Fire Blight of Apple Rootstocks

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The rootstock phase of fire blight is a serious threat to high value orchards of susceptible apple varieties planted at high tree densities on susceptible rootstocks, especially M.9 and M.26. We have calculated that one episode of 10% 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 they do not account for more than 50% 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 (e.g., 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.

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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 Delicious trees at 41 days (Figure 1). Just 12 days after inoculation, fire blight bacteria were detected in

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. weeks after inoculation	Date assayed	Bacteria in scion[a]	Bacteria in rootstock[b]
Early (inoculated May 16)	3	Jun 6	2/6	0/6
	6	Jun 27	1/6	0/6
	15	Aug 30	2/6	1/6
Mid (inoculated June 11)	3	Jul 3	0/6	0/6
	6	Jul 26	0/6	2/6
	15	Sep 25	0/6	0/6
Late (inoculated July 6)	3	Jul 27	4/6	5/6
	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.

symptomless 1-year-old scion tissue more than 20 inches below the shoot-tip in Empire and Golden Delicious, and also in 2-year-old tissue in Golden Delicious. 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.

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 3 weeks after inoculation. Fire blight bacteria were detected in the rootstocks of 5 out of 6 plants inoculated at the late growth stage compared with 1 of 6 and 2 of 6 plants inoculated at the early and mid-growth stages, respectively. Thus, late-season shoot infections may be particularly hazardous for the rootstock.

Inoculation of blossoms of 2-year-old Empire, Liberty, and Jonamac trees on M.26 in the field resulted in 8% tree death due to fire blight infection. Approximately 50% 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. Trees of the resistant variety Liberty and the more susceptible variety Empire showed the same frequency of rootstock infection. Apparently it is the *number* of infections, rather than their severity, that increases the likelihood of rootstock infection.

ECONOMICS OF PRUNING FIRE BLIGHT INFECTIONS

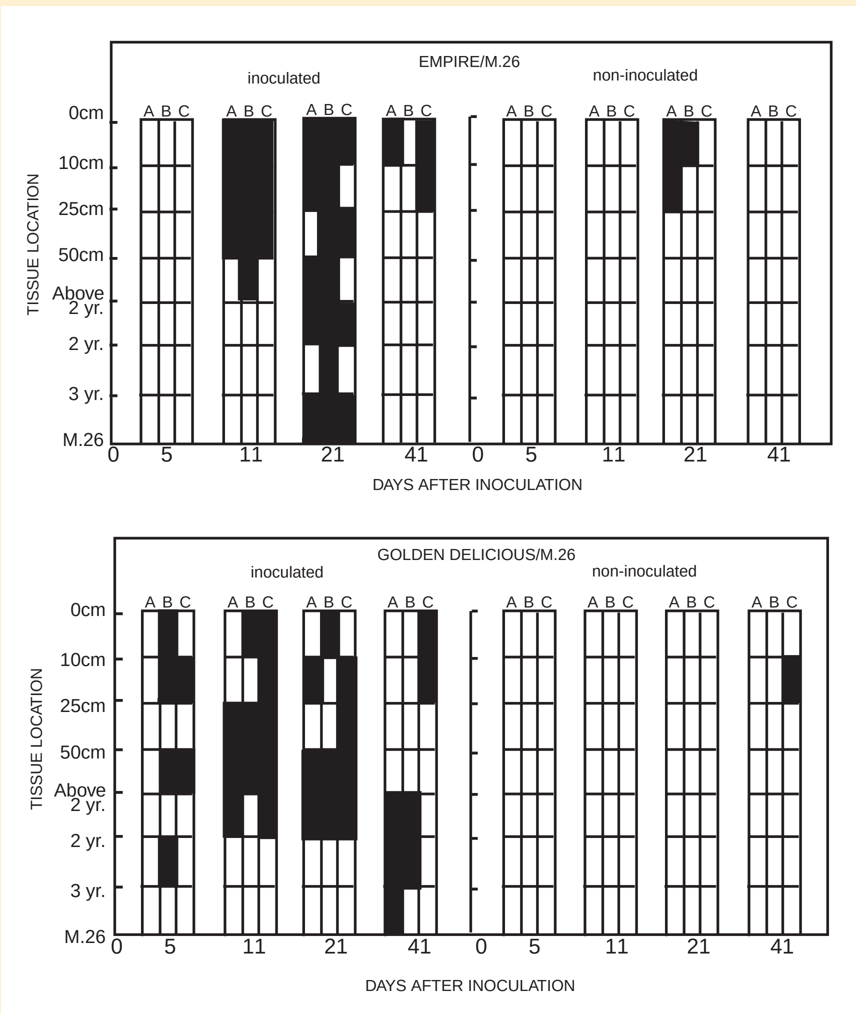
It is often recommended that fire blight infections be pruned out of young apple trees during the growing season to prevent rootstock infection. We evaluated how effective removal of infected shoots was on Empire, Jonamac and Liberty trees on M.26 rootstock and trees of Empire, Liberty and Mutsu on M.9 rootstock. Pruning out scion infections 3 weeks after blossom inoculation and then repeatedly during the growing season gave variable results in 3 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, 2 to 3 consecutive years of pruning reduced fruit yield. In comparison to non-inoculated trees, fruit yield on M.9 trees was reduced by 6% on unpruned inoculated trees, but by 62% on pruned inoculated trees (2 years of pruning). On M.26 trees, yields were reduced by 8% on unpruned inoculated trees, but by 79% on pruned inoculated trees (3 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

FIGURE 1

Detection of fire blight bacteria in Empire/M.26 (upper) and Golden Delicious/M.26 (lower) apple plants following inoculation. Black 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.



out of infected trees, may be cost effective if severe fire blight occurred in trees in their 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% 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.

TREE AGE AND ROOTSTOCK BLIGHT

We still have not 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 3 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, nonbearing 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 (second year of fruiting), and blossom inoculation of trees on M.9 in their 3rd leaf, resulted in 11% and 5% rootstock infection, respectively. This suggests that trees coming into bearing may be at greater risk of rootstock infection than nonbearing 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 3 feet from the rootstock graft union and had initiated terminal budset, but the last-formed terminal leaves were still expanding. Rootstock blight was evaluated on September 23, 1999.

Trees in their 3rd leaf were significantly more susceptible to infection than those in their 1st or 2nd leaf (Table 2). 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 already would have occurred before the fruitlets were removed and thus already might have increased susceptibility to rootstock infection.

RESISTANCE OF GENEVA APPLE ROOTSTOCKS

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 Geneva rootstocks then thought to be promising, and for which sufficient trees could be obtained, was planted in 1997. The trial included 6 to 12 trees of 18 Geneva rootstocks and 6 check rootstocks, all grafted with Royal Gala.

In 1999, 3-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 4 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 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. The greatest incidence of tree death by October 1999 occurred on M.26 (83% and 40% on two clones), and M.9 (75%) (Table 3). 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 B.9 died. It is unclear why B.9 was so resistant since, although it is regarded as less susceptible than M.26 and M.9, death of B.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% tree death, and G.11 had 25%. G.11 always has 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

TABLE 2

Incidence of rootstock blight in newly planted, 2nd and 3rd leaf Royal Gala/M.26 shoots inoculated in June 1999.

Tree age	Year planted	Crop load treatment	Crop load (# fruit/cm^2)	Incidence of rootstock blight (Sept. 1999)
1st leaf	1999	nonbearing	—	1.4% (1/70)
2nd leaf	1998	fruiting	3.8	0.0% (0/28)
		defruited[a]	0.0	3.3% (1/30)
		mean	—	1.7% (1/58)
3rd leaf	1997	fruiting	8.2	13.8% (4/29)
		defruited	0.0	25.8% (8/31)
		mean	—	20.0% (12/60)

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

trial had 0% tree death, and six others had 0-17% tree death. CG.103 had 58% tree death. Several of the Geneva rootstocks that were included in the trial when it was planted in 1997 now have 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.

FUTURE RESEARCH

Research is continuing on several aspects of rootstock blight, especially 1) the resistance of different rootstocks; 2) the influence of tree age, of time of scion infection, and of scion varieties with different levels of resistance; 3) the desirability of pruning out infections; and 4) 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 already have 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.

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TABLE 3

Symptoms observed on the rootstocks of 3-year-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. 1
M.9VF (McIntosh scion)	12	58	75
M.26E	12	92	83
M.26VF	10	40	40
MM.111 EMLA	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