Development and Optimization of the Steam Auger for Management of Almond Replant Disease in the Absence of Soil Fumigation

Project No.: **10-AIR6-Hanson**

Project Leader: Bradley D. Hanson
Department of Plant Sciences, MS-4
UC Davis
One Shields Ave
Davis, CA 95616
(530) 752-8115
bhanson@ucdavis.edu

Project Cooperators and Personnel:
Steven Fennimore, Department of Plant Sciences, UC Davis
Greg Browne, USDA-ARS Crops Pathology and Genetics Res. Unit, Department of Plant Pathology, UC Davis
David Doll, UCCE - Merced County

Objectives:

The overall goal of this project is to develop and optimize steam spot treatments for control of almond replant disease without the use of soil fumigants. The specific objectives include:

1. Monitor early vigor of the almond orchard planted following winter 2009 steam treatments.
2. Optimize the design and application techniques for steam treatments of future tree sites in two additional field trials.
3. Scale-up of the steam auger soil disinfestations treatments to larger areas in order to better assess the technical feasibility and economic viability of this promising non-fumigant technique.

Interpretive Summary:

This series of almond orchard replant trials are in the early stages as they were replanted in January 2010, January 2011, and June 2011. However, early results suggest that the replant disease complex is present in at least two of the sites and interesting comparisons will be made among the various fumigant and non-fumigant disease management strategies. The redesigned steam augers function well and the current experiments should help us understand the effects of various levels of soil disturbance, thermal disinfestation, and various soil amendments as part of an integrated management strategy for the replant disease of almonds in California. Data collected over the next few years on tree establishment, early growth, disease progression, and early yield will lead to management and research recommendations.

Materials and Methods:

Objective 1. Two trials were established near Atwater and Madera, CA in December 2009 in an experimental design that will allow comparison of steam treatments to various shank-applied fumigants. Bare-root almond nursery stocks were planted by the cooperating growers in January 2010. Research personnel are monitoring tree height and trunk diameter after planting and annually for several growing seasons. Monthly overall health ratings on a scale of 0 to 5 where 0 = very healthy plant and 5 = death are being taken during the growing season. Before and after treatments, soil samples are being collected and characterized for microbial population, nematode population, soil pH, electrical conductivity and nutrient levels.

Objective 2. Develop data on the effects of steam auger diameter, steam application depth, time, and soil temperature requirements for soils with different physical properties using the steam auger application methods. According to Baker (1957) soil temperature of 158^{o}F is needed to properly disinfest soil. In our 2009 trials, steam was applied for four minutes per tree site to reach or exceed this temperature threshold. While this appears to be an effective application for the soil tested, it is not known if this treatment is uniformly applicable to other soil types or soil moisture conditions. If the treatment duration can be shortened without reducing efficacy, the economic viability of steam auger treatments can be greatly improved. Treatments in the 2010 trials will include several combinations of steam application duration and auger depth. Additionally, reengineering of the application auger will be considered (auger diameter, flight pitch, steam orifice size and location, etc.) in an effort to maximize efficiency. Steam application time will be varied from less than one minute to over five minutes per tree site and soil temperatures will be monitored for a 24 hour period before and after steam application at depths of 2, 12 and 24 inches. Data will be analyzed using regression techniques and the most efficient yet effective treatment schedule will be determined.

Objective 3. In our 2009 trials, there were three to four replicate plots of six to 12 tree sites per steam treatment. Control plots received augering with no steam. In each plot, the tree sites were lined up sequentially in a single row. In 2010, we proposed building an additional auger and simultaneously treating two-row plots approximately 0.25 A in size (number of trees per plot may vary depending on grower preferred spacing). Larger plot size will more closely approximate commercial conditions and will allow much more detailed economic analyses. Tree growth and vigor will be monitored as previously described. The trials will include yield and cost benefit analysis and be conducted under the companion projects "*Developing improved strategies for management of replant problems" (*Almond Board project 10.PATH1.Browne) and the "*Pacific Area-Wide Pest Management Program for Integrated MB alternatives: Almond and Stone Fruits"* (USDA-ARS, Browne, Lampinen, Upadhyaya, Klonsky, Hanson, Fennimore).

Results and Discussion:

Objective 1. The two trials established in fall 2009 were replanted in winter 2009-10 with dormant bareroot almond trees and are ongoing. The integrity of the Madera trial was compromised in 2010 by severe and inconsistent glyphosate herbicide injury. A large number of trees were killed and replanted while many others with less severe symptoms were stunted.

This trial is not likely to provide meaningful data and will be terminated. The Atwater site also had minor inconsistencies in growth due to irrigation and other horticultural practices; however, second season growth and disease ratings suggest that treatment effects may become apparent. Clearly, though, the effects of the non-fumigant treatments are much more subtle than the fumigation treatments (**Table 1**).

Objective 2. Two new augers were designed and built during 2010 and tested in commercial orchards near Delhi (November/December 2010) and Wasco (May 2011). The augers were similar in design except that one has a 24 inch diameter and one is 36 inches across. Compared to the prototype augers used in 2009, the new equipment was redesigned with carbide tips and cutting teeth for easier digging, steeper flight pitch for greater soil mixing, and truncated flighting to minimize the amount of soil ejected from the hole (**Figure 1**). Before the spring trial, additional holes were cut in the flighting of the 36-inch auger to increase the vertical mixing of soil.

The experimental design was somewhat different between the two new trials. At Delhi, the steam auger was tested in two separate experiments. A small plot experiment was conducted to directly compare the effects of three levels of soil disturbance (24 inch auger, 36 inch auger, and 4x4x2 ft backhoe plots) compared to 24 and 36 inch steam auger thermal treatments (**Table 2**). Individual plots in this experiment consisted of two tree sites and the treatments were replicated 10 times in three almond varieties (5 in Nonpareil, 3 Aldrich, 2 Sonora). In a separate large plot experiment at the same site, 24-tree plots were treated with several soil fumigation treatments or the 36 inch steam auger (**Table 3**). A steam injection regiment of 4 minutes per tree site with the 36 inch auger and 2 to 2.5 minutes per tree site was used to achieve the target temperature in this cool, moist, sandy soil. The Delhi site was planted with bareroot trees in January 2011, base line trunk caliper data were collected, and first year disease severity ratings were made. Initial disease severity ratings made in mid-July at the Delhi site suggest that a minor case of the replant disease exists but at this early stage there were few statistical differences among treatments (**Tables 2 and 3**). Growth and disease progression will be monitored for the next several years and it is likely that treatment efficacy will become more obvious over time.

At the Wasco site, 24 and 36 inch auger treatments with and without steam injection were compared in four-tree plots replicated eight times each (4 Nonpareil, 4 Monterey). The treatments in this experiment also included a high rate of shank-injected chloropicrin and several non-fumigant fungicides or soil amendments (**Table 4**). A separate study was conducted at this site to evaluate the effects of chloropicrin rate and rootstocks but those treatments cannot be directly compared to the steam treatments due to the experimental design. Due to moist soil conditions and lingering fumigant residues, this site was planted in June 2011 with potted, non-dormant almond nursery stock. Initial base line trunk caliper data were collected and first year disease severity ratings will be made in summer 2011. Growth and disease progression will be monitored for the next several years in both experiments.

Objective 3. The larger plots proposed in this objective were previously discussed under objective 2 (24-tree plots at the Delhi site). However, all treatments were applied with a single auger rather than two identical augers as proposed due to late delivery and corresponding lack of pre-testing of the redesigned equipment. Discussion among the investigators and industry

advisors led to the conclusion that this step should be postponed and reconsidered for future trials once the equipment and treatment protocols are more fully defined. Additionally, the feasibility of this objective may need to be revisited due an unanticipated withdrawal of Propane Education and Research Council co-funding for this project following their funding realignment towards annual crop projects.

Research Effort Recent Publications:

Hanson, B., S. Fennimore, G. Browne, and D. Doll. 2010. Development and optimization of the steam auger for management of almond replant disease. Almond Board of California Annual Conference. December 8-9, 2010. Modesto, CA

References Cited:

None.

Figure 1. Redesigned steam-injection auger for treating almond tree planting sites. A 24-inch diameter auger (in use) and a 36 inch auger (foreground) were tested in trials near Delhi and Wasco, CA.

Table 1. Selected fumigant and non-fumigant treatments in an almond orchard replant trial initiated in winter 2009 near Atwater, CA[1]

Trt #	Fumigant treatment[2]	Tree site treatment[3]	Disease rating July 12, 2010 (0-5 scale)	Disease rating July 19, 2011 (0-5 scale)
1	None	None	0.42	0.81
2	None	Auger-only	0.17	0.42
3	None	Auger + steam	0.23	0.73
4	None	Auger + BSM	0.21	0.54
5	None	Auger + BSM + steam	0.09	0.80
6	Telone C35 (8 ft strip)	None	0.04	0.08
7	Telone C35 (8 ft strip)	Auger-only	0.17	0
8	Telone C35 (8 ft strip)	Auger + steam	0	0.08
9	Telone C35 (8 ft strip)	Auger + BSM	0	0
10	Telone C35 (8 ft strip)	Auger + BSM + steam	0	0
P-value for tree site treatment (within fumigant)			NS	NS

[1] The experimental design was a randomized split block with fumigant or non-fumigant as the main plot and auger treatments as the subplots. Individual subplots included 6 trees within a row.

[2] Telone C35 (540 lb/A) was applied with a commercial application rig in an 8.3 ft strip.

[3] Steam was applied through a 30-inch diameter auger for sufficient time to raise the soil temperature above 156 F for at least 30 minutes. Brassica seed meal (BSM) was applied at an estimated rate of 4000 lb/A by pouring dry meal into the tree site while the auger was mixing the soil.

Table 2. Steam auger treatments in an almond orchard replant trial initiated in winter 2010 near Delhi, CA

Trt #	Application equipment	Treatment[1]	total number of trees[2]	Disease rating July 19, 2011 (0-5 scale)
1	none	none	14	0.81
2	24 inch auger	disturbance only	20	0.53
3	36 inch auger	disturbance only	20	0.76
4	backhoe	4x4x2 ft disturbance only	14	0.92
5	24 inch auger	steam injection	20	0.63
6	36 inch auger	steam injection	20	0.50

[1] Steam was applied for enough time to raise the soil temperature above 156 F for at least 30 minutes (2-4 minutes of steam injection).

[2] Usually 2-tree plots with 10 replicates except where limited by row length.

Table 3. Large plot steam auger and soil fumigation treatments in an almond orchard replant trial initiated in winter 2010 near Delhi, CA

Treatement[1]		Treated area	total number of trees[2]	Disease rating July 19, 2011 (0-5 scale)
1	Untreated	None	120	0.49 a
2	methyl bromide	400 lb/A – 11 ft strip	120	0.27 bc
3	Telone II	340 lb/A – 11 ft strip	120	0.20 c
4	Telone II	340 lb/A – 22 ft strip	120	0.15 c
5	Telone C35	540 lb/A – 11 ft strip	120	0.15 c
6	36 inch steam auger	steam injection	120	0.40 ab

[1] Fumigants were applied by TriCal, Inc. Steam was applied for enough time to raise the soil temperature above 156 F for at least 30 minutes (2-4 minutes of steam injection).
[2] 24-tree plots with 5 replicates.

Table 4. Non-fumigant treatments in an almond orchard replant trial initiated in spring 2011 near Wasco, CA

Trt #	Application equipment	Treatment[1,2]	total number of trees[3]
1	Shank fumigation rig	300 lb/A chloropicrin	88
2	none	none	32
3	24 inch auger	disturbance only	32
4	30 inch auger	disturbance only	32
5	36 inch auger	disturbance only	32
6	24 inch auger	steam injection	32
7	36 inch auger	steam injection	32
8	30 inch auger	fludioxonil	32
9	30 inch auger	fludioxonil + tebuconazole + azoxystrobin	32
10	30 inch auger	azoxystrobin	32
11	30 inch auger	tebuconazole	32
12	none	Fungiphite root drench and foliar spray	32
13	30 inch auger	dried yeast extract	32
14	none	Actigard preplant root drench	32
15	30 inch auger	brassica seed meal	32

[1] Steam was applied for enough time to raise the soil temperature above 156 F for at least 30 minutes (2-4 minutes of steam injection).
[2] Treatments applied with the 30 inch auger were injected in 3 gallons of water. Trt 8 was 5.15 g Cannonball 50 WP, Trt 9 was 5.15 g Cannonball plus 4 ml Abound SC plus 4.3 ml Ridomil EC, Trt 10 was 4 ml Abound SC, Trt 11 was 4.3 ml Ridomil EC, Trt 12 was 5% and 2% solutions, Trt 13 was 150 g dried yeast extract, Trt 14 was 0.85 g Actigard, and Trt 15 was 400 g brassica seed meal. More details on non-steam treatments are available in Browne et al. (10.PATH1.Browne)
[3] Usually 4-tree plots with 8 replicates except the fumigation treatment which had 11-trees per plot.