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

Project No.: 14-AIR9-Doll

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Objectives:

1. To continue monitoring the efficacy 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 set forth by the USDA-ARS Pacific Area-Wide Methyl Bromide Alternatives project that concluded in June 2012. Several field trials have been established in Merced County over the last couple of years to evaluate 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. Three new trials were established in the spring of 2015 testing Telone-II alternatives. In all trials that have been established to date, fumigated soils have outperformed the unfumigated control. Fumigants containing Telone-II applied either as a broadcast or rowstrip treatments have provided the greatest growth response. Yield data for the oldest trial has been collected since 2012, from two plots since 2013, and three plots since 2014. All fumigated plots had a higher yield than the control. The effect of field fumigation on nematode populations has been variable. Populations appear to be suppressed in fumigated soils. Re-infestation of soils occurs within 2-3 years after fumigation and sooner if significant soil movement occurs after fumigation. Regardless of nematode re-infestation, trees planted in fumigated soils appear to grow more vigorously and to date have

produced more yield. Interestingly, tree growth within the C35 spot fumigation treatments has provided similar growth to rowstrip and broadcast fumigant treatments. We have not been able to identify any non-fumigant alternatives that have performed as well as pre-plant soil fumigants. In two trials, backhoed tree sites have outperformed the control in tree growth. Yield and growth performance are being or will be followed and will be annually reported.

Materials and Methods:

Continued work on determining the efficacy of fumigants and fumigant alternatives is critical to manage replant problems associated with successive generations of almond plantings. Over the past eight years, multiple trials have been established to determine alternatives to methyl bromide, and more recently, techniques that reduce fumigant rates and alternatives to 1,3-dichloropropene (Telone II) and chloropicrin (Pic). The trials include:

Ballico Trial. Planted in the spring of 2011 and located on a sand soil near Ballico, CA. This site compares the effect of tree row strip applications from fall of 2010 of methyl bromide (MB) at 400 lb/ treated acre; a 65% Telone II and 35% pic mixture (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 applied at 540 lb/acre. 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 (BSM). The Soilguard and BSM treatments 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 applied using a GPS guided rig to inject fumigant in a 7'x7' area centered on the tree site applied at 540 lb/ treated acre; C35 tree site spot application, using the method described above, applied at 340 lb/ treated acre, chloropicrin tree site spot application, using the method described above, 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; soil dis-infestation using steam applied through a 36" diameter by 24 inch 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 at 540 lb/acre. 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. The Soilguard® and Basamid® treatments 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.

South Livingston Trial. Planted in the spring of 2010 and located on a loamy sand soil near Livingston, CA. This plot compares the effect of the applications of methyl bromide (MB) tree row strip applied at 350 lb/ treated acre; 65% C35 tree row strip applied at 350 lb/ treated acre; C35 tree site spot application which uses a GPS guided rig to inject fumigant in a 7'x7' area centered on the tree site 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 inch length soil auger; applications of Brassica seed meal applied at two rates, 4,000 and 8,000 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.

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 will not be fumigated due to regulations. This trial is in non-fumigated areas adjacent to Telone II tree row strip fumigated trees that have been included in analysis for comparison. All treatments were applied to the tree planting hole/site. The project includes two tree replicates with five blocks (10 tree total), in order to provide the ability to test multiple products.

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.), 1% hydrogen peroxide solution, and an untreated control.

Steam treatments were made using 24"diameter and 36" 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.

Ballico Trial #2-1. Fumigant area (Trial 1). Fumigated in Fall 2014 and located in a sandy soil near Ballico, CA. This site compares the effect of broadcast, tree row strip, and an 8.3' x 8.3' tree spot of C35 at 540 lbs/ treated acre to a control. C35 was applied in the fall of 2014 and injected with 24" shanks using a commercial applicator. The plot contains four replicate blocks containing 10 trees of each variety for each treatment. Trees were planted in January 2015. Varieties include Nonpareil, Aldrich, and Sonora planted on Viking rootstock and irrigated with drip-line and solid-set sprinklers.

Ballico Trial #2-2. Telone-II alternatives (Trial 2). Fumigated in Fall 2014 and located in a sandy soil near Ballico, CA. This site compares the effectiveness of Telone-II alternatives, including Pic rowstrip applied at 200 lbs/treated acre; Pic-Chlor 60 (a mixture of 60% Pic, 40% Telone II) rowstrip applied at 338.8 lbs/treated acre; stabilized ally isothiocyanate (Dominus) rowstrip applied at 340 lbs/treated acre; a combination of Dominus and Pic rowstrip applied at 340 and 200 lbs/treated acre, respectively; Telone-II row strip applied at 340 lbs/treated acre; and an unfumigated control. The plot contains six replicate blocks containing six 'Aldrich' trees grafted to Viking rootstock. Trees were planted in January 2015. The plot is irrigated with drip-line and solid-set sprinklers.

Ballico Trial #2-3. Fumigant Alternative Trial (Bayer - Trial 3). Located in a sandy soil near Ballico, CA, this plot is testing an available non-fumigant alternative. Treatments include Telone-II row strip applied at 340 lbs/treated acre; an unfumigated control; and a treatment that includes a spring and fall application of Movento applied at 9 fl oz/treated acre and spring and summer chemigaton of an unregistered product from Bayer Crop Sciences at 6.84 fl/oz/treated acre. The plot contains six replicate blocks of seven 'Sonora' trees grafted to Viking rootstock. Trees were planted in January 2015. The plot will be irrigated with drip-line and solid-set sprinklers.

With the exception of the newly planted trials and the North Livingston trial, treatments within the trials have been monitored for tree growth, yield, and nematode control. Harvest data will be collected upon first harvest – usually the third year, and continued through the fifth year, possibly longer. Diameter and circumference measurements will be made in the dormant period following the year of growth through the fifth year. 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 annually or semi-annually 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. Trees within the North Livingston trial will only be monitored for growth.

Results and Discussion:

Ballico Trial: Cumulative change in trunk diameter for all fumigants (83.9 mm-98.0 mm) was greater than the control and steam treatments (66.8-73.0 mm) (**Table 1**). Trees planted in soil preplant fumigated with the Telone-II broadcast (BC) (98.0 mm) treatment outgrew C35, Telone-II, and MB rowstrip (RS) treatments (85.5, 91.1, and 83.9 mm, respectively). Disease severity ratings (DSR) mirrored tree growth (**Table 2**). All fumigants

were rated healthier (0.1-0.6) than the control and steam plots (1.0-1.5) with the Telone-II BC and RS treatments rated healthier than the other fumigant treatments (0.1 and 0.3 for Telone-II broadcast and rowstrip, respectively versus 0.6 and 0.5 for C35 RS and MB RS, respectively). 2014 and cumulative yield for the Telone-II broadcast treatment outperformed the methyl bromide, control, and steam treatments (**Table 3**). All Telone-II containing fumigants have a higher cumulative yield than the control or steam treatments. There were no differences in nematodes detected with the annual sampling (**Table 4**).

In the second experiment testing fumigant alternatives, cumulative increase in trunk diameter over the four years was greatest in plots treated with Telone C35 applied to the tree row strip (93.8 mm) (**Table 5**). Aluminum phosphide added to the backhoe hole (82.2mm) and the backhoe treatment (80.3 mm) outperformed the untreated, SoilGuard, and auger control (68.6, 66.2, and 67.5 mm, respectively). Disease severity ratings indicated healthier trees in Telone C35 treated and backhoe plots (**Table 6**).

Winton Trial: After three seasons, all fumigant treatments (78.3-82.88 mm) outgrew the untreated control (72.5 mm) (**Table 7**). Steam and PIC applied to the tree site grew similarly (71.3 and 78.3 mm, respectively), while all other fumigation treatments outperformed steam (80.8mm - 82.8 mm). DSR indicated that all fumigated trees appeared healthier (0.0-0.5) than the control or steam treatments (0.9-1.0) (**Table 8**). There were no differences in first year (2014) of yield in any of the treatments (**Table 9**). There were no differences in nematodes detected with the annual sampling (**Table 10**).

In the second experiment testing fumigant alternatives, cumulative increase in trunk diameter was greatest with C35 rowstrip (64.0 mm) and SoilGuard (72.7 mm) (**Table 11**), but only the C35 rowstrip outperformed the other treatments and control. DSR indicated that the C35, backhoe, and backhoe plus aluminum phosphide were similar (**Table 12**). Yields and nematode counts were taken from the C35, backhoe, and untreated plots only, and there were no differences in yield (**Table 13**) or nematodes detected with the annual sampling (**Table 14**).

South Livingston: In the third year of harvest data, all fumigant treatments performed similarly (497.1 - 597.2 kernel lbs/acre), and Telone-II and MB rowstrip outperformed the control (**Table 15**). All fumigants (748.0 - 881.1 kernel lbs/acre), however, have outperformed the control (501 kernel lbs/acre) in cumulative yields. Nematodes were not significantly different among treatments four years after treatment (**Table 16**).

North Livingston Trial: All treatments grew similarly in 2014 (**Table 17**). Differences in cumulative growth between treatments were not as large as in previous years, and statistical separation between Telone-II row strip and the control was not found.

Table 1. Pre-plant soil treatment effects on Nonpareil variety tree growth in an almond replant trial (treated 2010/planted 2011) near Ballico, CA comparing steam and chemical fumigants. Different letters indicate statistically significant difference (ANOVA, Tukey-Kramer HSD $p < 0.05$)

| Treatment | | Change in Trunk Diameter (mm) | | | | |
|----------------------------------|----------------|-------------------------------|-------------------|-------------------|-------------------|-------------------|
| Fumigant | Rate (lb/acre) | 2011 | 2012 | 2013 | 2014 | Cumulative |
| Untreated | 0 | 21.2 b | 20.3 d | 19.0 b | 12.6 ab | 73.0 d |
| Steam Spot | 0 | 20.7 b | 20.7 d | 16.8 b | 8.6 b | 66.8 d |
| Methyl Bromide | 400 | 24.8 a | 25.0 c | 20.2 b | 14.0 a | 83.9 c |
| Telone II Broadcast ¹ | 340 | 26.1 a | 32.7 a | 24.8 a | 14.4 a | 98.0 a |
| Telone II Strip ¹ | 340 | 24.8 a | 29.7 ab | 24.0 a | 12.6 ab | 91.1 b |
| Telone C-35 Strip ¹ | 540 | 25.6 a | 28.9 b | 20.0 b | 11.0 ab | 85.5 bc |
| P-value | - | <i><0.05</i> | <i><0.0001</i> | <i><0.0001</i> | <i><0.0001</i> | <i><0.0001</i> |

¹ Strip and broadcast applications were 11- and 22- feet wide and the length of the plot.

Table 2. Pre-plant soil treatment effects on Nonpareil disease severity in an almond replant trial/ (treated 2010/planted 2011 near Ballico, CA comparing steam and chemical fumigants. Disease Severity Ratings (DSR) varies from 0 to 5, where 0 is healthy and 5 is dead. Different letters indicate statistically significant difference (Steel-Dwass All Pairs or ANOVA Tukey-Kramer HSD $p < 0.05$)

| Treatment | | Disease Severity Rating (0-5; 0 = healthy, 5 = dead) | | | |
|----------------------------------|----------------|--|-------------------|-----------------|-------------------|
| Fumigant | Rate (lb/acre) | 2011 | 2012 | 2013 | 2014 |
| Untreated | 0 | 0.3 | 1.1 a | 1.5 d | 1.0 b |
| Steam Spot | 0 | 0.3 | 1.2 a | 1.5 d | 1.5 a |
| Methyl Bromide | 400 | 0.1 | 0.2 b | 0.8 c | 0.5 c |
| Telone II Broadcast ¹ | 340 | 0.1 | 0.1 b | 0.1 a | 0.1 d |
| Telone II Strip ¹ | 340 | 0.4 | 0.2 b | 0.4 ab | 0.3 cd |
| Telone C-35 Strip ¹ | 540 | 0.3 | 0.2 b | 0.7 bc | 0.6 bc |
| P-value | - | <i>0.1</i> | <i><0.0001</i> | <i><0.05</i> | <i><0.0001</i> |

¹ Strip and broadcast applications were 11- and 22- feet wide and the length of the plot.

Table 3. Pre-plant soil treatment effects on Nonpareil yield in an almond replant trial (treated 2010/planted 2011 near Ballico, CA comparing steam and chemical fumigants. Different letters indicate statistically significant difference (Steel-Dwass All Pairs or ANOVA Tukey-Kramer HSD $p < 0.05$).

| Treatment | | Yield (lbs/acre) | | |
|----------------------------------|----------------|------------------|---------|------------|
| Fumigant | Rate (lb/acre) | 2013 | 2014 | Cumulative |
| Untreated | 0 | 158 b | 377 c | 535 c |
| Steam Spot | 0 | 138 b | 358 c | 496 c |
| Methyl Bromide | 400 | 230 ab | 499 bc | 729 bc |
| Telone II Broadcast ¹ | 340 | 318 a | 764 a | 1082 a |
| Telone II Strip ¹ | 340 | 266 a | 652 ab | 918 ab |
| Telone C-35 Strip ¹ | 540 | 258 a | 526 abc | 784 ab |
| P-value | - | <0.0001 | <0.0001 | <0.0001 |

¹ Strip and broadcast applications were 11- and 22- feet wide and the length of the plot.

Table 4. Nematode counts from fumigant and steam treatments taken after two years of growth at the Ballico fumigant trial (treated 2010/planted 2011). Sampling performed in 2014. No significant differences among treatments were observed (Steel-Dwass All Pairs of $\ln(\text{count}+1)$, $p>0.05$).

| Treatment | | Root Knot | Ring | Lesion | Stubby Root | Pin | Free Composite |
|----------------------------------|----------------|---------------------------------|-------|--------|-------------|-----|----------------|
| Fumigant | Rate (lb/acre) | ----- nematodes/500g soil ----- | | | | | |
| Control | 0 | 1 | 268.5 | 22.9 | 31.7 | 0 | 336.5 |
| Steam | 0 | 0 | 50.4 | 7.6 | 23.5 | 0 | 343.6 |
| Methyl Bromide | 400 | 1.8 | 84.4 | 11.5 | 3.8 | 0 | 292.1 |
| Telone II Broadcast ¹ | 340 | 5.3 | 39.6 | 38.5 | 65 | 0 | 389.6 |
| Telone II Strip ¹ | 340 | 7.6 | 84 | 38.7 | 24.5 | 0 | 478.8 |
| Telone C-35 Strip ¹ | 540 | 10 | 65.7 | 20.2 | 35.7 | 0 | 361.8 |

¹ Strip and broadcast applications were 11- and 22- feet wide and the length of the plot.

Table 5. Effects on tree growth of various non-fumigant treatments compared to Telone C35 row strip near Ballico, CA (treated 2010/planted 2011). Different letters indicate statistically significant difference (ANOVA, Tukey-Kramer HSD $p < 0.05$)

| Treatment | Change in Trunk Diameter (mm) | | | | |
|----------------------------------|-------------------------------|-------------------|---------------|-------------------|-------------------|
| | 2011 | 2012 | 2013 | 2014 | Cumulative |
| C-35 Tree Row Strip ¹ | 26.5 a | 31.2 a | 20.4 a | 15.6 a | 93.8 a |
| Backhoe-incorporated AIP | 24.2 b | 25.0 b | 20.9 a | 12.5 ab | 82.2 b |
| Backhoe | 22.1 c | 24.1 bc | 20.5 ab | 13.6 ab | 80.3 b |
| Brassica Seed Meal | 22.9 bc | 21.3 bcd | 17.9 ab | 12.1 ab | 70.9 bc |
| Untreated | 19.5 d | 21.2 cd | 16.6 b | 11.6 b | 68.8 c |
| Soilguard | 21.7 c | 17.9 d | 19.1 ab | 9.9 ab | 66.2 c |
| Auger Control | 20.2 cd | 19.5 cd | 18.0 ab | 10.7 ab | 67.5 c |
| P value | <0.001 | <0.0001 | 0.0046 | <0.0001 | <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.

Table 6. Effects on disease severity of various non-fumigant treatments compared to Telone C-35 row strip near Ballico, CA (treated 2010/planted 2011). Different letters indicate statistically significant difference (Steel-Dwass All Pairs $p < 0.05$).

| Treatment | Disease Severity Rating (0-5; 0 = healthy, 5 = dead) | | | |
|----------------------------------|---|-------------------|-----------------|-------------------|
| | 2011 | 2012 | 2013 | 2014 |
| C-35 Tree Row Strip ¹ | 0.2 a | 0.2 a | 0.3 a | 0.2 c |
| Backhoe incorporated AIP | 0.2 a | 0.7 b | 0.9 b | 0.7 abc |
| Backhoe | 0.2 a | 0.9 bc | 0.9 b | 0.5 bc |
| Brassica Seed Meal | 0.1 a | 1.1 cd | 1.5 bc | 1 ab |
| Untreated | 0.5 bc | 1.2 d | 1.5 bc | 1.2 a |
| Soilguard | 0.4 b | 1.4 d | 1.8 c | 1.4 a |
| Auger Control | 0.1 a | 1.1 cd | 1.8 c | 1.1 ab |
| P-value | 0.1 | <0.0001 | <0.05 | <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.

Table 7. Pre-plant soil treatment effects on Nonpareil variety tree trunk diameter in a 2011 almond replant trial/planted 2012 near Winton, CA comparing steam and chemical fumigants applied in pounds per acre (lb/acre). Changes in tree trunk diameters are in millimeters (mm). Different letters indicate statistically significant difference (ANOVA, Tukey-Kramer HSD $p < 0.05$).

| Treatment | | Change in Trunk Diameter (mm) | | | |
|-----------------------------|----------------|-------------------------------|---------|---------|------------|
| Fumigant | Rate (lb/acre) | 2012 | 2013 | 2014 | Cumulative |
| Untreated | 0 | 28.7 c | 28.1 ab | 15.7 a | 72.5 c |
| Steam | 0 | 30.4 bc | 23.9 b | 17.0 a | 71.3 bc |
| Chloropicrin Tree Spot | 340 | 34.8 ab | 29.5 ab | 14.0 a | 78.3 ab |
| Telone II Broadcast | 340 | 30.0 bc | 33.8 a | 17.0 a | 80.8 a |
| Telone II Strip | 540 | 33.1 abc | 30.3 a | 17.7 a | 81.1 a |
| Telone C-35 Row Strip | 540 | 37.2 a | 29.5 ab | 16.0 a | 82.7 a |
| Telone C-35 Tree Spot | 340 | 36.3 a | 30.5 ab | 15.8 a | 82.8 a |
| Telone C-35 Tree Spot | 540 | 33.4 abc | 32.3 a | 17.1 a | 82.6 a |
| P-value | - | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

Table 8. Pre-plant soil treatment effects on Nonpareil variety disease severity ratings (DSR) in an almond replant trial (treated 2011/planted 2012) near Winton, CA comparing steam and chemical fumigants applied in pounds per acre (lb/acre). DSR ratings vary from 0 to 5, where 0 is healthy and 5 is dead. Different letters indicate statistically significant difference (ANOVA, Tukey-Kramer HSD $p < 0.05$).

| Treatment | | Disease Severity Rating (0-5; 0 = healthy, 5 = dead) | | |
|------------------------|-------------------|---|---------|-------|
| Fumigant | Rate (lb/acre) | 2012 | 2013 | 2014 |
| Untreated | 0 | 0.9 b | 0.8 b | 1.0 b |
| Steam | 0 | 0.8 b | 0.9 b | 0.9 b |
| Chloropicrin Tree Spot | 340 | 0.4 a | 0.1 a | 0.5 a |
| Telone II Broadcast | 340 | 0.4 a | 0.0 a | 0.1 a |
| Telone II Strip | 540 | 0.6 a | 0.3 a | 0.3 a |
| Telone C-35 Row Strip | 540 | 0.7 a | 0.2 a | 0.3 a |
| Telone C-35 Tree Spot | 340 | 0.4 a | 0.2 a | 0.3 a |
| Telone C-35 Tree Spot | 540 | 0.4 a | 0.1 a | 0.4 a |
| P-value | - | 0.049 | <0.0001 | <0.05 |

Table 9. Pre-plant soil treatment effects on Nonpareil variety 2014 yields in an almond replant trial (treated 2011/planted 2012) near Winton, CA comparing steam and chemical fumigants applied in pounds per acre (lb/acre). Different letters indicate statistically significant difference (ANOVA, Tukey-Kramer HSD $p < 0.05$).

| Treatment | | Yield |
|------------------------|-------------------|--------------------|
| Fumigant | Rate (lb/acre) | 2014 (lbs/acre) |
| Untreated | 0 | 391 a |
| Steam | 0 | 349 a |
| Chloropicrin Tree Spot | 340 | 473 a |
| Telone II Broadcast | 340 | 441 a |
| Telone II Strip | 540 | 414 a |
| Telone C-35 Row Strip | 540 | 512 a |
| Telone C-35 Tree Spot | 340 | 531 a |
| Telone C-35 Tree Spot | 540 | 493 a |
| P-value | - | 0.1 |

Table 10. Nematode counts from various treatments taken after two years of growth at the Winton fumigant trial (treated 2011/planted 2012). Sampling performed in 2014. No significant differences among treatments were observed (Steel-Dwass All Pairs of $\ln(\text{count}+1)$, $p>0.05$).

| Treatment | | Root Knot | Ring | Lesion | Stubby Root | Pin | Free Composite |
|----------------------------------|----------------|---------------------------------|-------|--------|-------------|-------|----------------|
| Fumigant | Rate (lb/acre) | ----- nematodes/500g soil ----- | | | | | |
| Control | 0 | 6.7 | 83.9 | 26.2 | 14.2 | 30.6 | 437.9 |
| Steam | 0 | 1.4 | 121.0 | 26.5 | 31.4 | 47.4 | 457.5 |
| Chloropicrin Tree Spot | 340 | 1.5 | 212.8 | 9.7 | 7.7 | 66.9 | 440.5 |
| Telone II Broadcast ¹ | 340 | 11.3 | 41.7 | 25.3 | 10.9 | 52.6 | 426.2 |
| Telone II Strip | 540 | 9.3 | 92.6 | 16.5 | 25.9 | 40.0 | 364.7 |
| Telone C-35 Row Strip | 540 | 12.1 | 32.2 | 31.1 | 5.1 | 62.7 | 639.4 |
| Telone C-35 Tree Spot | 340 | 3.8 | 73.0 | 66.8 | 55.0 | 112.3 | 685.6 |
| Telone C-35 Tree Spot | 540 | 3.8 | 9.9 | 89.4 | 67.2 | 253.2 | 532.0 |

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 11. Comparison of the effects of various non-fumigant treatments and Telone C-35 on Nonpareil trunk diameter growth near Winton, CA. Different letters indicate statistically significant difference (ANOVA, Tukey-Kramer HSD $p < 0.05$).

| Treatment | Change in Trunk Diameter (mm) | | | |
|------------------------------------|-------------------------------|---------------|---------------|-------------------|
| | 2012 | 2013 | 2014 | Cumulative |
| Telone C-35 Row Strip ¹ | 33.5 a | 30.6 a | 18.4 a | 81.4 a |
| Untreated | 29.7 b | 25.8 a | 16.5 a | 72.5 b |
| 24" Auger | 28.4 ab | 24.3 a | 12.3 a | 65.0 b |
| Al Phosphide | 28.3 b | 27.5 a | 15.6 a | 70.2 b |
| Backhoe | 28.0 b | 27.2 a | 18.4 a | 70.4 b |
| Soilguard | 27.2 b | 27.2 a | 18.3 a | 72.7 ab |
| Basamid | 27.5 b | 27.1 a | 14.9 a | 69.7 b |
| P value | 0.0002 | 0.3433 | 0.1263 | <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.

Table 12. Comparison of the effects of various non-fumigant treatments and Telone C-35 on disease severity ratings near Winton, CA. DSR ratings vary from 0 to 5, where 0 is healthy and 5 is dead. Different letters indicate statistically significant difference (ANOVA, Tukey-Kramer HSD $p < 0.05$).

| Treatment | Disease Severity Rating (0, 5; 0 = healthy, 5 = dead) | | |
|-----------------------------------|---|---------------|-------------------|
| | 2012 | 2013 | 2014 |
| Telone C35 Row Strip ¹ | 0.6 b | 0.2 a | 0.2 c |
| Untreated | 0.8 b | 0.9 b | 1.2 a |
| 24" Auger | 1.0 ab | 1.0 b | 1.1 ab |
| Al Phosphide | 0.7 b | 1.0 b | 0.7 abc |
| Backhoe | 0.7 b | 1.0 b | 0.5 bc |
| Soilguard | 0.5 b | 0.6 b | 1.4 a |
| Basamid | 1.5 a | 1.1 b | 1.0 ab |
| P value | 0.0047 | 0.0047 | <0.0001 |

Table 13. Comparison of the effects of non-fumigant treatments and Telone C-35 on Nonpareil variety yields near Winton, CA. No significant difference among treatments was observed (ANOVA, Tukey-Kramer HSD $p < 0.05$).

| Treatment | 2014 Yield (lbs/acre) |
|-----------------------|-----------------------|
| Untreated | 382.7 |
| Backhoe | 404.1 |
| Telone C-35 Row Strip | 511.6 |

Table 14. Nematode counts from various treatments taken after two years of growth at the Winton non-fumigant trial. Sampling performed in 2014. No significant differences among treatments were observed (Steel-Dwass All Pairs of $\ln(\text{count}+1)$, $p > 0.05$).

| Treatment | Root Knot | Ring | Lesion | Stubby Root | Pin | Free composite |
|-----------------------|---------------------------------|------|--------|-------------|-----|----------------|
| | ----- nematodes/500g soil ----- | | | | | |
| Telone C-35 Row Strip | 2 | 92 | 38 | 45 | 358 | 1890 |
| Untreated | 0 | 150 | 39 | 53 | 86 | 940 |
| Backhoe | 2 | 288 | 33 | 49 | 29 | 536 |

Table 15. Comparison of the effects on yield of various fumigant treatments in South Livingston, CA (treated 2009/planted 2010) Different letters indicate statistically significant difference (log10(yield) ANOVA, Tukey-Kramer HSD).

| Treatment | Yield (lbs/acre) | | | |
|-----------------------|------------------|-----------------|-----------------|-----------------|
| | 2012 | 2013 | 2014 | Cumulative |
| Telone C-35 Row Strip | 73.0 ab | 210 a | 531.6 ab | 790.2 a |
| Telone C-35 Tree Spot | 65.9 ab | 210 a | 497.1 ab | 748.0 a |
| Telone II Strip | 65.0 b | 184 a | 597.2 a | 824.4 a |
| MeBr Strip | 84.0 a | 235 a | 590.4 a | 881.1 a |
| Untreated | 40.8 c | 105 a | 367.4 b | 501.0 b |
| P-value | <0.05 | <0.05 | <0.05 | <0.05 |

Table 16. Nematode counts from various treatments taken after three years of growth at the South Livingston fumigant trial (treated 2009/planted 2010) . Sampling performed in 2014. No significant differences among treatments were observed (Steel-Dwass All Pairs of ln(count+1), p>0.05).

| Treatment | Root Knot | Ring | Lesion | Stubby Root | Pin | Free Composite |
|---------------------------------|-----------|------|--------|-------------|-----|----------------|
| ----- nematodes/500g soil ----- | | | | | | |
| Telone C-35 Row Strip | 0 | 44 | 6 | 43 | 155 | 603 |
| Telone C-35 Tree Spot | 0 | 62 | 10 | 32 | 96 | 455 |
| Telone II Strip | 2 | 74 | 11 | 24 | 231 | 451 |
| MeBr Strip | 0 | 176 | 7 | 34 | 183 | 376 |
| Untreated | 0 | 61 | 34 | 44 | 67 | 425 |

Table 17. Comparison of non-fumigant pre-plant treatments in North Livingston, CA (treated 2011/planted 2012). Different letters indicate statistically significant difference (ANOVA, Tukey-Kramer HSD $p < 0.05$).

| Treatment | Change in Trunk Diameter (mm) | | | |
|----------------------------------|-------------------------------|-----------------|------------|------------------|
| | 2012 | 2013 | 2014 | Cumulative |
| Untreated | 23.2 bc | 37.2 b | 26.8 a | 89.9 ab |
| 24" Steam Injection ¹ | 26.4 b | 33.4 b | 29.0 a | 91.3 ab |
| 36" Steam Injection | 25.2 bc | 33.4 b | 28.5 a | 87.0 b |
| 24" Auger | 23.3 bc | 36.5 b | 28.2 a | 85.4 b |
| 36" Auger | 21.8 c | 36.5 b | 27.8 a | 91.6 ab |
| 1% Peroxide Solution | 24 bc | 31.6 b | 27.6 a | 83.8 b |
| Backhoe | 23.9 bc | 40.6 ab | 30.4 a | 93.1 ab |
| Yeast Extract | 23.4 bc | 36.2 b | 23.6 a | 83.8 b |
| LCS Compost Tea | 23.1 bc | 34.2 b | 27.8 a | 84.3 b |
| Basamid ² | 22 bc | - | - | - |
| Telone II Strip ³ | 33.8 a | 44.1 a | 29.6 a | 105 a |
| P value | <0.0001 | <0.05 | 0.6 | <0.001 |

¹ Steam injections were raised to a temperature of at least 160°F rip applications were 11- feet wide and length of plot. Basimid was incorporated with 24" auger only as a dry granular, and other treatments were applied as a slurry with a 24" liquid injection auger.² Applications of Basamid caused phytotoxicity due to lack of soil moisture and rain. Due to replanted trees, measurements were not taken in 2013. ³ Telone II was adjacent to plots and was included in analysis as a grower standard.



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