main structural wood was old Red Delicious interstems which are not very susceptible to symptomatic infection.

In some orchards managers are employing breaking rather than cutting to remove fire blight infected wood. This practice is designed to be quick and avoid the use of loppers which require sanitization. This practice is primarily used in V-trellis training systems where limbs are trained to a wire where they are difficult to remove. In case study trials we implemented the treatment Breaking where limbs with infections were broken back by hand, snapping the wood at the joint between the first-year growth and the second-year growth. In case study 'Washington 2021 Pink Lady' where 4th leaf trees were trained to the wire, treatment Breaking resulted in significantly more new infections than other cutting treatments, similar to the NTC (Table 7). In 3 of 9 case studies Breaking resulted in more canker tissue left in the tree at the end of the season (Table 8) compared to BMP. The larger number of remaining cankers provide a greater source of infection in the following year. In 2 of 9 case studies Breaking also resulted in significantly higher numbers of cankers on structural wood than BMP and cankers on structural wood were numerically higher in 2 additional case studies (Table 9). While Breaking provides a fast fire blight removal method it can leave many cankers in the orchard which provide a source for infection in subsequent years.

Objective 4. Provide outreach. Twenty fire blight management presentations were given in Washington between 2019 and 2021 to a total of 2291 participants. This included a talk given by the four-researcher grant team to 353 participants.

In a 2021 survey 79% of respondents managing 89,000 acres said they used WSU Extension information to inform their fire blight management decisions (N=230). 28% believed WSU information improved their control programs. 52% said they avoided a product with low efficacy. Avoiding non-efficacious fire blight programs is critical to preventing outbreaks which can kill trees and result in orchard removal. For example, one large grower removed 56,000 trees in 2018 due to fire blight. At $8 average per tree plus labor costs and 3 years of lost production he estimates one fire blight event cost their orchard over $1,000,000 in one season (approx. $18/tree). With 24 million apple trees less than four years old in Washington (WA Tree Survey 2017), a susceptible age for death from fire blight, and 20% of apple acres affected in a bad year, 52% of growers avoiding a non-efficacious product may have saved the industry $215 million in a year with high disease pressure.

For a copy of this report which contains materials and methods email tianna.dupont@wsu.edu or visit http://treefruit.wsu.edu/tianna-dupont/

Table 1. Effect of Fire Blight Materials for Prevention of Blossom Blight in 2019β**

Treatment	Rate per 100 gal	Timing	strikes per 100 clusters Washington*‡ 'Red Delicious'	Oregon§ Bartlett Pear	New York[χ] 'Gala'	Pennsylvania† 'Cameo'
Streptomycin standard[y] (Firewall 17)[x] (Firewall 50)[v]	 24 oz 8 oz	50% bloom, 100% bloom, petal fall	4.8 ± 2.8 c	1.7 ± 0.5 c	5.5 ± 2.1 de	1.4 ± 3.8 e
Oxytetracycline standard[y] (Fireline 17)	24 oz	50% bloom, 100% bloom, petal fall	5.7 ± 3.1 c			10 ± 12.5 e
Blossom Protect Buffer Protect	21.4 oz 150 oz	70% bloom, 100% bloom		2.7 ± 0.7 bc	8.0 ± 4.9 de	
Blossom Protect Buffer Protect Previsto or Alum	1.24 lb 8.75 lb 3 qt 8 lb	20% bloom, 80% bloom, 100% bloom, petal fall	6 ± 1.1 c	2.3 ± 1.4 bc		
Serenade[v]	20 oz	100% bloom -1 day, 100% bloom + 1 day, petal fall	16 ± 3.2 abc	5.1 ± 1.3 b	24.6 ± 5.6 bc	67 ± 11.9 c
Serenade	40 oz	100% bloom -1 day, 100% bloom + 1 day, petal fall	20.3 ± 8.2 abc			71 ± 31.7 bc
Cueva	4 qt	100% bloom -1 day, 100% bloom + 1 day, petal fall	11.5 ± 4.1 abc			
Previsto	4 qt	100% bloom -1 day, 100% bloom + 1 day, petal fall	8 ± 3.7 bc			
Alum	8 lb	80-100% bloom, petal fall	4.3 ± 2.7		20.3 5.5 bcd	40 ± 20.9 d
Water-treated check	NA	100% bloom, petal fall[x]	21 11 abc	9.0 1.3 a	88.1 ± 3.3 a	94 ± 5.9 a

[y] Amended with Regulaid: 30 fl. oz. per 100 gallons. Pennsylvania had an additional 80% bloom timing.
* Transformed log(x + 1) prior to analysis of variance; non-transformed means are shown.
**Values within columns followed by the same letter are not significantly different ($P < 0.05$) according to the LSMEANS procedure in SAS 9.4.
‡Inoculation was conducted on the evening of April 27, 2019 at full bloom (of king blooms), and May 1 petal fall using a suspension of freeze-dried cells of Erwinia amylovora strain 153N (streptomycin and oxytetracycline sensitive pathogen strain). 2019 application dates were: April 21 (pink), April 23 (20% bloom), April 24 and 25 (50% bloom), April 26 (full bloom minus 1 day), April 27 (full bloom), April 28 (full bloom plus 1 day), May 1, 2019 (petal fall), May 2, May 4 and May 6, and May 10, 2019.
§Oregon bartlett pear, trees inoculated on 24 April with 1 x 106 CFU/ml Erwinia amylovora strain Ea153N (streptomycin- and oxytetracycline-sensitive fire blight pathogen strain). Application dates included 10% bloom (April 23), full bloom (April 26), petal fall (May 1) of 2019.

[χ]New York 2019 application dates were pink (8 May), 40% bloom (13 May), 80% bloom (16 May), 100% bloom (23 May) petal fall (May 30), terminal shoot growth (5 Jun).
[†]Pennsylvania application dates were: Pink (17 Apr); 50% bloom (24 Apr); 80% bloom (26 Apr); 100% bloom (29 Apr); petal fall (2 May).
[x]Full bloom only in Washington. [x]Oregon had full bloom only timings. Pennsylvania had an additional 80% bloom timing. [v]Oregon.
[u]Additional application of Serenade Opti at 80% bloom and June terminal shoot growth in New York. Amended with Regulaid at 3 qt in New York.
[β]No noticeable fruit marking occurred with any treatments.

Table 2. Effect of Fire Blight Materials for Prevention of Blossom Blight in 2020[**]

Treatment	Rate per 100 gal	Timing	infections per 100 clusters				
			Washington[*‡]	Oregon[§]	Oregon[¥]	New York[χ]	Pennsylvania[†]
Streptomycin standard[y] (Firewall 17)[x] (Firewall 50)[v]	28.8 oz[x] 2.7 oz[v]	100% bloom	2.8 ± 1.2 a	3.8 ± 1.5 a	1.5 ± 0.4 a	12.0 ± 2.2 bc	4.6 ± 7.5 c
Oxytetracycline standard[y] (Fireline 17)	28.8 oz[x] 16 oz[v]	50% bloom, 100% bloom, petal fall	8.2 ± 2 b	±	4.1 ± 0.6 b	27.5 ± 9.4 b	10.1 ± 9.4 a-c
Organic Standard Blossom Protect/Buffer + Soluble Copper (Previsto)	1.24 lb 8.75 lb 3 qt	50% bloom, 80% bloom, 100% bloom, petal fall	9.5 ± 1.3 bc	1.8 ± 0.4 a	---	7.0 ± 2.3 c	6.8 ± 6.2 a-c
Organic Alternative Blossom Protect/Buffer + Soluble Copper (Previsto) Thymegard	1.24 lb 8.8 lb 3 qt 2 qt	80% bloom, 100% bloom, petal fall	---	2.1 ± 0.8 a	---	---	---
Thyme Gard (0.5%)	2 qrt	80% bloom, 100% bloom +1 day, petal fall	17 ± 2.3 cd	---	---	---	4.9 ± 5.5 a-c
Alum[y]	8 lb	100% bloom, petal fall	22 ± 4.2 d		4.2 ± 1.6	28.0 ± 16.3 b	11.5 ± 6.2 ab
Cinnerate	1 qt	50% bloom, morning after inoc, petal fall	19 ± 3.5 d	---	---	24.0 ± 8.7 b	15.4 ± 26.6 a
Cinnerate	1 qt	100% bloom, petal fall	---	---	28 ± 1.7 c	---	---
Water-treated check	NA	100% bloom[x,v], +1 day[x], petal fall[x,v]	31 ± 7.1 d	24 ± 5 b	31 ± 1.7 c	80.1 ± 6.5 a	7.2 ± 3.4 a-c

[y] Amended with Regulaid: 30 fl. oz. per 100 gallons.
[x]Washington. Washington had additional 50% and petal fall applications. [v]Oregon.
* Transformed log(x + 1) prior to analysis of variance; non-transformed means are shown.
**Values within columns followed by the same letter are not significantly different ($P \leq 0.05$) according to the LSMEANS procedure in SAS 9.4.
[‡]Washington application dates were: April 14 (20% bloom), April 16 (50% bloom), April 17 (80% bloom) and April 18 (full bloom), April 19 (full bloom plus 1 day), April 22 (petal fall). Inoculation was conducted on the evening of April 18, 2020 at full bloom (of king blooms) using a suspension of 50% freeze-dried cells of *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain) and 50% live cells, which was prepared at 24 x 10^6 CFU per ml.
[§] Oregon Golden delicious apple, application dates were 17 April and 21 April, 2020 (petal fall). On the evening of 19 April, a motorized 25-gallon tank sprayer equipped with a hand wand was used to fog a suspension (~2 liters per tree) of freeze-dried cells of *Erwinia amylovora* strain 153N (1 x 10^6 CFU per ml).
[¥] Oregon Gala apple, application dates were 17 April and 21 April, 2020 (petal fall). Inoculation was done on the evening of 15 April.
[χ]New York 2020 application dates were 29 April (tight cluster), 7 May (pink), 16 May (40% bloom), 20 May-(80% bloom), 22 May(100% bloom/petal fall), 29 May (petal fall/early terminal shoot growth).

[†]Pennsylvania application dates were: 4 April (tight cluster); 13 April (pink); 20 (20% bloom); 22 April (50% bloom; first inoculation); 23 April (+12 h post inoculation); 27 April (100% bloom, second inoculation); 28 April (+12 h post inoculation); 4 May (Petal fall). A frost occurred on 17 April, damaging a significant number of blossoms, thereby affecting results. In addition, the average temperature during the trial period was 49°F and no fire blight infection periods occurred.

Table 3. Effect of Fire Blight Materials for Prevention of Blossom Blight in 2021

			Infections per 100 clusters [w]	
Treatment	Rate per 100 gal	Timing	Washington* [z, y]	New York[u]
Streptomycin standard (Firewall 17) [x]	8 oz	100% bloom	16.1 ± 2.3 a[w]	
Oxytetracycline standard (Fireline 17) [x]	16 oz	100% bloom, petal fall	17.0 ± 5.7 a	
Organic standard apple Blossom Protect + Buffer Protect Previsto	 1.24 lb + 8.75 lb 3 qt	 70% bloom, 100% bloom, 100% bloom + 1 day, petal fall	17.8 ± 4.5 a	0.0 ± 0.0 cd
Organic standard pear Blossom Protect + Buffer Protect Serenade Opti	 1.24 lb + 8.75 lb 20 oz	 70% bloom, 100% bloom, 100% bloom + 1 day, petal fall	13.9 ± 2.6 a	---
Blossom Protect + Buffer Protect Previsto Thyme Gard [v]	1.24 lb + 8.75 lb 3 qt 2 qt	50% bloom, 100% bloom, 100% bloom + 1 day, petal fall	16.0 ± 1.9 a	0.0 ± 0.0 cd
Thyme Gard [v]	2 qt	100% bloom, 100% bloom + 1 day, petal fall	21.4 ± 3.9 ab	13.9 ± 10.8 bcd
Cinnerate + Probald Verde	32 oz + 40 oz	100% bloom, 100% bloom + 1 day, petal fall, petal fall + 3 days	17.6 ± 3.2 ab	12.8 12.8 bcd
Cinnerate	32 oz	100% bloom, 100% bloom + 1 day, petal fall, petal fall + 3 days	20.8 ± 3.7 ab	11.0 1.0 bcd
Alum [v]	*8 lb*	100% bloom, 100 bloom + 1 day, petal fall	19.3 ± 2.4 ab	10.0 ± 10.0 bcd
Jet Ag	128 oz	100% bloom + 1 day, petal fall, petal fall + 3 days	12.8 ± 1.6 a	
Oxidate 5.0 (1%)	128 oz	100% bloom + 1 day, petal fall, petal fall + 3 days	14.2 ± 1.2 a	
Water-treated check	NA	100% bloom, petal fall, petal fall + 3 days	38.6 ± 5.1 c	75.1 ± 11.1 a

[z] Application dates were: 18 Apr (70% bloom), 19 Apr (full bloom), 20 Apr (full bloom + 1 day), 23 Apr (petal fall), 26 April (petal fall + 3 days). Inoculation was conducted on the evening of 19 Apr 2021 at full bloom (of king blooms) using a suspension of 50% freeze-dried cells and 50% live cells of *Erwinia amylovora* strain Ea153 (streptomycin and oxytetracycline sensitive strain) prepared at 1 $x10^6$ CFU ml^{-1} (verified at 40-94 $x10^6$ CFU ml^{-1}).

[y] Transformed $\log(x + 1)$ prior to analysis of variance; non-transformed means are shown.

[x] Amended with Regulaid: 16 fl. oz. per 100 gallons. Buffered to 5.6 pH.

[w] Treatments followed by the same letter are not significantly different at P=0.05 Fisher's T test (LSD).

[u] Application dates 24 Apr "tight cluster", 27 Apr "pink"; 2 May-20% bloom; 4 May-50% bloom; 6 May- 80% bloom; May 7 FB -1, 8 May-100% bloom/petal fall; May 9 FB + 1, 11 May-petal fall/early terminal shoot growth; 17 May- terminal shoot growth PF + .3. Trees were inoculated at 80 to 90% bloom (7 May) with *Erwinia amylovora* strain Ea 273 at $1x10^6$ CFU ml^{-1} using a hand-pumped Solo backpack sprayer.

Table 4. Plant defense elicitors and prohexodine calcium for fire blight suppression in 2019.

Treatment	Rate per 100 gal	Timing	strikes per 100 clusters: Washington[‡] Red Delicious	Oregon[§] 'Gala'	New York[χ] 'Gala'	Pennsylvania[†] 'Cameo'
Water check	---	10% bloom, full bloom, petal fall	21 ± 11 a[**]	26.7 ± 4.25 a[#]	88.1 ± 3.3 a[**]	94.1 ± 5.9 a[#]
Untreated check	---	-----		13.8 ± 1.58 bc		
Kudos[x, y] or Apogee	3oz	10% bloom	21.8 ± 12.5 a	17 ± 1.21 ab	17.8 ± 8.1 bcd	
Kudos[x, y] or Apogee	6 oz	10% bloom	24 ± 6.9 a	10.2 ± 3.42 bc	15 ± 4.9 bcde	65.3 ± 25.8 c
Actigard[x, y]	6 oz	10% bloom		12.2 ± 4.38 bc		
Kudos[x, y], Actigard[y]	2 oz, 3.2oz	10% bloom		11.2 ± 3.53 bc		
Actigard	2 oz	10% bloom, full bloom, petal fall		5.33 ± 2.04 c		
Regalia	**	pink, 50% bloom, petal fall				88.3 ± 8.1 a
Lifegard	13.5 oz				16.3 ± 3.1 bcde	

[x] Amended 1:1 with ammonium sulfate. [y] Amended with Regulaid: 16 fl. oz. per 100 gallons. [z] Amended with BioLink Spreader-Sticker: 4 fl. oz. per 100 gallons.

[#]Means within a column followed by same letter do not differ significantly (*P* = 0.05) based on Fischer's protected least significance difference.

[‡] Washington inoculation was conducted on the evening of April 27, 2019 at full bloom (of king blooms), and May 1 petal fall using a suspension of freeze-dried cells of Erwinia amylovora strain 153N (streptomycin and oxytetracycline sensitive pathogen strain). 2019 application dates were: April 21 (pink/ 10% bloom), April 27 (full bloom), May 1(petal fall).

[§] Gala trees inoculated on 18 April with 1 x 10^6 CFU/ml *Erwinia amylovora* strain Ea153N (streptomycin- and oxytetracycline-sensitive fire blight pathogen strain). 70% bloom (April 18), full bloom (April 20), petal fall (April 24).

[†]Twelve year-old 'Cameo' trees on B.9 rootstocks were used and two- tree treatments were arranged in a randomized complete block with four replications. All blossoms were inoculated on the tree, with the exception of the top 1-2 feet of the tree (could not be reached, unless with a ladder). Blossoms were inoculated late afternoon at 26 Apr with a bacterial suspension of 10^7 *Erwinia amylovora* cells/ml using a spray bottle. Blossom clusters were rated during the third week of May. Blossom clusters were rated infected if at least one blossom was dead. Due to the trees being overwhelming infection of blossoms for the majority of the treatments, shoot blight incidence was not counted.

[χ]Treatment timings were: 8 May "pink" (application 1) 13 May-40% bloom (application 2); 16 May- 80% bloom (application 3); 23 May-100% bloom (application 4); 30 May-petal fall/early terminal shoot growth (application 5); 5 Jun- terminal shoot growth (application 6).

[**] Values within columns followed by the same letter are not significantly different ($P \leq 0.05$) according to the LSMEANS procedure in SAS 9.4 with an adjustment for Tukey's HSD to control for family-wise error.

Table 5. Effect of Products Applied for Prevention of Blossom and Shoot Blight in Young Trees on Blossom Blight in 2020.

Treatment	Rate per 100 gallons	*Timing*	Strikes per 100 clusters				
			Washington[‡] 2nd leaf WA38	Oregon[§] 6-yr-old Gala	Oregon[§] 2-yr-old Gala	New York[#] 2nd leaf Gala	Pennsylvania[†] 3rd leaf Gala
Inoculated Check	water	100% bloom, +1 day, petal fall	0 ± 0	41 ± 6 a	39 ± 7 a	77.2 ± 4.4 a	71 ± 20.1 a
Flower removal	NA	Pink	0 ± 0	---	---	0 ± 0 d	0 ± 0 d
Basic Copper	1.5 lb	3 applications	5 ± 0	---	---	27.3 ± 3.3 b	8.3 ± 12.1 c
Previsto Or Cueva	3 qt 4 qt	3 applications	0 ± 0	---	---	5.5 ± 2.1 c	17.3 ± 17.2 c
PhCa[y z]	6 oz	tight cluster, petal fall	0 ± 0	---	---	6.5 ± 1.7 c	42.4 ± 24.0 b
PhCa[y z]	6 oz	full pink	---	34 ± 3 a	36 ± 4 a	29.5 ± 9.7 b	---
PhCa[y z]	12 oz	tight cluster, petal fall	0 ± 0	---	---	10.5 ± 1.0 c	21.8 ± 23.5 c
Actigard	2 oz	10% bloom, 80% bloom, petal fall	0 ± 0	---	---	17.8 ± 2.3 bc	14.4 ± 16.1 c
PhCa[z y] Actigard	6 oz 2 oz	full pink	---	31 ± 5 a	32 ± 5 a	20.8 ± 3.9 bc	---
Regalia	64 oz	10% bloom (pink), 80% bloom, petal fall	0 ± 0	33 ± 7 a	37 ± 5 a	26.5 ± 1.7 b	---
Employ	2 oz	10% bloom, full bloom, petal fall	0 ± 0	---	---	23.5 ± 2.9 b	---
Fireline 17 (standard oxytet)	28 oz	50% bloom, 100% bloom, PF	---	---	---	10.0 ± 1.3 c	---

[y] Amended with surfactant (Regulaid) at 16 fl oz per 100 (Oregon) 32 oz per 100 gal (Washington).

[z] Kudos amended with 1 lb of ammonium sulfate per 100 gal (Washington), 6 oz. ammonium sulfate (Oregon).

[‡] Washington application dates were: April 15, pink, April 19 (20% bloom), April 21 (50% bloom), April 23 (full bloom), April 24 (full bloom plus 1 day), April 28 (petal fall). Inoculation was conducted on the evening of April 23, 2020 at full bloom (of king blooms) using a suspension of freeze-dried cells of *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1.3 x10^6 CFU per ml. **Only 3 cluster infections occurred in the block.**

[§]Oregon application dates were: 11 April full pink). Inoculation was conducted on the evening of April 23. On the evenings of 15 and 19 April, a motorized 25-gallon tank sprayer equipped with a hand wand was used to lightly fog a suspension of freeze-dried cells of *Erwinia amylovora* strain 153N (streptomycin and oxytetracycline sensitive pathogen strain), which was prepared at 1 x 10^6 CFU per ml (0.1 to 0.2 liters per tree).

[#]New York application dates were New York application dates were 29 Apr "tight cluster", 7 May "pink", 16 May-40% bloom, 20 May- 80% bloom, 22 May-100% bloom/petal fall, 29 May- petal fall/early terminal shoot growth.

[†]Pennsylvania application dates were: 6 Apr (tight cluster); 20 Apr (pink); 27 Apr (20% bloom); 1 May (50-80% bloom); 8 May (Petal fall). Frost occurred on 17 Apr and a freeze occurred on 9 May. There were no days indicating an infection period for fire blight during our trial. The average temperature was ~50°F during the test period.

**Values within columns followed by the same letter are not significantly different ($P \leq 0.05$) according to analysis of variance (F>0.05).

Table 6. Response of Fuji apples trees to inoculation with *E. amylovora* after trunk treatment of Actigard 50WG prior to or after planting.

Disease response	Untreated		Pre-plant Actigard		Post-plant Actigard	
	July 24	Sept 18	July 24	Sept 18	July 24	Sept 18
No. infected shoots post inoculation*	4.1± 1.1	-	3.9 ± 1.1	-	3.1 ± 1.2	-
Incidence of trunk canker**	85%	88%	65%	79%	39%	42%
Canker length infected trunks***	29 ± 17	49 ± 33	25 ± 20	46 ± 36	10 ± 5	11 ± 5

* Five shoots per tree were inoculated on 7 June with 1 x 10^9 CFU/ml *Erwinia amylovora* isolate mixture and were assessed for fire blight on 24 July and 18 September (± standard deviation).
** Percent of inoculated trees that developed a trunk canker (of a total of 33 trees per treatment).
*** Mean canker length (cm ± standard deviation) on trunks with symptoms; zero values not included.

Table 7. Effect of treatment on the number of new infections after initial cutting and removal of fire blight infections.

Cutting method	Washington 2019 'Yarlington Mill' 4-yr-old on Red Delicious[z]	New York 2019 'Ever Crisp' 4-yr-old on G.41[y]	New York 2019 'Idared' 7-yr-old on B.9[y]	Pennsylvania 2019 'Gala' 4-yr-old on M.7[x]	Washington 2020 'Pink Lady' 14-yr-old on M9.337[w]	Oregon 2020 'Gala' 3-yr-old on M9.337	Washington 2021 'Pink Lady' 4-yr-old on M9.337[u]	New York 2021 'RubyFrost' 3-yr-old on G.41[y]	New York 2021 'Gala' 18-yr-old on B.9[t]
BMP	2.6 ± 0.7 b	5.5 ± 2.3 b	2.9 ± 1.1 b	---	0.7 ± 0.3 ab	0.0 ± 0.0 a	1.5 ± 0.3 a	4.5 ± 1.5 a	0.7 ± 0.3 ab
Aggressive	0.5 ± 0.3 a	4.3 ± 1.3 b	---	---	0 ± 0.0 a	0.0 ± 0.0 a	1.6 ± 0.6 a	3.2 ± 1.1 a	0.7 ± 0.3 ab
BMP NO-sanitize	2.7 ± 0.8 b	3.9 ± 0.5 b	3.6 ± 0.8 b	---	0.3 ± 0.2 ab	0.8 ± 0.3 a	1.2 ± 0.4 a	4.8 ± 1.1 a	0.6 ± 0.3 ab
Short Stub	2.4 ± 0.6 b	---	---	0 ± 0	0.4 ± 0.2 ab	---	0.8 ± 0.4 a	8.2 ± 1.9 a	0.0 ± 0.0 b
Long Stub	1.7 ± 0.5 ab	1.9 ± 1.1 b	3.5 ± 1.2 b	0 ± 0	0.3 ± 0.2 ab	---	1.7 ± 0.3 a	---	
Breaking	2.8 ± 0.5 b	5.2 ± 0.9 b	1.4 ± 0.3 b	0 ± 0	0.9 ± 0.7 b	1.7 ± 0.5 a	5.0 ± 0.8 b	3.4 ± 0.7 a	1.1 ± 0.2 ab
NTC	7.5 ± 1.4 c	14.8 ± 1.2 a	24.5 ± 2.4 a	0 ± 0	0.5 ± 0.3 ab	6.2 ± 2.3 b	4.8 ± 1.8 b	7.8 ± 1.5 a	2.7 ± 0.4 a
BMP + ASM	---	---	---	---	---	0.0 ± 0.0 a	---	---	
Aggr NO-san	---	6.0 ± 1.3 b	1.3 ± 2.2 b	---	---	---	---	---	
Short Stub NO-san	---	---	---	0 ± 0	---	---	---	---	
Long Stub NO-san	---	---	---	0 ± 0	---	---	---	---	

[z]4-leader grafts, [y]high-density tall spindle, high vigor [x]tall spindle, low vigor, [w]tall spindle, low vigor, [u]Auvil V trained to the wire, moderate vigor, [t]Vertical axe, high vigor.

Table 8. Effect of treatment on the average length (cm) of cankers left in trees at the end of the season.

Cutting method	Washington 2019 'Yarlington Mill' 4-yr-old on Red Delicious^{z}	New York 2019 'Ever Crisp' 4-yr-old on G.41^{y}	New York 2019 'Idared' 7-yr-old on B.9^{y}	Pennsylvania 2019 'Gala' 4-yr-old on M.7^{x}	Washington 2020 'Pink Lady' 14-yr-old on M9.337^{w}	Oregon 2020 'Gala' 3-yr-old on M9.337	Washington 2021 'Pink Lady' 4-yr-old on M9.337^{u}	New York 2021 'RubyFrost' 3-yr-old on G.41^{y}	New York 2021 'Gala' 18-yr-old on B.9^{t}
BMP	0.4 ± 0.2 a	2.3 ± 0.7 ab	0.9 ± 0.3 b	---	1.1 ± 0.1 a	0.0 ± 0.0 a	1.2 ± 0.4 a	10.1 ± 6.6 ab	0.5 ± 0.3 c
Aggressive	0.0 ± 0.0 a	0.6 ± 0.4 c	---	---	0.0 ± 0.0 a	0.0 ± 0.0 a	19.7 ± 17.6 b	4.2 ± 4.2 b	0.0 ± 0.0 c
BMP NO-sanitize	0.4 ± 0.1 a	2.7 ± 0.8 ab	1.4 ± 0.6 b	---	1.1 ± 0.1 a	3.0 ± 3.0 ab	1.8 ± 0.5 a	7.9 ± 4.3 ab	0.4 ± 0.6 c
Short Stub	0.1 ± 0.1 a	---	---	16.7 ± 37.8 b	0.8 ± 0.0 a	---	0.4 ± 0.2 a	1.5 ± 1.5 b	0.0 ± 0.0 c
Long Stub	0.5 ± 0.1 a	2.5 ± 0.4 ab	1.5 ± 0.4 b	25.0 ± 43.9 b	1.0 ± 0.2 a	---	4.5 ± 3.1 ab		
Breaking	5.9 ± 3.0 b	7.5 ± 0.4 ab	1.4 ± 0.5 b	33.3 ± 47.8 b	3.2 ± 0.2 a	5 ± 2.4 b	1.9 ± 0.4 a	5.5 ± 3.0 b	12.4 ± 2.2 b
NTC	34 ± 3.7 c	12.2 ± 1.6 a	19.6 ± 1.5 a	91.7 ± 28.0 a	29.1 ± 4.3 b	13.5 ± 1.6 c	8.4 ± 2.2 ab	26.1 ± 3.8 a	29.1 ± 1.7 a
BMP + ASM	---	---	---	---	---	0.0 ± 0.0 a	---		
Aggress NO-san	---	1.1 ± 0.6 bc	0.5 ± 0.2 b	---	---	---	---		
Short Stub NO-san	---	---	---	25.0 ± 43.9 b	---	---	---		
Long Stub NO-san	---	---	---	22.2 ± 42.2 b	---	---	---		

^{z}4-leader grafts, ^{y}high-density tall spindle, high vigor ^{x}tall spindle, low vigor, ^{w}tall spindle, low vigor, ^{u}Auvil V trained to the wire, moderate vigor, ^{t}Vertical axe, high vigor.

Table 9. Effect of treatment on the percent of strikes progressing to structural wood.

Cutting method	Washington 2019 'Yarlington Mill' 4-yr-old on Red Delicious	New York 2019 'Ever Crisp' 4-yr-old on G.41^{y}	New York 2019 'Idared' 7-yr-old on B.9^{y}	Pennsylvania 2019 'Gala'* 4-yr-old on M.7^{x}	Washington 2020 'Pink Lady' 14-yr-old on M9.337^{w}	Oregon 2020 'Gala' 3-yr-old on M9.337	Washington 2021 'Pink Lady' 4-yr-old on M9.337^{u}	New York 2021 'RubyFrost' 3-yr-old on G.41^{y}	New York 2021 'Gala' 18-yr-old on B.9^{t}
BMP	2.2 ± 2.2 abc	2.4 ± 1.0 b	2.7 ± 0.9 b	---	11.9 ± 6.6 ab	0.0 ± 0.0 a	2.0 ± 2.0 a	2.3 ± 0.8 b	0.2 ± 0.1 b
Aggressive	0.0 ± 0.0 a	1.8 ± 0.2 b	---	---	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a	1.7 ± 0.7 b	0.2 ± 0.1 b
BMP NO-sanitize	0.0 ± 0.0 a	1.6 ± 0.2 b	3.1 ± 0.4 b	---	12.4 ± 7.0 b	18.4 ± 9.0 b	3.0 ± 3.0 ab	2.4 ± 0.5 b	0.4 ±0.3 b
Short Stub	1.0 ± 1.0 ab	---	---	0 ± 0	14.4 ± 7.3 b	---	8.0 ± 7.0 ab	3.9 ± 1.1 b	0.2 ± 0.1 b
Long Stub	1.0 ± 1.0 ab	1.3 ± 0.8 b	3.9 ± 0.8 b	0 ± 0	0.0 ± 0.0 a	---	2.0 ± 2.0 a	---	---

Breaking	5.7 ± 3.1 bc	2.4 ± 0.5 b	2.3 ± 0.5 b	0 ± 0	18.7 ± 5.5 b	11.5 ± 3.0 ab	18.0 ± 7.0 b	2.0 ± 0.6 b	0.6 ± 0.5 b
NTC	7.2 ± 3.4 c	8.4 ± 0.2 a	7.4 ± 0.3 a	0 ± 0	10.5 ± 3.8 ab	63.7 ± 6.0 c	13.0 ± 6.0 ab	3.1 ± 0.5 b	1.2 ±0.1 b
BMP + ASM	---	---	---	---	---	0.0 ± 0.0 a	---	---	---
Aggress NO-san	---	2.8 ± 0.5 b	1.8 ± 0.4 b	---	---	---	---	---	---
Short Stub NO-san	---	---	---	0 ± 0	---	---	---	---	---
Long Stub NO-san	---	---	---	0 ± 0	---	---	---	---	---

*% Cuts progressing through previous season's growth were 2.8 (+/-16.7) short stub, 13.9 (+/-35.1) long stub, 27.8 (+/-45.4) breaking, 66.7 (+/-47.9) no-treatment.

Table 10. **Effect of treatment on the percentage of infected trees which develop rootstock blight in the fall or tree death in the spring.**

Cutting method	Washington 2019 'Yarlington Mill' 4-yr-old on Red Delicious[z]	New York 2019 'Ever Crisp' 4-yr-old on G.41 [y]	New York 2019 'Idared' 7-yr-old on B.9	Pennsylvania 2019 'Gala' 4-yr-old on M.7 [x]	Washington 2020 'Pink Lady' 14-yr-old on M9.337[w]	Oregon 2020 'Gala' 3-yr-old on M9.337	Washington 2021 'Pink Lady' 4-yr-old on M9.337 [u]	New York 2021 'RubyFrost' 3-yr-old on G.41[y]	New York 2021 'Gala' 18-yr-old on B.9[t]
BMP	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	---	0.0 ± 0.0		0.0 ± 0.0 a	TBD	TBD
Aggressive	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	---	0.0 ± 0.0		0.0 ± 0.0 a	TBD	TBD
BMP NO-sanitize	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	---	0.0 ± 0.0		16.7 ± 16.7 ab	TBD	TBD
Short Stub	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	---	0.0 ± 0.0		0.0 ± 0.0 a	TBD	TBD
Long Stub	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	---	0.0 ± 0.0		0.0 ± 0.0 a		
Breaking	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	---	0.0 ± 0.0		0.0 ± 0.0 a	TBD	TBD
NTC	0.0 ± 0.0	100% death	100% death	---	0.0 ± 0.0		37.5 ± 18.3 b	TBD	TBD
BMP + ASM	---	---	---	---	---		---		
Aggress NO-san	---	0.0 ± 0.0	0.0 ± 0.0	---	---	---	---		
Short Stub NO-san	---	---	---	---	---	---	---		
Long Stub NO-san	---	---	---	---	---	---	---		

TBD – To be determined in 2022 spring evaluation.

[z]4-leader grafts, [y]high-density tall spindle, high vigor [x]tall spindle, low vigor, [w]tall spindle, low vigor, [u]Auvil V trained to the wire, moderate vigor, [t]Vertical axe, high vigor.

Executive Summary

Integrated Fire Blight Management

keywords: fire blight, *Erwinia amylovora*, apple, cutting, biopesticides

Abstract: Fire blight is serious disease affecting apple and pear caused by a bacterial pathogen which infects blooms and shoots resulting and can result in tree death. In 2019 and 2020 a multi-state collaboration was initiated between Washington, Oregon, New York and Pennsylvania. Trials focused in three areas: 1) test materials to prevent bloom infections including biologicals, tank mixes, and mixes with bioregulators, 2) demonstrate management strategies for young trees including coppers, plant defense elicitors, and prohexodine calcium (PhCa) and 3) test cutting strategies to manage blocks once they are infected.

In trials testing biopesticide ability to prevent bloom infections alum performed well in 7 of 8 blossom blight prevention trials in WA, NY, PA and OR. Thyme and cinnamon oil products provided intermediate control. Thyme oil products performed well as part of an organic program with Blossom Protect and soluble copper when applied at petal fall. The 40 oz rate of Serenade Opti performed no better than the 20 oz standard for blossom blight control.

For protection of young non-bearing trees flower removal was best followed by 3 weekly applications of soluble copper (Previsto/Cueva) at 3-4 qt/ A or basic copper 1.5 lb/100 gal. Prohexadione calcium (Apogee/Kudos) performed best when applied 2 weeks before inoculation. 6 oz or higher rates may be important in WA/OR compared to success at the 3 oz rate in NY. In a replacement tree trial in OR only 42% of trees treated 3 days before infection with Actigard (vs 88% untreated, 79% preplant) developed trunk cankers.

In trials comparing cutting treatments to remove fire blight infected tissue timely summer cutting of fire blight infections significantly reduced the number of trees which developed rootstock blight and died from fire blight infections. The standard best management fire blight cutting practice where cuts are made 12 inches from the edge of the noticeably infected tissue into 2-year or older wood with sanitized loppers significantly reduced the number of new systemically caused infections compared to no-treatment controls in 8 of 9 case study trials. While Breaking treatments provided a fast fire blight removal method it left many cankers in the orchard which provide a source for infection in subsequent years. In 2 of 4 case studies cutting which left a 5-inch Long Stub from structural wood significantly reduced the number of cankers on structural wood compared to flush cut or 1-inch stub.