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

Project No.: **11-AIR6-Hanson/Fennimore**

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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. Optimize spot steam treatment equipment and techniques for replanting orchards with varying soil texture, moisture, temperature, and soil borne pest pressure.
2. Monitor effects of spot steam treatments on early growth of stonefruit and almond trees, compared to conventional fumigant-based treatments for preventing replant disease.
3. Evaluate the economic viability and technical feasibility of spot steam treatments using large, commercially relevant field plots.

Interpretive Summary:

Reducing dependence on pre-plant soil fumigation has become a strategic priority for several commodities, and some non-fumigant treatments have shown promise for controlling replant problems. With funding from the Almond Board of California in 2009 (project 09-AIR6-Fennimore) and in 2010 (project 10-AIR6-Hanson/Fennimore), we initiated research to test steam treatment of future tree sites in almond replant situations. During the development stage of this project, our initial equipment design was abandoned in favor of an auger-based steam injection technique which was tested in two field trials initiated in late-December 2009. In 2010, we built a larger diameter (36 vs 24 inches) injection auger and initiated a rigorous test of the two auger systems, conventional fumigants, and biological amendments in several orchards in 2010-12 in the San Joaquin Valley.

The two preliminary trials established in fall 2009 were replanted in winter 2009-10 with dormant bareroot almond trees and are ongoing. 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. 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**).

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 to one another 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.

New field trials were initiated in fall 2010, spring 2011, and winter 2012 with slightly different experimental design and objectives. Two trials were established in an almond replant orchard near Delhi, CA in December 2010. First, 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, and 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 6 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 (**Figure 2**). The Delhi site was planted with bareroot trees in January 2011, base line trunk caliper data were collected, and disease severity ratings were made in 2011. Caliper data was collected from the Delhi site on February 22, 2012 and disease severity will be evaluated in late summer 2012. 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, while caliper data show that all treatments performed better than the untreated control (**Tables 2 and 3**). Growth and disease progression in both experiments will be monitored for the next several years and it is likely that treatment efficacy will become more obvious over time.

A third experiment was initiated near Wasco, CA in spring 2011. At this 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 disease severity ratings were made in summer 2011 and are planned for summer 2012. Growth and disease progression will be monitored for the next several years in both experiments (non fumigant and fumigant).

Finally, two additional new trials were established in January and February 2012 near Atwater and Livingston, CA using experimental protocols similar to those used in the 2010 Atwater trials described above (**Figure 3, Tables 5 and 6**). These sites were replanted in February 2012 and initial trunk caliper data were collected after planting. Disease severity ratings will be made in late summer 2012 and tree performance and growth will be monitored for the next several years.

Research plans:

For the remainder of the project, efforts will focus in three areas:

1. Continue collecting data to determine effects of preplant soil treatments on orchard tree establishment and productivity. Data will include tree growth measurements, disease severity evaluations, and assessments of tree canopy development.
2. Conduct mechanistic studies in non-orchard areas to determine the effect of soil texture and moisture on the amount of time and fuel required to reach target soil temperature. This work, originally planned for spring 2012, was delayed by a major equipment malfunction and will instead be conducted in summer and fall 2012.
3. Determine treatment costs and economic feasibility of steam disinfestation as an alternative to preplant soil fumigation. This objective can only take place near the end of the project after suitable orchard productivity data has been collected.

Accomplishments and challenges:

Significant progress has been made towards the objectives of the project. Steam injection augers were designed and delivered in fall 2010 and three new field trials were initiated in several commercial orchards representing almond production in the San Joaquin Valley. However, a few challenges have been encountered. As discussed previously, the two experiments established in 2009 have horticultural issues related to herbicide drift or irrigation management. The Madera site (glyphosate drift) will be terminated but the Atwater site (irrigation problem) will be monitored through the end of this project. The experiment established in spring 2011 near Wasco also had horticultural problems due to a very late planting (delayed fumigation and planting due to a wet spring) that may present problems; however, following a meeting with the grower, we elected to severely prune these trees and monitor regrowth in 2012 rather than replant the site. Two separate major equipment malfunctions (boiler control failures leading to internal damage) presented challenges to the implementation of the 2012 trials near Atwater; however, the trials were successfully installed following parts exchanges in the field and the experiments established look promising and have no

apparent problems. Major repairs and maintenance to the boilers were completed in early summer 2012 and the equipment is ready for operation in fall 2012.

Although this work is still underway, technology transfer efforts have been initiated. A graduate student involved in the project, Andrew Johnson, presented research posters at the California Almond Board Conference on December 7, 2011 and at the California Chapter of the American Society of Agronomy meeting on February 7, 2012 to around 300 and 100 attendees, respectively. An extension field day was organized on June 6, 2012 at the Delhi site and Cooperators Doll, Hanson, and Browne each discussed various aspects of our orchard replant research with over 150 farmers and advisors in attendance.

Publications:

Browne, G.T., L. Schmidt, R. Bhat, D. Doll, and B. Hanson. 2011. Developing improved strategies for management of replant problems. Interim report to the Almond Board of CA. 15 pg.

Johnson, B., B. Hanson, D Doll, G. Browne, and S. Fennimore. 2012. Development and optimization of the steam auger for management of almond replant disease. Proc. Calif. Plant and Soil Conf. p 162.

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 in 2011 and Livingston and Atwater in early 2012. Orchard performance will be monitored during the 2012 and 2013 growing seasons.

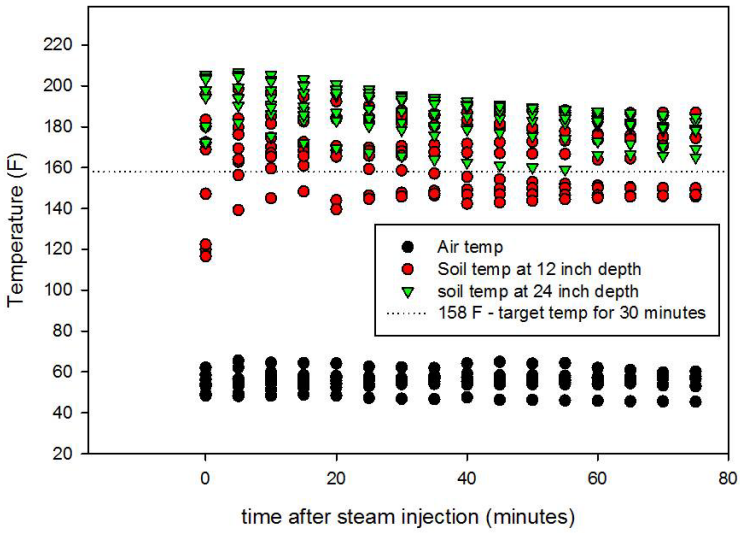

Figure 2. Soil temperature profiles in almond tree sites treated with the 36 inch steam auger in a replant trial near Delhi, CA in December 2010. Target temperatures over 158 F were easily maintained at 24 inches but were less dependable at a depth of 12 inches and near the soil surface.

Figure 3. Two new orchard replant trials were initiated in January and February 2012 near Atwater and Livingston, CA. The Livingston site (left) is in an orchard next to a housing subdivision; this area cannot be fumigated with any conventional treatments due to buffer zone restrictions. Both new trials include the steam auger treatment protocol used in the 2010 Atwater trail (**Table 2**).

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

	Application equipment	Treatment[1]	trees	Disease rating 7/19/10	Disease rating 7/24/12	Trunk diam. 2/22/12	Change in Diam. 2011-12
			#	----- 0-5 scale ---		---------- mm ----------	
Nonpariel							
1	none	none	8	.88	1.63	27.90	14.38 b
2	24 inch auger	disturbance only	10	.60	1.20	30.25	16.35 ab
3	36 inch auger	disturbance only	9	.89	1.22	31.12	18.30 ab
4	backhoe	4x4x2 ft disturbance	8	1.00	1.00	31.25	19.21 ab
5	24 inch auger	steam injection	10	.50	.90	32.63	20.33 a
6	36 inch auger	steam injection	10	.60	1.40	32.55	19.74 a
Aldrich							
1	none	none	2	1.00	1.50	29.10	16.40
2	24 inch auger	disturbance only	6	.33	1.00	32.80	20.78
3	36 inch auger	disturbance only	6	.83	1.00	32.48	19.65
4	backhoe	4x4x2 ft disturbance	3	.33	1.00	32.80	19.43
5	24 inch auger	steam injection	5	.60	1.20	33.48	21.16
6	36 inch auger	steam injection	6	.33	1.17	35.28	21.70
Sonora							
1	none	none	2	0.00 ab	1.00	35.85	23.35
2	24 inch auger	disturbance only	4	0.75 ab	1.00	33.70	21.9
3	36 inch auger	disturbance only	4	0.50 ab	1.00	33.43	21.3
4	backhoe	4x4x2 ft disturbance	2	0.50 ab	1.00	40.65	27.05
5	24 inch auger	steam injection	4	1.00 a	1.00	34.13	21.7
6	36 inch auger	steam injection	4	0.00 b	1.00	37.45	24.58

[1] Steam was applied for enough time to raise the soil temperature above 158 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

	Application equipment	Treatment[1]	trees	Disease rating 7/19/10	Disease rating 7/24/12	Trunk diam. 2/22/12	Change in Diam. 2011-12
			#	0-5 scale		---------- mm ----------	
Nonpariel							
1	Untreated	None	30	0.27	1.10 b	33.20 b	20.76 b
2	methyl bromide	400 lb/A – 11 ft strip	30	0.13	0.20 a	37.55 a	24.80 a
3	Telone II	340 lb/A – 11 ft strip	29	0.24	0.20 a	37.81 a	25.67 a
4	Telone II	340 lb/A – 22 ft strip	30	0.13	0.10 a	38.78 a	26.22 a
5	Telone C35	540 lb/A – 11 ft strip	29	0.10	0.17 a	38.84 a	26.20 a
6	36 inch steam auger	steam injection	30	0.33	1.23 b	33.09 b	20.32 b
Aldrich							
1	Untreated	None	30	0.63 a	0.90 a	33.89 a	20.95 a
2	methyl bromide	400 lb/A – 11 ft strip	30	0.30 ab	0.37 b	36.86 ab	23.13 ab
3	Telone II	340 lb/A – 11 ft strip	30	0.23 b	0.30 b	37.51 b	24.79 b
4	Telone II	340 lb/A – 22 ft strip	30	0.23 b	0.00 c	40.35 c	27.77 c
5	Telone C35	540 lb/A – 11 ft strip	30	0.07 b	0.00 c	41.90 c	29.49 c
6	36 inch steam auger	steam injection	30	0.37 ab	1.07 a	35.50 ab	22.28 a
Sonora							
1	Untreated	None	30	0.67 a	1.17 a	32.96 a	21.28 a
2	methyl bromide	400 lb/A – 11 ft strip	30	0.40 ab	0.53 b	37.96 bc	26.36 bc
3	Telone II	340 lb/A – 11 ft strip	30	0.23 b	0.20 bc	40.28 cd	28.28 cd
4	Telone II	340 lb/A – 22 ft strip	30	0.20 b	0.13 c	40.53 d	28.94 d
5	Telone C35	540 lb/A – 11 ft strip	30	0.23 b	0.50 b	39.73 cd	27.88 cd
6	36 inch steam auger	steam injection	30	0.40 ab	1.27 a	35.79 b	24.17 b

[1] Steam was applied for enough time to raise the soil temperature above 158 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 4. Non-fumigant treatments in an almond orchard replant trial initiated in spring 2011 near Wasco, CA

	Application equipment	Treatment[1,2]	total number of trees[3]	Change in trunk diam.[4]
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.

[3] Usually 4-tree plots with 8 replicates except the fumigation treatment which had 11-trees per plot.

[4] Trunk caliper data were collected after planting and at the end of the 2011 growing season. However, these data are not included in this report to allow for further interpretation and analysis following a confounding irrigation issue and subsequent pruning regime.

Table 5. Steam auger treatments in an almond orchard replant trial initiated in winter 2012 near Atwater, CA

	Application equipment	Treatment[1]	trees	Disease rating 7/24/12
			#	0-5 scale
Nonpariel				
1	none	none	3	1.33 ab
2	24 inch auger	disturbance only	6	1.50 a
3	36 inch auger	disturbance only	6	1.17 ab
4	backhoe	4x4x2 ft disturbance	3	1.00 ab
5	24 inch auger	steam injection	5	0.80 ab
6	36 inch auger	steam injection	4	0.25 b
Sonora				
1	none	none	7	0.86
2	24 inch auger	disturbance only	12	1.00
3	36 inch auger	disturbance only	12	0.75
4	backhoe	4x4x2 ft disturbance	6	0.33
5	24 inch auger	steam injection	8	1.13
6	36 inch auger	steam injection	4	0.75

[1] Steam was applied for enough time to raise the soil temperature above 158 F for at least 30 minutes (2-4 minutes of steam injection).

Table 6. Steam auger treatments in an almond orchard replant trial initiated in winter 2012 near Livingston, CA

	Application equipment	Treatment[1]	trees	Disease rating 7/24/12
			#	0-5 scale
Nonpariel				
1	none	none	12	1.0
2	24 inch auger	disturbance only	12	1.25
3	36 inch auger	disturbance only	12	1.37
4	backhoe	4x4x2 ft disturbance	12	0.83
5	24 inch auger	steam injection	12	0.83
6	36 inch auger	steam injection	12	1.08

[1] Steam was applied for enough time to raise the soil temperature above 158 F for at least 30 minutes (2-4 minutes of steam injection).