

Alternatives to Fumigation for Control of Apple Replant Disease in Washington State Orchards

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Introduction

The poor growth of fruit trees that occurs after replanting on a site that previously supported the same or closely related species is termed “replant disease.” In apple, replant disease is widespread and has been documented in all of the major fruit-growing regions of the world (Traquair, 1984). Apple replant disease is characterized by uneven growth of young trees but, when severe disease pressure is encountered, poor growth may be exhibited by a majority of trees on the site and death of young trees may occur. Symptoms of apple replant disease include severe stunting, shortened internodes, rosetted leaves, small root systems, decayed or discolored roots, and reduced productivity. Affected trees have less lateral roots and few root hairs.

Replant disease has significant economic implications due to the continuous reduction in productivity over the life of the orchard. In addition to tree replacement costs for sick or dead trees, affected trees generally bear fruit 2 to 3 years later than healthy trees and fail to attain comparable yields. In Washington State, failure to control replant disease typically results in nearly a \$100,000 (US) per hectare reduction in gross returns over a 10-year period (Smith, 1995).

Although difficulty in reestablishing old orchard sites has been documented for over 200 years (Mai and Abawi, 1981), the cause of the disease has remained unclear. Supposed causal factors have varied among geographic regions or between orchards in the same area. Apple replant disease has been attributed to a number of possible abiotic factors (low or high soil pH, phytotoxins, poor soil structure, heavy metal and arsenic contamination) as well as biotic factors (pathogens, nematodes). While abiotic factors may be important in some instances, the dramatic tree growth response to soil pasteurization or fumigation indicates that replant disease is primarily a biological phenomenon (Mai and Abawi, 1981; Jaffee et al., 1982; Slykhuis and Li, 1985).

Currently, control of apple replant disease in commercial Washington State orchards is accomplished primarily through the use of pre-plant soil fumigation with materials such as methyl bromide, metam sodium, and chloropicrin. This practice is discouraged by Integrated Fruit Production (IFP) programs and is being restricted by loss of chemical fumigants. With the increase in acreage of organic apple production (Granatstein and Dauer, 2000a) and the shorter life of an apple planting due to variety renewal, the need for alternative control strategies has intensified. A new research program was launched in 1996 at the USDA-ARS Tree Fruit Research Laboratory to clarify the causes of replant disease in the state and to explore

alternative control strategies, especially those that could replace the use of methyl bromide.

Causes of Replant Disease

Recent studies in Washington State indicate that a fungal pathogen complex is the predominant cause of replant disease (Mazzola, 1997; Mazzola, 1998a). Soil and root samples were collected from five apple orchards in several parts of the state. Samples were evaluated for the presence of bacterial and fungal organisms, as well as for nematodes. The only plant parasitic nematode found at a level of concern was *Pratylenchus penetrans*, and it exceeded the population threshold for damage in only one orchard. In contrast, a fungal complex, consisting of *Cylindrocarpon destructans*, *Phytophthora cactorum*, *Pythium* spp., and *Rhizoctonia solani* was consistently isolated from symptomatic trees in all orchards. These fungi were pathogenic to apple in greenhouse tests.

When soil from replant orchards was pasteurized, the growth response of apple seedlings was consistent and generally large (Table 1). Bioassays of selective biocides produced mixed results, with seedling growth generally less than pasteurization. The studies indicated that elimination of one fungal pathogen often led to the proliferation of another on the roots.

Replant disease develops quickly in apple orchards. At one location, soils from contiguous apple plantings ranging in age from 0 to 5 years were sampled and bioassayed. The site had previously been in dryland wheat production for decades, with no history of orchard. By the third year in orchard, apple seedling growth suppression was evident relative to the control (Table 2). A part of this can be attributed to the loss of natural soil suppressiveness to *R. solani*. Significant shifts in the bacterial community of the apple rhizosphere were identified that correlate with the increase in replant disease (Mazzola, 1999). For example, *Burkholderia* declined from 86% of bacterial isolates examined from soil prior to apple production to 8% of the isolates from soil after 5 years of apple. The fluorescent pseudomonad population was initially dominated by *P. putida* (>65%), but within 3 years of orchard establishment, >85% of isolates were identified as *P. fluorescens* bv. III.

There is also a spatial component to replant disease. Growers often report a “wave” effect when a new planting is made with rows perpendicular to the former rows. Where the new row intersects the old, trees are often stunted. Bioassays of soil taken at different distances from the tree trunk showed that disease severity does decline with distance, especially in higher density plantings where the majority of tree roots, and thus the changes in microbial community, are confined to a 1.5-2 m band generally kept weed-free. (Table 3))

Alternative Control Strategies

Based on the research into the cause of replant disease, four general strategies of control emerged: directly kill pathogens; change the environment to inhibit pathogens; avoid the pathogens through time or space; utilize plants resistant to the pathogens or tolerant of damage. Several alternative control strategies under investigation are discussed below.

The use of microbial biocontrol agents was explored. One commercial product, RootShield (a *Trichoderma* product from BioWorks, Geneva, NY) was tested in several locations and did not provide any improved tree growth over a non-treated control. A potential biocontrol organism was identified during the investigation of the microbial community shifts in orchards (Mazzola, 1998b). Suppression of *R. solani* AG-5 was induced by *Pseudomonas putida* strain 2C8, a naturally occurring inhabitant of the apple rhizosphere from an orchard soil previously cultivated to wheat. This organism has been tested as a possible biocontrol agent for replant disease in the greenhouse and in the field, using it as a root dip and a soil drench. As greenhouse results have been superior to field results, a procedure was developed to enhance field survival of the organism by raising it in a carbon-limited culture (Gu and Mazzola, 2000 in press). On-going studies show that this procedure has enhanced suppression of *R. solani* over both the original strain and the untreated control (Table 4). As the strain 2C8 appears to have primary activity against *R. solani*, it is likely that it will be effective only in conjunction with other treatments that suppress the remaining components of the pathogen complex.

A series of on-farm tests evaluated the potential for compost to provide general suppression of replant disease. Organic apple growers have been relying on this strategy, but no data were available to evaluate its effectiveness. While there was a weak (but statistically significant) increase in apple tree growth with increasing compost rate, the more important finding was the difference in average tree growth (cumulative % increase in trunk cross-sectional area over 3 years) from sites not previously planted to apple (500-800%) compared to replant sites that had been fumigated, ripped, fertilized and amended (200-500%) (Granatstein and Dauer, 1999; Granatstein and Dauer, 2000b). Thus, even with the best current practices, it appears that tree growth does not reach its biological potential on many replant sites.

Another major avenue of research has been the use of fallow and cover crops to alleviate replant disease. Disease severity did not decline in the field with a one-year bare ground fallow treatment. Greenhouse experiments with short-succession wheat planting prior to apple seedling planting led to consistent improvements in tree growth relative to the control (Table 5). Recovery of *Rhizoctonia* and *Pythium* from apple root was lower from the wheat treatments, while *Cylindrocarpon* and *Fusarium* increased. Wheat cropping also reduced populations of *P. penetrans*. The suppression of *Rhizoctonia* varied greatly by wheat cultivar, as did the composition of the fluorescent pseudomonad community. The growth-promoting wheat cultivars (for apple) elicited a reduction in *Pseudomonas fluorescens* and *Pseudomonas syringae* levels, but enhanced levels of *P. putida*. The mechanism at work may be a combination of lack of substrate from wheat roots for apple pathogens and antibiotic suppression of pathogens by *P. putida* (Mazzola and Gu, 2000). Trials are in progress to validate this alternative control in the field setting.

As the wheat treatment did not lead to tree growth equal to soil pasteurization in many cases, the use of a biofumigant crop was evaluated. Much recent research has been done in this area, particularly with *Brassica* spp. (Brown and Morra, 1997). Experiments were conducted growing rapeseed plants and incorporating the residue into the soil, as well as amending soils with rapeseed meal, a by-product of the oil extraction process. The rapeseed meal appears to be more promising than the cover crop approach. Tree growth in rapeseed meal amended soil (0.1%) has been similar

to pasteurization and fumigation in greenhouse and field studies, respectively (Mazzola et al., 2001). However, at higher amendments rates, the meal can be phytotoxic and kill trees (Table 6). The meal also appears to be providing substantial amounts of nutrients that may be enhancing tree growth in addition to any biological mechanism. Various sequences of rapeseed meal and wheat are being tested to search for optimal combinations, which may need to be adapted to different soil types.

A final alternative control relates to cultural manipulation of the field soil. Several growers report success in replanting apple without fumigation by digging planting holes in the autumn prior to planting, and leaving them exposed to the elements over winter. A field test of this approach was conducted on a replant site, and autumn trenching led to tree growth similar to fumigation. Fruit yield was also improved relative to the untreated control. Trenching suppressed *Rhizoctonia*, *Pythium*, and *Phytophthora*, but not *Cylindrocarpon*. Another field strategy tested was planting new trees in the former orchard drive alley versus in the former tree row. This approach also improved tree growth and yield similar to trenching (Table 7).

Developing an integrated approach

Given that no single alternative strategy for controlling apple replant disease can currently provide the level and consistency of control obtained with methyl bromide or other broad-spectrum soil fumigants, researchers must now work with the promising alternatives and integrate them into various configurations for eventual field testing. The biological cause of replant disease can vary substantially among orchards, soil types, and regions. And biologically based controls are likely to be less consistent in their effectiveness than chemical biocides. As promising combinations of practices for replant disease control are identified, these can then be evaluated in the context of overall orchard management, especially that of the orchard floor. Soil amendments for replant control will impact tree nutrition. Cover crops such as wheat will influence weed control and insect fauna. For example, current studies of orchard mulching in British Columbia have identified significant reductions in *P. penetrans* under certain mulch materials (Hogue, 1999). Where feasible, replanting a former apple site to a non-affected crop such as cherry is a biologically viable strategy, a form of crop rotation. Systems for delivering microbial biocontrol agents to turf (e.g. golf courses) are commercially developed and could be utilized in tree fruit for both disease control and crop nutrition. The on-going research on apple replant disease in Washington State points to the wealth of biological resources and relationships that may be exploited to control the disease in a more sustainable manner.

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Table 1. Effect of pasteurization and selective fungicides on growth of ‘Gala’ apple seedling (mg) in replant soils from 5 orchards (greenhouse bioassay).

Treatment	Orchard							
	CV	DR-1	DR-2	GC-1	GC-2	GC-3	KM	WVC
Control	626	549	633	661	249	504	435	495
Pasteurize (70°C)	731	720	828	1213	601	729	572	629
Benomyl	611	470	649	971	279	641	402	541
Metalaxyl	722	734	687	913	496	557	558	552
<i>LSD (0.05)</i>	70	91	69	127	84	101	104	113

Table 2. Interaction of orchard age and inoculation of soil with *Rhizoctonia solani* AG-5 on suppression of ‘Gala’ apple seedling growth (greenhouse bioassay of field soils).

Orchard Age	Plant weight (g)	
	Control	+ <i>R. solani</i>
Non-cultivated	0.88a	0.89a
First year	0.83a	0.77a
Second year	0.82a	0.81a
Third year	0.66a	0.36b
Fourth year	0.67a	0.47b
Fifth year	0.58a	0.37b

Means in the same row with the same letter are not significantly different ($P=0.05$).

Table 3. Effect of location and fumigation on growth of ‘Gala’ apple seedlings in replant soil (bioassay of field soil).

Treatment	Root weight (g)	Shoot weight (g)
Row (control)	0.26a	0.69
Row – fumigated	0.52b	0.83
Aisle	0.61b	0.74
	$p < 0.0001$	$p = 0.051$

Table 4. Colonization of the apple rhizosphere and suppression of *Rhizoctonia solani* AG-5 root infection by *Pseudomonas putida* strain 2C8 and its carbon starved derivatives at 30 days after planting (greenhouse study).

<i>P. putida</i> strain	CFU(x 10 ⁵)/g root	% <i>R. solani</i> root infection
Control	--	54.3c
2C8	1.8a	42.3b
2C8-26A	11.6b	16.7a
2C8-28C	13.2b	17.9a

Means in a column followed by the same letter are not significantly different ($P=0.05$).

Table 5. Impact of prior wheat cultivation on growth of ‘Gala’ apple seedlings in CV orchard replant soil artificially infested with *Rhizoctonia solani* AG-5 (greenhouse study).

Treatment	Root weight (g)	Shoot weight (g)	Shoot height (cm)	% Root infection
Control (-)	1.14a	1.13a	9.8a	17.3b
Control (+)	0.91a	0.98a	9.1a	29.4c
Pasteurization (+)	1.37ab	2.28b	12.2a	44.0d
‘Eltan’ wheat	1.84bc	3.01c	16.4b	13.3b
‘Penawawa’ wheat	2.16c	3.38c	17.8b	2.2a
‘Rely’ wheat	1.42ab	2.93bc	16.8b	17.7b

All soils were inoculated with *R. solani* except Control (-). Means in a column followed by the same letter are not significantly different ($P=0.05$).

Table 6. Impact of rapeseed meal amendment on growth of ‘Gala’ apple seedlings in orchard replant soil (greenhouse study).

Treatment	% Seedling mortality	Root weight (g)	Shoot weight (g)	Shoot height (cm)
Control	2a	1.01b	0.96a	8.5a
Pasteurization	0a	1.72c	3.52c	17.0c
0.1% rapeseed meal	0a	2.13d	3.19c	15.1bc
1.0% rapeseed meal	7a	1.92cd	5.64d	21.6d
2.0% rapeseed meal	77b	0.43a	1.56b	11.2b

Means in the same column followed by the same letter are not significantly different ($P=0.05$).

Table 7. Effect of soil treatment on apple tree (Gala/M26) growth and yield in a replant soil (field study planted 1998).

Treatment ¹	1998-99 Increase in trunk dia. (mm)	2000 Fruit yield (kg/tree)
Control	11.06 cde	4.6 cd
Fumigation	12.19 bc	7.2 a
Trench	14.30 a	5.4 bc
Aisle	12.74 ab	6.4 ab
Strain 2C8	10.06 def	4.1 cd
Strain IBX	11.79 bc	4.8 cd
Trichoderma	9.45 ef	4.7 cd
Dividend	11.50 bcd	3.4 d
Moncut+metalaxyl	10.72 cde	4.5 cd
Moncut	8.73 f	4.3 cd
Humic acid	9.73 ef	3.4 d

¹Treatment explanation: Trench = autumn trenching in planting row left exposed over winter. Aisle = moving new planting row to former drive aisle. Strain 2C8, Trichoderma, and IBX = microbial biocontrols. Moncut, metalaxyl, and Dividend = selective fungicides. Humic acid = soil amendment.