EVALUATION OF STEAM INJECTION AUGER FOR MANAGEMENT OF ALMOND REPLANT PROBLEMS

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Almond replant problems, including almond replant disease (ARD) and nematode parasitism, can reduce early and cumulative productive potential of second and later generation orchards. Pre-plant soil fumigation can effectively control replant problems, however increasing regulatory restrictions are complicating use of these treatments. Non-fumigant alternatives are needed for areas where grower preference or regulations limit fumigant use. Steam and other forms of heat treatment have been used to effectively disinfest soil in greenhouses, cut flower production and recently in strawberries which showed a 200% increase in yield when compared to untreated control following steam treatment. In the last decade it has been demonstrated that pre-plant spot fumigation at tree planting sites, administered by hand-held probes, GPS-controlled tractor-mounted shanks, or subsurface drip have provided acceptable but not optimal control of ARD. The objective of this research was to develop and test a steam injection system combining heat disinfestation with spot treatments of tree planting sites for the management of ARD and nematode parasitism. Specific objectives included.

- Compare the effects of disturbance from different diameter injection augers and disturbance combined with steam injection on subsequent performance of replanted trees.
- Compare the effects of steam injection using the 36" auger to methyl bromide and other conventional fumigants in large plot trials.

At the beginning of the project, two steam injection augers (24" diameter and 36" diameter) were designed and built. After initial tests, the augers were slightly modified to increase vertical mixing of soil and increase temperature uniformity and heating efficiency. Mechanistic studies revealed that to generate the target soil temperature of 158° F throughout the target profile to a depth of 24", steam injection plus soil mixing times of 2.5 min and 4.5 min were necessary for the 24" and 36" augers, respectively, and that dry soil heated faster and more uniformly than wet soil.

Field trials were initiated in 2010, 2011, and 2012 in Central Valley orchards with a high risk of replant problems to evaluate a steam injection auger system for management of almond replant problems (Table 1). Four non-fumigant trials were designed to compare the effects of disturbance from different diameter injection

augers and disturbance combined with steam injection on subsequent performance of replanted trees. Treatments in these trials were applied to individual tree sites with one or two trees per plot and included an untreated control, 24" steam injection, 36" steam injection, 24" auger disturbance, 36" auger disturbance, and a 4' x 4' x 4' backhoe pit. Untreated control received no pre-plant treatment. Steam treatments were applied for 2.5 min and 4.5 min for the 24" and 36" augers respectively. The 24" and 36" disturbance was made by inserting the auger and mixing soil for approximately 1 min. The largest disturbance treatment was applied by using a tractor-mounted backhoe to excavate and immediately replace the soil from a 4' by 4' area approximately 4' deep at a tree site.

- After two seasons of growth at the oldest site near Delhi all treatments resulted in trees with similar increases in trunk diameter to the untreated control and each other excepting the backhoe treatment which resulted in greater tree growth than the untreated control (Table 2)
- No differences in disease ratings were evident among treatments at any site (Tables 2 and 3).
- In the trials at Wasco, Atwater, and Livingston increases in trunk diameter and visual disease ratings were similar across all treatments (Table 3).

Two large plot fumigant trials were initiated in 2010 and 2011 with 24 trees per plot and designed to compare tree growth following treatment with the 36" steam injection auger or conventional fumigant treatments including methyl bromide (MB), chloropicrin (CP) and 1,3-dichloropropene (1,3-D)(Table 1). Bareroot almond nursery stock was planted 1-2 months after treatments were applied.

- At the Delhi site increases in trunk diameter in the first and second season was greater for trees in all fumigant plots when compared to steam injection or untreated control plots.
- After one year at Delhi, tree growth in all fumigant treatments was similar, however treatments with 1,3-D resulted in greater tree growth after two years than did treatment with methyl bromide (Table 4).
- At the Atwater trial after one season of growth the differences between treatments were not as apparent as the Delhi trial (Table 5). The pre-plant steam treatment did not significantly improve tree growth compared to the control (Table 5). All fumigant treatments containing CP resulted in greater increases in trunk diameter than the untreated control; but of these, only strip application with 1,3-D plus CP resulted in greater increases in trunk diameter than steam treatment.

These early growth data at this site suggests that tree site steam disinfestation with a 36" injection auger does not provide acceptable control of the almond replant problems in these sandy soils. Tree growth and nematode re-infestation monitoring will continue and nut yield and economic analyses will be conducted as the orchard reaches the bearing phase of its lifespan.

Table 1. Location and details of steam injection system trials in California almond orchards from 2010-13.

Trial location	Soil type	Trial type[1]	Nematodes present[2]	Treatments initiated	Orchard planted
Delhi, CA	Delhi sand	F, NF	Yes	Nov-10	Jan, 2011
Wasco, CA	Wasco sandy loam	NF	No	May-11	June, 2011
Atwater, CA	Atwater loamy sand	F, NF	Yes	Dec-11	Feb, 2012
Livingston, CA	Delhi loamy fine sand	NF	Yes	Feb-12	Mar, 2012

[1]NF is non-fumigant trial, F is fumigant trial.
[2]All trials were at risk of ARD, nematode sampling was carried out prior to trial initiation.

Table 2. Effects of pre-plant soil treatments on growth and visual disease ratings in 'Nonpareil' almond in a 2010-13 orchard replant trial near Delhi, CA

Treatment	Increase in trunk diameter 2011-12	Increase in trunk diameter 2011-13	Disease rating 2011	Disease rating 2012
	---------- mm ----------		--------- 0-5 scale[2] ---------	
Untreated	14.4 b[1]	31.5 b	0.9	1.6
24" auger	16.4 ab	34.9 ab	0.6	1.2
24" auger + steam	20.3 a	38.9 ab	0.5	0.9
36" auger	18.3 ab	35.1 ab	0.9	1.2
36" auger + steam	19.7 a	37.3 ab	0.6	1.4
Backhoe	19.2 ab	41.0 a	1.0	1.0
P value	0.0267	0.0251	0.5031	0.0653

[1]Letters indicate statistical difference at the alpha = 0.05 level according to Tukey's HSD.
[2]Disease ratings made on a 0-5 scale where zero is healthy and 5 is dead.

Table 3. Effects of pre-plant soil treatments on growth and disease severity in 'Nonpareil' almond at orchard replant sites near Wasco, Atwater, and Livingston, CA from 2011 to 2013.

	----------Wasco----------			------Atwater------		----Livingston---	
Treatment	**Increase in trunk diameter 2011-12**	**Disease rating 2011**	**Disease rating 2012**	**Increase in trunk diameter 2012-13**	**Disease rating 2012**	**Increase in trunk diameter 2012-13**	**Disease rating 2012**
	mm	--- 0-5 scale[1] ---		mm	0-5 scale	mm	0-5 scale
Untreated	10.1	0.4	1.1	30.2	1.3	22.2	1.2
24" auger	7.8	0.7	1.3	26.2	1.5	24.7	1.0
24" auger + steam	8.9	0.6	1.1	34.3	0.8	27.6	0.7
36" auger	9.3	0.2	1.4	35.1	1.2	24.4	1.2
36" auger + steam	9.5	0.8	1.5	41.0	0.3	28.5	0.8
Backhoe	--	--	-	34.5	1.0	25.2	1.0
P value	0.5582	0.2353	0.6497	0.2763	0.1155	0.1176	0.7852

[1]Disease ratings made on a 0-5 scale where zero is healthy and 5 is dead.

Table 4. Pre-plant soil treatment effects on tree growth and disease severity in 'Nonpareil' almond in a 2010-13 almond replant trial near Delhi, CA comparing steam and chemical fumigants.

Treatment		Increase in trunk diameter	Increase in trunk diameter	Disease rating	Disease rating
Treatment	Rate	2011-12	2011-13	2011	2012
	lb/A	--------- mm ----------		----- 0-5 scale[3] -----	
Untreated	--	20.8 b	41.2 d[2]	0.3	1.1 a
Steam	--	20.7 b	42.1 d	0.3	1.2 a
1,3-D broadcast[1,4]	340	26.0 a	59.7 a	0.1	0.1 b
1,3-D strip	340	25.7 a	55.7 ab	0.4	0.2 b
1,3-D plus CP strip	540	26.1 a	54.1 bc	0.3	0.2 b
MB	400	24.8 a	50.0 c	0.1	0.2 b
P value		<0.0001	<0.0001	0.0011	<0.0001

[1] Strip and broadcast applications were 11- and 22- feet wide and the length of the plot.
[2]Different letters indicate statistical difference at the alpha = 0.05 level according to Tukey's HSD.
[3]Disease ratings made on a 0-5 scale where zero is healthy and 5 is dead.
[4]1,3-D is 1,3-dichloropropene, CP is chloropicrin, and MB is methyl bromide.

Table 5. Pre-plant soil treatment effects on tree growth and disease severity in 'Nonpareil' almond in a 2011-13 orchard replant trial near Atwater, CA comparing steam and chemical fumigants.

Treatment		Increase in trunk diameter 2012-13	Disease rating 2012
Fumigant	**Rate**		
	lb/A	mm	0-5 scale[3]
Untreated	--	28.5 c[2]	0.9 b
Steam	--	29.6 bc	1.0 b
1,3-D plus CP strip[1,4]	540	37.5 a	0.6 a
1,3-D plus CP tree spot	340	36.2 ab	0.4 a
CP tree spot	340	34.8 ab	0.4 a
1,3-D plus CP tree spot	540	34.2 ab	0.3 a
1,3-D strip	340	33.1 abc	0.6 a
1,3-D broadcast	340	30.9 bc	0.6 a
P value		<0.0001	<0.0001

[1] Strip and broadcast applications were 11- and 22- feet wide and length of plot, tree spot applications were 11-feet wide and 8 feet long centered on the future tree site.
[2]Letters indicate statistical difference at the alpha = 0.05 level according to Tukey's HSD.
[3]Disease ratings made on a 0-5 scale where zero is healthy and 5 is dead.
[4]1,3-D is 1,3-dichloropropene, CP is chloropicrin, and MB is methyl bromide.