Using TIF Tarp and Reduced Fumigation Rates for Almond Replanting

Project No.: **14-AIR5-Gao/Doll**

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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 (nematodes, pathogens and/or weeds) 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 with regards to soil-borne pest control and almond tree performance.

Interpretive Summary:

Earlier fumigation trials demonstrated that most fumigated treatments at or above 2/3 of full rate provided 100% kill for residential nematodes in the soil above 3 ft (~1 m) depth. However, all treatments including the full rate under TIF showed survival of nematodes in soil below 1 m depth due to less fumigant delivered to the deeper depths. From Dec. 9, 2014 through Jan. 6, 2015, we conducted a field trial in an almond orchard to be replanted and tested if a deeper injection with or without TIF could help improve fumigant (Telone C35®) delivery while reducing emissions. The trial was conducted at Littlejohn's Farm in Ballico, Merced County. The soil was Delhi sand. Treatments included two injection depths: regular 18" (~45 cm) injection depth and a deeper

injection depth at 28” (~70 cm) with full rate, 2/3 rates at regular injection depth, and non-fumigated controls, all with three surface sealing methods (bare or no tarp, standard PE tarp, and TIF) except the 0 rate under PE. Fumigant movement, which included emissions and gaseous fumigant concentration changes under the tarp and in soil profiles, was monitored. After four weeks of fumigant application, soil samples from 0 to 150 cm depth were collected for all treatments to determine residual fumigants and survival of parasitic nematodes. After tarp removal, young almond trees were planted in late January. Data show that the deep injection facilitated fumigant movement to soil below 1 m depth as fumigant concentrations at 120 cm soil depths from deep injection were consistently higher in the bare soil although less clear from TIF. The TIF, however, was confirmed to give lowest emissions by most effectively retaining fumigants under the tarp. Also from this trial, significantly higher emissions were measured from PE tarped soils than untarped soils due to higher precipitation received on bare soil during the trial. Except for 1 surface soil sample, all fumigated treatments resulted in no survival of parasitic nematodes down to 150 cm depth in this coarse textured soil. Tree growth is being monitored and nematode recovery will be determined to examine fumigation treatment effects.

Materials and Methods:

2014-2015 fumigation trial in Ballico, Merced County

Fumigation trial and treatment. A fumigation trial was conducted after the mature almond trees were pulled out at Littlejohn’s Farm, Ballico, Merced County from Dec. 9, 2014 through Jan. 6, 2015. The soil was Delhi sand (Mixed, thermic Typic Xeropsamments), a very deep and somewhat excessively drained soil (NRCS, https://soilseries.sc.egov.usda.gov/OSD_Docs/D/DELHI.html). Telone® C35 (35% CP, 63% 1,3-D, and 2% other ingredients) was used in this trial. A total of 11 treatments were tested to determine the effects of fumigant injection depth, different rates, and surface sealing methods on fumigant distribution, emission, and control of residential soil pests. The treatments included two injection depths: regular 18” (~45 cm) injection depth and a deeper injection depth at 28” (~70 cm) at full rate, 2/3 (~66%) rate at regular injection depth and non-fumigated controls with three surface sealing methods (no tarp, standard PE tarp, and TIF). The treatments were tested with 4 replicates in a randomized complete block design. During fumigation trial, three replicated blocks were monitored for fumigant and efficacy on nematode and pathogens. All plots will be monitored for tree growth.

Telone® C35 was shank-applied on Dec. 9, 2014. For the regular injection depth, a John Deere 8400T and a Telone® rig were used with 7 shanks at 20” (50 cm) shank spacing (fumigation width 3.6 m). For the deep injection, a more powerful Challenger tractor was used instead with 5 shanks (2.5 m fumigation width). Both standard PE tarp and TIF were 4.1 m wide and a single sheet of each film was installed to tarp fumigated plots. The plots were about 65 m (195 ft) long. The plastic tarps were installed immediately following fumigant application. Field sampling equipment were then installed and samples for monitoring fumigant movement were collected for 4 weeks with the last sampling done on Jan. 6, 2015. Also on Jan. 6, 2015 soil samples down to 150 cm depth at 30 cm intervals from all plots were collected for residual fumigant determinations as well as nematode survival counting. The tarps were then removed. Young almond trees were planted on Jan. 27, 2015. All 4 replicates are being monitored for tree growth to determine treatment effects.

Field sampling for monitoring fumigant movement. Following fumigation and tarping treatment applications, three replicates were selected for monitoring gaseous fumigant movement including emissions, distribution in soil profile, and concentration changes under the tarp. Soil gas sampling probes, passive flux chambers, and apparatus for sampling air under plastic tarps were immediately installed. Sampling methods were similar to that reported in Gao's 2012 - 2013 Almond Project Report. The treatments monitored for emissions included both regular and deeper injections with no tarp and PE tarp plus a regular injection with TIF and all were at full rate. The purpose was to determine if TIF was still required to control emissions from deep injection of fumigants. Treatments monitored for fumigant movement in soil profile included the full rates with both regular and deeper injection depths under no tarp, PE tarp, and TIF plus a 2/3 rate with the regular injection depth. Soil probes were installed at soil depth of 15, 30, 45, 60, 75, and 100 cm. The deep injection treatments with bare soil and TIF tarp were also monitored at 120 cm soil depth. All 6 tarped treatments were monitored for fumigant concentration changes under the tarp. All sampling equipment was installed near the center location of a plot. The passive chamber method provides discrete emission flux estimates and may not be accurate for calculating total or cumulative emission loss (Gao and Wang, 2011); thus only flux was used to analyze the emission data. Sample collections, storage, and processing in the laboratory followed previously developed protocols (Gao et al., 2009).

Efficacy. On Jan 6, 2015, soil samples down to 1.5 m (5 ft) depth (0-30, 30-60, 60-90, 90-120, 90-120, and 120-150 cm) were collected for both residual fumigant determination and live nematode counting. 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 determined to be dead or alive and identified under the microscope at 4× magnification (Mai and Lyon, 1975).

Others. Prior to fumigant application five locations across the field were selected to determine soil bulk density and water content. Rain events were encountered during the trial. Temperature at soil surface and at soil depth of 15 and 45 cm was monitored from a bare plot and a TIF tarped plot. Fumigation is done more often in the fall than in the winter because of chances of rain. Sometimes growers are pressed with time between pulling out old orchard and replanting. The precipitation events encountered during this fall fumigation experiment enable us to evaluate a number of issues for fumigation during the cool and wet winter season in the Central Valley. These issues would include fumigation efficacy, emission, and potential leaching risks etc.

Results and Discussion:

Weather and soil conditions during field trial. Due to the fact that the trial was conducted in December, rain events were encountered before and during the fumigant trial. About 27 mm rain was received within the week before fumigation, following the fumigation 51 mm was received on day 3-4, and 29 mm was received between day 7-12. On the day before fumigant injection, the average soil water content and bulk density in the top 1 m soil were 6.6% (w/w), and 1.62 g cm^{-1}, respectively. At the end of the trial, the soil water content in surface 20 cm was 6.2%. Plots without tarping must have received much higher amount of rain that would affect some of the results. The temperature at soil surface (or under tarp), at 15 and 45 cm depths for a bare plot, and a TIF tarped plot are given in **Figure 1**. Diurnal changes in temperature near soil surface were the greatest, followed by that at 15 cm depth, and the least at 45 cm soil depth. Generally speaking, tarping with TIF showed larger diurnal temperature changes and warmer temperature (up to 30^{o}C) than the bare plot.

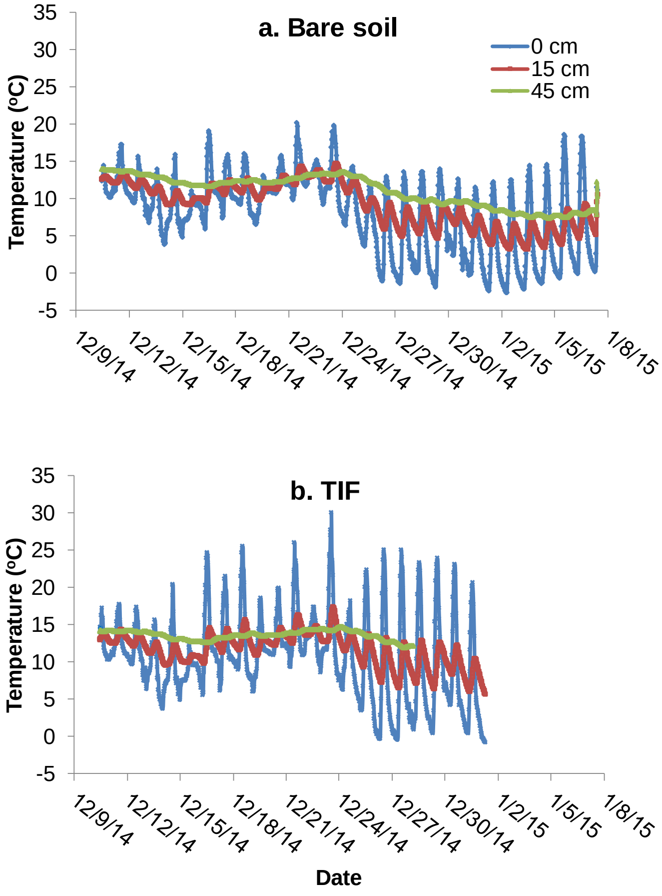

Figure 1. Temperature in soil surface, at 15 cm and 45 cm soil depths from a. bare plot, b. TIF tarped plot during fumigation trial from Dec. 9, 2014 – Jan. 6, 2015 at Littlejohn's Farm, Ballico, CA.

Emission. All plots selected for emission monitoring were at the same full application rate; thus differences in the emission flux were due to application method and/or surface sealing. The results of 1,3-D and CP emission flux are provided in **Figure 2**. Fumigant emission fluxes from the PE tarped plots (both regular and deep injection depths) were much higher than bare plots, which was due to the large amount of rain received in the bare soil that formed a type of water seal and increased resistance of fumigant diffusion to soil surface. This proposal was also supported by the suddenly reduced emission flux on day 3 after a short period of heavy rain fell. After that 1,3-D emission flux increased slightly around day 9 before another rain event occurred. TIF tarped plots, however, gave consistent and the lowest emission flux from beginning to the end of the trial. The results confirm that regardless of weather conditions, TIF can always significantly control emissions.

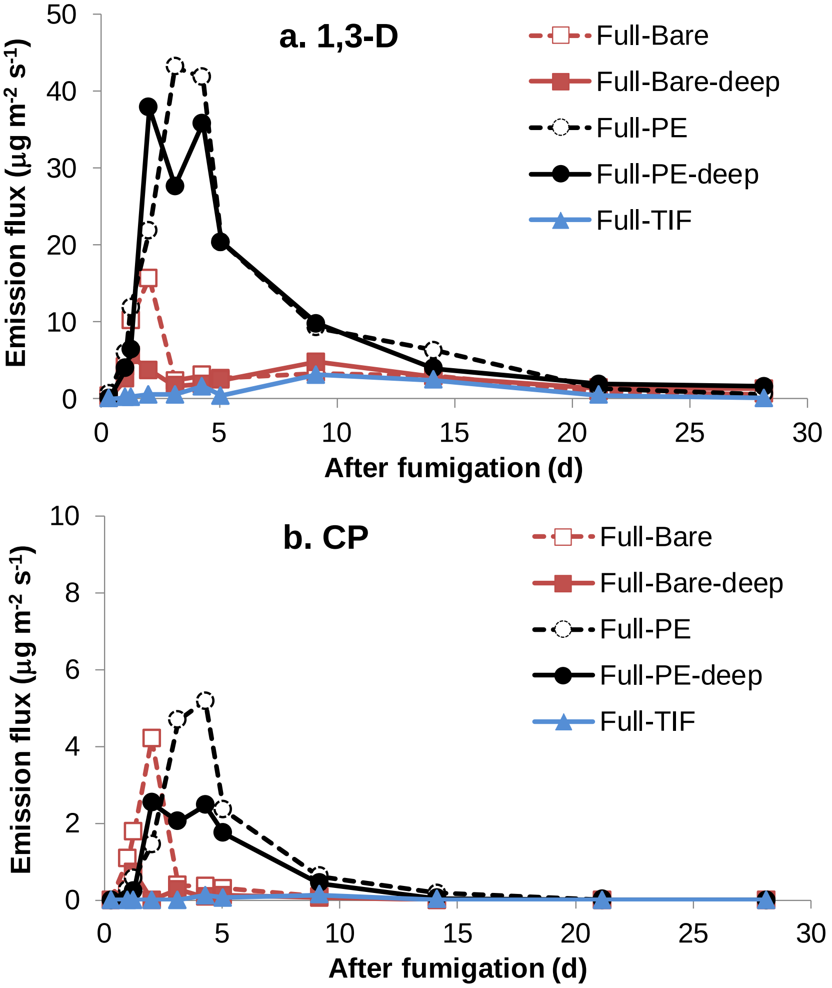

Figure 2. Emission flux of 1,3-dichloropropene (1,3-D) and chloropicrin (CP) from regular and deep injection depths at full rates with different surface sealing. The lower emission rates from bare soil than that from PE tarp was most likely due to bare plots received more rain, which formed a type of water seal and increased resistance of fumigant transport.

Fumigant concentration under tarp. Figure 3 shows fumigant concentration changes over time under plastic tarp (above soil surface). The TIF was proven again to retain much higher fumigant concentrations than standard PE film. With TIF the 1,3-D concentrations at 2/3 rate were even higher than the full rate with PE. Fumigant concentrations from TIF at regular injection depth were consistently higher than those from the deeper injection and this could be caused by the increased path length for fumigant from injection depth to soil surface as three weeks later there were no difference in the concentrations under the tarp. This observation was not found for CP.

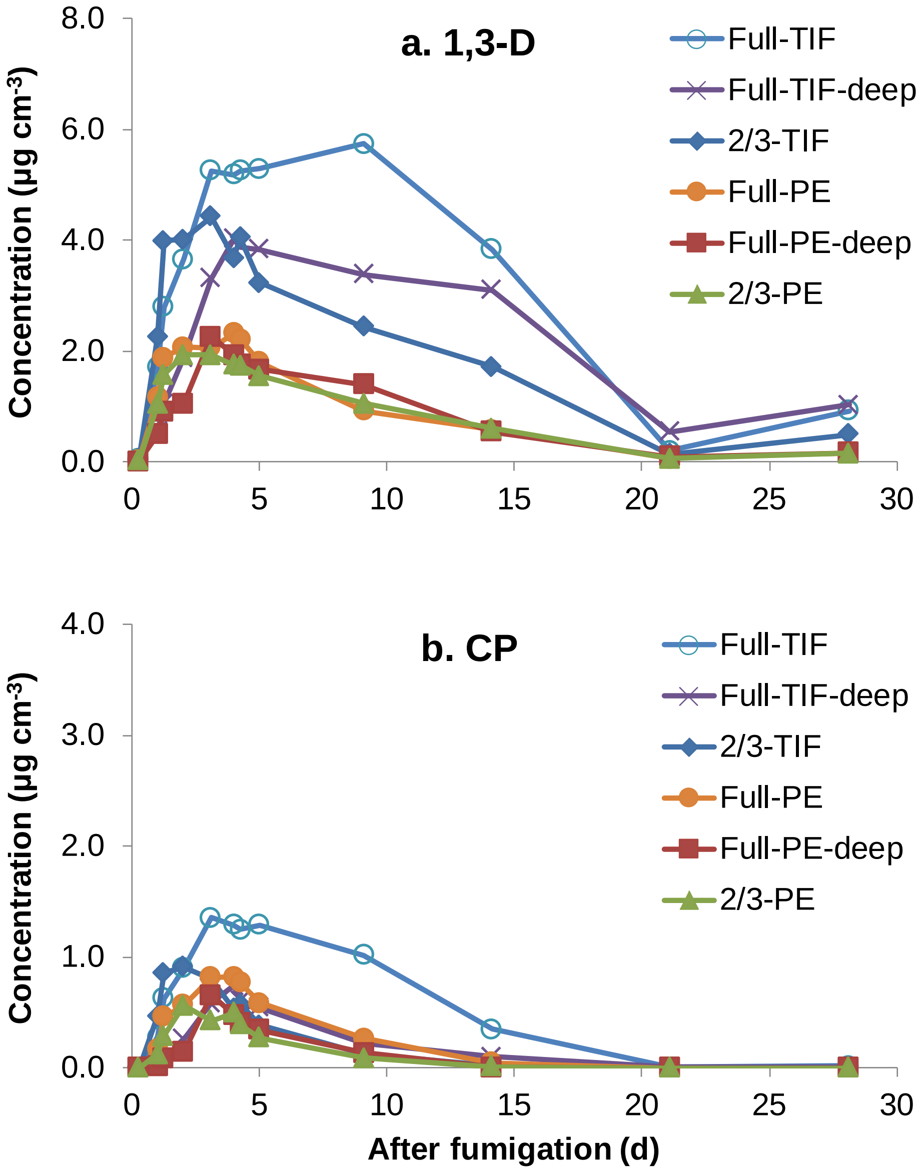

Figure 3. 1,3-Dichloropropene (1,3-D) and chloropicrin (CP) concentrations in air under tarp (above soil surface) after fumigant application. Plotted are averages of three replicates. Error bars are omitted for readability.

Fumigant distribution in soil profile. Distribution of 1,3-D and CP in soil profile over time is provided in **Figures 4** and **5**, respectively. Both fumigants followed the same distribution pattern except 1) higher concentrations for 1,3-D than CP because of the higher ratio of 1,3-D/CP in Telone® C35 applied and 2) due to faster degradation rate of CP. In two weeks, CP concentrations in soil profile were near zero while 1,3-D concentrations were still substantial after 3 or even 4 weeks. The deeper injection resulted in the maximum concentration observed at 60 cm compared to the 45 cm from the regular injection depth. Also the deeper injection resulted in higher fumigant concentration at 120 cm depth in the bare soil although there were no apparent differences under TIF tarp.

Residual fumigant. Four weeks after fumigant application and tarping, residual soil fumigants were determined and the results are shown in **Figure 6**. Most soil samples had non-detectable chloropicrin with a few samples under 0.1 mg kg^{-1} mostly from full rate, which again indicates faster dissipation/degradation of CP than 1,3-D. **Figure 6** also shows large variation in the residual 1,3-D, which would result in non-significant difference at most depths between any of the fumigation treatments. We do see that the highest concentrations were all from TIF. Also at the depths of 120-150 cm, higher 1,3-D concentrations from the full rates (**Figure 6b**) than the 2/3 rates (**Figure 6a**) may indicate potential downward movement during the trial due to the rain. This is puzzling as tarped plots would have received less rain than bare plots. However, the tarping effect might have not affected water transport at such deep depth in this very course-textured soil. The results should be confirmed by further investigation.

The overall results from this trial indicate that deep injection of fumigants could facilitate fumigant movement to deeper soil, which may have provided good efficacy in soils down to 150 cm soil depth. All fumigation treatments at or above 2/3 Telone® full rate provided good nematode control regardless of tarping. Although TIF was the most effective to minimize emissions, rain events also reduced emissions significantly compared to standard PE tarp, but may have increased leaching risks, which needs to be confirmed. All the observations in this trial were made from the very coarse textured sandy soil that should not be directly inferred to other types of soils and/or when no occurrence of rain events.

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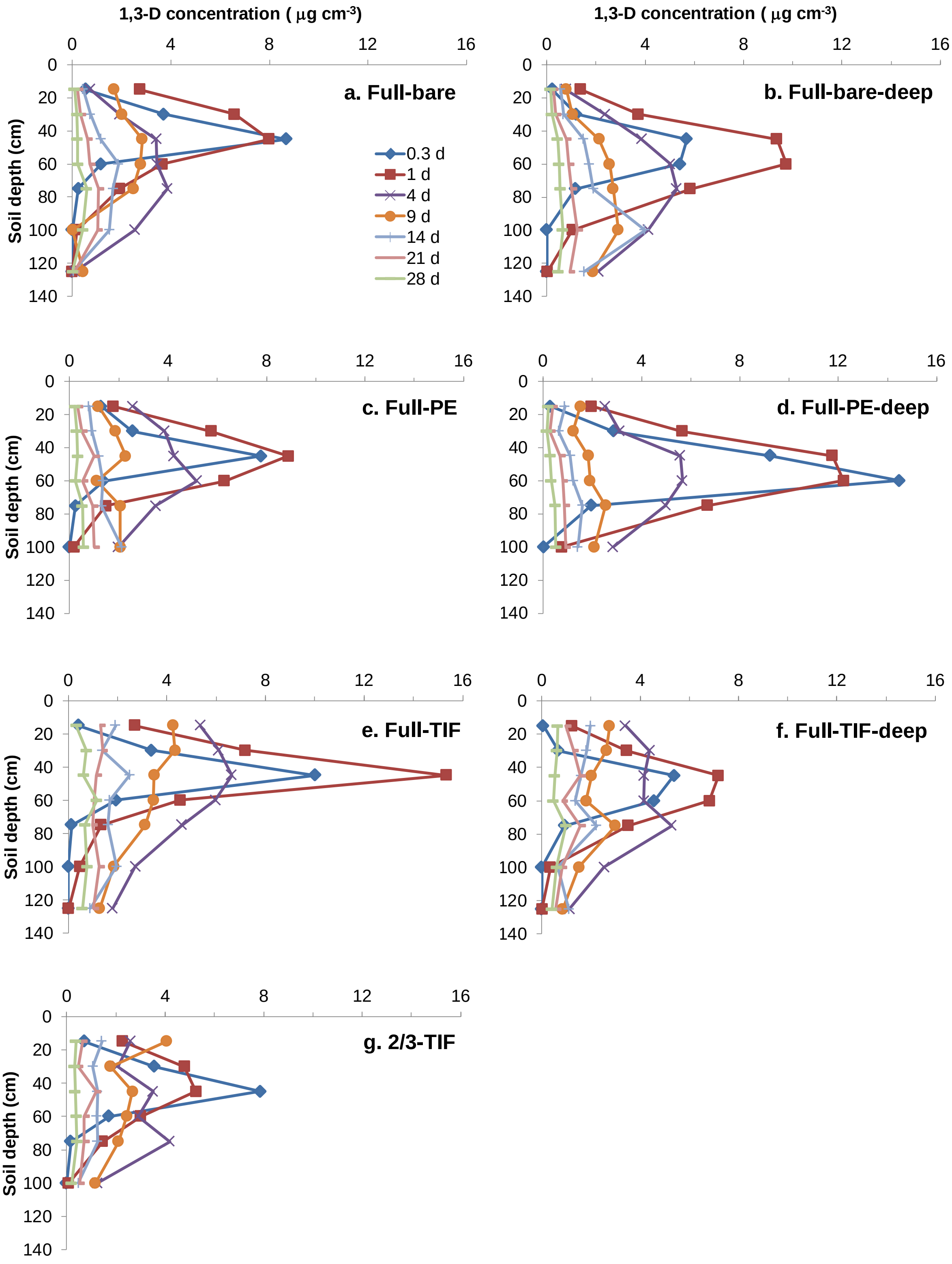

Figure 4. 1,3-Dichloropropene concentrations in soil-gas phase from full and 2/3 rate of regular or deep injected Telone® C35. Plotted are averages of three replicates. Error bars are omitted for readability.

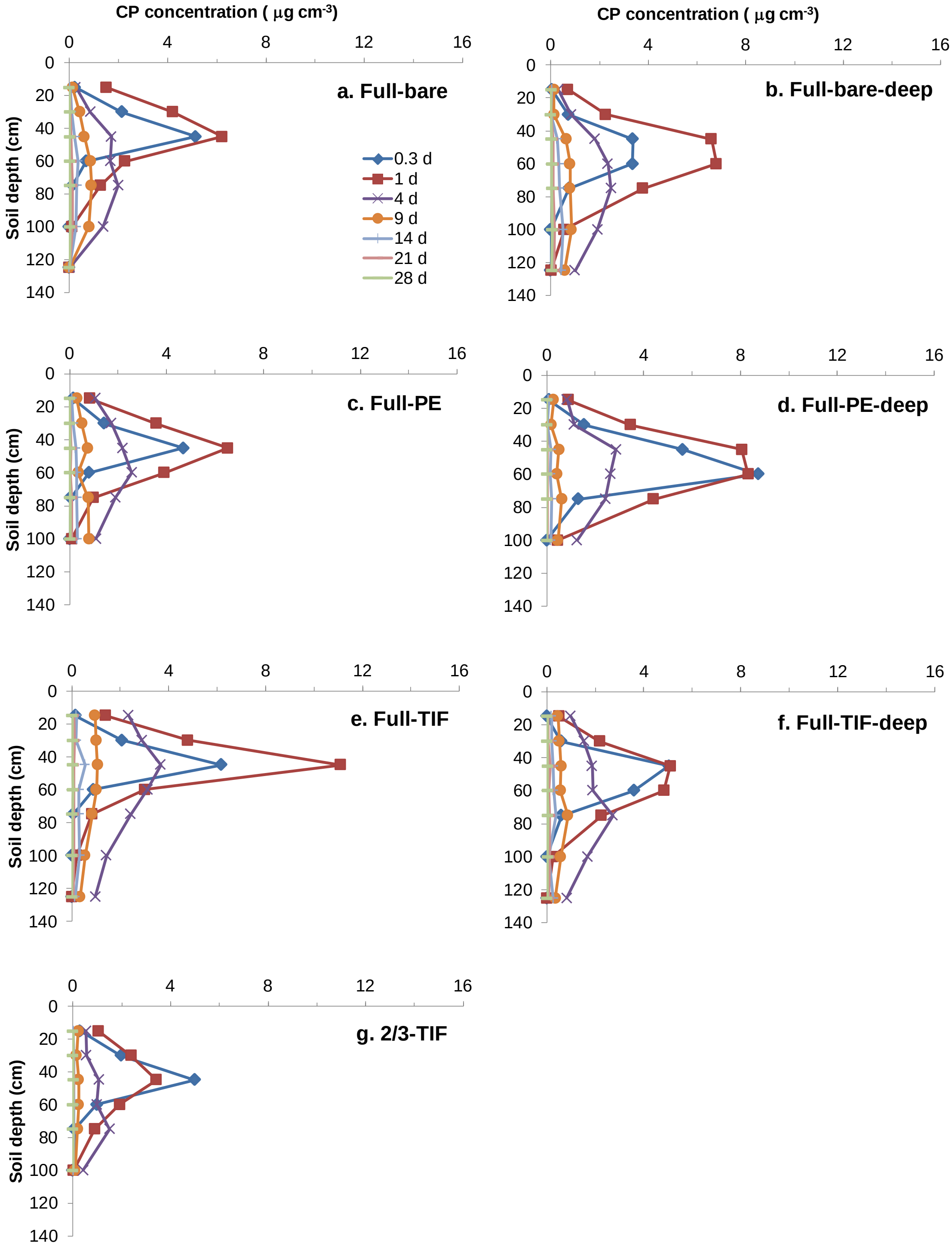

Figure 5. Chloropicrin concentrations in soil-gas phase from full and 2/3 rate of regular or deep injected Telone® C35. Plotted are averages of three replicates. Error bars are omitted for readability.

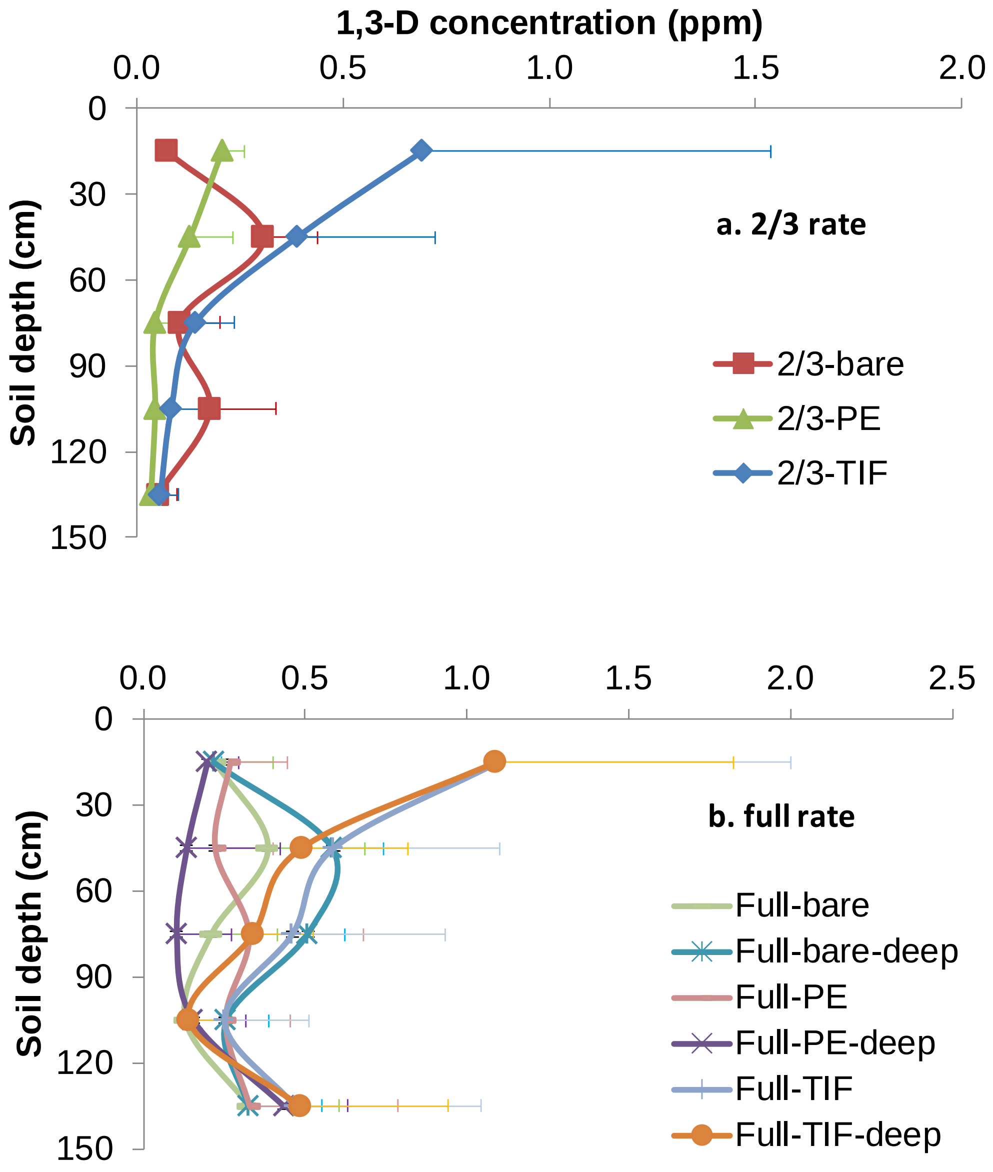

Figure 6. Soil residual fumigant concentrations at the end of fumigation trial (4 weeks after fumigant application). Error bars are standard error of the mean (n=3).

Research Effort Recent Publications:

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.

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.

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