Post-symptom Sprays of Prohexadione-calcium Affect Fire Blight Infection of 'Gala' Apple on Susceptible or Resistant Rootstocks

J.R. Schupp and D.A. Rosenberger

Hudson Valley Lab, Cornell University, Highland, NY 12528

T.L. Robinson, H. Aldwinkle, and J. Norelli

New York State Agricultural Experiment Station, Geneva, NY 14456

P.J. Porpiglia

K-I Chemical U.S.A. Inc., White Plains, NY 10606

Additional index words. Apogee, *Erwinia amylovora*, *Malus ×domestica*

Abstract. Three studies were conducted to evaluate the effect of post-infection sprays of prohexadione-calcium on the severity of naturally occurring fire blight infections on 3- and 4-year-old 'Gala' apple trees on blight-susceptible or blight-resistant rootstocks. Although post-infection prohexadione-calcium reduced the dry weight of fire blight strikes removed by pruning in one commercial orchard site, this treatment did not reduce mortality of young 'Gala' trees on M.9 or M.26 rootstocks, and did not reduce the incidence of scion or rootstock cankers on any of the rootstocks tested. We conclude that post-infection treatment with prohexadione-calcium is of no practical value in reducing fire blight symptoms on apple. Our results suggest that resistant apple rootstocks will be very valuable in increasing orchard survival in a fire blight epidemic.

Changing consumer preferences for new apple (*Malus ×domestica* Borkh.) cultivars has led to widespread planting of new cultivars, many of which are susceptible to fire blight, a bacterial disease caused by *Erwinia amylovora* (Burrill) Winslow et al. The trend toward high-density orchards has exacerbated the risk of fire blight because the most widely available size controlling rootstocks, M.9 and M.26, are highly susceptible to this disease. When fire blight infects trees on M.9 or M.26 rootstock, there is a strong possibility that bacteria will travel via the vascular system to infect the rootstock (Norelli et al., 2000; Steiner, 1998). This phase of the disease, termed "rootstock blight", leads to cankers that can completely girdle the rootstock and kill the tree.

Prohexadione-calcium [(PC) trade name Apogee; BASF Corp., Research Triangle Park, N.C.] is a new plant growth regulator for shoot growth control (Byers and Yoder, 1999; Greene, 1999). Studies have shown that PC can reduce the severity of shoot blight infection of apple and pear (*Pyrus communis* L.) (Costa et al., 1999; Yoder et al., 1999a) when applied prior to the expression of symptoms. The mechanism by which this resistance is imparted is not known, but it could simply result from a reduction in the production of

succulent tissue which is more susceptible to infection (van der Zwet and Beer, 1999). Rademacher et al. (1999) proposed that PC mediated changes in phenylpropanoid metabolism were responsible for reduced fire blight susceptibility of apple shoots. If PC activates a resistance mechanism in the tree, then post-symptom application of PC might hold promise for reducing the severity of scion injury and for increasing the survival of apple trees on highly susceptible rootstocks by reducing the incidence of rootstock blight.

Young trees that have not yet filled the allotted space in the row would not normally be treated with PC under New York conditions because the reduction in vegetative growth would slow the development of productive bearing surface and increase the time required for the orchard to reach the financial break-even point. However, losses to fire blight could easily exceed the cost of arresting growth prematurely, so growers might choose to treat young orchards with PC if they knew blight infections had occurred during bloom. Young trees appear to be more susceptible to fire blight than older trees of the same cultivar (van der Zwet and Beer, 1999). Currently, streptomycin sprays applied during bloom provide the primary line of defense against blossom infections. However, streptomycin may fail to provide complete control under severe infection conditions or where streptomycin-resistant strains of *E. amylovora* are present. In the absence of a reliable system for predicting when infections have become established in young orchards, growers might opt to wait until the first symptoms of blight appear in the orchard before applying PC so as to avoid

arresting growth where no fire blight occurs. However, it is unknown if an application of PC at the first evidence of symptoms could lessen the severity of fire blight infections in young trees.

The objective of these studies was to determine if PC could lessen the severity of preexisting fire blight infections and increase survival of 3-year-old 'Gala' trees on blight-susceptible or blight-resistant rootstocks.

Materials and Methods

These studies were carried out in 2000 at two commercial orchards in the Hudson Valley region of eastern New York and at a replicated research orchard on nine rootstocks in western New York. The eastern New York blocks were composed of 3-year-old 'Gala' trees while the western New York block had four-year-old 'Gala' trees. All three orchards were trained to the vertical axis system.

Eastern New York experiments. The first orchard, located in Livingston, N.Y., was on M.26 rootstock planted at 2.1 × 4.8 m spacing. The second, located in Modena, N.Y., was on M.9 planted at 1.8 × 4.8 m spacing. A natural fire blight epidemic developed in the region during May and June 2000. Both orchards had blossom infections resulting from two infection periods at the end of bloom (9 and 11 May). Flowers on fruiting spurs had passed petal fall by 9 May, but later-opening lateral bloom on 1-year-old wood was still susceptible to blossom blight infection. Cooler temperatures beginning 12 May reduced the likelihood of any blossom infections after that date. Numerous rain events throughout late May and early June provided favorable conditions for shoot blight infections. The source of fire blight inoculum in Livingston was attributed to abandoned apple trees growing on adjacent property, while the source in Modena was attributed to over-wintering cankers in an adjacent block of 'Gala' trees. The growers first observed blight symptoms in Livingston on 1 June and in Modena on 13 June.

The treatments were: 1) untreated control; and 2) two applications of PC at 250 mg·L⁻¹ a.i. In Livingston, treatments were applied to 40-tree plots with eight replications, while in Modena there were four replications of 70 trees per plot. Both studies were configured as a randomized complete-block design. Treated and untreated plots in each replicate were in close proximity to one another and were separated by an untreated buffer row to minimize spray drift. Replicates were arranged down the tree rows to account for any gradient in disease severity due to location in the orchard. PC was applied in dilute concentration by air-blast sprayer with 0.125% by volume Regulaid spreader-activator (Kalo, Overland Park, Kans.). The PC was first applied ≈1 week after fire blight symptoms were first noticed. In Livingston, the first application was made on 7 June, with a second application on 21 June. The applications in Modena were made on 17 June and 1 July.

Received for publication 25 June 2001. Accepted for publication 11 Dec. 2001. We thank BASF Corp. for support of this research. Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by Cornell Univ. and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

At both locations, all visible shoot blight infections were removed by the grower-cooperators prior to the initiation of treatment, and infected shoots were removed a second time by the grower-cooperator in Modena during the week following the first PC application. Thereafter, new fire blight strikes at both locations were removed at about weekly intervals until there were none. The first evaluations in the Livingston block were made on 13 June, 6 d after the first PC application, and the first evaluations in the Modena orchard were made on 6 July, 19 d after the first PC application. Pruning cuts were made several inches below the visible extent of the infection, consistent with current recommendations (Steiner, 1998).

Each week the number of pruning cuts per tree was recorded, and the prunings from each plot were collected, air dried at 70 °C, and the dry weight recorded. The total weight of prunings removed, and the total number of cuts per plot for the season were calculated. The number of primary scaffold limbs removed was recorded and the ratio of scaffolds removed relative to the total number of scaffolds per tree was calculated. The extent of leader damage was rated on a scale where 1 = leader intact; 2 = up to a third of the leader height removed; 3 = leader cut back to within 15 cm of the bottom tier of scaffolds; 4 = leader cut back to include at least one, but not all scaffolds; and 5 = leader cut off below all scaffolds. The number of trees with visible fire blight cankers in the rootstock or scion, and tree mortality were recorded at the end of the growing season. All data were subjected to analysis of variance and the F test was used to determine significance of treatment, replicate, and week main effects and interactions.

Western New York experiment. The treated orchard was a replicated randomized complete-block rootstock experiment located in Geneva, N.Y., with nine rootstocks, B.9, M.26, M.26EMLA, M.26VF, M.7EMLA, M.9VF, MM.106EMLA, MM.111EMLA, and P.14, with seven replications, and two trees per replicate. The trees were planted in May 1997 at 2.4 × 4.9 m spacing. A severe natural blossom blight infection occurred during bloom on 6–9 May 2000. All trees had abundant bloom, and almost all flower clusters were infected. Fire blight symptoms became appar-

ent on 6 June, and five of the seven replicates of each rootstock were sprayed with PC while two replicates were left unsprayed. PC was sprayed at 593 mg·L⁻¹ a.i. using 393 L water/ha (12 oz Apogee/acre applied at 2.4× concentrate spray) with an air-blast sprayer. Regulaid spreader-activator was added at a rate of 0.125% by volume. The PC spray treatment was repeated on 22 June. On 11 Oct, the number of trees with fire blight symptoms on the rootstock (ooze or blackening on the stock) and the number of trees with a severe shoot infection of the scion (most of the leader and several scaffolds dead) were recorded. Data were analyzed by calculating the chi square value for the frequency of rootstock and severe scion infection of PC vs. untreated trees. Comparisons among rootstock were made by calculating the least significant difference (LSD) ($P = 0.05$) for the PC and control trees separately.

Results

Eastern New York. The incidence of trees with fire blight was higher in Livingston than in Modena, but PC treatment had no effect on disease incidence at either site (Table 1). Prohexadione-calcium reduced the total dry weight of fire blight strikes removed by pruning in Livingston, but not in Modena (Table 1). Most of the reduction occurred in week 2, while new strikes were still numerous. Although new strikes were observed and removed for most of the growing season, the greatest amount of infection had already taken place prior to the time that PC affected shoot growth. The number of cuts per week did not differ among treatments, however the values followed trends similar to those of the pruning weights, suggesting that the number of new strikes, as well as the severity of the individual cuts contributed to differences in the total amount of diseased wood that was removed. Although post-infection applications of PC reduced shoot growth by 20%, these sprays had no effect on tree mortality, the incidence of scion or rootstock cankers, the number of scaffolds removed, or the amount of leader removed (Table 2).

Western New York. PC sprays did not reduce the frequency of rootstock infection of any rootstock (Table 3). Overall the fre-

quency of rootstock infection was 37% for the untreated trees and 38% for the PC treated trees. The incidence of rootstock infection differed significantly among rootstocks. B.9 had no rootstock infections while M.26, M.26EMLA, M.26VF, M.7EMLA, M.9VF, MM.106EMLA, and P.14 had high levels of rootstock infection. MM.111EMLA had a low level of infection.

There was no effect of PC on the frequency of severe scion infection (Table 3). Among rootstocks, B.9, M.26, M.7EMLA, MM.106EMLA, MM.111, and P.14 all had moderate frequencies of severe scion infections while M.26EMLA, M.26VF, and M.9VF had no trees with severe scion infections.

Discussion

Fire blight is an increasingly important disease in the apple and pear growing regions of the eastern and midwestern United States. The current trend of planting susceptible cultivars on highly susceptible rootstocks has greatly increased the likelihood of rootstock blight and the risk of tree mortality, as evidenced in southwest Michigan in 2000 (Longstroth, 2000). Prophylactic treatment with PC has been shown to reduce the severity of shoot blight infections (Yoder et al., 1999a). Yoder et al. (1999b) reported that PC followed 7 d later by streptomycin gave better suppression of shoot blight than either chemical alone. Where PC is used to suppress shoot blight during summer, inoculum levels in orchards may be lower the following year, thereby resulting in reduced selection pressure for development of streptomycin resistance in the bacterial pathogen.

Hickey et al. (2001) reported that PC applications to 1- and 2-year-old trees in Pennsylvania reduced the incidence of shoot blight with minimal effects on total shoot length at the end of the season. In that experiment, shoots were artificially inoculated with *E. amylovora* 14 to 17 d after PC was applied in late May or early June. In our experiments, PC applications failed to slow the progress of naturally-occurring epidemics in two commercial orchards despite the fact that moderate temperatures and extensive summer rains during 2000 kept trees growing until late in the summer. Active shoot growth throughout

Table 1. Effects of post-infection application of prohexadione-calcium (PC) on the percentage of trees infected by fire blight, the number of cuts required to removed blight infections during summer, and the dry weight of prunings removed from 'Gala' apple in eastern New York, 2000.

	Infected trees (%)		Dry wt (kg/plot) of infected wood, leaves, and fruit removed during summer								Total no.
Treatment	13 June	10 July	13 June	19 June	23 June	27 June	30 June	3 July	10 July	Total	of cuts/tree
Livingston, N.Y.											
Control	88.0	94.9	5.1	1.7	0.4	0.4	0.1	0.3	0.1	8.0	5.1
PC	83.5	89.2	3.5	0.9	0.4	0.2	0.1	0.2	0.0	5.2	4.0
Prob (F)	0.28	0.35	0.14	0.05	0.83	0.26	0.28	0.54	0.25	0.02	0.0009
	Infected trees (%)		Dry wt (kg/plot) of infected wood, leaves, and fruit removed during summer								Total no.
Treatment	3 July	22 Sept.	3 July	13 July	20 July	22 Sept.	Total		of cuts/tree		
Modena, N.Y.											
Control	45.4	52.4	5.6	0.6	0.5	0.5	7.1		1.1		
PC	32.0	35.3	4.9	0.5	0.3	0.1	5.7		0.7		
Prob (F)	0.06	0.09	0.85	0.73	0.41	0.11	0.72		0.0003		

Table 2. Effect of post-infection prohexadione-calcium (PC) application on tree mortality, canker incidence, scaffold removal, and leader loss of 'Gala' / M.9 apple trees in eastern New York, 2000.

Treatment	Tree (%)					Shoot length (cm)
	Mortality	Scion canker	Rootstock canker	Scaffolds removed	Leader loss	
<i>Livingston, N.Y.</i>						
Control	29	9	28	25	2.0	47.7
PC	29	6	27	24	1.8	38.0
Prob (F)	1	0.31	0.94	0.91	0.2	>0.0001
<i>Modena, N.Y.</i>						
Control	6	6	6	43	1.1	40.3
PC	4	1	4	24	1.1	32.3
Prob (F)	0.45	0.11	0.52	0.34	0.8	<0.0001

Table 3. Effect of post infection prohexadione-calcium (PC) application on fire blight infection of the rootstock and scion of 'Gala' apple trees in western New York, 2000.

Rootstock	No. of test trees	Rootstock infection (% of trees)			Scion infection (% of trees)		
		Control	PC	Prob (F)	Control	PC	Prob (F)
B.9	14	0	0	1.00	0	20	0.33
M.26	13	50	67	0.57	50	0	0.02
M.26EMLA	14	100	90	0.51	0	0	1.00
M.26VF	14	50	60	0.73	0	0	1.00
M.7EMLA	13	50	22	0.32	25	11	0.52
M.9VF	11	67	25	0.20	0	0	1.00
MM.106EMLA	14	50	40	0.73	0	20	0.33
MM.111EMLA	13	0	22	0.31	0	11	0.45
P.14	11	50	78	0.43	0	11	0.62
All Rootstocks	117	37	38	0.84	15	10	0.40

summer provided an exceptionally long season for continued spread of fire blight and therefore should have been ideal for demonstrating the value of post-infection sprays of PC. Effects of PC on shoot growth become evident 10 to 14 d after application. Until shoot growth is arrested, trees sprayed with PC presumably remain susceptible to fire blight infection, and infections occurring after PC application but before shoot growth is arrested may require another 10–14 d before they are visible. Therefore, fire blight control benefits of PC sprays may not be evident until 3 or 4 weeks after the PC application, a timing that would correspond to the 3 July observation date in Livingston and 20 July in Modena. Even during the cool wet summer of 2000, there was relatively little spread of blight after those dates as evidenced by the low dry weights of the prunings removed and the relatively small changes in the percentages of trees infected at between the first and final observation at each site (Table 1). Thus, in northern growing regions, PC applications made after fire blight symptoms become visible will be too late to have any significant impact on the epidemic.

Hickey et al. (2001) reported that PC applications had little effect on total shoot growth in Pennsylvania, but young trees treated with PC would be less likely to "catch up" to non-treated trees in New York, where a shorter growing season and weaker soils would allow less late-season growth than commonly occurs in Pennsylvania. As a result, PC applications in young orchards in northeastern United States could have significant indirect costs that accrue as a result of delayed productivity.

Considering the value of pre-infection applications of PC, and the possibility that PC may induce resistance mechanisms in the tree that are not coupled to the cessation of shoot growth, it was hoped that post-infection applications might reduce the severity of shoot blight damage and increase tree survival. Although PC was effective in reducing shoot growth in this study, we have demonstrated that, under these conditions, post-infection treatment with PC is of no practical value in reducing fire blight symptoms and does not reduce the incidence of either rootstock blight or mortality of young 'Gala' trees on M.9 or M.26. This finding is consistent with the theory that the suppression of shoot blight conferred

by PC is a result of growth control, and therefore PC must be applied well in advance of the appearance of fire blight symptoms to be effective for fire blight suppression.

In these studies, many more trees were lost due to rootstock infection than from infections to the scion, suggesting that resistant apple rootstocks will be very valuable in helping an orchard survive a fire blight epidemic. Although a resistant rootstock will not prevent the loss of some of the scion canopy following blossom infection, it may prevent the loss of the entire tree. If the rootstock does not die, the canopy can be re-grown the following year.

Literature Cited

- Byers, R.E. and K.S. Yoder. 1999. Prohexadione-calcium inhibits apple, but not peach, tree growth, but has little effect on apple fruit thinning or quality. *HortScience* 34:1205–1209.
- Costa, G., C. Andreotti, F. Bucchini, E. Sabbatini, C. Bazzi, S. Malaguti, and W. Rademacher. 1999. Prohexadione-Ca: Growth regulation and reduction of fire blight incidence in pears, cv. 'Abate Fetel'. *HortScience* 34:481. (Abstr.)
- Greene, D.W. 1999. Tree growth management and fruit quality of apple trees treated with prohexadione-calcium (BAS 125). *HortScience* 34:1209–1212.
- Hickey, K.D., N.O. Halbrendt, J. May, and E. Anderson. 2001. Evaluation of Apogee™ for prevention of fire blight shoot infection on newly planted apple trees, 2000. *Fungic. Nematic. Tests* 56:pf-3. On-line publication at <www.scisoc.org/online/FNtests/>.
- Longstroth, M. 2000. The fire blight epidemic in southwest Michigan. Mich. State Univ. Internet publication: <http://www.msue.msu.edu/vanburen/fb2000.htm>
- Norelli, J., H. Aldwinkle, T. Momol, B. Johnson, A. DeMarree, and M.V.B. Reddy. 2000. Fire blight of apple rootstocks. *N.Y. Fruit Quart.* 8(1):5–8.
- Rademacher, W., J.B. Speakman, G. Krack, M. Scholtissek, R. Wolf, J.R. Evans, S. Roemmelt, and D. Treutter. 1999. Prohexadione-Ca: Induction of resistance against bacterial and fungal pathogens in apple. *HortScience* 34:535. (Abstr.)
- Steiner, P. W. 1998. Problems in managing fire blight in high density orchards on M-9 and M-26 rootstocks. West Virginia Univ. Internet publication: <http://www.caf.wvu.edu/kearneysville/articles/SteinerHort1.html>
- van der Zwet, T. and S.V. Beer. 1999. Fire blight—its nature, prevention, and control: A practical guide to integrated disease management. U.S. Dept. Agr. Agr. Info. Bul. 631.
- Yoder, K.S., S.S. Miller, and R.E. Byers. 1999a. Suppression of fire blight in apple shoots by prohexadione-calcium following experimental and natural inoculation. *HortScience* 34:1202–1204.
- Yoder, K.S., A.E. Cochran II, W.S. Royston, Jr., and S.W. Kilmer. 1999b. Suppression of fire blight infection of apple shoots by Apogee, 1998. *Fungic. Nematic. Tests* 54:38–39