Using TIF Tarp and Reduced Fumigation Rates for Almond Replanting

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Objectives:

1) Demonstrate that the use of totally impermeable film (TIF) tarp can improve fumigant distribution in soil and control pests while reducing emissions in orchard replanting field fumigation.
2) Evaluate pest control efficacy, especially nematodes under TIF tarp and reduced fumigation rates.
3) Monitor almond tree vigor and growth from different fumigation treatments in fumigated growers' fields.
4) Determine the effective field fumigation rates under TIF tarp in regard to soil-borne pest control and almond tree performance.

Interpretive Summary:

During the reporting period, our main research activities were field monitoring from two almond orchards (Merced trial and Ballico trial) that were fumigated in previous years. Fumigation for the Merced trial at Bluff Ranch was conducted in November 2012 and fumigation for the Ballico trial at Littlejohn's Farm was fumigated in December 2014. Both orchards were replanted shortly after fumigation was completed. Tree growth has been monitored since replanting with the first yield data collected at the Merced trial site. Nematode recovery approximately three years after fumigation and residual fumigants were also determined. In the Merced trial site, the first yield data and tree diameters from the 100% and the 66% rates of Telone® C35 were all significantly higher than those from the unfumigated control, but there were no significant differences

between the two rates or among the surface sealing methods. The nut yield in the 33% rate plots was not significantly different from the unfumigated control. The observation of lower nematode population with lower fumigant rate was seen, but needs further investigation. The data confirm that pre-plant soil fumigation did improve tree establishment and early yield. However, nematode recovery, which is dominated by pin and ring nematode, three years after fumigation appeared to be reaching the nematode populations as before fumigation. Further verification may help evaluate long-term fumigation impact on orchard soil health and relationship to soil-borne pest recovery, which is an unknown area. Trace amounts of residual fumigant were also detected at the Merced trial site three years after fumigation indicating a small amount of persistent fumigants in soil. For the Ballico trial, tree growth has shown significant improvement from fumigation treatment at 100% and 66% rate including deep injection at 100% rates with no differences among all fumigated treatments. A second nut yield at the Merced trial site is scheduled to be measured in fall 2016 to confirm previous yield data. In summary, all fumigation treatments have shown positive effects on tree performance from both trials and early yield and we continue field monitoring to observe long term fumigation effects.

Materials and Methods:

Merced trial – field monitoring of tree growth, almond yield, nematode recovery, and residual fumigants in an orchard fumigated in 2012

The Merced trial fumigation was conducted from November 29, 2012 through January 12, 2013 at Bluff Ranch, about 13 miles northeast of Merced. Almond trees were planted in February 2013. Fumigation treatments included non-fumigated control and three rates (full or maximum allowed label rate 100%, 66%, and 33% of Telone® C35) under three surface sealing methods [bare, standard polyethylene (PE), and TIF]. A total of 12 treatments with 6 replicates were applied in a randomized complete block design and monitored. All treatments have been monitored for tree growth since replanting in early 2013. Fumigant movement and some of the tree growth data were reported in previous years' reports (Gao 2013, 2014, and 2015 annual reports to Almond Board). The first nut yield measurement was achieved in fall 2015. On April 16, 2016, about three years after fumigation, we collect soil samples down to 5 ft. depth at one ft. increments and determined parasitic nematode populations in soils. All plant parasitic nematodes in the soil samples were extracted by the sugar-flotation and centrifugation method utilizing a 25 µm sieve (Jenkins, 1964). Extracted nematodes were identified under the microscope at 4× magnification (Mai and Lyon, 1975). Residual fumigants [1,3-dichloropropene (1,3-D) and chloropicrin) in the soil were also determined to evaluate persistence of fumigant in soil. Sample extraction and analysis followed methods described in Gao et al., (2009). These data are intended to answer the questions about how long fumigation treatments provide the benefits to suppress nematode recovery under field conditions and if there is a significant correlation with tree growth and yield.

Ballico trial - orchard establishment and tree growth monitoring in an orchard fumigated in 2014

The Ballico trial fumigation was conducted at Littlejohn's Farm, Ballico, from December 9, 2014 through January 6, 2015. The treatments included full rate Telone® C35 with the regular injection depth (18 inch), full rate with a deeper injection depth (~28 inch), and a reduced (66% rate) under three surface sealing methods (bare, PE and TIF) and non-fumigated control (non-tarped and TIF). A total of 11 treatments with four replicates in randomized complete block design were used in field layout. Fumigant fate and movement as well as nematode control data were reported in Gao et al., 2015 annual report to Almond Board. Young trees were planted in mid-January, 2015. Tree diameters were measured from all plots immediately following planting and nine months later. The monitoring will continue through the second and third year until yield data can be collected.

Statistical analysis

Data on tree diameter and almond yield were statistically analyzed using two-way ANOVA and a mixed model with both fixed and random effects. Within the model, treatments were selected as fixed effects and blocks were chosen as random effects. The model allowed multiple comparisons among the means from all treatments using Tukey-Kramer adjustment to avoid Type I error. For nematode recovery data in the soil profile, all data were transformed by logarithm prior to fitting repeated measures mixed model where the counts at increasing depths on the treatment x block experimental units were considered repeated measures. The first order autoregressive covariance structure among the repeated measures was incorporated in the model. The residual diagnostics showed that the log transformation did a good job in stabilizing the variance and normalizing the distribution of the errors. The "Type 3 Tests of Fixed Effects" showed that treatment was not significant either as a main effect or in interaction with depth; so focus concentrated on the significant depth main effect. Linear and quadratic contrasts across the depths were also obtained and the result was significant for linear and not for quadratic, i.e., decrease in nematode counts with increasing depth was linear. All analyses were done using SAS 9.2 (SAS Institute, Cary, NC).

Results and Discussion:

Tree growth, almond yield, nematode recovery, and residual fumigants in Merced trial

Table 1 shows selected tree growth measurements within the first three years and the first yield data collected in the third year at Bluff Ranch. There were no significant differences ($P<0.05$) in tree diameter at planting (measured on 8 March 2013). Ten months after replanting (measured on 15 December 2013) significant differences in tree diameter were observed between fumigated treatments and the unfumigated control. Although the treatment effects were less pronounced at 14 months (measured on 9 May 2014), these differences carried through to the following year. The last measurement data on tree growth indicate that all fumigated treatments regardless of rate and film type, resulted in larger tree diameter, but only those at 100% and 66% rates were significantly greater than the unfumigated control. Among the fumigated treatments, there were no significant differences in tree diameter. The first yield data (Year 3 after replanting) showed the same trend as the tree diameter measurements. The full rate and the 66% rate had significantly higher almond yield than trees in the unfumigated control plots with no differences between the two rates or among the surface sealing methods. The nut yield in the 33% rate plots was not different than the unfumigated control. The yield data confirm that preplant soil fumigation did improve tree establishment and early yield. If pest pressure is low, trees in unfumigated plots may overcome early slow growth; however, this is not currently predictable and presents a serious risk to growers at the beginning of a long-lived crop like almond. Thus, in an orchard replanting situation, especially in fields infested with nematodes, this research suggests that soil fumigation or any other type of soil disinfestation method can bring immediate benefits and reduce the risks to growers.

Table 1. Almond tree diameter and yield measurement after soil fumigation treatments in the 2012 field trial, SJV, CA

Treatment (Telone® C35 tarp & rate)	Tree diameter[a] (mm)			Yield[b] (field wt, kg $tree^{-1}$)
	3/8/2013[c]	12/15/2013	11/14/2014	8/7/2015
Bare-100%	11.4 a	46.3 a	87.2 a	17.3 a
PE-100%	10.6 a	46.2 a	86.4 a	16.9 a
TIF-100%	10.8 a	45.6 a	85.1 a	16.5 a
Bare-66%	11.2 a	44.1 ab	87.0 a	17.3 a
PE-66% PE	11.0 a	45.5 a	87.0 a	15.6 a
TIF-66%	11.6 a	45.7 a	85.9 a	15.9 a
Bare-33%	11.1 a	43.2 abc	82.8 ab	14.2 ab
PE-33%	11.1 a	43.8 ab	84.4 a	14.5 ab
TIF-33%	11.4 a	43.1 abc	82.8 ab	13.8 ab
Bare-0%	10.8 a	37.6 d	73.9 c	8.6 c
PE-0%	11.0 a	39.3 bcd	75.9 bc	9.8 bc
TIF-0%	10.4 a	38.2 dc	74.5 dc	10.0 bc

[a] Different letters in the same column indicate significance at $P<0.05$.
[b] The field weight includes the hull, kernel and shell.
[c] Initial measurement after planting, prior to leaf expansion. Young almond trees were transplanted end of February, 2012.

Nematode recovery three years after fumigation in Merced trial

The total plant parasitic nematode population (TNP) data in the fumigated field three years later were plotted in **Figure 1**. Pin (*Paratylenchus* spp.) and ring (*Criconemella* *xenoplax)* nematodes were the dominant species (70 and 29% of total population respectively with <1% of stunt (*Merlinius* spp.) and lesion (*Pratylenchus spp***.)** nematodes**.** The field was infested similarly with mostly pin and ring nematodes before fumigation (**Figure 2**). Several weeks after fumigation, the 66% and 100% rate had non-detectable live nematodes in top 1 m soil depth. The data indicate that nematodes in the fumigated field can recover within several years. Further we noted that the higher fumigated rate (e.g., 100%) had a similar population as the unfumigated control. Although statistical analysis showed no significant difference it appears that average population decreased as fumigation rate decreased across all three surface sealing methods (bare, PE, and TIF) at various depths (**Figure 1**). The cause could be due to low vigorous root system development at low fumigation rate (e.g., 33%); however, without significant differences in tree performance including yield between the 100% and 66% fumigation rates (**Table 1**), most of the average nematode population were lower in 66% rate fumigated plots than those from 100%. A second possible reason is that high fumigation rate may have negatively impacted soil microbial community resulting in a less resistant environment that may have played role in faster nematode recovery. The latter is an unknown area that future research should look into. The observed phenomenon should be further investigated due to its long term implications.

Soil residual fumigant

Three years after fumigation in the Merced trial, residual fumigants (1,3-D and chloropicrin) were determined in soil profile. The detection limit of instrument used for the analysis was 0.01 mg/L (translating to 0.01 mg/kg) for both 1,3-D isomers and 0.001 (translating to 0.001 mg/kg) for chloropicrin using the extraction and analytical protocols developed in our laboratory. Chloropicrin was below the detection limit for all soil samples, but 1,3-D was detected in 70% of the samples collected with most values below 0.2 mg/kg. The data may indicate that 1,3-D could be tied up with soil organic matter or mineral particles and became persistent in soil that may or may not have affected microbial community, which in turn may or may not affect the fast nematode recovery reported above.

Ballico trial - almond tree growth after fumigation in 2014

Tree growth data were collected during the first year after replanting and the results are shown in **Figure 3**. There were no any differences immediately following tree planting (measurement on February 6, 2015, **Figure 3a**) but there were significant differences in growth about nine months later (measurement in November 2015) (**Figure 3b**). The tree response to fumigation treatments in the Ballico trial was similar to that in earlier Merced trial (**Table 1**). The data confirm that preplant soil fumigation provides immediate benefits for the establishment of new trees in perennial orchards. We will continue the monitoring until yield data collection.

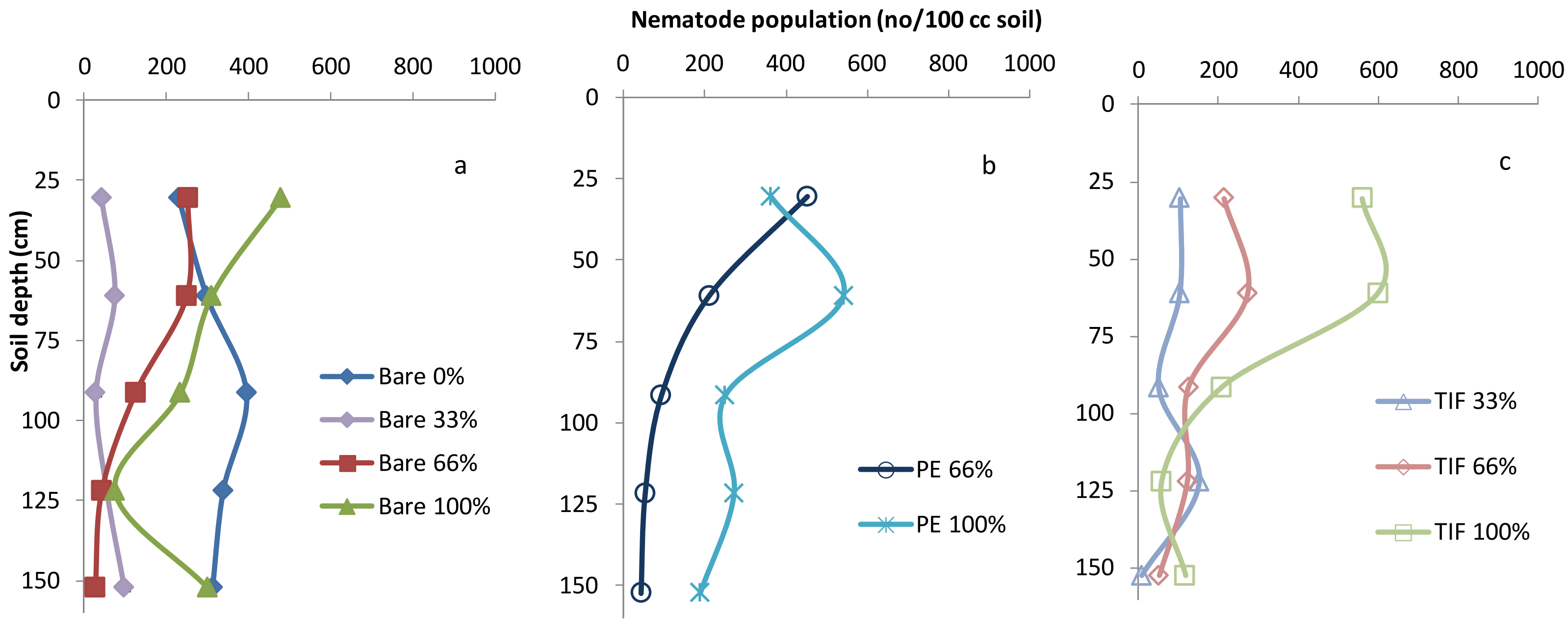

Figure 1. Total population of parasitic nematodes (avg. 29% ring, 70% pin, <1% stubby root, and <1% lesion) detected three years after fumigation in Bluff Ranch, Merced. Plotted are averages of three replicates. Error bars are omitted for improvement of readability.

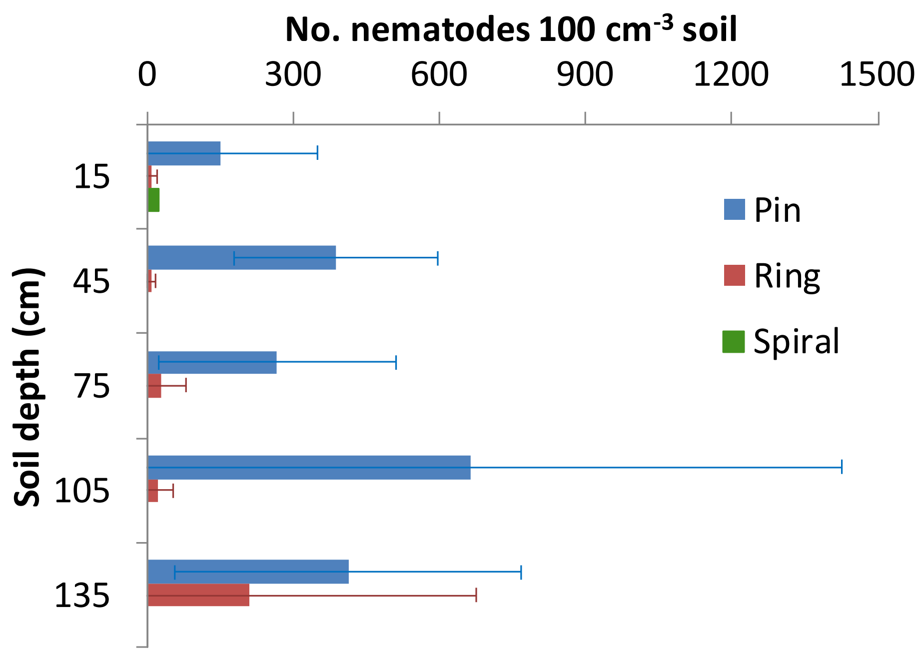

Figure 2. Nematode diversity and population density at different soil depths before soil fumigation in 2012. The population was comprised of chiefly *Paratylenchus* spp. (Pin), and *Criconemella xenoplax (ring*). Error bars are the standard deviation of the mean (n=5).

Additionally, we investigated the potential of using biochar to reduce fumigant emissions. Biochar has many good factors to be considered such as its low cost when comparing to plastic film, environmental friendliness, and improvement on soil biophysiochemical properties that will increase soil productivity. This research was done in collaboration with a visiting scientist from Chinese Academy of Agricultural Sciences. Only a laboratory study was completed and the research result has been published in Wang et al. (2016). This research determined the role of adsorption and degradation rate in 1,3-D disappearance with six biochar products. All biochars showed stronger adsorption (49−93%) than degradation (7−42%), with variation due to biochar properties, and/or soil/environmental factors. The data indicate that amendment with biochar in soil fumigation will lead to emission reduction but also tend to increase fumigant residence time in soil, which may or may not have side effects that need further investigation especially. A field test is scheduled this fall for this purpose.

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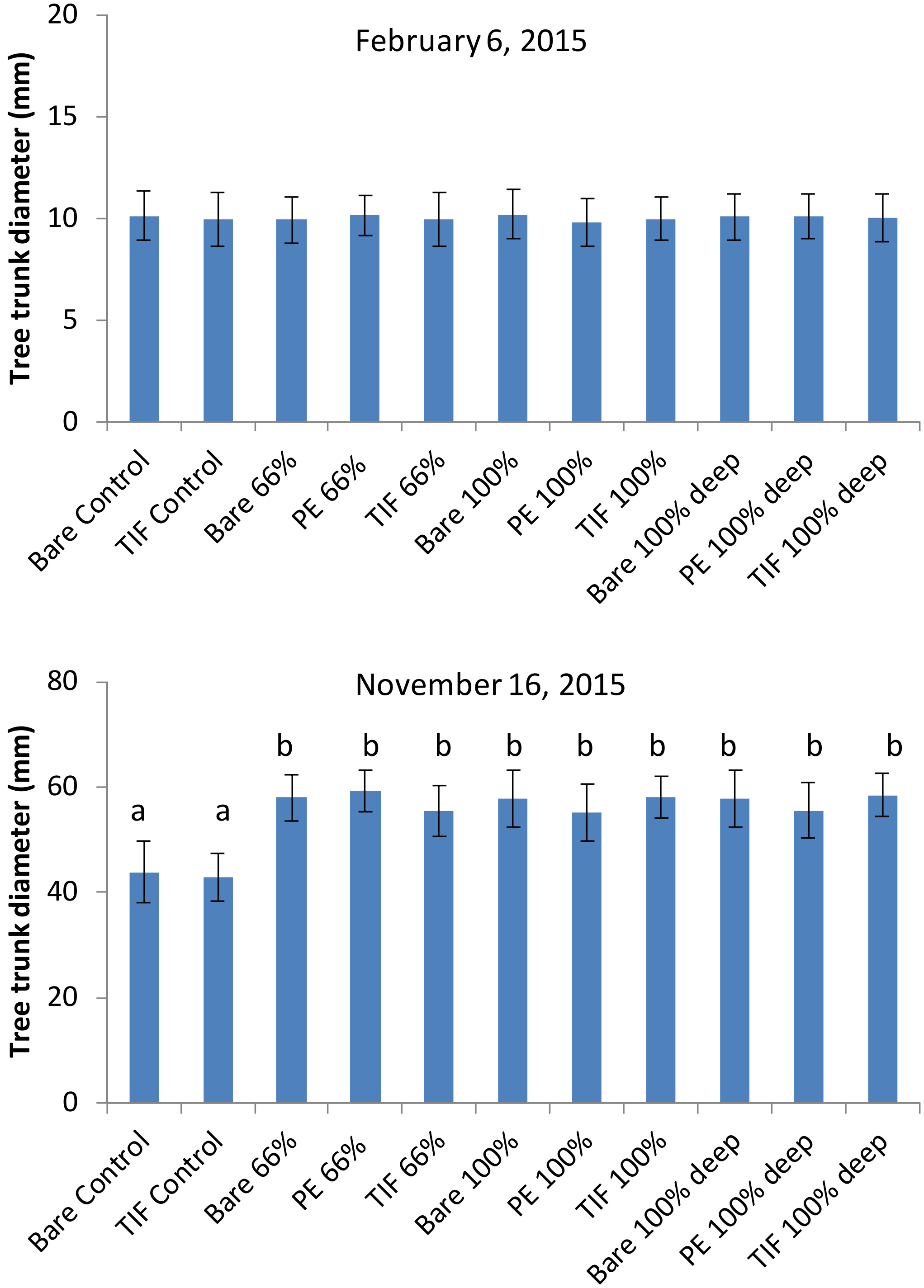

Figure 3. Almond tree trunk diameter immediately following tree planting (top) and nine months after fumigation treatments in Littlejohn's Farm, Ballico, CA. Different letters at the top of columns in figure indicate significance in tree diameter grown at $P<0.05$.

Research Effort Recent Publications:

Cabrera, J.A., B.D. Hanson, J.A. Gerik, S. Gao, R. Qin, and D. Wang. 2015. Pre-plant soil fumigation with reduced rates under low permeability films for nursery production, orchard and vineyard replanting. Crop Protection. 75:34-39.

Gao, S., L.M. Sosnoskie, J.A. Cabrera, R. Qin, B.D. Hanson, J. Gerik, D. Wang, G.T. Browne, and J.E. Thomas. 2015. Fumigation efficacy and emission reduction using low permeability film in orchard soil fumigation. Pest Manag. Sci. DOI 10.1002/ps.3993. wileyonlinelibrary.com.

Qin, R., S. Gao, H. Ajwa, and B.D. Hanson. 2016. Effect of application rate on fumigant degradation in five agricultural soils. Sci. Total Environ. 541:529–534.

Wang, Q., S. Gao, D. Wang, K. Spodas, A. Cao, and D. Yan. 2016. Mechanisms for 1,3-dichloropropene dissipation in biochar-amended soils. J. Agr. Food. Chem. 64:2531–2540.

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