NEW YORK
FRUIT QUARTERLY
VOLUME 8 • NUMBER 1 • SPRING 2000

Editorial

Funding Apple Research

Over the past 10 years, our farm and many others have experienced an increase in fire blight pressure. This has been a combination of blossom, shoot and rootstock blight. Some of the increase may be due to the popularity of more highly susceptible scion varieties and rootstocks. Most of the new varieties demanded by the market and planted in New York in high density plantings are susceptible to fire blight. They include Ginger Gold, Gala, Fuji, Honeycrisp, Jonagold, Smoothie Golden, Fortune, NY 674, Cameo, and more. The combination of highly susceptible varieties with highly susceptible rootstocks such as M.9 and M.26 often results in rootstock blight and tree death. Although we have been growing M.9 rootstock for 30 years we have had far more tree death due to fire blight in the last few years. Storms such as the Labor Day storm of 1998 caused serious fire blight outbreaks, especially in nursery trees that were still growing vigorously at that time. Unfortunately, there are very few good control options to apply on the farm. Thus, the urgency to develop better control programs.

This issue of the *NY Fruit Quarterly* details the substantial research efforts undertaken at Cornell University to help growers in the battle against this disease. The work ranges from the very practical efforts to optimize disease prediction models so that applications of streptomycin can be better timed, to the futuristic efforts to insert resistance genes into susceptible apple varieties such as Gala to come up with fire blight resistant versions of popular varieties.

This research effort is funded from several sources including the State of New York and the federal government. However, through the grower funded NYS Apple Research and Development Program, the apple industry has also provided funds to assist in this effort. In some cases, our funds have been essential in getting the work done. In other cases, we have provided seed money which allowed researchers to obtain significantly more funds from the federal government. Fire blight research is an excellent example of this, how grower funds from the New York apple industry can be used to help convince the federal government that it should fund a significant grant on fire blight in New York.

My service on the board of the NYS Apple Research and Development Program has given me a broad look at the way money raised by growers is used and how it influences the research programs at Cornell. In general, the funds we provide are only a small portion of the costs of doing the research because the salaries of all the researchers are paid by the state. Nevertheless, our money provides operating dollars and has a significant impact on what the researchers choose to work on. If it were not for the Apple Research and Development Program, many of the people trying to help us solve the apple industries problems would be working on other crops where there are grower grant funds or federal grant funds.

On the inside front cover, directly across from this editorial, is a listing of the projects funded by the NYS Apple Research and Development Program for July 2000-July 2001. These projects total more than $155,000 from grower funds and $22,000 from voluntary processor contributions. The New York apple industry should be proud of the financial support we extend to researchers to help solve the production and marketing problems facing our industry.

Darrel Oakes
Board member of NYS Horticultural Society
and NYS Apple Research and Development Program
Lynoaken Farms
Lyndonville, NY

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Front cover: Watch out for first signs of new fire blight infections in apple orchards—adhering blackened flowers, some withdrops of sticky, honey-colored ooze (inset).

Back cover: This experimental transgenic Royal Gala apple contains a fire blight resistance gene and is fruiting in field trials. Inset: The resistance gene was transferred to apple in tissue culture.

NEW YORK
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This publication is a joint effort of the New York State Horticultural Society, Cornell University's New York State Agricultural Experiment Station at Geneva, and the New York State Apple Research and Development Program.

Editors:
Terence Robinson and Steve Hoying
Dept. of Horticultural Sciences
New York State Agricultural Experiment Station
Geneva, New York 14456-2227
Telephone: 315-787-2227
Fax: 315-787-2216
Advertising: Warren Smith: 914-255-1442

Fire Blight of Apple Rootstocks

Jay Norelli[1], Herb Aldwinckle[1], Timor Momol[4], Bill Johnson[2], Alison DeMarree[3], and M.V. Bhaskara Reddy[1]

[1]Plant Pathology and [2]USDA-ARS/Horticultural Sciences,
New York State Agricultural Experiment Station
Cornell University, Geneva, New York
[3]Cornell Cooperative Extension
7654 Town Line Rd., Williamson, NY
[4]North Florida Research and Education Center
University of Florida, Quincy, FL

This research is supported by the New York Apple Research and Development Program, and USDA-CSREES Northeast Regional IPM and Special Grants.

The infection of susceptible apple rootstocks like M.9 and M.26 with fireblight often results in the death of the tree. At present rootstock blight is poorly understood. Root suckers are one avenue of infection for the rootstock but it now appears that the fire blight bacteria can move from blossom and shoot infections in the scion downward inside healthy tissue into the rootstock where infection and girdling occur.

The rootstock phase of fire blight is a serious threat to high value orchards of susceptible apple varieties planted at high density on susceptible rootstocks, especially M.9 and M.26. We have calculated that one episode of 10 percent rootstock blight can result in losses of up to $3,500 per acre.

At present, rootstock blight is not well understood. We have shown that suckers are one avenue of infection for the rootstock, but do not account for more than 50 percent of such infections. It now appears that fire blight bacteria from blossom and shoot infections in the scion, moving downward inside healthy tissue into the rootstock, where they multiply and cause infection and girdling, are a very important avenue of infection for rootstocks. Thus, it is important to understand better how fire blight infects rootstocks, especially the rootstocks of young trees on M.9 and M.26, and what factors (for example, tree age and crop load) influence infection of rootstocks. It is also important to know at what time in the growing season scion infections pose most risk to the rootstock so that control of scion infections can be concentrated at the riskiest period. We must also determine experimentally in orchard trees, whether the new Geneva rootstocks are, as we expect, more resistant to rootstock blight than M.9 and M.26, and can be strongly recommended for future plantings in locations with high fire blight risk.

Internal Movement of Bacteria

Greenhouse and orchard experiments provide strong evidence that fire blight bacteria can be transported from blossom and shoot tip infections, down through apparently healthy scion tissue, into the rootstock.

The internal spread of bacteria can take place very soon after initial infections in the scion. When tips of potted Empire and Golden Delicious trees on M.26 were inoculated with fire blight in the greenhouse, bacteria were detected in the rootstock of Empire trees 21 days after inoculation and in the rootstock of Golden at 41 days (Figure 1). Just 12 days after inoculation, fire blight bacteria were detected in symptomless one-year-old scion tissue more than 20 inches below the shoot-tip in Empire and Golden, and also in two-year-old tissue in Golden. Mature scion shoots that had just ended rapid growth were inoculated in this experiment, and shoots developed only short lesions. That, however, did not appear to limit the systemic spread of bacteria down from the lesions into healthy scion tissue. Under the appropriate conditions, the internal spread of fire blight bacteria appears to take place very soon after the initial infection.

Complete tree loss results from a fire blight infection in the M.9 rootstock of this Royal Gala tree. The rootstock phase of fire blight can greatly reduce the profitability of high-density orchards.

To determine the effect of tree growth on the movement of bacteria through the scion, Empire trees on M.26 were inoculated in the greenhouse at different times during the growing season. Surprisingly, it was found that most internal spread occurred in the more mature shoots (10 weeks after growth initiation) rather than in younger, vigorously growing shoots. Table 1 indicates that the movement of fire blight bacteria to the rootstock is more closely associated with the growth stage of plants than with a specific amount of time after infection. For example, when plants were inoculated with fire blight bacteria at the early growth stage, bacteria were not detected in the rootstock until 15 weeks after inoculation or when the trees entered into late growth stage; whereas, in plants inoculated at the late growth stage, the fire blight bacteria could be detected in the rootstock only three weeks after inoculation. Fire blight bacteria were detected in the rootstocks of five out of six plants inoculated at the late growth stage compared with 1/6 and 2/6 of plants inoculated at the early and mid growth stages, respectively. Thus, late-season shoot infections may be particularly hazardous for the rootstock.

trees of the resistant variety Liberty and the more susceptible variety Empire showed the same frequency of rootstock infection. Approximately 50 percent of the infected trees were infected via suckers. Scion infections were also critical. The risk of rootstock infection increased with increasing numbers of scion infections, but the susceptibility of the scion variety (based on the *severity* of shoot infections) did not have a significant effect on rootstock infection. The same number of trees of the resistant variety Liberty had infections of the M.26 rootstock as that of the more susceptible Empire variety. Apparently it is the *number* of infections, rather than their severity, that increases the likelihood of rootstock infection.

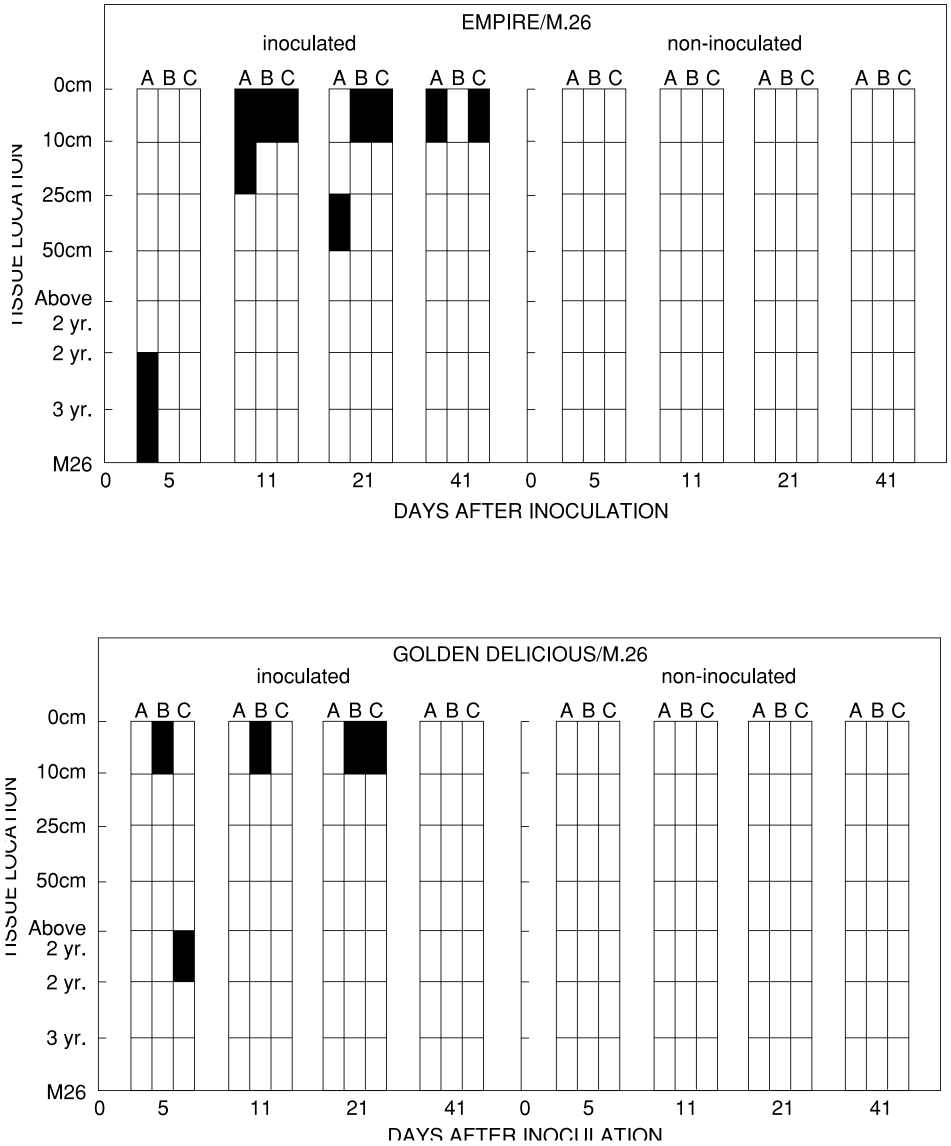


Figure 1. Detection of fire blight bacteria in 'Empire/M.26' (upper) and 'Golden Delicious/M.26' (lower) apple plants following inoculation. Green indicates the presence of the bacteria in three different replicate plants (A, B and C). Scion wood was assayed at 10 cm (4 in), 25 cm (10 in), and 50 cm (20 in) below the shoot tip in < 1-year-old wood, at 1 cm (1/2 in) above the margin with 2-year-old wood, at the mid-point of 2-year-old wood, and at the mid-point of 3-year-old wood. M.26 rootstock tissue was assayed 1 cm below the graft union.

Biological and Economic Analysis of the Costs and Benefits of Pruning Fire Blight Infections Out of Young Trees

It is often recommended that fire blight infections be pruned out of young apple trees during the growing season to prevent rootstock infection. We evaluated how effective removal of infected shoots was on Empire, Jonamac, and Liberty trees on M.26 rootstock and trees of Empire, Liberty, and Mutsu on M.9 rootstock. Pruning out scion infections three weeks after blossom inoculation and then repeatedly during the growing season gave variable results in three years of experiments. In 1995 and 1997, pruning had no beneficial effect on eventual death of the rootstock, but, in 1996, pruning out infections reduced rootstock death. However, two to three consecutive years of pruning reduced fruit yield. In comparison to non-inoculated trees, fruit yield on M.9 trees was reduced by 6 percent on unpruned inoculated trees, but by 62 percent on pruned inoculated trees (two years of pruning). On M.26 trees, yields were reduced by 8 percent on unpruned inoculated trees, but by 79 percent on pruned inoculated trees (three years of pruning). Despite these high yield reductions, an economic analysis indicated that pruning out fire blight infections was cost effective. Accumulated net present value (NPV) 20 years after planting for an M.26 planting (272 trees /acre, central leader) without fire blight was $4,684, compared with ***minus*** $47 for unpruned inoculated trees and ***plus*** $521 for pruned inoculated trees. The improved profitability in the pruned treatment was a result of the reduced tree loss in 1996.

Economic analysis also indicated that replanting, rather than pruning fire blight out of infected trees, may be cost effective if severe fire blight occurred in trees in their

TABLE 1

Detection of fire blight bacteria in inoculated Empire/M.26 apple plants that were assayed 3, 6, and 15 weeks after inoculation.

Growth stage of shoot at time of inoculation	No. wks after inoculations	Date assayed	Bacteria in Scion[a]	Bacteria in Rootstock[b]
Early	3	Jun 6	2/6	0/6
(inoculated May 16)	6	Jun 27	1/6	0/6
	15	Aug 30	2/6	1/6
Mid	3	Jul 3	0/6	0/6
(inoculated June 11)	6	Jul 26	0/6	2/6
	15	Sep 25	0/6	0/6
Late	3	Jul 27	4/6	5/6
(inoculated July 6)	6	Aug 18	2/6	0/6
	15	Oct 18	0/6	0/6

[a] Scion wood was assayed at the mid-point of symptomless 2-year wood.

[b] Rootstock was assayed 1 cm below the graft union.

TABLE 2

Incidence of rootstock blight in newly planted, 2nd and 3rd leaf trees.

Tree age	Year planted	Crop Load Treatment	(# fruit/ cm^2)	Incidence of Rootstock Blight
1st leaf	1999	non-bearing	-	1.4% (1/70)
2nd leaf	1998	overall mean		1.7% (1/58)
		fruiting	3.8	0.0% (0/28)
		defruited[a]	0.0	3.3% (1/30)
3rd leaf	1997	overall mean		20.0% (12/60)
		fruiting	8.2	13.8% (4/29)
		defruited	0.0	25.8% (8/31)

[a] Young fruit removed on June 8, 1999.

1st or 2nd leaf, but losses from replanting greatly increased for trees in their 3rd, 4th, or 5th leaf. For example, if a fire blight epidemic required replanting 50 percent of the trees in the second and third year, accumulated NPV was reduced from $4,684 to $3,191 and $2,001, respectively, whereas replanting in the fifth or sixth year gave NPV of ***minus*** $6,360 and ***minus*** $9,290, respectively.

Effect of Tree Age on Incidence of Rootstock Blight

We still have not yet determined what factors favor the multiplication of fire blight bacteria in the rootstock after they arrive there, and what factors determine how bacteria cause the fatal necrotic infection of the rootstock. In three years of greenhouse tests, we observed the spread of bacteria into the rootstock, but we have not observed the multiplication of bacteria and infection of the rootstock. Field inoculation of shoots of newly planted, non-bearing trees on M.26 indicated that bacteria moved systemically into the rootstock of first-year trees, but did not result in rootstock infection. In contrast, blossom inoculation of trees on M.26 in their 4th leaf (2nd year of fruiting), and blossom inoculation of trees on M.9 in their 3rd leaf, resulted in 11 percent and 5 percent rootstock infection, respectively. This suggests that trees coming into bearing may be at greater risk of rootstock infection than non-bearing trees.

Sets of Royal Gala trees on M.26 rootstock were planted in the springs of 1997, 1998, and 1999 to determine the effect of tree age on the incidence of rootstock blight. To determine the effect of fruit load on tree susceptibility, half of the trees were defruited on June 8, 1999. Three shoots per tree were inoculated at a late growth stage (June 24) with fire blight bacteria. Shoots selected for inoculation were approximately three feet from the rootstock graft union and had initiated terminal bud-set, but the last-formed terminal leaves were still expanding. Rootstock blight was evaluated on September 23, 1999.

As seen in Table 2, trees in their 3rd leaf were significantly more susceptible to infection than those in their 1st or 2nd leaf. Trees in their 3rd leaf had a very heavy fruit load. However, stress on young trees due to a heavy fruit load had no detectable effect on the susceptibility of the trees to rootstock infection, and there was not a significant difference in the incidence of rootstock infection between fruiting and defruited 3rd leaf trees. However, the stress of flowering would already have occurred before the fruitlets were removed, and thus might already have increased susceptibility to rootstock infection.

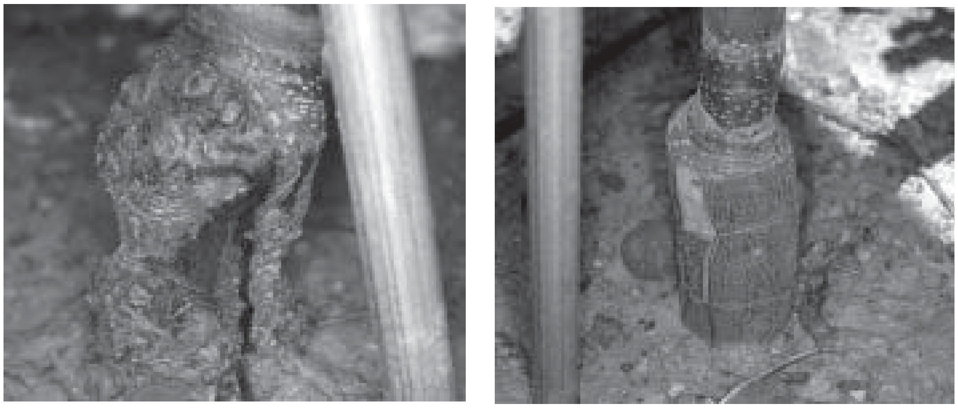
Resistance of Geneva Apple Rootstocks to Internally Transmitted Fire Blight Infection

One of the main goals of the Geneva apple rootstock breeding program is fire blight resistance. Fire blight resistant parents were used in the crosses, and seedlings were rigorously screened when young, and also when older, by artificial inoculation several times with fire blight bacteria. Shoot tips, as well as lower stems of the plants, were directly inoculated, and only resistant plants were retained in the program. Different degrees of resistance were observed in this study.

As described above, we now know that one mode of infection of the rootstock is by bacterial cells moving down from blossom or shoot infections in the scion, inside healthy appearing branches and trunk, into the rootstock, and there developing necrotic infections. A trial to determine the susceptibility to this mode of infection of as many of the Geneva stocks then thought to be promising, of which sufficient trees could be obtained, was planted in 1997. The trial included six to twelve trees of 18 Geneva rootstocks and six check rootstocks, all grafted with Royal Gala.

In 1999, three-year-old Royal Gala trees on the different rootstocks were spray inoculated twice during bloom with a very virulent strain of the fire blight bacterium. All trees developed severe fire blight infections in the scion. Subsequently, symptoms of rootstock infection were observed.

Presence of bacterial ooze on rootstocks was first observed on June 16, about four weeks after scion inoculation. Incidence of ooze increased during the next few weeks. Most, but not all, trees with ooze were clearly dead by mid-fall. Blackening of some rootstocks was also observed, with or without ooze. This blackening may be due to necrosis, but did not always appear to result in girdling and tree death. In several rootstocks, blackened tissue exfoliated, or peeled off, revealing underlying healthy tissue. Trees in which the rootstocks were apparently girdled were distinguished by yellow leaves if the trees died in the summer, or by purple/bronze leaves if the trees died in the fall. Trees in which the rootstock was not girdled had some branches with



Left: Fire blight infected M.26 rootstock. The presence of bacterial "ooze" and blackening were symptoms of infection leading to tree death. Right: Fire blight resistant G.16 rootstock. Although blackening of some G.16 rootstocks was observed following inoculation of the Gala scion with fire blight bacteria, blackened tissue exfoliated, or peeled off, revealing underlying healthy tissue. None of the inoculated trees on G.16 died.

green leaves in the fall, although many branches had brown, dead leaves because of scion infections.

The results on tree death are necessarily preliminary since it is expected that more trees will have died by the next spring and summer (2000). However, the incidence of tree death by mid-fall 1999 is probably a good indication of relative susceptibility to this type of fire blight infection. Table 3 shows the greatest incidence of tree death by October 1999 occurred on M.26 (83% and 40% on two clones), and M.9 (75%). M.9 trees were apparently not grafted with Royal Gala, but probably with McIntosh or a close relative. On these trees, scion infections were also severe, but perhaps not as severe as on the Royal Gala trees. No trees on MM.111, Maruba kaido, or Bud.9 died. It is unclear why Bud.9 was so resistant since, although it is regarded as less susceptible than M.26 and M.9, death of Bud.9 trees has been reported from growers' orchards. P.14 had 14% tree death.

Of the introduced Geneva rootstocks, G.16 and G.30 had 0 percent tree death, and G.11 had 25 percent. G.11 has always been described as only moderately resistant to fire blight, and this trial confirms that its resistance is not complete. Nevertheless it is substantially more resistant than M.26 and M.9. Nine other Geneva rootstocks in the trial had 0 percent tree death, and six others had 0-17 percent tree death. CG.103 had 58 percent tree death. Several of the Geneva rootstocks that were included in the trial when it was planted in 1997 have now been discarded from the program as a result of their inadequate pomological performance in other trials.

It must be emphasized that this trial was inoculated with fire blight in an extremely severe way, and tremendous scion infection resulted. It is unlikely that trees would encounter the same level of infection naturally. Thus the incidence of tree death observed is very much a worst-case scenario. Nevertheless the results give an indication of the relative susceptibility of selected Geneva rootstocks to internally transmitted rootstock blight.

TABLE 3

Symptoms observed on the rootstocks of three-yr-old Royal Gala trees grafted on Geneva and check rootstocks that were inoculated by spraying blossoms with fire blight bacteria.

Rootstock	Total Number of Trees	% with ooze on July 10	% Tree death on Oct 15
M.9VF (McIntosh scion)	12	58	75
M.26E	12	92	83
M.26VF	10	40	40
MM.111EMLA	12	0	0
Maruba kaido	12	8	0
B.9	12	0	0
P.14	7	29	14
G.11	12	25	25
G.16	6	0	0
G.30	11	0	0
CG.3	12	8	0
CG.8	12	0	0
CG.26	12	0	8
CG.60	9	11	0
CG.103	12	58	58
CG.134	11	9	9
CG.602	12	8	8
CG.3041	12	0	8
CG.4214	6	0	0
CG.4247	11	0	0
CG.5012	9	33	11
CG.5179	12	0	17
CG.5757	12	0	0
CG.6723	12	0	0
CG.6737	6	0	0

Future Research

Research is continuing on several aspects of rootstock blight, especially the resistance of different rootstocks; the influence of tree age, of time of scion infection, and of scion varieties with different levels of resistance; the desirability of pruning out infections; and the use of Apogee in young trees to control shoot infection. Biotechnology is also being used to transfer genes to increase fire blight resistance into susceptible rootstocks, like M.26 and M.9, so that resistant strains of these rootstocks can be made without affecting their desirable nursery and orchard characteristics. Genes have already been transferred into M.26, and transgenic lines are being tested. Research to develop improved methods to transfer genes into M.9 is under way.

Herb Aldwinckle is a Professor of Plant Pathology and leads the fire blight team at Cornell. Jay Norelli is a Senior Research Associate in Plant Pathology working with Dr. Aldwinckle and B. Reddy is a Postdoctoral Fellow also in Aldwinckle's group. Timor Momol was formerly a Postdoctoral fellow with Aldwinckle and is now an Assistant Professor at the University of Florida. Bill Johnson is Research Scientist with USDA-ARS located in the Horticultural Sciences Department who leads the Geneva rootstock breeding program. Alison DeMarree is a Regional Extension Educator with the Lake Ontario Regional Fruit Team located in Newark. She specializes in farm management and economics.

Successful Fire Blight Control is in the Details

Deborah I. Breth[1], M.V.Bhaskara Reddy[2], Jay Norelli[2] and Herb Aldwinckle[2]

[1] Lake Ontario Fruit Team, Cornell Cooperative Extension, Albion, NY
[2]Dept. of Plant Pathology, New York State Agricultural Experiment Station Cornell University, Geneva, NY

This research is supported in part by the New York Apple Research and Development Program and the USDA Special Grant.

Over the past 10 years there has been an increase in fire blight pressure giving urgency to the development of better control programs. There are very few new options to apply on the farm, but changes may be on the horizon. At present, the use of precise disease prediction models is critical in timing application of streptomycin for blossom blight control and resistance management. In the future, integrating antibiotic sprays with other "softer" plant protection methods like biocontrol agents, SAR inducers and growth regulators offers promise to keep the development of antibiotic resistance and fire blight under control.

Controlling fire blight is an essential aspect of apple production in both young and old plantings. Since establishment costs for high-density plantings are as high as $5000 per acre, fire blight control in a new planting is even more critical than in an old established orchard. The intensity of the control program should be based on the susceptibility of the scion variety *and* the susceptibility of the rootstock. Susceptible varieties on susceptible rootstocks require the most comprehensive management program.

The basic fire blight management program is not described here in detail. The purpose of this article is to address specific fire blight problems and report results of ongoing research to solve these problems.

Figure 1. Weather stations are used to monitor maximum and minimum temperature and wetting periods from rain and dew. The data are entered into a disease prediction model to time streptomycin application to control blossom blight, and to predict symptom development for all phases of the disease.

Susceptibility of Varieties and Rootstocks

Most of the new varieties demanded by the market and planted in New York in high density plantings are susceptible to fire blight. They include GingerGold, Gala, Fuji, Honeycrisp, Jonagold, Smoothee Golden, Fortune, NY 674, Cameo, and more. A list of varieties susceptible to fire blight rated in previous research is included in Table 1. New varieties have not been rated experimentally as to the level of susceptibility. But the incidence of infections under natural inoculum conditions have been reported in the table from personal communication with consultants, and with Drs. Steven Miller and Alan Biggs from a variety trial in Kearneysville, WV, part of regional project NE183 to evaluate varieties.

Rootstock susceptibility is discussed in another paper in this issue of the *Fruit Quarterly.* The combination of highly susceptible scion varieties on highly susceptible rootstocks such as M.9 and M.26, often results in rootstock blight and tree death. In an ideal world, the market would only demand varieties that are resistant to fire blight. In the real world, however the first step in controlling fire blight is recognizing the potential for disaster and preventing it. Don't let fire blight get established in a new planting!

Fire Blight Control for New Plantings

Site selection is a critical component of an integrated fire blight control program for new plantings. Pick a planting site with well-drained soil, and good air drainage. Before planting, add soil nutrients such as potash, phosphorus, and lime to provide calcium and magnesium and to correct pH. These nutrient deficiencies are harder to correct after planting. Set the planting as far as possible from an infected apple or pear orchard. Isolation always helps. Many times, however, we have to plant that new orchard right next door to a processing orchard that has plenty of fire

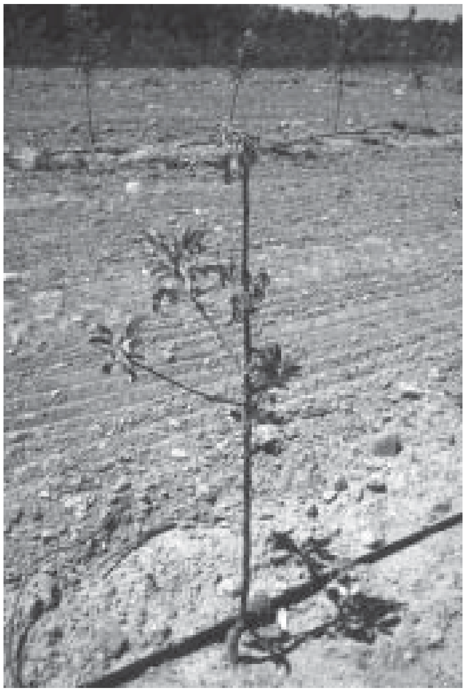


Figure 2. This newly planted orchard of Gala on M.9 with multiple blossom blight infections.

blight. This is often a recipe for disaster.

There are two major concerns that may contribute to the risk of fire blight in newly planted blocks. First, many nursery trees are purchased with "feathers" (scaffold branches) that produce some flower buds in the first year. Some varieties like Gala and GingerGold flower on one-year-old wood. Newly planted trees come into bloom after established orchards have bloomed, when growers have stopped monitoring for blossom blight conditions on the remainder of the farm. The blossoms in the new planting are then very vulnerable to infection. Second, many nursery trees come from areas where there may be streptomycin-resistant *Erwinia amylovora*. Resistance to streptomycin has not been documented in New York except for an isolated incidence. Most nurseries do a thorough job of controlling fire blight with streptomycin and copper as needed for high-risk infection conditions. But *E. amylovora* is a successful epiphyte, surviving on the surface of bark and leaves. So to get a theoretical "clean start" in the new orchard, an application of copper at budbreak after planting may kill any bacteria on the surface of the new trees.

To test management strategies for prevention of fire blight in susceptible high-density orchards, demonstration plots were established in newly planted blocks on two farms in 1997. Treatments were:

1) No copper with blossoms intact.
2) Copper with blossoms intact.
3) No copper with blossoms removed.
4) Copper with blossoms removed.

The plantings were followed through 1999. Orchard A was set up in eight rows of Jonagold on M.9 located windward of an established Idared orchard infected with fire blight. This block was not a replicated trial because the grower wanted to keep unprotected parts of the block very small to reduce the risk from fire blight. Orchard B was a block of Gala and Fuji on M.9 located on the windward side of a pear orchard with minimal fire blight infection due to cool bloom periods. Orchard B was replicated across varieties, and subsamples of treatment plots were evaluated for each treatment.

Copper applications were made the first year using Kocide DF at 4 lb/100 gal dilute applied to drip at budbreak and two weeks later. In the second leaf, only one copper application was made at budbreak. In the 1st and 2nd leaf, the blossoms were removed by pinching them off at the stems to prevent removal of any potential apical bud that would develop into a growing point. Timing of blossom removal preceded weather conditions that were conducive for blossom blight infection conditions. Both orchards were mapped to identify all trees in the block. These maps were used to document where blossoms were intact, and where any fire blight infections occurred.

Although insufficient incidence of infection occurred for statistical analysis, there was a trend in Orchard A that had more inoculum pressure from a nearby orchard. Plots with blossoms left intact had more fire blight infection than in those where blossoms were removed (Table 2). There was no apparent difference between treatments with and without copper. In Orchard B with randomized plots of equal size, the only infection reported was in a plot with no copper applied and with blossoms intact. Under natural inoculum levels, these data do not show striking differences between treatments. But as we continue to follow these plantings into the 4th leaf, observations will be made concerning the potential for rootstock blight development. So far, the major contributing factors for fire blight establishment in a new planting are the presence of blossoms and inoculum in nearby orchards. Over the years, there have been new plantings that have not had fire blight controls applied and no infection has resulted. Expensive disasters are becoming more common, though, and once established, fire blight will be a menace for the new planting for years to come.

Recommendations drawn from field experience and demonstration plots include:

1) Apply copper to "sanitize" the new trees at budbreak.
2) Remove blossoms in 1st and 2nd leaf plantings before the blossoms open or before the occurrence of a blossom blight infection. This can be done when central leader shoots are selected.
3) If blossoms are not removed, monitor weather conditions for blossom blight conditions and apply streptomycin as needed.
4) Monitor the planting weekly and re-

Figure 3. Experimental material is sprayed for control of fire blight.

TABLE 1

Cultivar susceptibility to fire blight compiled from several sources.

very resistant = no control needed; resistant = control needed only under high disease pressure;
susceptible = control usually needed where disease is prevalent; very susceptible = control

Apple cultivar	Relative susceptibility	Apple cultivar	Relative susceptibility
Ambrosia	?	Mollies Delicious	Susceptible[1]
Arlet	?	Monroe	Susceptible[2]
Beacon	Susceptible[1]	Mutsu	Very Susceptible[1]
Braeburn	Very Susceptible[2]	Northern Spy	Resistant-Susceptible[1,2]
Cameo	Susceptible[3]	NY674	Susceptible[4]
Cortland	Susceptible[1]	NY75414-1	Susceptible[3]
Creston (BC8m15-10)	Susceptible[3]	Orin	Susceptible[3]
Delicious (Red, all strains)	Resistant[1]	Paula Red	Susceptible-Very Susceptible[1,2]
Elliot	?	Pinova	?
Empire	Resistant[1]	Pioneer Mac	Susceptible[3]
Enterprise	Susceptible[3]	Prima	Resistant[1]
Fortune	Susceptible[4]	Priscilla	Resistant[1]
Fuji	Very Susceptible[2]	Pristine	Susceptible[3]
Fuji 2	Susceptible[3]	R.I. Greening	Very Susceptible[1]
Gala (all strains)	Very Susceptible[2]	Redfree	Resistant-Susceptible[1,2]
GingerGold	Very Susceptible[2]	Rome Beauty	Very Susceptible[1]
Gold Rush	Susceptible[3]	Sansa	Susceptible[3]
Golden Delicious	Resistant-Susceptible[1,2]	Senshu	?
Golden Russet	?	Shizuka	?
Golden Supreme	Susceptible[4]	Smoothee (Golden Del.)	Resistant-Susceptible[1,2]
Granny Smith	Very Susceptible[1]	Spartan	Susceptible[1]
Gravenstein	Susceptible[1]	Spigold	Very Susceptible[1]
Honeycrisp	Susceptible[4]	Stark Bounty	Resistant[1]
Idared	Very Susceptible[1]	Stark Splendor	Resistant-Susceptible[1,2]
Jerseymac	Susceptible[1]	Starkspur (Delicious)	Susceptible[1]
Jonafree	Resistant-Susceptible[1,2]	Stayman	Resistant-Susceptible[1,2]
Jonagold	Very Susceptible[1]	Suncrisp	?
Jonamac	Susceptible[1]	Sunrise	Susceptible[3]
Jonathan	Very Susceptible[1]	Twenty Ounce	Very Susceptible[2]
Liberty	Resistant[1]	Tydeman	Susceptible[1]
Lodi	Very Susceptible[1]	Viking	Resistant[1]
Macfree	Resistant[1]	Wealthy	Susceptible[1]
Macoun	Susceptible[1]	Yataka	Susceptible[3]
McIntosh	Resistant-Susceptible[1,2]	Zesta!	?

[1] Ratings from MSU Web site, Nancy J. Butler, "Disease on Apples".
[2] Ratings from WV University, Kearneysville website, K.S. Yoder and A.R. Biggs.
[3] Ratings from Drs. Steven Miller and Alan Biggs in NE183 plot, WV.
[4] Ratings from other field observations.

move any infections noted in the trees to prevent spread to other trees. The closer the planting is to an infected orchard, the more closely the new trees should be scouted.

5) Control aphids and leafhoppers, which are suspected to spread fire blight.

Blossom Blight—The Most Powerful Phase Of The Disease

Control Materials: Blossom blight is the epidemic phase of the disease that provides the inoculum for shoot blight, trauma blight, and rootstock blight for years to come. The most effective material for blossom blight control is streptomycin sprayed during bloom, when infection is predicted by the MARYBLYT™ model. However, streptomycin-resistant strains of *E. amylovora* have developed in many parts of the country due to too frequent use of streptomycin.

Streptomycin is effective in fire blight control because it limits the multiplication of bacterial cells. Bacterial diseases require a certain number of bacterial cells to result in disease symptoms. One bacterium does not result in disease. Streptomycin is only locally systemic—it is only absorbed by blossoms that are open at the time of application. Slow drying conditions increase the absorption of streptomycin and make it more effective. Current recommendations for streptomycin are to apply it at a rate of 8 oz/100 gal dilute rate, or at 4 oz/100 gal if mixed with Regulaid. Using lower rates will not give reliable results, and may increase the chance of resistance development. Dr. Tom Burr has shown reduced efficacy of streptomycin when mixed with calcium and phosphate ions. Streptomycin should not be applied with foliar nutrients. Tank mixing with mancozeb has not been documented to reduce control. Thorough spray coverage is critical.

Alternatives to streptomycin for controlling blossom blight, such as copper, are limited in their usefulness due to inferior efficacy and phytotoxicity, especially russeting. Other alternatives such as a biocontrol agent (BlightBan C9-1), SAR (systemic acquired resistance) inducers (e.g. Actigard 50 WG and Messenger), a growth regulator (Apogee 125 11W), and new formulations of copper (Phyton 27) and antibiotics (Pace-17) are being evaluated for blossom blight control in replicated plots at Geneva, NY. BlightBan C9-1 is a living bacterium that colonizes the habitats of *E. amylovora* on the plant when applied before the infection takes place and inhibits the pathogen from multiplying. An SAR inducer is a chemical agent which activates natural resistance in the plant, but does not have direct antibacterial activity. Most of these products are in the experimental phase of development and still require EPA and/or NYS-DEC registration for orchard use.

The materials listed above were evaluated in 1997-99 for control of blossom blight on 'Idared' apple trees in a research orchard at Geneva, NY. Treatments were replicated five times with 150-200 blossom clusters per replication in a randomized complete block design. The products were applied at 1/2-inch green, pink, 10 percent bloom, 24 h before inoculation and 24 h after inoculation, depending on their mode of action, using a single nozzle handgun sprayer at 150 psi and sprayed to run off. The blossom clusters were inoculated at full bloom with *E. amylovora* using a Solo backpack sprayer. Infected and healthy blossom clusters were recorded three weeks after inoculation and fruit russeting was assessed seven weeks after the last spray.

The results of 1997 field trials showed a significant reduction in blossom infection when trees were sprayed with SAR inducers and biocontrol agents compared to untreated trees (Table 3). The disease control by biocontrol agents (BlightBan C9-1 and A506) alone was approximately half the control achieved with Agrimycin at 14.7 g and 29.4 g/50 L (4 oz and 8 oz/100 gal dilute) treatment. A significant reduction of blossom blight incidence was observed in Actigard and Messenger treated trees compared to the untreated check, but control was not as good as it was with the Agrimycin treatments. Although Mankocide and Kocide treatments significantly reduced blossom blight infection, fruit russeting was observed in both the treatments. In 1998 the weather during bloom was favorable for blossom blight infections with 50 percent infected blossom clusters in the untreated inoculated check. Blightban A506 was not significantly different from the check. A 32 percent reduction in blossom blight was observed in BlightBan C9-1 treated trees. Less blossom blight was observed in Actigard and Messenger treatments but was not significantly different from the check. Kocide 2000 and Nu-Cop 3L, gave similar control to Agrimycin 4 oz/100 gal treatment (52-57 percent control). The addition of mancozeb to Kocide 2000 improved control over either treatment alone, but was not significantly better than Microsperse, Nu-Cop 50DF, or Agrimycin 4 oz/100 gal). Agrimycin at 4 oz/100 gal gave the best control, reducing infection by 73 percent.

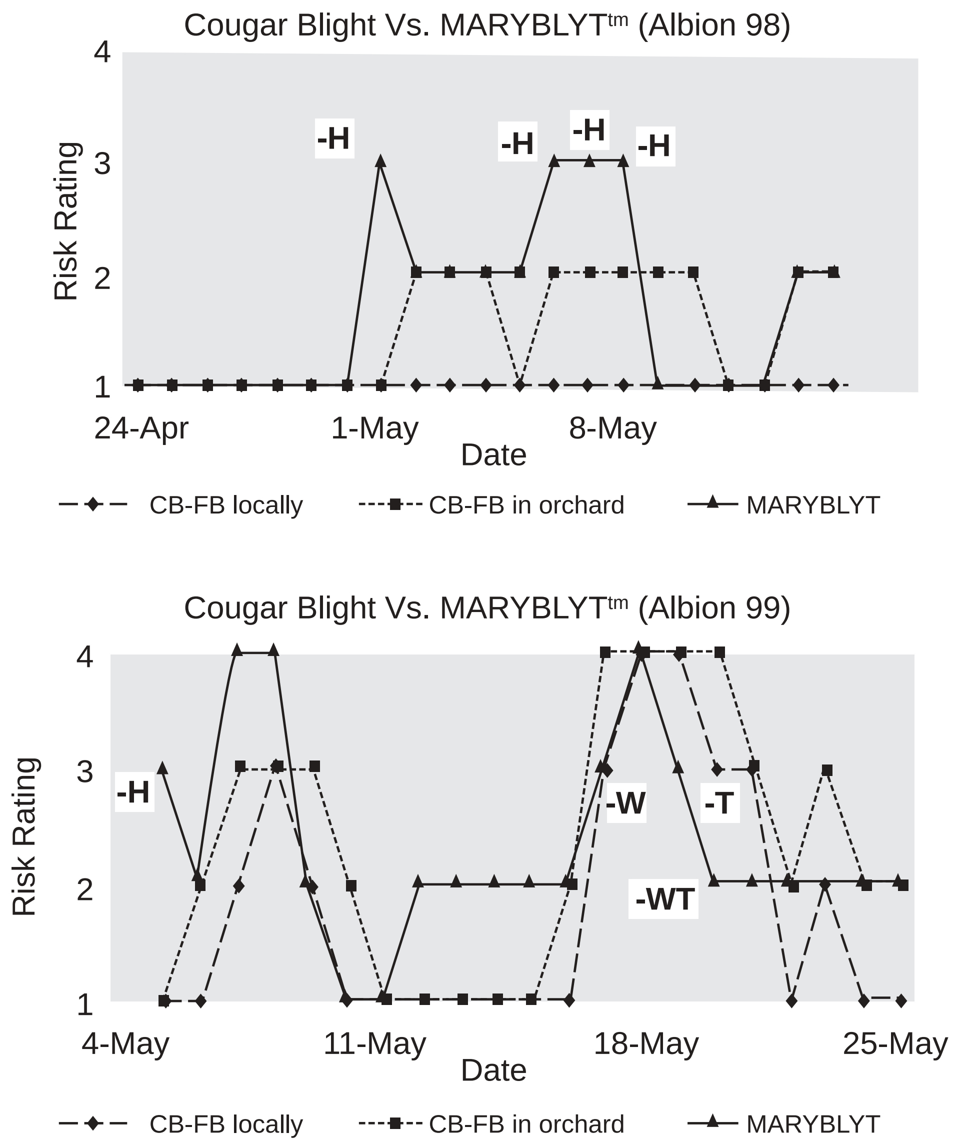


Figure 4. Comparison of MARYBLYT^{tm} blossom blight prediction with prediction by Cougar Blight in orchard with fire blight in orchard last season and fire blight in local area last season.

TABLE 2

Effect of copper and blossom removal on fire blight development in a newly planted Jonagold orchard.

		% trees with blossom blight			% trees with shoot blight
Treatment	# trees	1997	1998	1999	1999
+ Copper[z], - bloom	587	0.2	0.3	0.2	1.4
+ Copper, + bloom	32	3.1	3.1	0.0	3.1
- Copper, - bloom	52	0.0	0.0	0.0	0.0
- Copper, + bloom	26	0.0	3.8	11.5	23.1

[z] In 1997 Kocide DF applied at budbreak + 2 weeks. In 1998 Kocide DF applied at budbreak.

The results from 1997 and 1999 field trials were similar in the control of blossom blight infections. In 1999, the weather during bloom was hotter than usual and bloom lasted for 20 days (7 May-26 May). During this period the MARYBLYT^{tm} program predicted two high-risk days but no infection period. In our trials, inoculation coupled with high risk days for fire blight infection during bloom resulted in 25.7 percent of blossom clusters infected, and allowed for efficient screening of products for activity against blossom infection. Pace 17 (streptomycin) at 14.7 g/50L (4 oz /100 gal) with Regulaid applied 24 h before and after inoculation gave the greatest control (71.8 percent), closely followed by the same treatment with Agrimycin-17 (streptomycin at 4 oz/100 gal). Lower rates (7.35 g/50L (2 oz/100 gal dilute) of Pace 17 and Agrimycin 17 with Regulaid were tested at Geneva to compare the control of these treatments alone with the same rates used in combination with a biocontrol agent such as BlightBan C9-1. These rates are not recommended as standard practice for growers due to resistance development issues and normally provide less effective control. BlightBan C9-1 applied at 10 percent bloom and 24 h before inoculation gave 40.5 percent control. When BlightBan C9-1 was applied during bloom, and followed with streptomycin at the experimental low rate after inoculation, there was only slight improvement in control. Research from other states showed improved control from biocontrols if integrated with recommended rates of streptomycin. Sprays of Mankocide DF, Nucop 50 DF and Phyton 27, 24 h before and 24 h after inoculation all resulted in significant (50 percent) control of the disease. Mankocide and Nucop caused the greatest amount of fruit russeting, although russeting was significantly less when Mankocide was applied once, 24 h pre-inoculation, followed by Pace treatment. Phyton 27 is a very unusual copper compound that caused very little russeting. Messenger at 26 g/50L applied at 1/2-inch green and pink resulted in 46 percent control, which was numerically but not statistically different from streptomycin. The level of infection in Apogee treated blossoms was not significantly less than in the untreated inoculated check. Greater disease control was obtained with biocontrol agents when combined with SAR inducers or antibiotics suggesting that the alternative materials are compatible and have good potential for an integrated management of a blossom blight program. The biocontrol agents and SAR inducers are still experimental and not registered in New York, but show considerable promise, especially if used in combination. Further research on combination of biologicals and SAR inducers is being done in the lab, greenhouse and field in 2000.

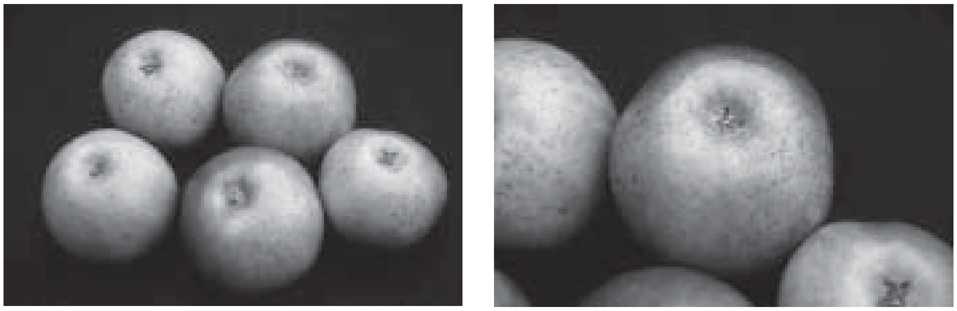


Figure 4. Black speckling and russet resulted from copper applications in cover sprays on Twenty Ounce apples. These are destined for the processor because they are not acceptable for fresh fruit.

TABLE 3

Effect of antibiotics, copper compounds, biocontrol agents and SAR inducers on blossom blight control in Idared trees, Geneva , NY 1997

Treatment	Rate/50L[z]	Time of application[y]	Infected blossom [x] clusters %
Untreated inoculated check			50.0 a
Agrimycin	29.4 g	3,4	6.9 gh
Agrimycin	14.7 g	3,4	6.1 gh
Vigor-Cal +Agrimycin	500 ml 14.7 g	2,3,4 3,4	8.8 fgh
Mankocide DF	79.75 g	3,4	12.0 cdef
GWN-9200 10W	37.5 g	3,4	10.7 defg
GWN-9200 10W	75.0 g	3,4	9.7 efgh
GWN-9200 10W	100.0 g	3,4	8.5 fgh
Kocide 101 77W	47.8 g	3,4	10.4 defg
BlightBanC9-1	12.6 g	2,4	14.1 bcde
BlightBan A506	13.1 g	2,4	16.4 bc
BlightBan A506 +Actigard 50 WG	13.1 g 6.0 g	2,4 1,4	18.7 b
BlightBan A506 +Agrimycin 17	13.1g 14.7 g	2,4 4	7.5 fgh
BlightBan A506 +Agrimycin 17	13.1g 14.7 g	2,4 3,4	5.2 h
Actigard 50 WG	6.0 g	1,4	15.3 bcd
Messenger	5.0 g	1,4	18.4 b
Messenger	10.0 g	1,4	15.9 bc

[z] All treatments were tank-mixed with Break-through (50 ml/50L), a surfactant from Plant Health Technology Inc.

[z] Time of application 1 = pink (8 May); 2=10% bloom (14 May); 3= 24 h before inoculation (20 May); 5= 24 h after inoculation (22 May)

[y] Treatments followed by the same letter did not differ significantly (*P*=0.05) as determined by Waller grouping.

In field trials on commercial farms in western New York without artificial inoculation, the use of copper/mancozeb to control fire blight during bloom gave comparable results to plots treated with streptomycin in low disease pressure conditions (no blossom blight infection predicted). However, commercial plots with natural inoculum and a blossom blight infection period showed that streptomycin provided superior control under high blossom blight disease pressure without the poor fruit finish that results from copper applications. If copper is used it must be applied at the lower rates stated on the labels (Champ 2F at 2/3 pt/acre) starting at 10 percent bloom, at 5-7 day intervals. Research data in trials at Geneva suggest better control when the copper is mixed with mancozeb.

TABLE 4

Effect of antibiotics, copper compounds, SAR inducers on shoot blight control in Idared trees, Geneva , NY 1999

Treatment (rate/50L)	Surfactants (rate/50L)	Time of application[1]	% blighted shoot length	% russeted fruit	% russeted fruit surface
Untreated control			89.7 a	0.2 c	1.0 bc
Empire (inoculated)			7.2 g		
Pace 17 14.7 g	Regulaid 15 ml	4,5	35.2 f	0.3 c	0.5 c
Agrimycin 17 14.7 g	Regulaid 15 ml	4,5	39.9 ef	0.0 c	0.0 c
Mankocide DF 79.75 g.	Regulaid 15 ml	4,5	55.8 bcd	21.3 a	4.5 a
Phyton 27 13.3 ml	Regulaid 15 ml	4,5	61.0 b	6.9 b	4.1 a
Actigard 50 WG 10.0 g	Regulaid 15 ml	2,3	50.8 bcde	0.6 c	0.6 c
Messenger 26.0 g	Reguard100 ml	2,3	43.9 def	0.6 c	3.0 ab

[1] 1 = Petal fall + 5 days (May 21), 2 = 2 weeks after #1 (June 4), 3 = 1 week before inoculation (11 June), 4 = 24 h before inoculation (16 June), 5 = 24 h after inoculation (18 June), 6 = 10 days after inoculation.

[2] Treatments followed by the same letter did not differ significantly (*P*>0.05) as determined by Waller grouping.

Timing of Control Sprays

Blossom blight control using streptomycin hinges on critical timing of the application. The old standard timing in the mid-1980s was to apply streptomycin when the temperature was above 65 °F and rainfall or relative humidity was above 60 percent during bloom. In the absence of anything better, some growers sprayed and some didn't. Many times, growers got away without spraying and had very little incidence of fire blight in apples. This gave growers a false sense of security when they ignored the system. However, more sophisticated predictive models have been developed that are risky to ignore when they predict blossom blight infections.

In New York, we have been working with MARYBLYT^{tm} since 1992, and Cougar Blight since 1997, and have gained experience and confidence in their predictions. MARYBLYT^{tm} 4.3 is a computer-based model, developed by Dr. Paul Steiner, designed to predict blossom blight infection potential and symptom development of most phases of fire blight. The model assumes an abundance of inoculum in the orchards. It predicts the potential risk of infection based on the occurrence of certain environmental conditions in sequence. These conditions include:

1) The presence of blossoms.
2) The accumulation of 198 DH (>65 F) from start of bloom.
3) A wetting event including rain, dew or a spray application, or 0.1 in. of rainfall the day before.
4) The average temperature of 60 F the day of infection.

A second model, Cougar Blight, was developed in Washington State by Tim Smith. It is not a computer model, but can be set up on a spreadsheet. The model uses a lookup chart to determine daily degree hours accumulated based on the maximum and minimum temperatures. Users calculate the sum of degree hours over four days during bloom leading up to a potential wetting period. Users must select the appropriate inoculum potential based on proximity to the inoculum source. Neither of these models will predict how many infections may result if the risk of infection is high.

We have collected weather data since 1997 from weather sensors across the region. The data were entered in the MARYBLYT^{tm} 4.3 model for many sites, and into the Cougar Blight spreadsheet as well. The predictions of both models were entered into a spreadsheet for comparison of blossom blight predictions. Comparison of predictions from both models for two seasons showed that the models are closely correlated in terms of heat units accumulated. Both models rely on growers to determine the occurrence of a wetting event. MARYBLYT^{tm} 4.3 requires data entry for the wetting event; Cougar Blight assumes a wetting event has occurred or will occur. Figures 1 and 2 show the risk prediction of both models on the Y axis, where 1 = low, 2 = moderate, 3 = high, and 4 = "Infection" for MARYBLYT^{tm} or "Extreme" risk for Cougar Blight. The "-H" (insufficient heat units), "-W"(lack of wetting event), "-WT"(lack of wetting event and temperature below 60), etc., indicate the required factor missing for MARYBLYT^{tm} when it predicted a lower risk potential than Cougar Blight, in 1998 and 1999.

One factor that seems to reduce the correlation between models is the MARYBLYT^{tm} requirement for 60 °F average temperature.

If the MARYBLYT^{tm} infection risk is "high" (three of four requirements for blossom infection are met) with the only missing factor being the average temperature of 60 °, the model will recommend the consideration of a streptomycin application to protect open blossoms. If a wetting event is the only factor missing, growers need to do some critical thinking about the potential for dew in low spots in orchards or note any spray applications that are made that could wet the blossoms resulting in an infection. When growers are inputting maximum and minimum temperatures to run the models, it is important they run a range of temperatures in the forecast to cover differences across the microclimates of the farm. There are always warmer spots on a farm that will surprise us with fire blight infections.

It is important to remember that all models rely on accurate weather data and forecasts. All models have some flexibility in risk prediction for growers to adjust risk according to variety, rootstock, inoculum source, etc. Based on three years of comparison, the two models correlate well when enough heat units have accumulated and there is a wetting event. Accuracy of the model predictions is evident from the severe level of fire blight incidence in blocks not treated with streptomycin when they predicted infection in 1999. In order for either model to be useful for blossom blight control, streptomycin must continue to be bothe available and effective. When we start to use the new SAR inducers and biocontrols, the models will need to be modified to recommend applications earlier than 24 hours before or after an infection.

Shoot Blight Control

If blossom blight is completely prevented, shoot blight will usually be minimal. To date, there is no effective registered control for shoot blight. We recommend streptomycin be sprayed after bloom to control shoot blight only in the case of hail or severe wind and rain. Repeated applications of streptomycin in a heavily infected orchard will quickly lead to selection of resistant strains of *E. amylovora* and loss of this valuable material for blossom blight control. Alternative controls have been tested in replicated inoculated plots in Geneva and in two replicated commercial plots with natural inoculum.

Note: exciting results on control of shoot blight with the growth regulator, Apogee, are reported in a separate article in this issue, and are not repeated here.

The efficacy of two antibiotics, two copper compounds, and two SAR inducers against infection of shoots by fire blight was evaluated on 'Idared' trees in a research orchard at Geneva. Treatments were replicated five times with each replicate consisting of a single tree in a randomized complete block design. All treatments were applied to run off using a single nozzle handgun sprayer. Following the treatments, 20 growing tips of current season shoots, 20-40 cm long, from each tree, were inoculated by bisecting the two youngest leaves with scissors dipped in *E. amylovora* inoculum. Shoots of Empire were inoculated as an untreated moderately resistant check. All inoculated shoots were labeled. Six weeks after inoculation the lengths of necrotic infection and of the whole shoots, including the infected length, were determined. A week later, the proportion of fruit with russet and of the russeted fruit surface area was estimated.

In inoculated untreated checks, 89 percent of shoot length became blighted, which was significantly higher than for all other treatments (Table 4). Pace and Agrimycin treatments, which are both streptomycin formulations, applied before and after inoculation, gave the highest level of control (61 percent and 56 percent, respectively). There was no significant difference in the level of control obtained with Agrimycin, Actigard or Messenger treatments applied prior to inoculation. The Mankocide and Phyton 27 treatments were both significantly better than the untreated check, but not as effective as the streptomycin treatments. Both resulted in fruit russet, although Phyton 27 caused significantly fewer russeted fruits than Mankocide.

Copper does not have systemic activity against fire blight bacteria and will not provide control of the internal spread of *E. amylovora* within the tree once a shoot is infected. However, it does have the potential to reduce the population of epiphytic bacterial populations from oozing infections to limit further spread to wounded tissue in the tree. In 1999 there were no differences in levels of shoot blight in replicated commercial plots where Champ 2F (2/3 pt/acre) cover sprays were applied starting at 1-2 weeks after petal fall and 10-14 day intervals. However, 1999 was a very dry season causing terminal buds to set early, shutting down succulent growth that probably limited the spread of fire blight. There was significantly more fruit russet in copper treated plots than in the plots without copper.

Summary

In conclusion, there are very few new options to apply on the farm for fire blight controls, but changes may be on the horizon. The one big change that has occurred over the past ten years is the increase in disease pressure and an increase in the urgency for maintaining a tight, full season management program for fire blight on the whole farm. At present, the use of precise disease prediction models is critical in timing application of streptomycin for blossom blight control and resistance management. In the future, integrating antibiotic sprays with other "softer" plant protection methods like biocontrol agents, SAR inducers and growth regulators is a potential option to keep the development of antibiotic resistance and fire blight under control. Unfortunately, the cost of these integrated programs with antibiotics will be more expensive. For now, streptomycin continues to be the critical control material to manage fire blight.

Deborah Breth is an Area Extension Educator with the Lake Ontario Area Fruit Team located in Albion. She specializes in integrated pest management. B. Reddy is a Postdoctoral Fellow in Herb Aldwinckle's group at Geneva. Jay Norelli is a Senior Research Associate in Plant Pathology working with Dr. Aldwinckle. Herb Aldwinckle is a Professor of Plant Pathology and leads the fire blight team at Cornell.

Cornell Student Wins Scholarship

Rebecca Lynn Scott, a Junior Plant Science major at Cornell, is the recipient of the Valent BioSciences Corporation – NYS Horticultural Society Scholarship. The 3.5 GPA student plans to do graduate work in pomology after graduation, and her ultimate career goal is to be a cooperative extension agent or something related to that. In the essay that accompanied her application for the scholarship, she wrote ,"I hope to become a cooperative extension agent and fruit specialist so that I can give back something to the community that supported my ambition."

Rebecca has worked during the summer at The New York State Experiment Station's Hudson Valley Lab. She credits that experience, along with the support of the community, as providing her with inspiration to pursue her chosen profession. Rebecca has just recently accepted an internship in Cornell's Fruit Science program where she will work with Drs. Merwin, Watkins, Pritts, and Cheng.

On winning the scholarship Rebecca says, "I am honored to accept this award from the New York State Horticultural Society and the Valent BioSciences Corporation. I plan to put it to good use in furthering my interest and education in fruit research."

The Hort Society and Valent wish Rebecca the best of luck in all her future endeavors.

Rebecca Lynn Scott

Controlling Shoot Blight with 'Apogee'

Herb Aldwinckle[1], Terence Robinson[2], Jay Norelli[1], Timor Momol[3] and M.V. Bhaskara Reddy[1]

[1]Departments. of Plant Pathology and [2]Horticultural Sciences
Cornell University, New York State Agricultural Experiment Station,
Geneva, NY
[3]North Florida Research and Education Center, University of Florida,
Quincy, FL

This work is supported in part by the New York Apple Research and Development Program.

A new growth regulator named Apogee, which controls excessive shoot growth and reduces the need for summer pruning, may have an additional valuable use in controlling shoot fire blight infections of both young and mature apple and pear trees. This should help reduce the risk growers face when planting new varieties and dwarfing rootstocks that are extremely susceptible to shoot blight and rootstock blight.

Infection of vegetative apple shoots with fire blight (*Erwinia amylovora*) can cause devastating losses to apple and pear growers following hail storms, severe wind storms, or when blossom fire blight is not controlled. Shoot blight is especially dangerous with many of the most popular new apple varieties (Gala, Gingergold, Fuji, and Pink Lady) and with the dwarfing M.9 and M.26 rootstocks. A recent example occurred in May 1998 when a severe wind storm hit the Grand Rapids area of Michigan. Several hundred acres of trees were blown down but the epidemic of shoot fire blight that followed killed 2000 acres of trees (Phil Schwalier, personal communication). Many of the losses were with dwarf, high-density orchards. A similar storm hit New York State on Labor Day 1998, and significant fire blight outbreaks followed, especially in nursery trees that were still growing vigorously at that time.

Vigorously growing shoots are much more susceptible to infection with fire blight than shoots that have ceased growth. This has led pear growers in New York to maintain orchards in a low state of vigor to try to avoid vigorous shoot growth and thus fire blight epidemics. Thus, it seems reasonable that chemical growth regulators that control vegetative shoot growth, such as Apogee, would make the shoots less susceptible to fire blight.

Apogee (Prohexadione-Calcium) is a new growth regulator being developed by BASF Corporation for use on apples and pears. It will be registered for use in the 2000 season. Its primary horticultural benefit is a reduction of shoot growth. Apogee inhibits the synthesis of the growth promoting plant hormones, gibberellins, thus reducing shoot growth. In trials at Geneva with McIntosh in 1997, 1998, and 1999, shoot growth was reduced from 18 inches average shoot length to ten inches average shoot length or about a 40 percent reduction (Table 1). This reduced the need for summer pruning to get good color on McIntosh. In our trial we did not summer prune the trees and there was an increase in red color of fruit from 38 to 55 percent. Apogee will be marketed as a chemical method of reducing the need for summer pruning on vigorous cultivars. A secondary horticultural effect is that Apogee increases fruit set. In many cases this is an unwanted side effect since we usually need to reduce cropload to achieve proper fruit size. Thus, Apogee treated trees generally have slightly smaller fruit size unless they are thinned aggressively.

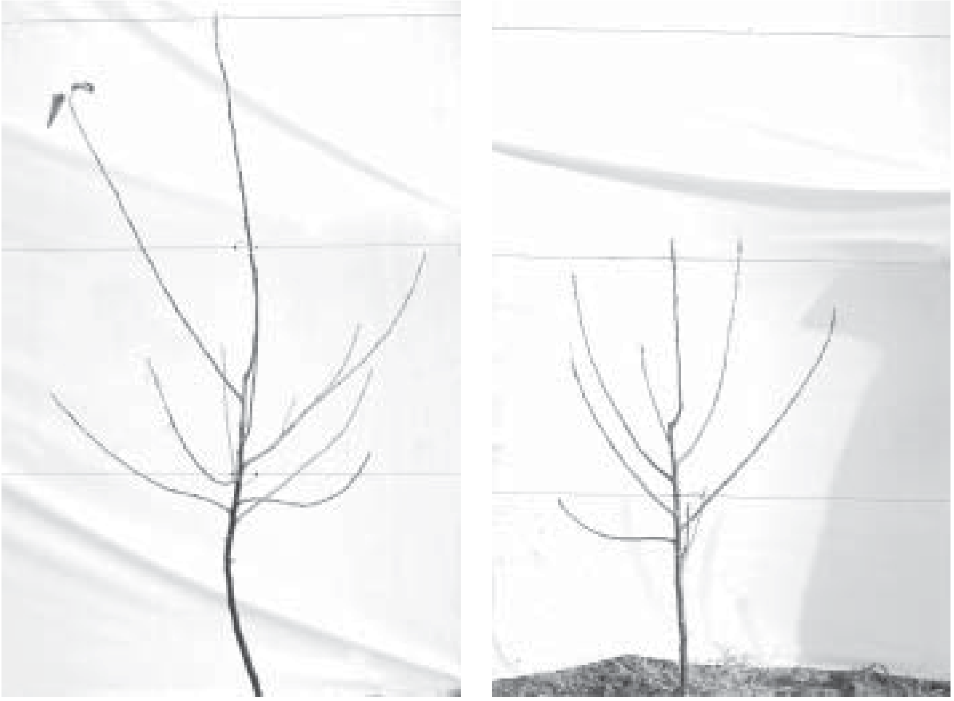
We have also shown experimentally that Apogee limits fire blight development in apple shoots. Several recent reports confirm that Apogee reduces the secondary spread of fire blight to vegetative shoots by controlling shoot growth (Breth et al., 1998; Yoder et al., 1999). Trials conducted during 1995 at Kearneysville with a single application of Apogee at 250 ppm or two applications at 125 ppm reduced shoot growth and resulted in 40-58 percent reduction in number of fire blight strikes per tree (Yoder et al., 1999). Trials in Michigan with Jonathan (susceptible variety) and Golden Delicious (moderately resistant variety) showed 30 and 50 percent control of shoot blight respectively, in Apogee treated trees, compared to untreated trees. Recent work by Jones et al. (1999) showed that Apogee can be used with streptomycin to achieve good control of both blossom and shoot blight. In their trial, streptomycin was used

TABLE 1

Effect of Apogee on tree growth of 20 year old 'McIntosh/M.9' apple trees. (1997)

Treatment[z]	Apogee Application Rate (mg a.i./l)	Application Dates[z]	Total Shoot Growth (cm)	Cropload (fruit number/cm^2 TCA)	Fruit Size (g)	Fruit Red Color (%)
Untreated Control	—	—	45 a	0.83 a	136 a	38 b
Two Applications	125	1,2	25 b	0.89 a	129 ab	50 a
Single Application	250	1	26 b	1.08 a	122 b	58 a

[z]1= June 4, 2= June 13.



These GingerGold trees are at the end of the first year. The tree on the left was untreated and the tree on the right was treated with Apogee in July.

TABLE 2

Effect of Apogee on tree growth and fire blight infection of inoculated 'Gingergold/M.9' apple trees in their first year (1999).

Treatment[z]	Apogee Application Rate (mg a.i. / l)	Applications[y]	Central Leader Growth after Treatment Date (cm)	Total Shoot Growth after Treatment Date (cm)	Disease Severity (%)[x]
Untreated Control	—	—	26.5 a	109.0 a	34.4 a
Multiple Low Doses	62.5	1,2,3,4	9.2 b	51.1 b	2.2 b
Standard Dose 2 times	125	1,3	9.5 b	32.7 b	0.6 b
Single High Dose	250	1	7.7 b	28.8 b	4.6 b

[z] All spray treatments were tanked mixed with the surfactant "Kinetic" (0.63 ml / l)

[y] 1= July 12, 2= July 19, 3= July 26 and 4= Aug. 2

[x] Shoots were inoculated on August 6. Disease severity (% of shoot length infected with fire blight) was recorded on Oct 27.

to prevent blossom blight infection, was followed by Apogee at petal fall to control shoot blight. In addition to controlling shoot growth and fire blight, Apogee has also shown pronounced effects on the incidence of apple scab in experiments in Europe (Rademacher et al., 1999). This effect is apparently not due to any fungicidal or bactericidal effects of Apogee, but to the induction of natural defense compounds.

Use Of Apogee On Young Trees

Apogee has no effect on blossom blight infection and will not protect young trees from infection during bloom. However, removal of blossoms in the first and second year is a suitable management strategy for control of blossom blight. Apogee's use on young trees will be limited to summer shoot blight control. With young apple trees the dilemma in developing a use strategy for Apogee is that although Apogee may limit fire blight susceptibility, it may also limit tree canopy development, which is counter to the horticultural goal of rapidly filling the space to get a return on the investment. With mature trees, Apogee must be applied at petal fall or soon after to have a major effect on shoot growth, but with young trees, such an early application timing will cause too much growth inhibition. Therefore, later timings are probably more suitable.

In 1999, we began an experiment to determine if a use strategy for Apogee could be developed whereby significant fire blight protection could be achieved without sacrificing tree growth or yield. Our first year results were very promising. On first year GingerGold/M.9 trees Apogee provided excellent fire blight protection when applied in early August (Table 2). However, it also caused more growth reduction than optimal from a horticultural perspective. The economic effect of the growth reduction from Apogee may yet prove to be positive if the untreated trees die or have to be pruned severely to save them. A possible strategy for growers to use on young trees that are at risk of fire blight would be to wait until much of the current season's shoot growth is developed before treating with Apogee in early July. This will then provide significant fire blight protection from devastating late-season shoot blight infections caused by hail storms or wind storms. Further work is needed on even lower rates and other timings than those used in this study to determine if lower rates will allow better tree growth while still providing fire blight protection.

Shoot Blight Control In Older Trees

With mature trees, in general, Apogee must be applied at petal fall or soon after to have a major effect on shoot growth. The chemical will begin to affect shoot growth about ten days after application, and the duration of the effect depends on dose and tree vigor. A low dose controls growth for only about three to four weeks, while a high dose may provide season- long control in New York. Our suggested application strategy on mature trees is to apply two sprays, with the first spray at petal fall when shoot growth is about two to three inches long. A second application would come about two to three weeks later. On weaker-growing cultivars only one or two applications may be required while on vigorous soils and vigorous cultivars three applications may be needed.

During 1998 and 1999, the efficacy of Apogee against infection of shoots by fire blight was evaluated on 'Idared' trees in a research orchard at Geneva. In 1998, Apogee (250 ppm) was applied twice (2.5-5 in and 6-8 in of new shoot growth) followed by inoculation two weeks later. Following the treatments, 20 growing tips of current season shoots from each tree were inoculated with fire blight bacteria. Six weeks after inoculation the lengths of necrotic infection and total length of the shoot, including the infected length, was measured. The Apogee treated trees that showed only 8.4 percent of current shoot length was infected compared with 60 percent in untreated trees (Table 3).

In 1999, two sprays of Apogee at two concentrations (125 and 250 ppm) were applied five days after petal fall and again two weeks later to mature Idared trees. In separate treatments, Apogee was applied at 250 ppm a week before inoculation and ten days after inoculation to determine if there was any post-infection curative effect. Shoots were again inoculated as in 1998, and lesion length as a percentage of total shoot length was measured six weeks later. Empire trees were also inoculated as an untreated moderately resistant check. In 1999, the best Apogee treatment showed 36 percent of shoot length infection compared to 89 percent in the untreated Idared trees (Table 4). Control of shoot blight was not significantly different at lower or higher concentrations if Apogee was applied before infection. If Apogee was applied ten days after infection, there was less control than when applied before infection. Early application of Apogee, prior to the development of fire blight, appears to be critical for optimal control of shoot blight.

White arrows indicate trees that are untreated and black arrows indicate Apogee treated tops.

TABLE 3

Effect of Apogee on shoot blight control in mature 'Idared/M.7' trees. Geneva , NY, 1998.

Treatment/Product	Rate/50L	Time of Application[1]	% Blighted Shoot Length[2]
Untreated inoculated control			59.6 ab
Untreated non inoculated control			0.0 d
Empire (inoculated)			38.2 c
Agrimycin 17	29.5 g	3	36.6 c
Apogee	45.5 g	1,2	8.4 d
Apogee non inoculated	45.5g	1,2	0.0 d

[1] 1 = 2.5-5 in of current shoot growth, 2 = 6-8 in of current shoot growth, 3 = 24 h before inoculation.

[2] Treatments followed by the same letter did not differ significantly (P=0.01) as determined by Waller grouping.

Summary

Apogee will likely prove to be very useful in the control of shoot blight on susceptible varieties and with susceptible rootstocks. Although blossom blight is often controllable with bactericide sprays, summer shoot blight and rootstock blight are often not controlled well with bactericides. Apogee offers an improved control method for shoot blight on both mature trees and on young apple trees of highly susceptible cultivars. In addition, induction of defenses and compatibility with other disease control agents makes Apogee a prime candidate for the integrated management of fire blight of apple. The primary horticultural benefit of Apogee is reducing shoot growth in vigorous trees. It may also have a secondary benefit of improving spray coverage because of more open canopies. In addition, treated orchards may require fewer gallons of spray per acre, which will reduce the amount of other chemicals used.

TABLE 4

Effect of Apogee and other treatments on shoot blight control in 'Idared/M.7' trees. Geneva , NY, 1999.

Treatment	Rate/50L	Surfactants (rate/50L)	Time of application[1]	% blighted shoot length[2]	% russeted fruit[2]	% russeted fruit surface[2]
Untreated control				89.7 a	0.2 c	1.0 bc
Empire (inoculated)				7.2 g		
Pace 17	14.7 g	Regulaid 15 ml	4,5	35.2 f	0.3 c	0.5 c
Agrimycin 17	14.7 g	Regulaid 15 ml	4,5	39.9 ef	0.0 c	0.0 c
Apogee	22.4 g	Kinetic 31 ml	1,2	47.2 cdef	0.3 c	0.7 bc
Apogee	44.8 g	Kinetic 31 ml	1,2	47.5 bcdef	0.0 c	0.0 c
Apogee	44.8 g	Kinetic 31 ml	3	35.9 f	0.5 c	0.5 c
Apogee	44.8 g	Kinetic 31 ml	6	60.0 bc	0.2 c	1.0 bc

[1] 1 = Petal fall + 5 days (May 21), 2 = 2 weeks after #1 (June 4), 3 = 1 week before inoculation (11 June), 4 = 24 h before inoculation (16 June), 5 = 24 h after inoculation (18 June), 6 = 10 days after inoculation.

[2] Treatments followed by the same letter do not differ significantly (P>0.05).

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Herb Aldwinckle is a Professor of Plant Pathology and leads the fire blight team at Cornell. Jay Norelli is a Senior Research Associate in Plant Pathology working with Dr. Aldwinckle and B. Reddy is a Posdoctoral Fellow also in Aldwinckle's group. Timor Momol was formerly a Postdoctoral fellow with Herb Aldwinckle and is now an Assistant Professor at the University of Florida. Terence Robinson is an Associate Professor of Pomology in the Horticultural Sciences Department.

Genetic Engineering of Apple for Resistance to Fire Blight

Herb Aldwinckle,[1] Jay Norelli,[1] Susan Brown,[2] Terence Robinson,[2] Ewa Borejsza-Wysocka,[1] Herb Gustafson,[1] Jean-Paul Reynoird,[1] and M.V. Bhaskara Reddy[1]

[1]Departments of Plant Pathology and [2]Horticultural Sciences
New York State Agricultural Experiment Station
Cornell University, Geneva, New York

The research reported here has been supported by the New York Apple Research and Development Program, the Cornell University Center for Advanced Technology, the USDA-CSREES Northeast Regional IPM Program, and the USDA-CSREES Special Grants Program.

Conventional breeding of apple is very long term and cannot reproduce the desirable qualities of our best commercial varieties and rootstocks. Genetic engineering offers an attractive alternative to conventional breeding for the creation of resistant varieties since it is faster, can use genes from many sources, and will preserve the desirable qualities of the transformed variety or rootstock.

Other articles in this issue describe the efforts being made to control fire blight in orchards of susceptible apple varieties and rootstocks. Streptomycin is effective for control of blossom blight, when applied with the right timing. However, sometimes sprays are not applied and infection occurs, and sometimes sprays are applied unnecessarily. Every year losses are incurred and money lost. Some newer products look quite promising as alternatives for streptomycin, and Apogee may help with control of shoot blight. Nevertheless the apple industry is under great pressure from government and the public to reduce the use of chemicals in fruit production. The ultimate solution to fire blight, other diseases, and insect pests, would be resistant varieties and rootstocks. However, conventional breeding of apple is very long-term and cannot reproduce the desirable qualities of our best commercial varieties and rootstocks. Genetic engineering offers an attractive alternative to conventional breeding for the creation of resistant varieties since it is faster, can use genes from many sources, and will preserve the desirable qualities of the transformed variety or rootstock.

Genetic engineering has been used very successfully with other crops, including corn, cotton, soybean, potato, tomato, and papaya to produce disease, insect, and herbicide-resistant varieties that were grown on over 75 million acres in the United States in 1999. Similar technology should solve many of our apple problems. It will allow us to improve the shortcomings of our present varieties and rootstocks, without altering their desirable features, especially familiarity to nurseries and growers, and recognition in the market by brokers, supermarkets, and consumers. Genetic engineering leaves the thousands of genes of the popular variety or rootstock intact, except for one or a few genes to remedy the problem character, such as susceptibility to diseases or insects, or premature fruit drop and softening. It will also make it possible to combine genes to control several different problems in the same variety.

Figure 1. Transgenic tree bore fruit within two years of initial gene transfer experiment. Transgenic buds were grafted onto M.9 at a cooperating nursery in California in April 1998, planted at Geneva in May 1999, after which they flowered, were successfully pollinated and developed mature fruit.

Several researchers, particularly David James at East Malling, United Kingdom, pioneered methods to transfer genes into apple. We drew upon their work and our own early work to develop the techniques we now use for efficient genetic transformation of several varieties. We use modified strains of the common soil bacterium, *Agrobacterium tumefaciens*, which transfers genes into plants in nature, as the gene delivery system. We use a kanamycin resistant gene to select the transformed cells, and have added other techniques to improve the efficiency and speed of the process. The cooperation of a nursery in California has allowed us to accelerate growth of grafted plants of transformed ("transgenic") fruit varieties. About eight

TABLE 1

Disease evaluation in the field of two-year-old plants of Royal Gala lines transformed with lytic protein genes.

Vigorously growing shoot-tips were inoculated with the fire blight pathogen and eight weeks after inoculation the percent of the current season's shoot length blighted was used as a measure of resistance ("% shoot blighted" in table below). Three to five shoots were inoculated per plant on one to nine plants of each transgenic line and the total number of individual inoculated shoots is indicated as "N" in the table below. Waller Group: cultivars followed by the same letter did not differ in their fire blight resistance.

Cultivar	Lytic Protein	N	% shoot blighted	Waller Group
TG149	cecropin	21	81	a
TG267	vector	3	80	ab
TG243	cecropin	40	78	abc
TG163	attacin	26	75	abc
TG204	cecropin	29	69	abcd
TG242	cecropin	16	67	bcde
TG182	vector	30	65	cdef
TG550	egg lysozyme	25	62	defg
TG192	cecropin	14	61	defg
TG224	attacin	23	60	defgh
TG145	cecropin	20	60	defgh
TG226	attacin	19	58	defghi
Royal Gala	parent	12	56	defghij
TG160	cecropin	33	55	efghijk
TG244	egg lysozyme	28	54	efghijkl
TG135	attacin	25	54	efghijkl
TG142	cecropin	28	54	efghijkl
TG254	cecropin	19	54	efghijkl
TG248	cecropin	29	53	fghijkl
TG223	egg lysozyme	35	52	fghijkl
TG262	cecropin	22	52	fghijkl
TG180	attacin	37	51	fghijkl
TG468	cecropin	29	51	fghijklm
TG181	cecropin	29	51	ghijklmn
TG125	cecropin	14	49	ghijklmno
TG251	cecropin	12	48	ghijklmno
TG126	cecropin	34	47	hijklmnop
TG545	cecropin	22	47	hijklmnop
TG141	attacin	36	45	ijklmnopq
TG172	vector	25	45	ijklmnopqr
TG179	cecropin	17	44	jklmnopqr
TG208	cecropin	32	44	jklmnopqr
TG466	egg lysozyme	34	44	jklmnopqr
TG207	attacin	20	43	jklmnopqr
TG247	cecropin	25	42	klmnopqr
TG193	cecropin	39	42	klmnopqr
TG171	vector	44	42	klmnopqr
TG221	cecropin	20	41	lmnopqrs
TG225	cecropin	39	41	lmnopqrs
TG272	cecropin	24	40	lmnopqrst
TG549	cecropin	20	38	mnopqrstu
Liberty	resistant	22	37	nopqrstu
TG546	cecropin	10	37	nopqrstu
TG154	cecropin	30	36	opqrstu
TG228	cecropin	25	36	opqrstu
TG161	attacin	17	34	pqrstu
TG201	cecropin	4	33	qrstu
TG203	attacin	25	33	qrstu
TG222	egg lysozyme	23	31	rstu
TG159	vector	29	28	stu
TG253	cecropin	5	27	tu
TG547	cecropin	5	27	tu
TG202	attacin	44	26	u
TG250	cecropin	28	26	u
TG205	attacin	22	26	u
TG138	attacin	26	5	v

Figure 2. To contain the pollen of experimental transgenic trees in order to prevent it pollinating bearing trees in the plantings around our field trial, a large netting structure supported on steel hoops was erected to cover flowering transgenic trees. Netting was removed from structure after flowering.

months after the start of a transformation experiment, we can ship buds from transgenic plants raised in the greenhouse to California for budding on to plants there in early spring. During the very long growing season in California, the budded trees make excellent growth (6 ft), and are then shipped back to Geneva for planting the following spring. Some of these trees have flowered in their first year in the field at Geneva, allowing us to examine fruit of a transgenic line within two years of the initial transformation experiments (Figure 1). This improvement in our ability to obtain transgenic fruiting trees quickly will allow us to insert new, better gene constructs much more quickly than in the past.

We hypothesized that by transferring genes for antimicrobial proteins into apple, we might be able to make the apple plants more resistant to the bacteria that cause fire blight. Therefore, using Agrobacterium-mediated transformation, we introduced genes for several lytic proteins, which are known to inhibit plant bacteria, into several apple varieties. Using molecular techniques, we confirmed the presence of the genes in the transformed plants, and showed that the proteins were actually being produced in the plants. We did preliminary tests in the growth chamber and greenhouse, and found that some lines did in fact have in-

Figure 3. Fruit on experimental transgenic trees appeared indistinguishable from normal Royal Gala. All transgenic fruit was evaluated for size, color, firmness, soluble solids and acidity.

creased resistance to fire blight. However, we wanted to make sure the plants remained resistant under field conditions, and also produced normal trees and fruits.

In 1998, tests of the fire blight resistance of two- and three-year-old trees in the field of Royal Gala transgenic lines, containing lytic proteins (attacin, cecropins, or avian lysozyme), showed that several lines had significantly increased resistance. This was the first demonstration in a well replicated test of increased shoot resistance of transgenics in the field. The greatest level of fire blight resistance was observed with transgenics containing the attacin protein. One attacin-transgenic line had only 5 percent shoot blight compared with approximately 60 percent in non-transgenic Royal Gala controls and approximately 40 percent in the moderately resistant Liberty controls (Table 1). In the case of transgenics containing the cecropin and the lysozyme protein, several lines were identified that are significantly more resistant than the Royal Gala parent, but the observed resistance was generally at a lower level than that observed with attacin.

In 1999, we again carried out several field trials of the resistance to fire blight of two- to four-year-old trees of Royal Gala transgenic lines containing lytic proteins (attacin, cecropins, and avian lysozyme). Many lines had significantly increased resistance. It was particularly noteworthy that many of the lines that had been identified as resistant in 1998 tests also were resistant in 1999 tests. This was especially true for line TG138, transgenic for the attacin gene, which was most resistant of all lines tested in 1998, and was again most resistant in 1999.

The first flowering of transgenic trees occurred in 1998, and, as expected, many more trees flowered in 1999. These included Royal Gala lines transgenic for attacin and avian lysozyme. To contain the pollen of the transgenic trees, and prevent it from pollinating bearing trees in the plantings around our field trial, a large netting structure supported on steel hoops, and covering the two rows containing most of the flowering transgenic trees was erected. Flowers on trees in rows outside the netting structure were bagged to contain pollen. Flowers were manually pollinated under the netting and a good crop of fruit was obtained (Figure 2). Transgenic fruits appeared indistinguishable from normal Royal Gala. All transgenic fruit, along with fruit of normal Royal Gala from the same rows, has been graded for size and color, pressure tested for firmness with and without skin, and assayed for soluble solids and titratable acidity (Figure 3). Data are now being analyzed.

The results show the potential for using lytic protein genes in apple to increase resistance to fire blight, while retaining normal fruit characteristics. More information is needed on field resistance and tree performance of transgenic apples. Now that transgenic lines are flowering, progeny analysis from crosses will allow conclusive determination of the role of the transgenes in resistance.

Besides the lytic protein genes, other genes derived from apple, other plants, and also the fire blight bacterium itself are being tested for their ability to make apple plants more resistant to fire blight. These new genes should act to enhance apple's own natural defenses against pathogens, rather than acting directly against the fire blight bacterium by producing proteins that are antimicrobial. The natural protection of plants against pathogens is partly based on a variety of barriers already present in the plant before pathogen invasion. Plants can activate protective mechanisms upon detection of invading pathogens. If this protection is expressed locally at the site of pathogen invasion and also systemically in parts of the plant remote from the initial invasion, it is called systemic acquired resistance (SAR). SAR has now been demonstrated in many different plants, with many different pathogens. Often SAR is active against a broad range of pathogens, including fungi, bacteria, and viruses.

Commercial products, such as benzothiadiazole (Actigard, Novartis) have now been registered for use as an inducer of SAR against wheat powdery mildew and is effective against certain diseases of rice and tobacco. Similarly, Harpin, a protein (discivered by Dr. Steve Beer, Cornell University, Ithaca) produced by the fire blight bacteria, has been shown to induce host resistance in tomato and is commercially available as Messenger (Eden Bioscience). Orchard trials conducted by our group have shown that when apple trees are sprayed with Actigard or Harpin, significant reductions (40-50 percent) in the amount of blossom blight of apple can result. By expressing Harpin transgenically in apple we hope to either pre-activate its natural defenses against fire blight and apple scab, or activate them earlier in the infection process to render apple plants more resistant to these diseases. The Harpin gene has been transferred to M.26 apple rootstock and is currently being evaluated for its effect on fire blight resistance.

Basic research in the Arabidopsis model system has identified a gene that is necessary for that plant to be able to detect pathogen invasion and activate SAR resistance. When this "signaling" gene was over expressed in Arabidopsis it resulted in significantly enhanced resistance to bacterial and fungal pathogens. Researchers in the laboratory of Dr. Sheng Yang He, Michigan State University, have identified and cloned this same signaling gene from apple. We will be cooperating with Dr. He to enhance the expression of the apple signaling gene and determine its effect on fire blight resistance. Arabidopsis is also being used as a source of plant resistance genes with potential application to confer resistance to fire blight in transgenic apples.

The transgenic lines reported in this paper are experimental. Transgenic lines designed for use in commercial apple growing will likely differ in genes, promoters, and regulatory sequences from those described here. Before being commercialized, transgenic apple varieties will go through rigorous deregulation requirements to demonstrate their complete safety for consumers, the environment, and agriculture.

Herb Aldwinckle is a Professor of Plant Pathology and leads the fire blight team at Cornell. Jay Norelli is a Senior Research Associate in Plant Pathology working with Dr. Aldwinckle who specializes in Genetic Engineering. Susan Brown is an Associate Professor of Horticulture and leads the apple breeding program at Cornell. Terence Robinson is an Associate Professor and leads Cornell's orchard management program. Ewa Borejsza-Wysocka and Herb Gustafson are technicians and Jean-Paul Reynoird and Bhaskara Reddy are postdoctoral research associates in Dr. Aldwinckle's group.