Almond Fumigant Studies: Continual Research on Methyl Bromide Alternatives and Fumigant Alternatives for Buffer Zones

Project No.: **12-AIR9-Doll**

Project Leader: David Doll
ANR Central Valley Region, Merced County
UC Cooperative Extension
2145 Wardrobe Ave
Merced, CA 95340
209.385.7403
209.722-8856 (fax)
dadoll@ucdavis.edu

Project Cooperators and Personnel:
Greg Browne, USDA-ARS, Davis, CA
Andrew (Bob) Johnson, UC Davis
Brad Hanson, UC Davis
Steve Fennimore, UC Davis. Salinas, CA

Objectives:
1. To continue the assessment of established fumigant plots for control of Prunus Replant Disease and plant pathogenic nematodes.
2. To continue the development of non-fumigant based control measures for almond replant disease and plant pathogenic nematodes within fumigant buffer zones.

Interpretive Summary:
This project continues the efforts initiated by the USDA-ARS Pacific Area-Wide Methyl Bromide Alternatives project that concluded in June 2012. Four field trials have been established in Merced County where we are evaluating fumigant alternatives to methyl bromide and non-fumigant alternatives for buffer zones. These trials are located on sandy soils in almond replant situations with the presence of ring nematode. In all trials, fumigated soils have outperformed the unfumigated control. Telone-II C35 (C35) applied as a rowstrip and Telone II broadcasted have provided the greatest growth response. Yield data for the oldest trial was collected in 2012. All fumigated plots had a higher yield than the control, and C35 out yielded the Telone-II rowstrip treatment. The effect of field fumigation on nematode populations has been variable. Populations appear to be suppressed in fumigated soils. Re-infestation of soils appears to occur within 2-3 years of fumigation and sooner if significant soil movement occurs after fumigation. We have not been able to identify any non-fumigant alternatives that have performed as well as the fumigants. In two trials, backhoed tree sites have outperformed the control in tree growth. Yield and growth performance will be followed for the next five years and be reported annually.

Materials and Methods:
This work continues the efforts set forth by the USDA-ARS Pacific Area-Wide Methyl Bromide Alternatives project which concluded in June of 2012. Three fumigant projects within Merced County were established over the past three years. All three projects included main plot designs testing fumigant alternatives to methyl bromide. A fourth was established in 2012 to determine non-fumigant alternatives for buffer zones. The trials include:

South Livingston Trial. This trial was planted in the spring of 2010 and is located on a loamy sand soil near Livingston, CA. This plot compares the effect of the applications of methyl bromide tree row strip applied at 350 lb/treated acre, 65% Telone/35% chloropicrin mixture (C35) tree row strip applied at 350 lb/treated acre, C35 tree site spot application applied at 350 lb/treated acre, Telone II® 100% soil broadcast applied at 340 lb/treated acre, and un-fumigated soil on tree growth. This trial also contains a secondary experiment investigating tree site applied non-fumigant alternatives in comparison to a control and a C35 fumigated row strip. These treatments include soil disinfestation using steam applied through a 30" diameter by 24" length soil auger, applications of brassica seed meal applied at two rates - 4000 and 8000 lbs/treated acre, and a combination of soil disinfestations and the high rate of the brassica seed meal.

Varieties include Price, Sonora, and Nonpareil, planted on Viking rootstock and flood irrigated. This is a low vigor plot.

Ballico Trial. This trial was planted in the spring of 2011 and is located on a sand soil near Ballico, CA. This site compares the effect of tree row strip applications of methyl bromide at 400 lb/treated acre, C35 tree row strip applied at 340 lb/ treated acre, Telone II tree row strip applied at 340 lb/treated acre, Telone II 100% soil broadcast applied at 340 lb/treated acre, tree site soil dis-infestation using steam injected through a 36" diameter by 24 inch long soil auger, and un-fumigated soil on tree growth.

This trial also contains a secondary experiment investigating tree site applied non-fumigant alternatives in comparison to a control and a C35 fumigated tree row strip. These treatments included backhoeing, 50 grams of aluminum phosphide applied to a backhoed tree site, 50 grams of Soilguard biological soil fungicide® (Certis USA) and 12,000 lbs/treated acre of brassica seed meal which were both injected as a liquid suspension using a 24" diameter by 24" length prototype auger.

Varieties include Aldridge, Sonora, and Nonpareil, planted on Nemaguard rootstock and irrigated with solid-set sprinklers. This is a medium vigor plot.

Winton Trial. Treatments were applied to this loamy sand soil near Winton, CA in November, 2011 and trees were planted in the spring of 2012. This trial compares the effect of the several fumigants applied at different rates and treated area on tree growth and yield. Treatments included C35 tree row strip applied at 540 lb/ treated acre, C35 tree site spot application applied at 540 lb/treated acre, C35 tree site spot application applied at 340 lb/treated acre, chloropicrin (CP) tree site spot application at 340 lb/treated acre, Telone II tree row strip applied at 340 lb/ treated acre, Telone II 100% soil broadcast applied at 340 lb/treated acre, soil dis-infestation using steam applied through a 36" diameter by 24" length soil auger applied at the tree site, and an un-fumigated control.

This site also contains a secondary experiment investigating tree site applied non-fumigant alternatives in comparison to a control and a C35 fumigated row strip. These treatments included backhoeing, 150 grams of aluminum phosphide applied to a backhoed tree site, 50 grams of Soilguard® biological soil fungicide (Certis USA) and 10 ozs of Basamid® (Certis

USA) granular fumigant which were both augured into the hole using a 30” diameter by 24” length prototype auger.

Varieties include Sonora, and Nonpareil, planted on Nemaguard rootstock and irrigated with solid-set sprinklers. This is anticipated to be a medium vigor plot.

North Livingston Trial. Planted in the spring of 2012 and located in sand soil near Livingston, CA. This plot is surrounded by houses, a daycare, and a school. There are considerable areas within the plot that can not be fumigated due to regulations. This trial uses the the adjacent tTelone II tree row strip fumigated trees for comparison. All non-fumigant treatments were applied to the tree planting hole/site and included three different experiments investigating non-fumigant alternatives and delivery systems. The project includes two tree replicates with five blocks (10 tree total), in order to provide the ability to test multiple products. Products that have a positive growth effect will be directed to a larger scale trial in 2013.

Treatments in the first experiment included backhoe, Basamid® (Certis USA), steam soil dis-infestation, commercial yeast extract, compost tea (Mid-Valley Ag’s L.C.S.), 10% hydrogen peroxide solution, and an untreated control.

The second experiment compared different methods for application of Serenade Soil® (Agraquest) or Soilguard® biological soil fungicide (Certis USA) applied pre-plant using a liquid injection auger or a bucket, with or without additional post-plant applications of Soilguard® biological soil fungicide or Melecon®, a post-plant nematicide (Certis USA), to backhoe treatment and an untreated control.

A third experiment compared post-plant applications of 1.5oz/tree and 3 oz/tree rates of Serenade Soil ® (Agraquest) to an untreated control.

Steam treatments were made using a 24”diameter and a 36” diameter steam injection auger, while other treatments were applied using a 24” diameter by 24” length auger. Granular applications (i.e. Basamid) were sprinkled on the top of the soil and distributed into the soil using a specially designed auger (**Figure 1**). Other products were suspended in 5 gallons of water and injected through the auger at 15 pounds of pressure to help increase product distribution. After application of the products, the auger continued to mix the soil for 45 seconds in order to thoroughly distribute the products in the planting hole.

Treatments within the trials are being monitored for tree growth, yield, and nematode control. Harvest data will be collected upon first harvest – usually the third year, and continued through the tenth year, possibly longer. Diameter and circumference measurements will be made in the dormant period following the year of growth. Visual disease severity rating are assigned during the growing season to on a scale from 0 to 5 (0=healthy and vigorous, 5=dead). Nematodes will be sampled from established plots following the first, third, fifth, and tenth year of growth in mid-October by collecting soil from the depth of 18 inches within the dripline of the tree. Samples from the same treatment within the block will be pooled, with one sample per block sent in for analysis. Samples will be analyzed for ring, lesion, and rootknot nematode by Nematodes Inc. Samples will include roots and organic debris as a bucket auger will be used

to sample the soil. A timeline of the nematode sampling and growth and yield for the next five years is outlined in **Table 1**.

Results and Discussion:

South Livingston: This trial was harvested for the first time in 2012. All fumigant treatments out yielded the control (**Figure 2**), and C35 row strip yielded more than Telone II row strip. Nematodes, although higher in the control and spot fumigated plots, were not significantly different among treatments (data not shown). Analyses of spot treatments within this trial were discontinued due to mis-application of fumigant controls.

Ballico Trial: After one year of growth increases in trunk diameter were greater for all fumigant plots when compared to steam injection and untreated control plots, yet increases in trunk diameter were similar across all fumigant treatments. Fumigated plots showed a greater total increase in trunk diameter after two years compared to steam injection and untreated control plots. However more differences among fumigant treatments became apparent after two years , with Telone II broadcast application resulting in the greatest increase in trunk diameter (59.7-mm) (**Table 2**). Second year disease severity ratings mirrored the differences in first year growth with all fumigant treated plots resulting in healthier, more vigorous trees than did treatments with steam injection auger or untreated control.

In the second experiment at this site increases in trunk diameter over two years were greater in plots treated with Telone C35 applied to the tree row strip (57.7-mm) when compared to all other treatments (**Table 3**). Aluminum phosphide added to the backhoe hole (50.2-mm) resulted in greater increases than backhoe treatment alone (46.2-mm), but both backhoe treatment with aluminum phosphide and alone resulted in greater tree growth than other treatments (</=41.8-mm). Disease severity ratings indicated healthier trees in Telone C35 treated plots when compared to other treatments. Soilguard treated plots had the highest disease severity ratings and lowest vigor, but were not significantly different than plots treated with brassica seed meal, 24” auger alone, or the untreated control.

Winton Trial: After one season of growth the differences between treatments were not as apparent as in the Ballico trial (**Table 4**). All fumigant treatments containing CP, Telone C35 (34.2-mm to 37.5-mm) resulted in greater increases in trunk diameter than the untreated control (28.5-mm). Only strip application with Telone II C35 resulted in greater increases in trunk diameter than steam treatment. All other fumigant treated plots showed similar increases in trunk diameter to steam treatment and to each other. Disease severity ratings and vigor taken in the first growing season were similar for all fumigant treatments. However fumigated trees had lower disease severity ratings and greater tree vigor when compared to plots receiving steam injection or no treatment (**Table 5**).

In the second experiment at this site, soil treatment with Telone C35 applied to the tree row strip resulted in greater increases in trunk diameter when compared to all other non fumigant treatments. Disease severity ratings were greatest in Basamid treated plots (1.5) which were also higher than other treatments excepting 24” auger alone (**Table 6**).

North Livingston Trial: In experiment one after one season of growth there were no significant differences between the non-fumigant alternatives, other than treatment with 24" steam injection auger which resulted in greater increases in trunk diameter (26.4-mm) than treatment with the 36" auger alone (21.8-mm) (**Table 7**). All non-fumigant treatments (21.8- to 26.4-mm) had less increase in trunk diameter than did adjacent trees (33.8-mm) that received treatment with Telone II strip applied in the tree row.

In experiment two, after one season of growth no treatments significantly differed in trunk diameter (**Table 8**).

Table 1: Sampling Timeline for 2012-2016.

	Nematode Sampling				**Growth/Yield**			
Trial	S Livingston	Ballico	Winton	N Livingston	S Livingston	Ballico	Winton	N Livingston
2012	Yes	No	Yes	Yes	Both	Growth	Growth	Growth
2013	No	Yes	No	N/A	Both	Both	Growth	Growth
2014	Yes	No	Yes	N/A	Both	Both	Both	Growth
2015	No	Yes	No	N/A	Both	Both	Both	Growth
2016	No	No	Yes	N/A	Both	Both	Both	Growth

Table 2. Pre-plant soil treatment effects on Nonpareil variety tree growth and disease severity in a 2010 almond replant trial near Ballico, CA comparing steam and chemical fumigants.

Treatment		**Increase in trunk diameter 2011-12 (mm)**	**Increase in trunk diameter 2011-13 (mm)**	**Disease Rating 2011 (0-5 , 0=healthy, 5=dead)**	**Disease Rating 2012 (0-5 , 0=healthy, 5=dead)**
Fumigant	**Rate (lb/A)**				
Telone II broadcast[1]	340	26.0 a	59.7 a[2]	0.1	0.1 b
Telone II strip	340	25.7 a	55.7 ab	0.4	0.2 b
Telone C35 strip	540	26.1 a	54.1 bc	0.3	0.2 b
MB strip	400	24.8 a	50.0 c	0.1	0.2 b
Steam	0	20.7 b	42.1 d	0.3	1.2 a
Untreated	0	20.8 b	41.2 d	0.3	1.1 a
***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 letter indicate statistical difference.

Table 3. Effects on tree growth of various non-fumigant treatments compared to Telone C35 row strip near Ballico, CA.

Treatment	Increase in trunk diameter 2011-12 (mm)	Increase in trunk diameter 2011-13 (mm)	Disease Rating 2011 (0-5 , 0=healthy, 5=dead)	Disease Rating 2012 (0-5 , 0=healthy, 5=dead)
C35 tree row strip[1]	26.5a[2]	57.7a	0.2a	0.2a
Backhoe incorporated aluminum phosphide	24.2b	50.2b	0.2a	0.7b
Backhoe	22.1c	46.2c	0.2a	0.9bc
Brassica seed meal	22.9bc	41.8d	0.1a	1.1cd
Untreated	19.5d	41.2d	0.5ab	1.2d
Soilguard	21.7c	39.3d	0.4b	1.4d
Auger Control	20.2cd	39.1d	0.1a	1.1cd
P value	**<0.001**	**<0.0001**	**0.0019**	**<0.0001**

[1] Strip applications were 11- feet wide and length of plot. Aluminum phosphide was incorporated with backhoe, and other treatments were applied with a 24" liquid injection auger.[2]Different letters indicate statistical difference.

Table 4. Pre-plant soil treatment effects on Nonpareil variety tree growth and disease severity in a 2011 almond replant trial near Winton, CA comparing steam and chemical fumigants.

Treatment		Increase in trunk diameter 2012-13 (mm)	Disease Rating 2012 (0-5 , 0=healthy, 5=dead)
Fumigant	**Rate (lb/A)**		
Telone C35 row strip[1]	540	37.5 a[2]	0.6 a
Telone C35 tree spot	340	36.2 ab	0.4 a
Chloropicrin tree spot	340	34.8 ab	0.4 a
Telone C35 tree spot	540	34.2 ab	0.3 a
Telone II strip	340	33.1 abc	0.6 a
Telone II broadcast	340	30.9 bc	0.6 a
Steam	0	29.6 bc	1.0 b
Untreated	0	28.5 c	0.9 b
***P* value**		**<0.0001**	**<0.0001**

[1] Strip and broadcast applications were 11- and 22- feet wide and length of plot, tree spots applications were 6-feet wide and 6-feet long centered on the tree spot. [2]Different letter indicate statistical difference.

Table 5. Nematode counts from various treatments taken after one year of growth at the Winton trial. Sampling performed in 2012.

Treatment		Root Knot	Ring	Lesion	Stubby Root	Pin
Fumigant	**Rate (lb/A)**	**----- nematodes/500g soil -----**				
Telone C35 row strip[1]	540	0	0	0	63.6	0
Telone C35 low tree spot	340	0	9.6	101.6	104.8	0
Chloropicrin tree spot	340	0	22.8	12.4	224.8	0
Telone C35 high tree spot	540	0	13.2	0	126	0
Telone II row strip	340	0	3.6	0	80.4	0
Telone II broadcast	340	0	11.6	0	81.2	0
Steam	0	0	14.4	21.2	178.8	0
Untreated	0	0	104.4	89.2	216.8	0

[1] Strip and broadcast applications were 11- and 22- feet wide and length of plot, tree spots applications were 6-feet wide and 6-feet long centered on the tree spot.

Table 6. Comparison of the effects of various non-fumigant treatments and Telone C35 in near Winton, CA

Treatment	Increase in trunk diameter 2012-13 (mm)	Disease Rating 2012 (0-5 , 0=healthy, 5=dead)
Telone C35 row strip[1]	34.1a[2]	0.6b
Untreated	29.9b	0.8b
24” auger	28.6b	1ab
Aluminum phosphide	28.4b	0.8b
Backhoe	28.1b	0.7b
Soilguard	27.5b	0.5b
Basamid	26.9b	1.5a
P value	**<0.0001**	**0.0047**

[1] Strip applications were 11- feet wide and length of plot. Aluminum phosphide was incorporated with backhoe, and other treatments were applied with a 24” liquid injection auger.[2]Different letters indicate statistical difference.

Table 7. Comparison of non-fumigant pre-plant treatments in Livingston, CA

Treatment	Change in Diameter (mm)	LSD grouping
Untreated	23.2	BC[2]
24" steam injection[1]	26.4	B
36" steam injection	25.2	BC
24" auger	23.3	BC
36" auger	21.8	C
10% peroxide solution	24	BC
Backhoe	23.9	BC
Yeast Extract	23.4	BC
LCS compost tea	23.1	BC
Basamid	22	BC
Telone II strip[3]	33.8	A
P value	**<0.0001**	

[1] Steam injections were raised to a temperature of at least 160°Frip applications were 11- feet wide and length of plot. Basimid was incorporated with 24" auger only as dry granular and other treatments were applied as slurry with a 24" liquid injection auger.[2]Different letters indicate statistical difference. [3]Telone II was adjacent to plots and was included in analysis as a grower standard.

Table 8. Effects of various biological soil pre-plant treatments, application techniques and timing on tree growth in Livingston, CA.

Product	Application Equipment	Post-plant application	Change in Diameter (mm)	LSD grouping
Telone II	Backhoe		30.7	A
None	Untreated		25.0	ABC
None	Backhoe		24.4	BC
None	Auger		15.2	D
Serenade	Auger	Serenade[1]	24.4	BC
Serenade	Auger	---	23.9	BC
Serenade	Bucket	Serenade	21.4	BCD
Serenade	Bucket	---	20.1	CD
Soil Guard	Auger	Melecon	26.9	AB
Soil Guard	Auger	---	24.2	BC
Soil Guard	Bucket	Melecon	24.0	BC
Soil Guard	Bucket	---	26.1	ABC
P value			**<0.0001**	

[1]Post plant treatments were applied on Apr-18, 2012 and again on Aug-15, 2012.

Figure 1: The liquid injection auger that has been used within the trials to inject and mix the product within the root zone.

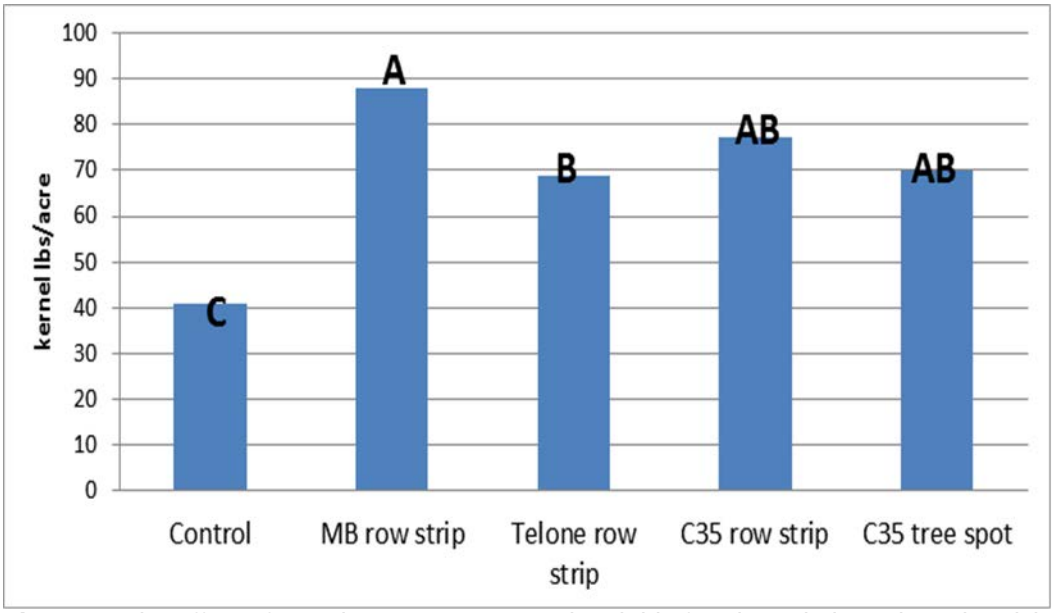

Figure 2: The effect of pre-plant treatments on the yield of replanted almonds at the Livingston trial in 2012. Treatments followed by different letters are statistically different ($p<0.05$).