Using TIF Tarp and Reduced Fumigation Rates for Almond Replanting

Project No.: **12-AIR5-Gao**

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Objectives:

1) Demonstrate that the use of TIF tarp can improve fumigant distribution in soil and increase fumigant concentration-time exposure index values for better pest control than standard PE tarp 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:

Almond replanting still relies on pre-plant soil fumigation to control soil-borne pests and diseases in order to establish productive and healthy trees. With the environmental constraints on fumigant use, fumigation methods for high pest control efficiency and low emissions are needed greatly. In late fall of 2012, a fumigation field trial was conducted in an almond orchard that was scheduled to be replanted in Merced County. The field had a high nematode population, chiefly pin nematodes and some ring nematodes. This trial was designed to test if low permeability tarps such as totally impermeable film (TIF) can improve efficacy and potentially reduce emissions when using reduced rates. Fumigation treatments included non-fumigated control, three rates (full or maximum allowed label rate, 2/3, and 1/3 of Telone® C-35), and three surface sealing methods (bare, standard

polyethylene (PE) tarp, and TIF) with six replicates in a randomized complete block design. Emissions, gaseous fumigant concentration under the tarp, and fumigant concentrations in soil profile were determined for about five weeks. Both soil-existing indigenous nematodes and bioassay bags containing soils infested with citrus nematodes were investigated for treatment efficacy. This trial emission data illustrated again that TIF tarp can significantly reduce emission peak flux compared to the standard PE tarp due to the ability of TIF to retain fumigants. All full rate treatments and the 2/3 rate under TIF provided 100% kill for residential nematodes in the top soil above 1 m depth. In soil below 1 m, however, all treatments including the full rate under TIF showed survival of nematodes. Thus controlling nematodes at deep soil depths continues to be a challenging task in replanting orchards.

Problem and its Significance:

Almond replanting, especially in fields infested with soil-borne pests and replanting diseases, requires pre-plant soil fumigation to establish productive and healthy orchards. Since the phase-out of methyl bromide (MeBr), the industry has begun using combinations of alternatives such as Telone® C-35, which is a mixture of 1,3-dichloropropene (1,3-D) and chloropicrin (CP), for the control of nematodes and pathogens. These alternative fumigants, however, are toxic chemicals and most of them are identified as air polluting, volatile organic compounds (VOCs). Thus their use has been highly regulated (e.g., buffer zone, township cap) to minimize potential exposure risks and to reduce the deterioration of air quality caused by emissions. Both federal and state regulatory agencies continue to develop more stringent regulations on fumigants or amend those already in place (CDPR, 2009; USEPA, 2009). To maintain the benefits of soil fumigants for orchard replanting, fumigation methods that lead to high pest control efficiency and low environmental impact are highly desirable (Gao et al., 2011a) and are the focus of the present research.

Recent research has found that using low permeability tarps (e.g., totally impermeable film or TIF) can significantly control emission loss, increase fumigant residence time in soil, and improve fumigant distribution for better efficacy in soil fumigation for annual crops (Qin et al., 2011). Similar findings are also reported in perennial fumigated fields (Gao et al., 2011b; see Gao's 2011 almond project report). Due to the ability of TIF to retain fumigants under the tarp, TIF has shown the potential for using reduced fumigant rates to achieve good efficacy. Applying less fumigant using TIF can also help address concerns about the surge of emissions that occurs upon tarp-cutting when rates similar to those used under standard polyethylene (PE) tarp are applied (Qin et al., 2011). The solution to preventing the surge of emissions is to wait a sufficient amount of time until the fumigants under the tarp degrade to a significantly low level. This has been verified in most recent reports (Gao et al., 2013; Sullivan et al., 2011; see Ajwa's 2011 almond project report or poster at the 2011 Almond Industry Conference). However, this may result in a delay of planting time that may not be desirable for some growers. Further, the presence of fumigants in soil at planting time may cause phytotoxicity or fumigant leaching (due to the rain in winter) that must be avoided. Double or greater concentration-time (CT) index values, which positively correlate to pest control, had been achieved under TIF in comparison with the PE film, so there is great potential to reduce fumigation rates, achieve satisfactory soil disinfection, and create productive soils for almond trees. However, field data on the possibility of using reduced rates in replanting orchard situations are very limited for drawing conclusions (Cabrera et al., 2011). This project is planned to conduct a series of trials and collect field data on the effects of TIF tarp with reduced fumigation rates on pest control, emission loss, and almond tree performance in growers' fields. The goal of this research is towards using less fumigant but more effectively in the development of environmentally sustainable and productive almond orchards.

Materials and Methods:

Fumigation trial and treatment. A fumigation trial was conducted in a replanting almond orchard at Braden's Farm, about 13 miles northeast of Merced from Nov. 29, 2012 through January 12, 2013. The treated area for this study was about 5 acres. The soil is Snelling Sandy loam (Fine-Loamy, mixed, superactive, thermic Typic Haploxeralfs). The Snelling series consists of deep and well drained soils formed in alluvium from predominantly granitic rock sources. They are typically on terraces and have slopes of 0 to 15 percent. This type of soil is located in Merced County, CA; northwest of Snelling; 1 mile north of SW corner of sec. 29, T. 4 S., R. 13 E. Detailed information about the soil can be found at https://soilseries.sc.egov.usda.gov/OSD_Docs/S/SNELLING.html. Almond trees in this field were pulled out after harvest. The soil was prepared by the grower following their common practices for fumigation. As new trees were to be planted after fumigation trial between January and February the fumigation date fell into the late fall season.

The trial was designed to evaluate the effects of three surface sealing methods (bare, standard PE, and TIF) and three application rates (full or 100% rate; 66% rate, and 33% rate) of Telone® C-35 (35% CP, 63% 1,3-D, and 2% other ingredients) on fumigant emission, changes and/or distribution in soil, and efficacy on pest control emphasizing on nematodes as well as tree response to fumigation treatment after replanting. Total 12 treatments with 6 replicates (**Table 1**) were applied in a randomized complete block design. The field was identified with high populations of nematodes prior to fumigation.

Table 1. Treatments (fumigant application rate and surface sealing) in field trial conducted in late fall 2012, Merced, CA

	Bare	PE	TIF
Telone® C-35 rate:			
0	x	x	x
33% (16 gallons/ac)	x	x	x
66% (32 gallons/ac)	x	x	x
100% (48 gallons(540 lb)/ac or 610 kg/ha)	x	x	x

The full rate refers to the maximum rate of 1,3-D used in CA, which is 48 gallons or 540 lb/ac (~610 kg/ha). The reduced rates were about 66% and 33% of the full rate. All applications in each plot achieved the target rate 87-94% (± 6-10%) for the three fumigant application rates. The TIF was VaporSafe™ product (1-mil thickness, clear, Raven Industries, Sioux Falls, SD, USA). Standard PE was provided by TriCal, Inc. (Hollister, CA).

Telone® C-35 was shank-applied at 18 inches (46 cm) deep with a 20 inch (51 cm) injection nozzle spacing using a conventional Telone® rig. The application was carried out on November 29, 2012. Fumigation plots were 132 m (432 ft) long [which would be plantedwith 24 trees spaced at 5.5 m (18 ft)] and about 3.4 m (11) ft wide. Each fumigation plot was split at equal distance with the three different surface sealing. The fumigant was applied to tree rows at 6 m (20 ft) spacing and this design reflected strip application with fumigated area of 55%. The plastic tarps were installed immediately following fumigant application. After about 6 weeks of field monitoring on emission and soil fumigant in air under the tarp and in soil profile, soil samples were collected for residual fumigant determinations. Then the tarps were removed the first week of January followed by bag retrievals the following week and final soil bulk density determination. All field measurement and sampling were done by January 12, 2013. Young almond trees were planted in February, 2013. The other 3 replicates for additional yield and tree response monitoring followed similar design and were located in the east side of the field.

Field sampling and monitoring on fumigant movement. Upon fumigant application, field sampling or monitoring were conducted including emissions, fumigant movement in soil, and concentration changes under tarp. Three replicates were selected for monitoring. Soil gas sampling probes, passive flux chambers, and apparatus for sampling air under plastic tarps were immediately installed. All six replicates were monitored for tree response after replanting, which was done in February 2013. Selected treatments were monitored for emissions, fumigant concentration in soil gas and air under tarp. Three treatments monitored for emissions were: full PE (fumigant rate and surface sealing), 66% PE, and 66% TIF; six treatments for soil gas movement in profile: full bare, full PE, 66% bare, 66% PE, 66% TIF, 33% TIF; and the six tarped treatments for air under tarp: full PE, full TIF, 66% PE, 66% TIF, 33% PE, and 33% TIF. Emissions on the tarp, immediately off tarp edge, and 50 cm from tarp-edge in all three plots of 66% TIF treatment were sampled. For the soil gas sampling, soil gas sampling probes were installed inside the plot plus a set of probes installed at 25 cm distance from tarp edge. The passive chamber samples provide discrete emission flux and are not accurate for calculating total or cumulative emission loss (Gao and Wang, 2011). Sample collections, storage, and processing followed previously developed protocols Gao et al., 2009).

Efficacy study. Soil samples down to 1.5 m (5 ft) depth (0-30, 30-60, 60-90, 90-120, 90-120, and 120-150 cm) and water content were collected and measured before and after fumigant application. The soil samples were analyzed for resident nematodes. Heavy rain was encountered on the day before and on the day of fumigant application. Soil bulk density was determined at the end of the trial. Prior to fumigant injection, five auger samples were collected across the field. After fumigation, all plots were sampled for nematode determination. 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).

In addition, efficacy in buried nematode bags was investigated. The bags contained soil infested with citrus nematodes (*Tylenchulus semipenetrans*). Nematode bags were buried at 15, 30, 60, and 90 cm depths. For the 0% PE, pest bags were buried at only shallow depth 15 cm assuming similar soil temperature at deeper depth as the TIF tarp would not provide different results. To avoid the pest bags being destroyed by the shanks of the fumigation rig, nematode bags at deeper depths (1-3') were buried between shank lines (10" from center flag, perpendicular to shank line), which was done before fumigant injection. The bags at the 6" depth were buried after fumigant injection and soil preparation, right before tarping. The bags were retrieved at the end of the trial and determined for vitality. Citrus nematodes were extracted from the soil in the bags using the Baermann funnel protocol (Hooper et al., 2005). Living citrus nematodes were identified under the microscope and counted.

Results and Discussions:

Weather condition during field trial. The trial in Merced was conducted in late fall after the grower harvested almonds from the orchard and before planting early the following year. This is a typical situation when growers do not want to miss a growing season for replanting. The temperature at soil surface (or under tarp) and in soil at 15 cm depth was given in **Figure 1**. Several rain events (with >5 mm precipitation) occurred during the trial are also shown in **Figure 1**. Precipitation resulted in less diurnal changes in temperature (**Figure 1a**) near soil surface. Generally speaking, tarping with either TIF or standard PE showed several degrees higher temperature than the bare soil. Similar phenomenon was observed at 15 cm depth except the diurnal temperature changes was much smaller than that near surface or under the tarp.

Emission. Fumigant emission fluxes from the full rate under PE and 66% rate from both PE and TIF tarp as well as off the TIF tarp are shown in **Figure 2**. The highest 1,3-D emission rate was from the PE tarp at the full rate, followed by the PE tarp at 66% rate. The TIF tarp showed over 50% reduction in emission flux compared to the PE tarp at the same rate for most measurements. The results confirm that TIF tarp continues to produce the lowest emissions. Immediately off tarp (0 and 50 cm distance from tarp edge), the emission flux measured was much lower than that measured from shallow injections in previous trials (Qin et al., 2011; Gao et al., 2013). From Telone® C-35 application, chloropicrin emission flux (<15 $\mu g\ m^{-2}\ s^{-1}$) (**Figure 2b**) was shown again much lower than 1,3-D (up to 120 $\mu g\ m^{-2}\ s^{-1}$, **Figure 2a**) and reduced to non-detectable in two weeks.

Fumigant concentration in air under tarp. Concentration of 1,3-D and chloropicrin in air under the PE and TIF tarp from all three application rates are shown in **Figure 3**. 1,3-D concentrations under TIF were higher than that under PE especially at higher application rates. Furthermore, the peak concentrations under TIF were measured about one week after fumigant application; while the peak concentrations under PE were observed the 2nd or third day after application before declining. This supports earlier observation that the TIF retains the fumigant more effectively and that led to the lower emissions (**Figure 2**). Chloropicrin concentration was much lower than 1,3-D except at the full rate under PE.

Fumigant distribution in soil profile. The average 1,3-D concentration over time in soil profile from selected surface sealing and application rates are shown in **Figure 4**. Similar distribution and patterns were followed for all monitored treatments except that higher concentrations were from higher application rates. There were no apparent differences in the soil fumigant concentrations at the same rate among bare soil, PE tarp and TIF tarp. Large variations were measured from three replicated plots for the same treatment. The field varied significantly in topography (**see Photos 1 & 2**). The rain event (**Figure 1**) occurred during the trial led to very different soil moisture profiles. In addition tarped plots received lower precipitation than bare soil. At the end of the trial when retrieving pest begs after tarp was removed, plots at lower elevations were found flooded while those in the upslope were dry.

Chloropicrin showed faster dissipation (**Figure 5**) than 1,3-D. Although the initial concentration (6 h) can be high, most of the plots showed non-detectable chloropicrin in about a week (**Figure 5**) while 1,3-D concentrations continued to be detected even at the last sampling (34 days after fumigant injection). At 25 cm distance off tarp edge, chloropicrin was only detected during the first few days after fumigant injection and 1,3-D off the tarp was detected for about two weeks.

Residual fumigant. About five weeks after fumigant application, the soil was collected and analyzed for residual fumigants with 1,3-D results shown in **Figure 6**. Chloropicrin was not detected in any of the treatment plots. Large variation in residual 1,3-D concentration was observed. Generally speaking, full rate under PE and 66% under TIF showed relatively higher residual fumigants in soil but all with concentrations around or below 0.2 mg kg^{-1}. The application rate of full, 66%, and 33% can be translated to about 34, 23, and 11 mg kg^{-1}. The residual fumigant data suggested ≥99% of the applied fumigants dissipated from the soil mostly due to degradation and emission.

Nematodes in soil. The field was infested with several resident plant parasitic nematodes with high populations of pin nematodes and low populations of ring nematode throughout the soil profile (**Figure 7**). Spiral nematodes were detected only in one location in surface soil. After fumigation, Telone® C-35 treatments with full and 66% rate under both PE and TIF provided 100% nematode control at all soil depths above 1 m (**Figure 8**). Nematode survival was detected in surface bare soil at full rate. Similar results were obtained for the 66% rate except nematode survival was detected in bare soil at all soil depths. Below 1 m soil depth, however, nematode survival was detected from all treatments including the TIF full rate although population is low. At 33% rate, more survivals were found in soil profile compared to the higher rates. The data indicate that the challenge to effectively control nematode at depth below 1 m continues in orchard soil. The soil gas data (**Figures 4 & 5**) with decreasing concentrations at lower soil depths support the efficacy results even in the relatively course textured soil.

Citrus nematodes in buried bags. For citrus nematodes buried in soil, significantly lower survival was determined for all monitored fumigated treatments compared to the non-fumigated control (**Figure 9**). The TIF 66% rate provided similar results as that from PE 100% rate, but both treatments had sporadic citrus nematode survival. No monitoring was done under TIF at full rate knowing that with higher fumigant concentrations, better efficacy would be warranted. However, using TIF with full rate does not provide much advantage in terms of controlling fumigation costs. As this trial was done in late fall, we do not know if the low temperature affected the efficacy. In our previous field trial during warmer temperature, the 66% rate under TIF provided 100% kill in an even finer textured soil (Gao et al., 2012 annual report to Almond Board). The Merced trial is the first fumigation trial we collected comprehensive data on fumigant fate and efficacy; thus some unknowns need to be resolved through further research.

Planting and nematode recovery monitoring. Almond trees were planted in February 2013 after the fumigation trial was ended. Preliminary growth measurements have been taken. End of season growth will be measured in December of 2013. Samples will be collected to monitor nematode recovery in the field. These data are not yet available by the time of preparing this report, but will be reported at the Almond Industry Conference and/or next year's report.

Conclusions:

The 2012 fumigation trial confirms previous findings that TIF reduces emissions much more effectively than standard PE tarp. Off tarp emission flux was minimal under the fumigation conditions (deep injection) for orchard replanting. The data show that the regular Telone® C-35 at 66% rate under TIF tarp showed similar effectiveness on nematode controls compared to the full rate in bare soil or under standard PE tarp above 1 m soil depths. However, most reduced fumigant rates did not provide good nematode control at soil depth below 1 m where lower fumigant concentrations were observed. The 33% rate showed much lower fumigant concentrations in soil profile than the full and 66% rates. There were no apparent differences in soil gas fumigant concentration among the full and 66% rates due to the large field variation in field topography and soil moisture conditions. The low temperature during the field trial may have contributed to the reduced effectiveness on nematode control. The challenges for control of nematode in deeper soils with alternative fumigants to MeBr in replanting orchard need to be addressed with further research.

Acknowledgements:

Funding support for this research was provided by Almond Board of California, and CDFA (USDA-AMS) Specialty Crop Block Grant . Fumigant and fumigation service were provided by TriCal, Inc. Personnel supporting this research include: Robert Shenk, Aileen Hendratna, Allison Kenyon, and Stella Zambrzuski from Water Management Research Unit, San Joaquin Valley Agricultural Sciences Center, USDA-ARS, Parlier, CA.

Research Effort Recent Publications:

Gao, S., H. Ajwa, R. Qin, M. Stanghellini, and D. Sullivan. 2013. Emission and transport of 1,3-dichloropropene and chloropicrin in a large field tarped with VaporSafe™ TIF. Environ. Sci. Technol. 47:406-411

Ajwa, H., M. Stanghellini, S. Gao, D.A. Sullivan, A. Khan, and R. Qin. Fumigant emission reduction using totally impermeable film in large field applications. Calif. Agr. (in press)

Cabrera, J.A., B.D. Hanson, M.J.M. Abit, J.S. Gerik, S. Gao, R. Qin, and D. Wang. Pre-plant soil fumigation with reduced rates under low permeable films for tree nursery production, orchard and vineyard replanting. Calif. Agr. (in press)

Gao, S., B.D. Hanson, R. Qin, J.A. Cabrera, J. Gerik, D. Wang, and G. Browne. Emission control and efficacy improvement by TIF tarp in soil fumigation for perennials. Calif. Agr. (in press)

Hanson, B.D., S. Gao, J. Gerik, R. Qin, J.A. Cabrera, A.J.M. Abit, D. Cox, B. Corriear, D. Wang, and G. Browne. A clean start to productive orchards and vineyards: recent research on methyl bromide alternatives for perennial crop nurseries. Calif. Agr. (in press)

Qin, R., S. Gao, and H. Ajwa. Effect of soil moisture on emissions and behavior of fumigants in different textured soils. Chemosphere. (in press)

Spurlock, F., B. Johnson, A. Tuli1, S. Gao, J. Tao, F. Sartori1, R. Qin, D. Sullivan, M. Stanghellini, and H. Ajwa. 2013. Simulation of fumigant transport and volatilization from tarped broadcast applications. doi:10.2136/vzj2013.03.0056. Available on web: https://www.soils.org/publications/vzj/view/first-look/v13-03-0056.pdf.

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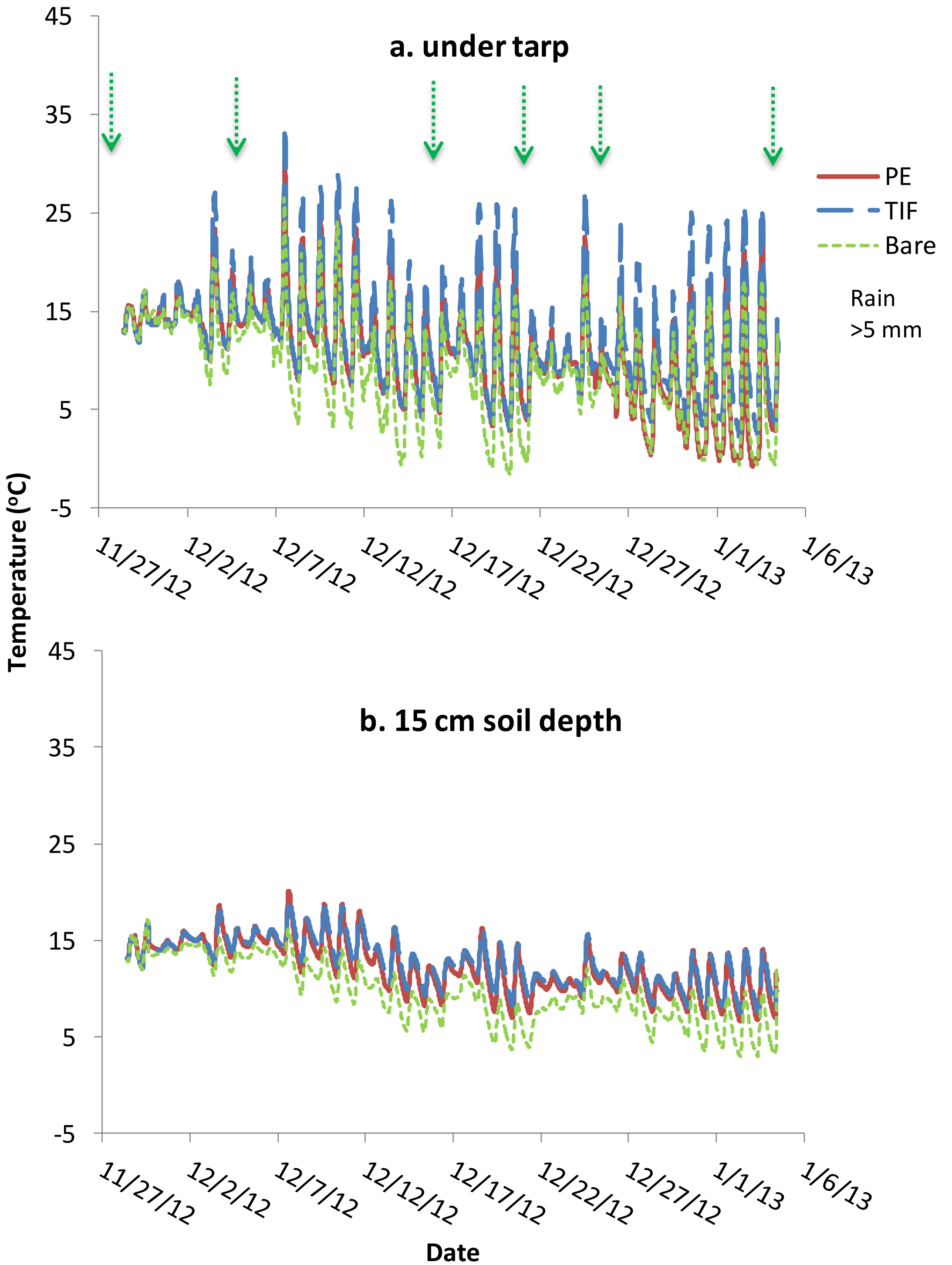

Figure 1. Temperature in a. air under tarp; b. soil at 15 cm depth and rain events during fumigation trial in fall 2012 at Braden Farm, Merced.

Photo 1. A view from north-west corner of the fumigation field at Braden Farm, Merced in fall 2012 trial.

Photo 2. A view from south side of the fumigation field at Braden Farm, Merced in fall 2012 trial.

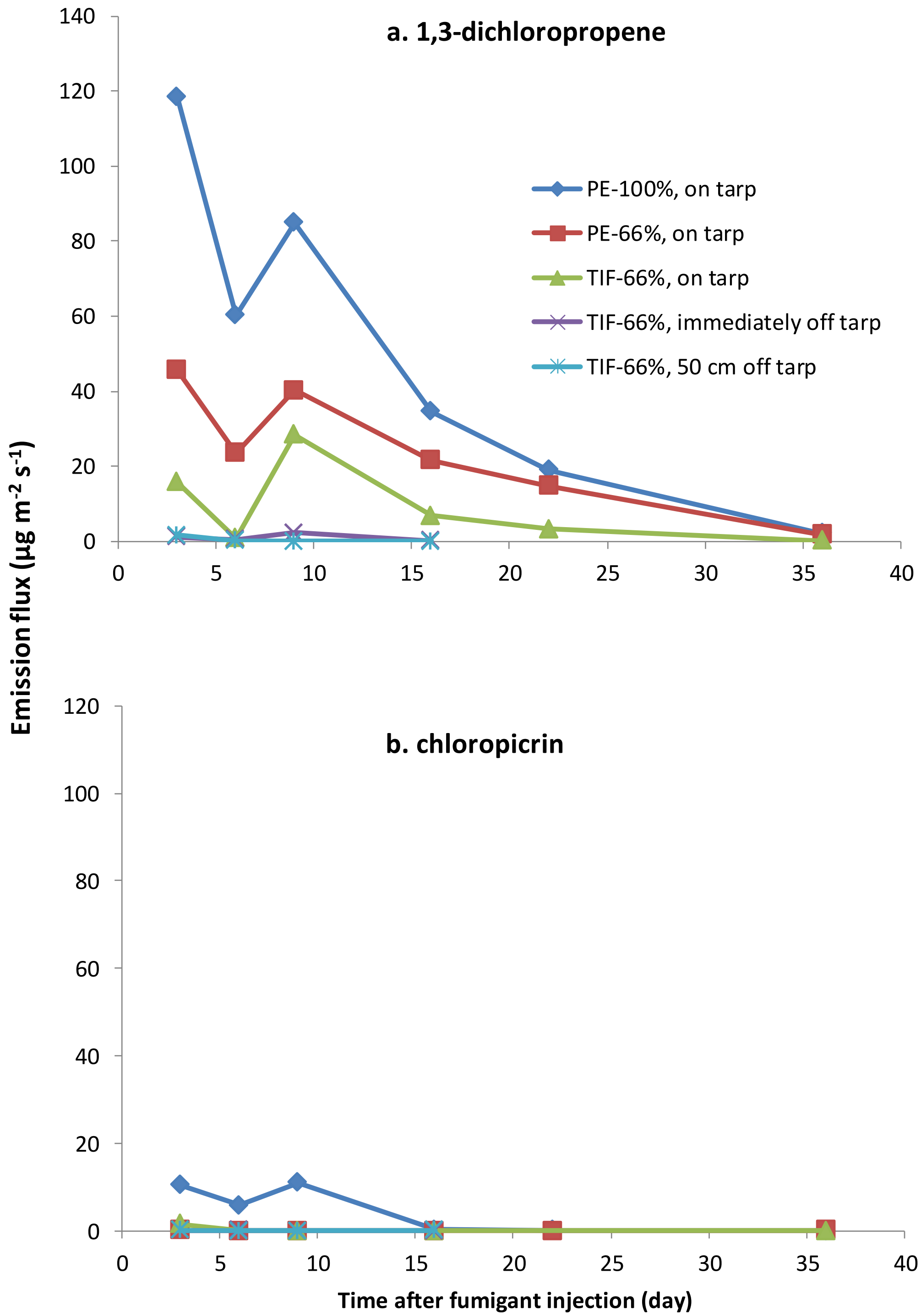

Figure 2. Emission flux of a. 1,3-dichloropropene and b. chloropicrin measured in fall 2012 field trial at Braden Farm, Merced.

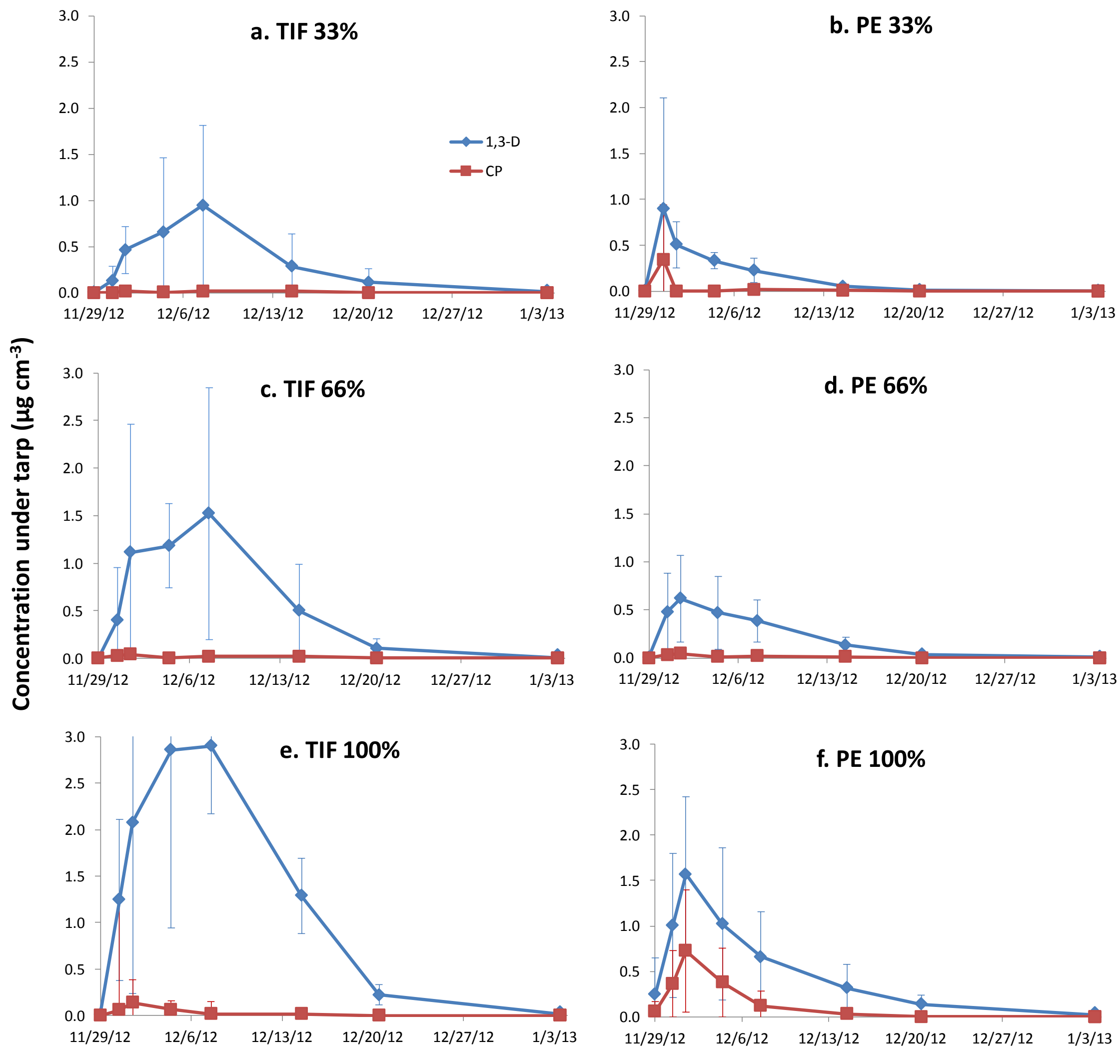

Figure 3. Gaseous fumigant concentrations in air under tarp: a. 1,3-Dichloropropene, and b. Chloropicrin. Error bars are standard deviation of the mean (n=3).

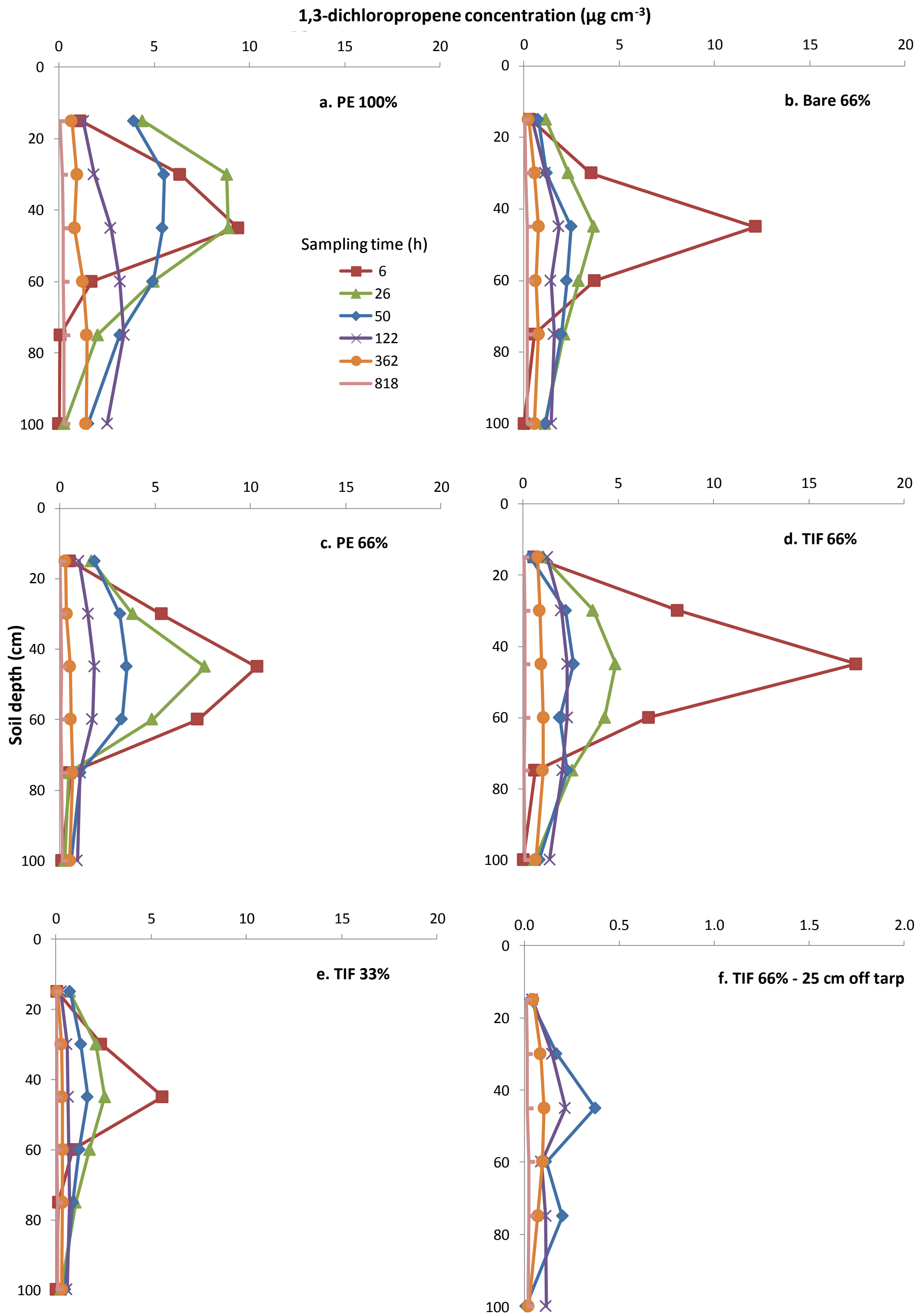

Figure 4. 1,3-dichloropropene concentrations in soil-gas phase from different rates of Telone® C-35 and surface sealing fall 2012 field trial at Braden Farm, Merced. Plotted are averages of three replicates. Error bars are omitted for readability.

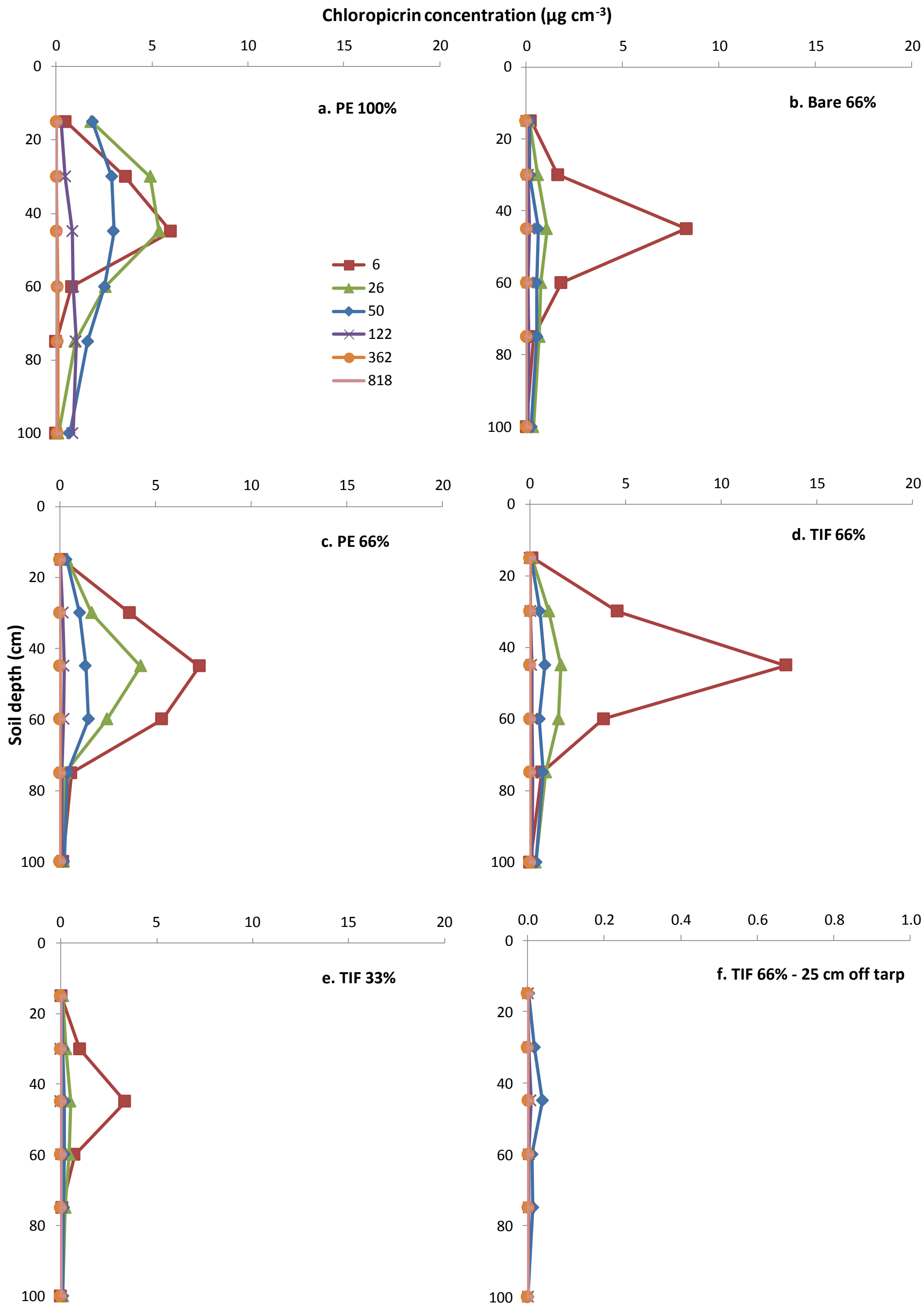

Figure 5. Chloropicrin concentrations in soil-gas phase from different rates of Telone® C-35 and surface sealing fall 2012 field trial at Braden Farm, Merced. Plotted are averages of three replicates. Error bars are omitted for readability.

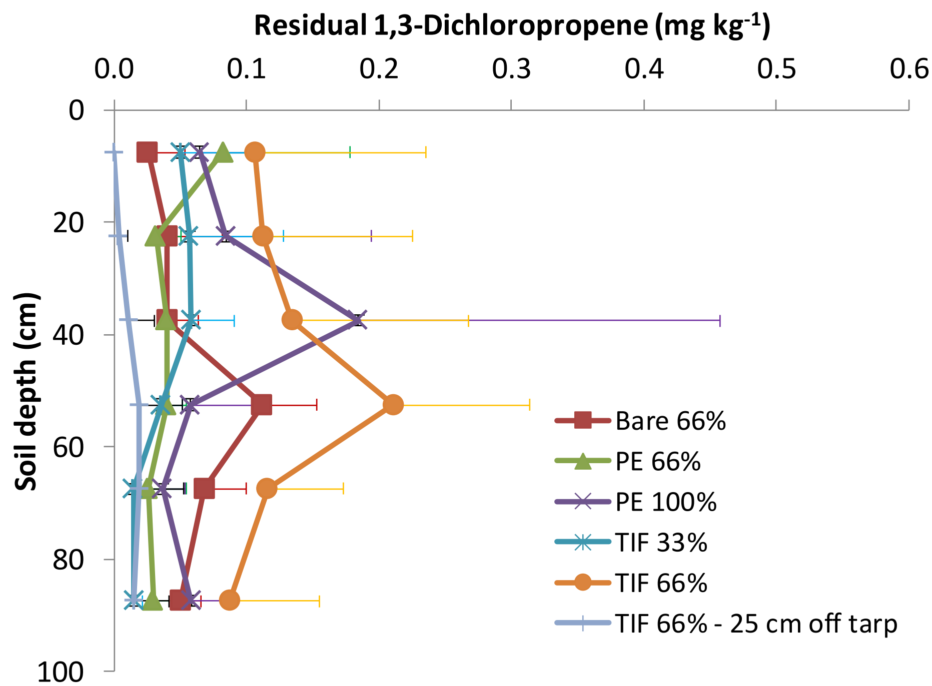

Figure 6. Residual 1,3-D concentration in soil after three weeks of application of Telone® C-35 in fall 2012 field trial at Braden Farm, Merced. Error bars are the plus standard deviations of the mean (n=3).

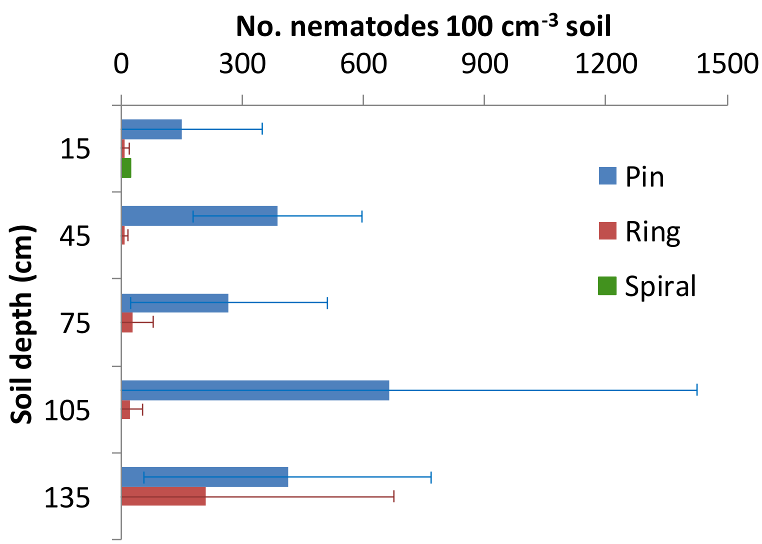

Figure 7. Nematode diversity and population density before soil fumigation at different soil depths. The population was comprised of chiefly *Paratylenchus* spp. (Pin), and ***Criconemella xenoplax (ring*****).** Error bars are the standard deviation of the mean (n=5).

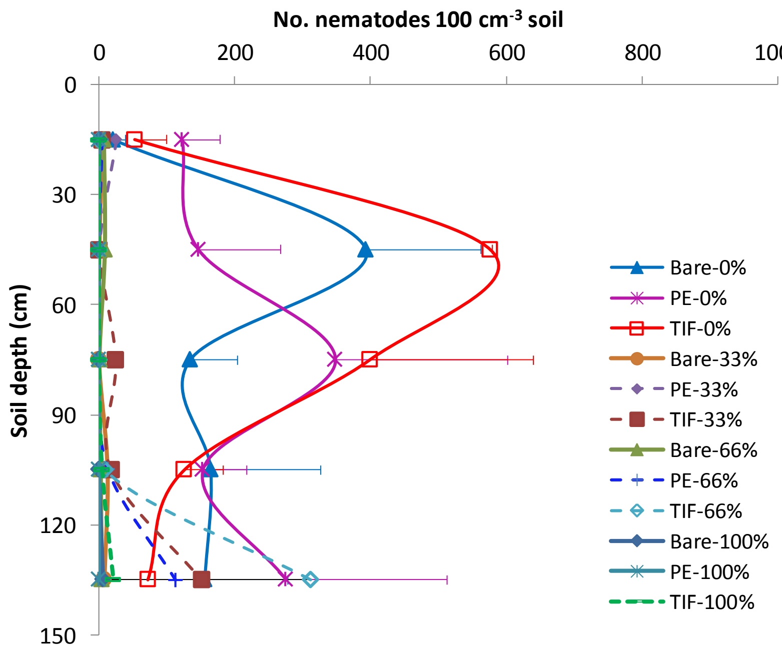

Figure 8. Total living resident plant parasitic nematodes (sum of Pin, Spiral, and Ring nematodes) found in different treatments after fumigation treatment. Samples are collected after about 6 weeks of fumigant application at Braden Farm, Merced. Plotted are averages of three replicates plus standard deviation.

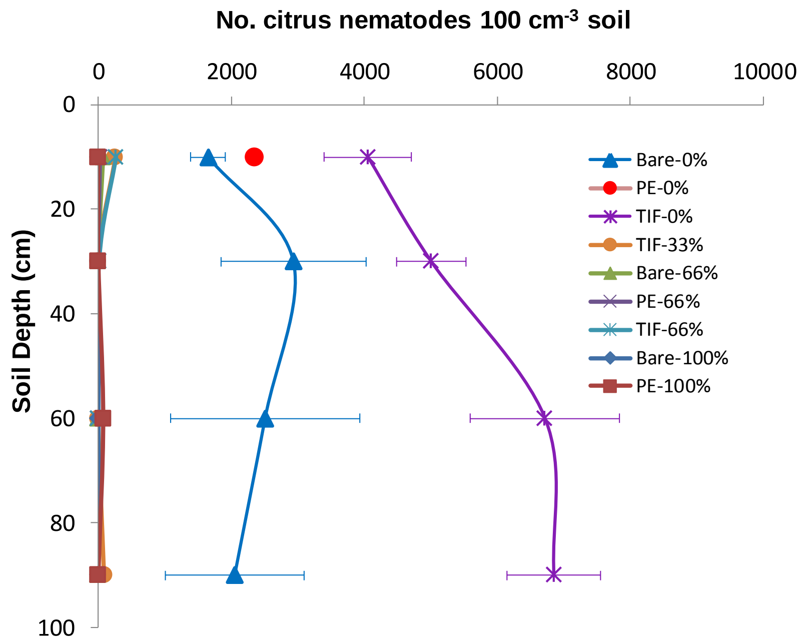

Figure 9. Citrus nematode survival in buried bags after 6 weeks of fumigation treatments in fall 2012 fumigation trial at Braden Farm, Merced. Plotted are averages of three replicates plus standard deviation.