Minimize Emissions and Improve Efficacy from Soil Fumigation Using TIF Tarps

Project No.: **11-AIR5-Gao**

Project Leader: Suduan Gao, Ph.D.
Research Soil Scientist
USDA-ARS
9611 S. Riverbend Ave.
Parlier, CA 93648
559.596.2870
559.596.2856 (fax)
Suduan.Gao@ars.usda.gov

Project Cooperators and Personnel:
Alfonso Cabrera, Plant Pathologist/Nematologist, UC Riverside, CA
James Gerik, Research Pathologist, USDA-ARS, Parlier, CA
Brad Hanson, CE Specialist, UC Davis, CA
Ruijun Qin, Assistant Project Scientist, UC Davis, CA
Lynn Sosnoskie, Visiting Scientist/Assistant Project Scientist, UC Davis, CA
Dong Wang, Research Leader, USDA-ARS, Parlier, CA
Greg Browne, Plant Pathologist, USDA-ARS, Davis, CA

Objectives:

The goal of the project is to develop field management practices using low permeability tarps (e.g., commercially available VaporSafe™, a totally impermeable film or TIF) to reduce emissions, improve efficacy, and reduce fumigant rates in soil fumigation for almond orchard replanting. Specific objectives are:

1. Demonstrate the ability of TIF to reduce emission and improve fumigant distribution in soil from broadcast shank application with alternative fumigants to methyl bromide (MeBr).
2. Determine the potential of using reduced fumigant application rates to achieve good efficacy under TIF.
3. Evaluate fumigant distribution and persistency under TIF tarp and treatment effects on nematodes, pathogens and weeds.

Interpretive Summary:

Most almond orchards apply soil fumigants to soil before replanting to control soil-borne pests and/or replanting diseases in order to establish vigorous and productive trees. Nursery growers also rely on soil fumigation to meet California's nursery certification program for producing parasitic nematode free crops. However, emission control for major alternative fumigants to MeBr, such as 1,3-dichloropropene (1,3-D) and chloropicrin (CP), is mandatory in air quality (ozone) non- attainment areas including the

San Joaquin Valley of CA where most of the almonds are produced. The main purpose of this project is to quantitatively assess fumigation treatments that minimize emissions and at the same time maximize fumigant use efficiency by using totally impermeable film (TIF). In fall 2011, a comprehensive field trial was conducted in a sandy loam soil with VaporSafe™ TIF to test fumigant emission, distribution in soil, and efficacy to determine the potential of using reduced fumigant rates of Telone C35. A total of 11 treatments were included: non-fumigated control, standard MeBr, two full rates under either no tarp or standard polyethylene (PE) tarp, four 2/3 rates under no tarp, PE tarp, TIF tarp, and a carbonated fumigant treatment under TIF; and three 1/3 rates under PE, TIF and a carbonated fumigant treatment under TIF. Carbonation refers to saturating the fumigants under pressure with CO_2; after the fumigant is injected, the CO_2 acts as a dispersant to improve fumigant distribution in soil. The fumigants were shank-injected to 45 cm depth and sealed with either PE or TIF immediately. The TIF reduced total emissions >95% relative to bare soil while standard PE tarp reduced emissions ~30%. The total emission loss from TIF tarped plots was 2% of total applied for 1,3-D and <1% for CP. Emissions from the bare soil adjacent to TIF tarp-edges were low as well. TIF significantly increased fumigant concentration or concentration-time (CT) exposure indices at 15 cm depth as compared to the PE film. Reduced 2/3 rate under TIF showed the possibility to provide effective nematode control in soil profile. Data on the effect of carbonation on fumigant distribution were inconclusive and will require more field tests to resolve. This research continues to determine and validate management strategies to maximize fumigation efficiency while minimizing environmental impacts.

Introduction

Soil fumigation continues to be an important practice for soil disinfestation prior to planting new trees after old orchards have been pulled out. Almonds, exclusively produced in California in the U.S., depend highly on soil fumigation to control soil-borne pests and/or replanting diseases. Furthermore, open-field perennial nursery growers rely on soil fumigation to meet the requirements of the CDFA's Nursery Stock Nematode Control Program, i.e., to deliver parasitic nematode-free crops (CDFA, 2008). Since the phase-out of methyl bromide (MeBr), 1,3-dichloropropene (1,3-D) and chloropicrin (CP) in combinations have been used increasingly. However, these alternatives are highly regulated because of the potential exposure risks and emission of volatile organic compounds (VOCs) that degrade air quality (CDPR, 2009; USEPA, 2009). In field tests, tarping fumigated field with low permeability tarps, such as virtually impermeable film or VIF, was shown to effectively reduce emissions with the potential to improve efficacy by increased fumigant concentration and retention under the tarp. However, various VIF products have shown inconsistency in emission reduction performance especially in large field application due to their susceptibility to film damage from tearing or stretching during field installation (Qin et al., 2008).

A relatively new film, VaporSafe™ totally impermeable film (TIF), has shown consistent performance in emission reduction based on field tests in the last couple of years. Data from a large field trial demonstrated that TIF effectively reduced emissions and can improve efficacy by increasing concentration-time (CT) exposure indices and improving the distribution uniformity of fumigants in the soil profile, as compared to the performance of standard PE tarp (Qin et al., 2011). These benefits have been documented in soil fumigation trials for annual crops when fumigants were injected to a shallow depth. The benefits of TIF to improve pest control for perennial crops are uncertain as deep fumigant injections are needed to control soil pests at a deeper root zone. Since fall 2009, emission reduction and fumigant behavior under TIF were evaluated in field trials (detailed results are reported to Almond Board in 2011). The TIF reduced emission flux and cumulative loss >95% compared to standard PE film during a 2-week tarp-covering with spiked emissions that were higher from TIF than standard PE tarp followng tarp-cutting. Using reduced rates under TIF were then proposed under this project. In fall 2010, a fumigation trial was conducted and data were collected on fumigant fate and distribution in soil profile as well as efficacy on nematodes, pathogens and weeds. Three fumigant rates (full, half, and quarter] of Telone C35 were evaluated under TIF in comparison with standard PE tarp. The TIF maintained consistently higher fumigant concentrations under the tarp than PE films. Most fumigation treatments provided 100% kill of nemtodes including the reduced rates under TIF with little differences between tarp types. In 2011, a field trial was designed to collect further comprehensive data to determine how TIF can be efficiently used in soil fumigation in terms of emission control and efficacy improvement.

Materials and Methods:

Field trial and treatment: In fall 2011, a comprehensive field trial was conducted in a 10-year old vineyard, which had its vines pulled out three months before fumigation, and was 2.8 acres in size. The soil is Hanford sandy loam (coarse-loamy, mixed, superactive, nonacid, thermic Typic Xerorthents), a common soil type on the east side of San Joaquin Valley. The trial was designed to evaluate the effects of tarping with TIF, the use of a carbonation technique, and reduced rates on fumigant emission, distribution in soil, and efficacy on nematodes, pathogens and weeds. Carbonation refers to the process of dissolving carbon dioxide (CO_2) into the fumigant and using CO_2 as a dispersant in soil application. A total of 11 treatments were applied including the non-treated control, standard MeBr treatment, and various combinations of different Telone C35 application rates (full rate, 2/3 rate, and 1/3 rate) in carbonated or non-carbonated fumigants with different surface sealing (bare, tarped with standard PE, or tarped with TIF). The treatments are summarized in **Table 1**. There were two full rates of Telone C35 (bare and PE tarp), four 2/3 rates (bare, regular N_2 pressurized under the PE or TIF tarp, and carbonated under TIF), and three 1/3 rates (regular N_2 pressurized under either PE or TIF tarp, and carbonated under TIF). These combinations allow data collection for comparisons between different rates under same surface sealing condition, between regular N_2 pressurized and carbonated fumigant at the same rate, and between tarps under the same fumigation conditions.

Table 1. Treatments in field trial conducted in fall 2011, Parlier, CA.

	Bare	PE (N_2)	TIF(N_2)	TIF(CO_2)
Telone C35 rate:				
0	x			
1/3 (180 lbs/ac)		x	x	x
2/3 (360 lbs/acre)	x	x	x	x
full (540 lbs/acre)	x	x		
MeBr (MeBr:CP 67:33=400 lbs/ac);		x		

Telone C35, a fumigant product containing 35% CP, 63% 1,3-D, and 2% other ingredients, was shank-applied to 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 October 26, 2011. The full rate refers to the maximum rate of 1,3-D used in CA, which is 48 gallons or 540 lbs/ac (~610 kg/ha). The reduced rates were 2/3 and 1/3 of the full rate. The TIF was VaporSafe™ product (1-mil thickness, clear, Raven Industries, Sioux Falls, SD, USA). Fumigation plots were 100 ft long and about 23 ft wide, which allowed two application passes and also two sheets of film to be applied. The two sheets of TIF were joined along the edges with hot-glue and the installation appeared successful without apparent problems in the field. When necessary, a fumigation plot was split in the middle for two treatments, such as the tarped and bare treatments at the same application rate (50 ft long for each treatment). Three replicates were used for each treatment. There was a 12-ft non-fumigated distance between fumigation plots. Locations for sampling or measurements were chosen near the center of a fumigation pass and near the middle along a treatment plot. Plastic tarps were installed immediately following fumigant application. After 3 weeks of field monitoring on emission and soil fumigant movement, the tarps were cut on Nov. 22, 2011 and removed a week later.

Carbonation refers to the process of dissolving CO_2 into the fumigant and using CO_2 as a dispersant in soil application (Thomas et al., 2011). The procedure involves the addition of gaseous CO_2 to the fumigant to reach saturation at a CO_2 pressure of 50 psi, which is normally done overnight (~16 hours). However, during the 2011 Parlier field trial, due to concerns over safety regarding fumigant cylinder transport on the road, which took several hours to reach the fumigation field, CO_2 was added to a fumigant tank under 30 psi for only three hours. This resulted in a fumigant that was not saturated with CO2 and had a reduced amount of CO_2 than originally planned. Furthermore, the carbonated fumigant application was originally planned to be pressurized by CO_2 during application. Changing the pressurization tank would complicate the application system in the field for the licensed fumigator, so regular nitrogen gas (N_2) was used to pressurize the carbonated fumigants for application. One of the main purposes for testing the carbonation technique is to determine its feasibility for adoption by the industry. These modifications may reflect the necessary steps to take in the development process of a new technology while still retaining the current application procedure.

Emission measurement: Fumigant emissions and changes of fumigant concentrations in the soil profile were monitored for four weeks. Dynamic flux chambers (DFCs) and soil probes for gas sampling were installed immediately following tarp installation. All four 2/3 rate treatments of Telone C35 (bare, PE tarp, TIF tarp, and carbonated under TIF tarp) were chosen for emission monitoring sampling using DFCs. Details of the chamber methods can be found in Gao and Wang (2011). Emission monitoring continued for 3 weeks after fumigant application. Both emission flux (rates) and cumulative emission loss as percent of total applied were determined. Sample collections, storage, and processing followed previously developed protocols (refer to Gao et al., 2009; 2011).

Soil fumigant sampling: Fumigant concentrations in the soil-gas phase at 15 cm were monitored for all Telone C35 treatments. Teflon sampling tubing was attached to pest bags (see below) that were buried at 15 cm depth. In addition, fumigant movement in soil profile down to 1 m depth was monitored in 4 treatments: regular and carbonated fumigant at 2/3 and 1/3 reduced rates under TIF. The purpose was to collect information on whether carbonation promotes fumigant dispersion in soil profile under the studied conditions. Soil gas probes were installed at 0, 5, 15, 5, 35, 45, 55, 70, 85, and 100 cm depth below soil. Sampling for soil gas was conducted at varying time intervals (more frequent at earlier times than later) until the tarp was cut. The probes were installed between shank injection lines in all the monitored plots. Fifty mL of gas samples were withdrawn with gas-tight syringes and the fumigant was adsorbed on XAD-4 sampling tubes. The tubes were later brought to the lab, extracted and analyzed for 1,3-D and CP. Sampling continued for 3 weeks after fumigant injection and residual fumigants in the soil were also sampled by then. Procedures for soil sampling, sample storage, and processing can be found in Gao et al. (2009).

Efficacy investigations: This trial included full investigations of pest control including survival of residential nematodes and buried bags containing soil infested with nematodes, pathogens and weed seeds. Resident nematode evaluation was conducted by collecting soil samples before soil fumigation. A total of twelve soil samples were randomly taken throughout the field with a soil auger at 30 cm increment to 30, 60, 90, 120, and 150 cm soil depths. 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). After fumigation and following plastic tarp removal (a month after fumigant application), soil samples were collected at 30 cm increment to 30, 60, 90, 120, and 150 cm soil depths soil depths in every plot. All soil nematodes were extracted using the sugar-sieving centrifugation method as described above. Living nematodes were identified as aforementioned.

Evaluation of citrus nematodes in bags. Soil naturally infested with citrus nematodes (*Tylenchulus semipenetrans*) was collected from the top 30 cm soil depth of an orange orchard near Visalia, CA. Cloth bags (8.89 by 12.5 cm, Hubco, Inc. Hutchinson, Kansas) were filled with 100 cm^3 of the citrus nematode infested soil. One day before soil fumigation the bags were buried at 15, 30, 60, and 90 cm soil depth in every plot. After fumigation and following plastic tarp removal, the bags were removed from the soil. 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.

For pathogens, soil samples in the surface (0-15 cm) were collected from all field plots by the end of the fumigation trial. Pythium and fusarium in the soil were investigated for efficacy. In addition, bags with soil infested with pathogen species phytophthora and verticillium were prepared and buried at 15 cm soil depth in every plot on the fumigation day. The bags were retrieved at the end of the trial and determined for vitality. Weed recovery in all treatment plots after the fumigation trial was determined by counting weed density two times and biomass determination once. Statistical analyses were performed on differences between treatments.

Results and Discussions:

Emission reduction by TIF. Fumigant emission fluxes from the 2/3 application rates of Telone C35 with no tarp, standard PE tarp and TIF tarp are shown in **Figure 1**. 1,3-D emission flux was the highest from bare soil (peak flux up to 60 µg m^{-2} s^{-1}), followed by the PE tarp (up to 25 µg m^{-2} s^{-1}) and lowest in TIF (below 1.5 µg m^{-2} s^{-1}). This indicates >95% reduction in peak flux from bare soil in comparison with the 60% reduction by the PE. Cumulative emission loss (**Table 2**) over the four weeks of tarp covering period showed a 96% reduction by TIF and 30% reduction by PE from the untarped treatment, which had nearly half of fumigants volatilized to the air. Monitoring of emission near the tarp edges (**Figure 2d**) showed low emission flux and total loss (**Table 2**).

Fumigant concentration in surface soil at 15 cm soil depth. Concentration changes of 1,3-D and CP at 15 cm depth, where pest bags were buried, are shown in **Figure 2**. Large variations and a continuous rise in concentration were observed for the first 4 days after fumigant application. As time progressed, the 2/3 rate of regular Telone C35 under TIF showed the highest 1,3-D concentrations, followed by the carbonated fumigant under TIF, and then the full rate under standard PE tarp. Other treatments fell into similar ranges with the lowest from1/3 rate under PE tarp, then 2/3 rate in bare soil, and 1/3 rate under TIF. The data clearly show that the TIF tarp increased the concentration of 1,3-D in soil. Chloropicrin concentration was very low in this field trial, possibly due to fast degradation in this soil.

Fumigant distribution in soil profile. Figure 3 shows average 1,3-D concentration changes over time in soil profile from two application rates (1/3 and 2/3 of full rate) of either regular or carbonated Telone C35 under TIF. Although similar patterns appeared among the four treatments, the concentration near the soil surface and at lower depths appeared higher at 2/3 rate than the 1/3 rate indicating the higher application resulted in more uniform distribution of fumigants in soil to provide better efficacy. At 480 h, higher 1,3-D concentrations were observed at the 2/3 rate as compared to the 1/3 rates. Little difference in the concentration profile was observed between the regular and carbonated treatments. A higher amount of CO_2 in fumigants and using CO_2 to deliver fumigant application may be needed to see the benefits of better dispersion of fumigant. More field tests are needed to explore how carbonated fumigants can be used to assist in fumigant movement in the soil.

Table 2. Cumulative loss: % of applied

Surface seal	1,3-D	CP
Bare	53.5 (22.2)	0.5 (0.7)
PE	38.3 (17.3)	0 (0)
TIF	1.9 (0.5)	0 (0)
Off TIF tarp in bare soil*	0.6 (0.1)	0 (0)

* Based on TIF tarp application rate.

Residual fumigant. Three weeks after fumigant application, the highest residual fumigant concentration in the soil was found from the 2/3 rates of either regular or carbonated fumigants under the TIF (**Figure 4**). The data agreed with the gas data monitored in the soil and suggest that fumigant under TIF do persist longer in soils. The increased residence time of fumigants in soil from TIF tarping is not desired for two reasons. If fumigation is conducted late fall, the rainy season is approaching. If soil has sufficiently high fumigant, precipitation could cause potential downward movement of fumigants. Secondly, if fumigant is present at substantially high amount by planting time (winter or early spring) phytotoxicity could occur. A laboratory study indicated residue of methyl iodide in soil had high leaching potentials (Guo et al., 2004). Although there have been no detailed examination on the possibilities of these occurrences under field conditions, every effort should be made to minimize these risks because they can significantly determine the fate or availability of fumigants for agricultural use in the future.

Regarding TIF use in soil fumigation, the tarp is concluded to effectively control emissions during tarp-covering. The emission data (**Figure 1**) also show that by 3 weeks after fumigant application emission from all plots were relatively low and the lowest was still from the TIF tarp (<0.1 $\mu g\ m^{-2}\ s^{-1}$ as compared to 0.3 $\mu g\ m^{-2}\ s^{-1}$ from the PE tarp for 1,3-D; CP was non-detectable). Emission after tarp-cutting was not measured but expected to be low because of the generally low amount of 1,3-D in soil (<0.04 $mg\ kg^{-1}$ as shown in **Figure 4**). However, the unknown fate of the residual fumigants from the TIF tarped soil can be a concern because fumigant can persist longer towards when temperature drops that slow down fumigant degradation and precipitation can cause leaching. Thus, use of TIF in soil fumigation is not desirable at later times during the year.

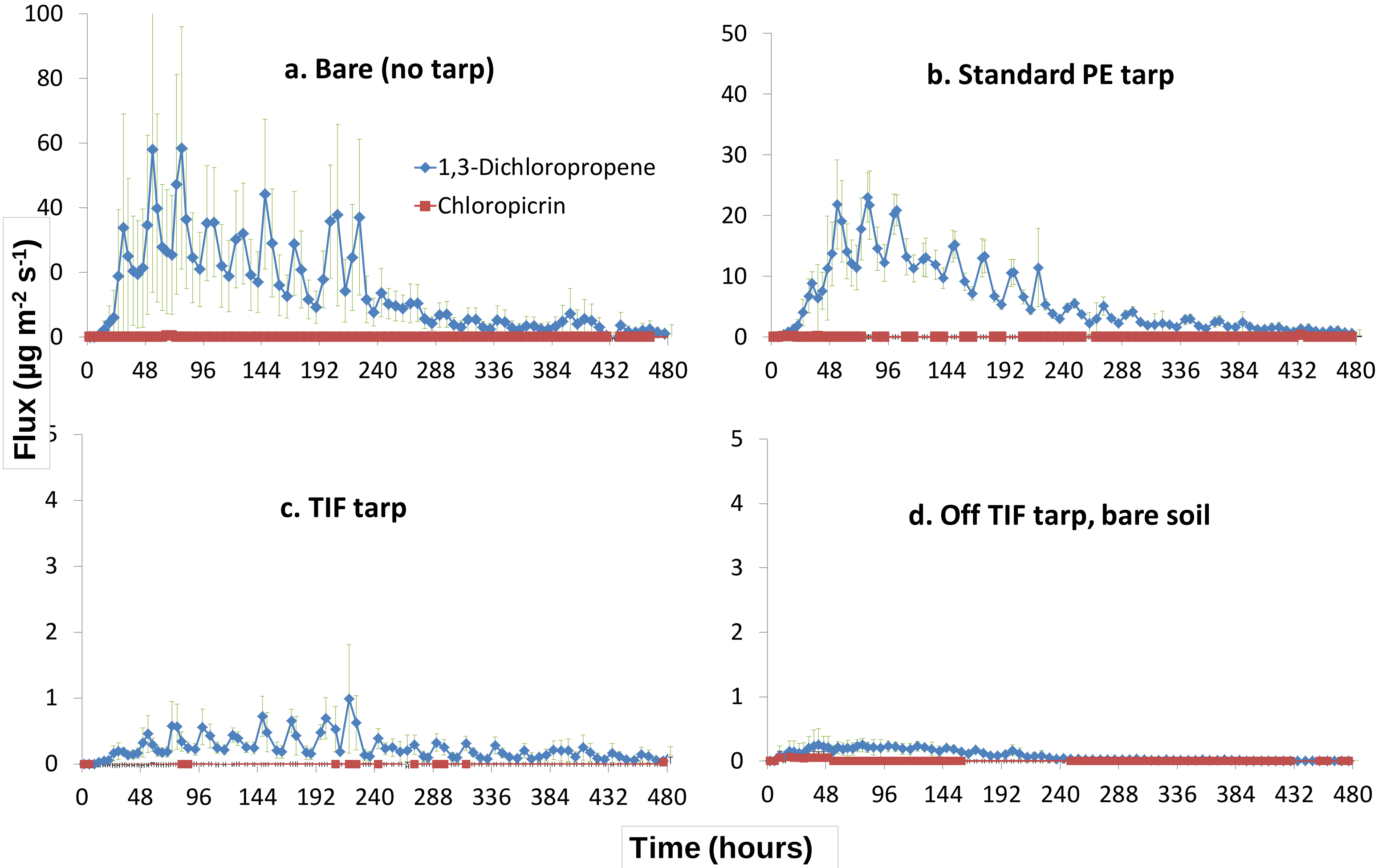

Figure 1. Emission flux of 1,3-dichloropropene and chloropicrin measured in fall 2011 field trial. Treatments were 2/3 of Telone full rate with different surface sealing: a. Bare (no tarp); b. Standard PE tarp; c. TIF tarp; and d. Off TIF tarp edge in bare soil.

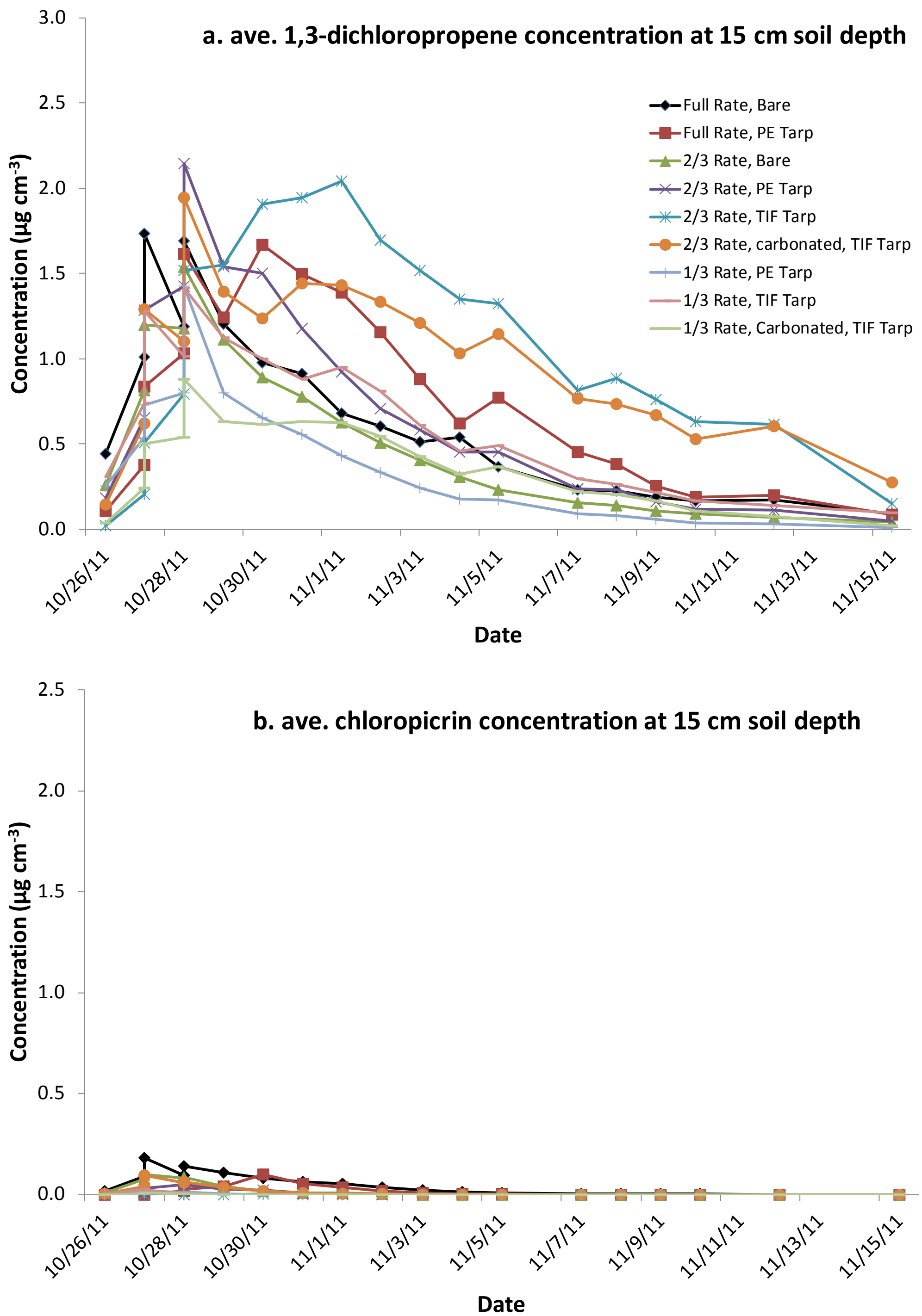

Figure 2. Gaseous fumigant concentrations, a. 1,3-Dichloropropene; b. Chloropicrin; at 15 cm soil depth adjacent to pest bags in fall 2011 field trial. Plotted are averages of three replicates. Error bars are omitted for readability.

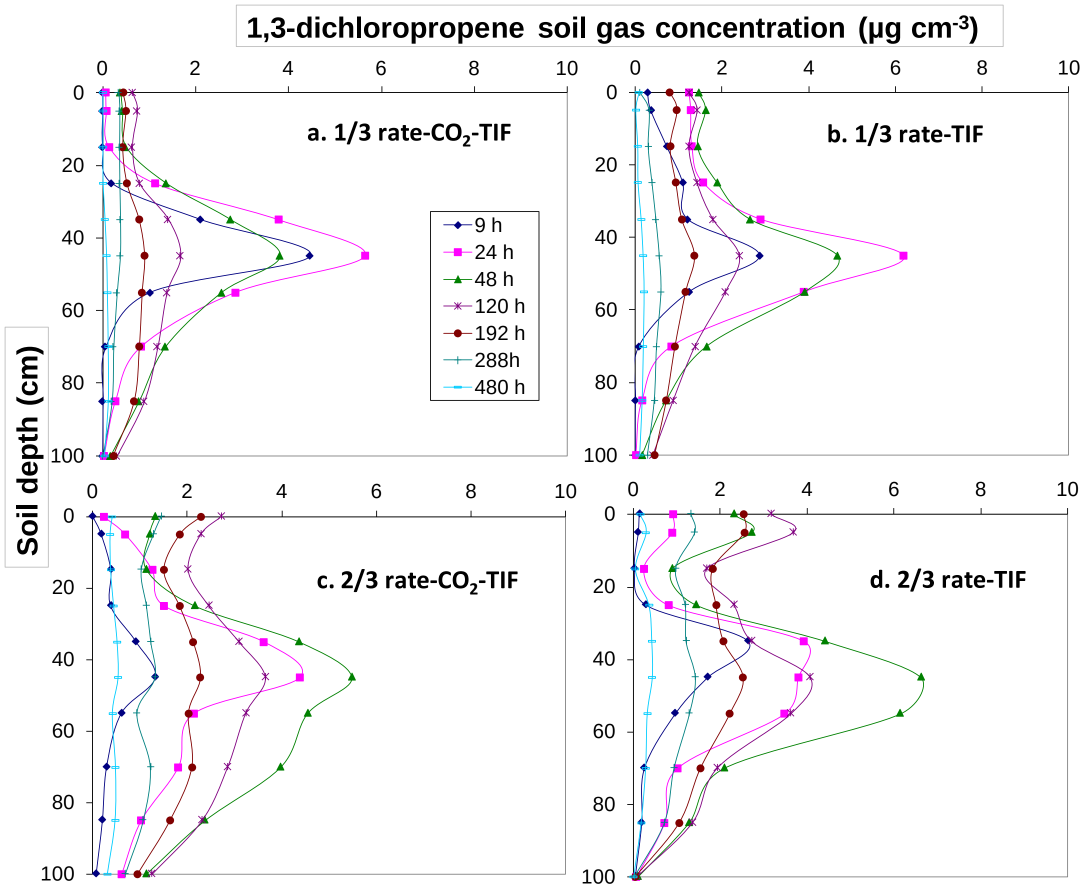

Figure 3. 1,3-D concentration changes in soil-gas phase from reduced rates of Telone C35 with carbonation (adding CO2 to fumigants) in fall 2011 field trial. Plotted are averages of three replicates. Error bars are omitted for readability.

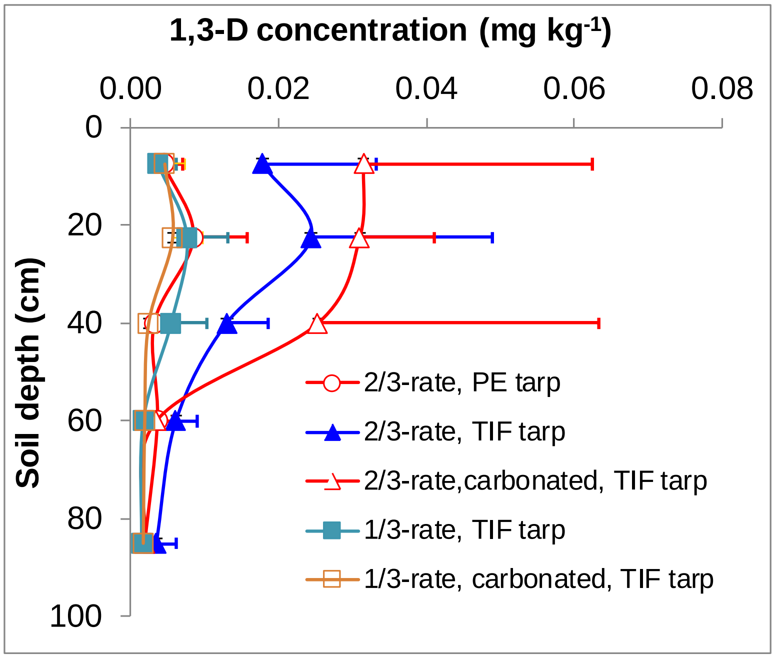

Figure 4. Residual 1,3-D in soil from tarped and reduced Telone C35 application rates after three weeks of application in fall 2011 field trial. Error bars are the plus standard deviations of the mean (n=3).

Efficacy Investigations

Nematodes. The field was infested with a variety of resident plant parasitic nematodes with high populations of citrus and pin nematodes and low populations of root-knot, dagger, and ring nematodes (**Figure 5**). After fumigation, all Telone C35 treatments provided 100% nematode control at 30 and 60 cm soil depth (**Figure 6**). Nematode survival was found in the MeBr treatment at 30 cm depth. At 90 cm depth, only the treatment with 1/3 rate under PE tarp was found with nematode survival. At 120 cm depth, five treatments (all three 1/3 rates and two 2/3 rates under no tarp or TIF with carbonation) were found with nematode survival. At 150 cm depth, nematodes were found in two treatments: full rate under PE and 2/3 rate carbonated under TIF. The regular Telone C35 2/3 rate under TIF provided 100% nematode control throughout the soil profile. The data indicate nematode control at deeper soil depths remains a challenge in perennial fields and the 2/3 Telone C35 rate under TIF provided effective nematode control as well as MeBr in deeper soils. For nematodes buried in soil bags (**Figure 7**), the non-fumigated control was found with 1317, 970, 661, and 892 nematodes/100 cm^3 soil at 15, 30, 60, and 90 cm soil depth, respectively. All fumigated treatments were 100% effective against citrus nematodes in the bags at all depth with one exception that the full rate under bare soil at 30 cm soil had nematode survival.

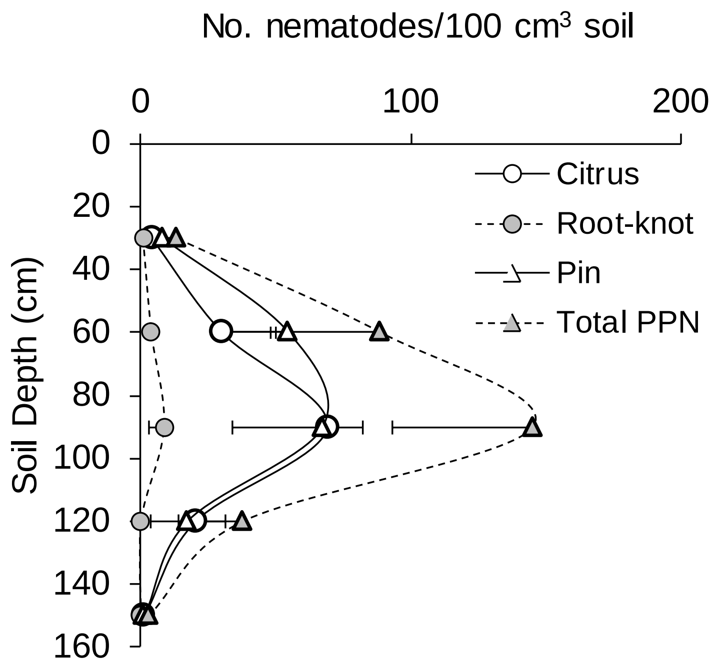

Figure 5. Nematode diversity and population density before soil fumigation at different soil depths. *Tylenchulus semipenetrans* (Citrus), *Meloidogyne* spp. (Root-knot), *Paratylenchus* spp. (Pin), and total population of nematodes (Total PPN) including *Xiphinema* spp. and *Mesocriconema* spp. Error bars indicate the standard error of the mean value (n=3).

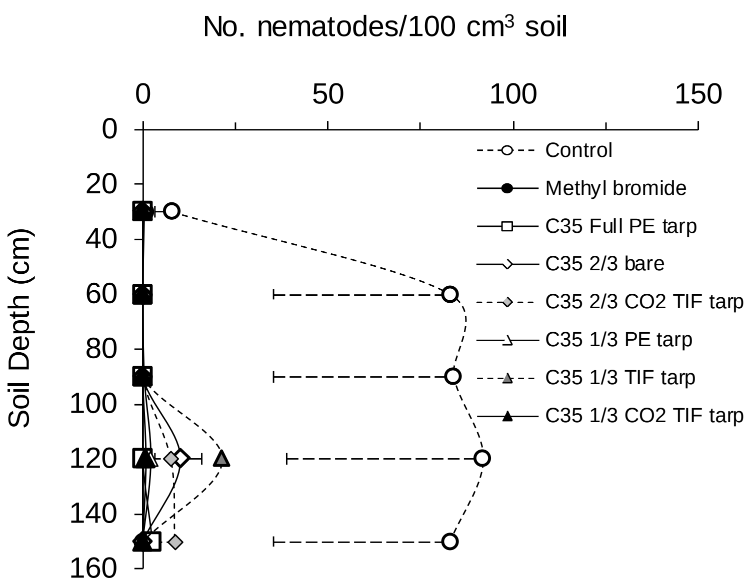

Figure 6. Total living resident plant parasitic nematodes (sum of Citrus, Root-knot, Pin, Dagger, and Ring nematodes) found in different treatments after fumigation. The treatments that are not shown in the legend [Telone C35 (C35) full bare, C35 2/3 PE tarp, and C35 2/3 TIF tarp) did not have any living resident plant parasitic nematodes providing 100% control. Error bars indicate standard error of the mean value (n=3).

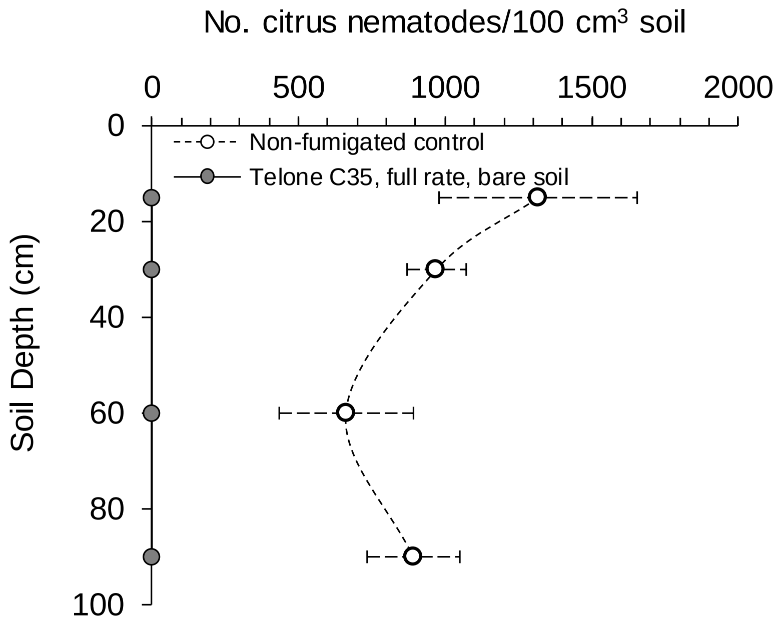

Figure 7. Citrus nematodes (in buried bags) found in different treatments after fumigation. All other fumigated treatments with Telone C35 regardless of application rate and tarping did not have any living citrus nematodes providing 100% control. Error bars indicate standard error of the mean (n=3).

Pathogens. Four species of pathogens were investigated in this study: Fusarium, Phytophthora, Pythium, and Verticillium. For Phytophthora, large variations among replicates were observed for most treatments and as a result, when original measurement data were analyzed there were no significant differences between the non-fumigated control and all other fumigated treatments and between any of the fumigated treatments including MeBr. After log-transformation, the data were reanalyzed and MeBr treatment had significantly lower population of Phytophthora than all other treatments. For Verticillium, the control had a significantly higher population than most fumigated treatments, except the non-tarped full rate of Telone C35, which was similar to the control. For Pythium, the control and the 1/3 rate under PE had significantly higher survival than all other fumigated treatments, and the MeBr and the 2/3 Telone C35 rate with carbonation under TIF had significantly lower survival than all other fumigated treatments. For Fusarium, the control had the highest survival, but was not significantly different from all three 1/3 rates (tarped or carbonated) and the 2/3 rate under bare soil; the Telone C35 full rate under PE, the 2/3 rate with carbonation under TIF, and the 2/3 rate without carbonation under TIF (with the lowest survival) provided similar control as MeBr.

Weed recovery after fumigation. Weed counts were taken on 19 January and 21 February, 2012 (about two and three months after fumigation trial, respectively). At least 13 weed species were identified and enumerated in the study including Redstem filaree, prostrate knotweed, assorted grass species, chickweed species, shepherd's purse, swine cress, cheeseweed, henbit, redmaids, clover species, groundsel, assorted Brassicacea, and *Conyza* species. Weed density profiles across treatments were similar for both evaluation dates. Total weed count data were analyzed to evaluate the effect of treatments on weed density development. For weed counts on 21 February, untarped treatments (regardless of application rates) were statistically similar to the non-fumigated control (156 plants m^{-2}). The untarped treatments and all 1/3 rates (regardless of tarp or carbonation) resulted in in-field weed densities that were significantly higher ($P<0.05$) than those observed in the MeBr standard (1 to 11 plants/m^2). Higher rates of Telone C35 (i.e. Full vs. 2/3 and 2/3 vs. 1/3) generally resulted in significantly reduced weed densities. In general, the lack of a soil sealant resulted in increased weed densities relative to tarped (PE or TIF) treatments; no differences were observed between the standard PE and TIF tarped treatments at the same application rate. Results suggest that the carbonated Telone C35 did not increase weed control efficacy. Weed control differences among treatments were attributed to either sealing method (film vs. bare soil) or fumigant rate (1/3 rate usually less effective). Due to the fact that most weeds that emerge in a field germinate near the soil surface, weed control is likely to be affected to a greater extent by fumigant retention compared to subsurface fumigant distribution. Weed biomass was determined on March 8, 2012 (**Figure 9**). Similar results and interpretation can be given as the weed density counts.

Table 3. Pathogen control from fumigation treatments in 2011 field trial in Parlier*

TRT#	Description	Fusarium	Phytophthora	Verticillium	Pythium
1	Control	2117.2 (a)	10863 (a)	132.7 (a)	90.7 (a)
2	Telone-Full-Bare	1201.5 (b, c, d)	6172 (a)	74.0 (a, b)	22.7 (b, c, d)
3	Telone-Full-PE	569.5 (c, d)	17252 (a)	53.3 (b)	8.0 (c, d)
4	Telone-2/3-Bare	1427.1 (a, b, c)	27021 (a)	54.7 (b)	38.7 (b, c)
5	Telone-2/3-PE	996.1 (b, c, d)	8328 (a)	57.3 (b)	8.0 (c, d)
6	Telone-2/3-TIF	504.7 (d)	1088 (a)	18.0 (b)	8.0 (c, d)
7	Telone-2/3-Carbonated-TIF	614.2 (c, d)	5761 (a)	34.7 (b)	2.7 (d)
8	Telone-1/3-PE	1679.5 (a, b)	14955 (a)	66.0 (b)	45.3 (b)
9	Telone-1/3-TIF	1293.1 (a, b, c, d)	2281 (a)	19.3 (b)	17.3 (b, c, d)
10	Telone-1/3-Carbonated-TIF	1248.4 (a, b, c, d)	6012 (a)	46.7 (b)	29.3 (b, c, d)
11	MeBr-PE	611.9 (c, d)	56 (b)	30.0 (b)	0.00 (d)

* Means with the same letter in the same column are not significantly different from each other.

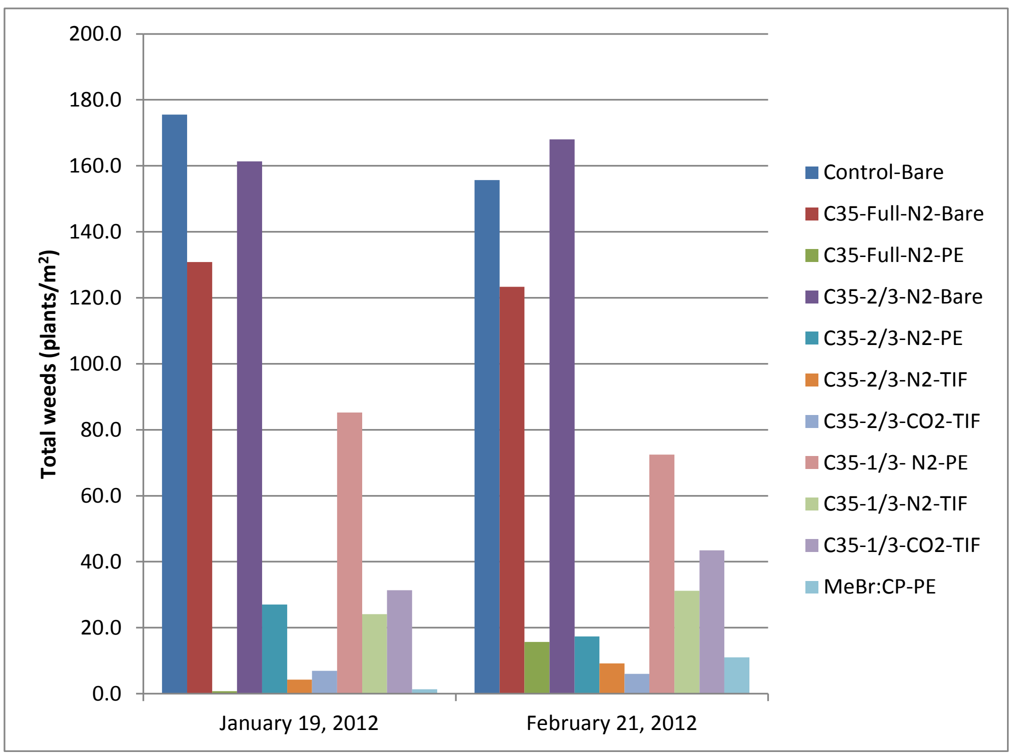

Figure 8. Mean weed counts (plants/m^2) per treatment on 19 January and 21 February, 2012. Values for 19 January represent the average of two to four 1 m^2 sub-samples per plot; values for 21 February represent the average of four to eight 0.25 m^2 sub-samples per plot.

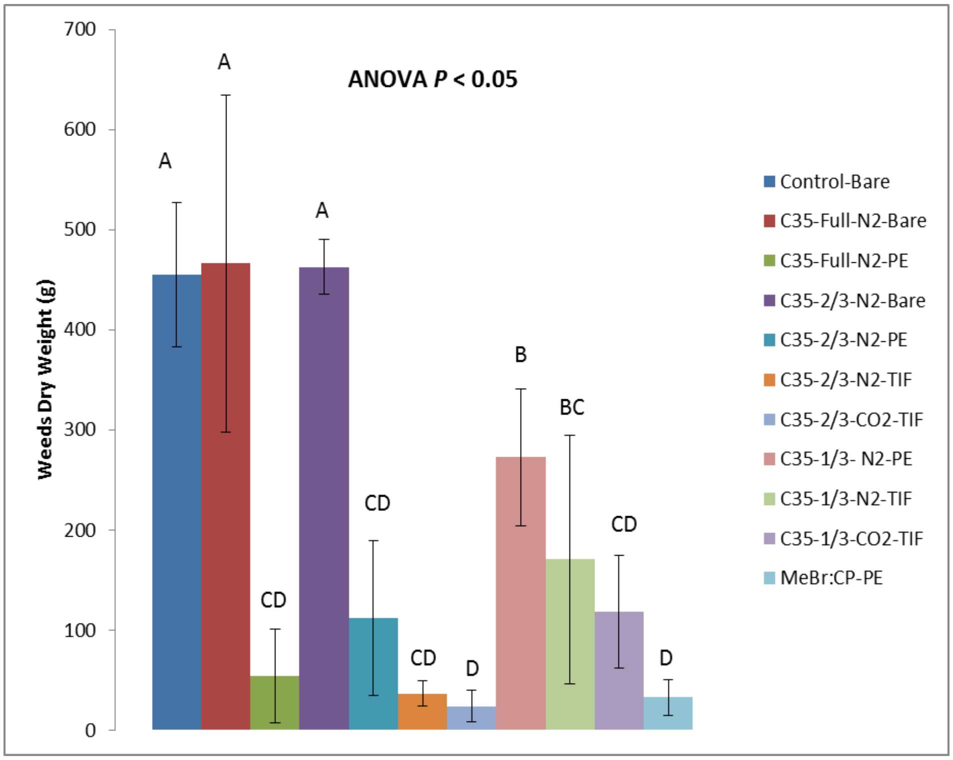

Figure 9. Mean weed dry weight (g/m^2) per treatment. Weeds were harvested on 8 March, 2012 and then dried before weighing. Values represent the average of three 1 m^2 sub-samples per plot.

Conclusions. The 2011 fumigation trial data show that the regular Telone C35 at 2/3 of full rate under TIF tarp showed similar effectiveness or better pest control as compared to the full rate in bare soil or under standard PE tarp and was equivalent to the standard MeBr treatment. The 1/3 Telone C35 rate was not sufficient to provide good control of nematodes, pathogens and weeds in the perennial field. Improvement of fumigant distribution by carbonation is inconclusive from this study and requires more field tests for more effective fumigation conditions. This research continues to provide information on effective use of soil fumigants with TIF tarp while minimizing environmental impact for perennial crops.

Acknowledgements:

Funding support for this research was provided by Almond Board of California, USDA-ARS Pacific Area-Wide Pest Management Program for Integrated Methyl Bromide Alternatives, and NIFA Methyl Bromide Transition Grants Program. Fumigant, fumigation service, and carbonation of fumigant were provided or performed by TriCal, Inc. Personnel supporting this research include: Robert Shenk, Aileen Hendratna, Allison Kenyon, Jim Gartung, Patricia Mungur, Matt Gonzales, Stella Zambrzuski, Alex

Jimenez, and Carl Hawk in San Joaquin Valley Agricultural Sciences Center, USDA-ARS at Parlier, CA.

Research Effort Recent Publications:

Cabrera, J.A., B.D. Hanson, M.J.M. Abit, J.S. Gerik, S. Gao, R. Qin, and D. Wang. 2011. p. 75:1–3 *In* Proc. Ann. Int. Res. Conf. on MeBr Alternatives and Emission Reductions, San Diego, CA

Gao, S. R. Qin, A. Cabrera, B. Hanson, J. Gerik, D. Wang, and Greg Browne. 2011. Application of low permeability tarp in perennial field fumigation. p. 12:1–4 *In* Proc. Ann. Int. Res. Conf. on MeBr Alternatives and Emission Reductions, San Diego, CA.

Hanson, B., S. Gao, J. Gerik, D. Wang, R. Qin, J.A. Cabrera, A.J. Jhala, and M.J.M Abit. 2011. Methyl bromide alternatives for the California perennial nursery industry. p. 28:1–3 *In* Proc. Ann. Int. Res. Conf. on MeBr Alternatives and Emission Reductions, San Diego, CA.

References Cited:

CDFA. 2008. Nematode Inspection Procedures Manual (NIPM) guidelines. Available at http://www.cdfa.ca.gov/phpps/pe/NIPM.htm.California Department of Pesticide Regulation (CDPR). 2005. Pesticide use report data. CDPR, Sacramento, CA.

CDPR. 2009. Volatile Organic Compound (VOC) Emissions from Pesticides. Available online at http://www.cdpr.ca.gov/docs/emon/vocs/vocproj/vocmenu.htm.

Chow, E. 2008. Properties of EVOH and TIF films for the reduction of fumigant dosage and VOC emission. p. 38 (1). *In* Proc. Ann. Int. Res. Conf. on MeBr Alternatives and Emission Reductions, 11−14 Nov. 2008, Orlando, FL. Available at http://www.mbao.org/2008/Proceedings/038ChowEMBAO2008Kuraray.pdf.

Gao, S., R. Qin, B.D. Hanson, N. Tharayil, T.J. Trout, D. Wang, and J. Gerik. 2009. Effects of manure and water applications on 1,3-dichloropropene and chloropicrin emission in a field trial. J. Agric. Food Chem. 57:5428−5434.

Gao, S. B.H. Hanson, D. Wang, G. Brown, R. Qin, H. Ajwa, S.R. Yates. 2011. Methods evaluated to minimize emissions from pre-plant soil fumigation. Calif. Agric. 65(1):41–46.

Gao, S. and D. Wang. 2011. Chapter 9 Vapor flux measurements – chamber methods. p. 191-207 *In* S. Saponaro, E. Sezenna, L. Bonomo (ed.) Vapor emission to outdoor air and enclosed spaces for human health risk assessment: site characterization, monitoring and modeling. Nova Science Publishers, Inc., Hauppauge, New York.

Guo, M., W. Zheng, S.K. Papiernik, and S.R. Yates. 2004. Distribution and leaching of methyl iodide in soil following emulated shank and drip application. J. Environ. Qual. 33:2149–2156.

Hooper D.J., Hallmann J., Subbotin S.A. (2005) Methods for extraction, processing and detection of plant and soil nematodes, in: M. Luc, et al. (Eds.), Plant parasitic nematodes in subtropical and tropical agriculture, CAB International, Wallingford. pp. 53–86.

Jenkins W.R. (1964) A rapid centrifugal-flotation technique for separating nematodes from soil. Plant Disease Reporter 48:692.

Mai W.F., Lyon H.H. (1975) Pictoral key to genera of plant-parasitic nematodes. 4th edition ed. Cornell University Press, Ithaca, New York.
Qin, R., S. Gao, J.A. McDonald, H. Ajwa, *S. Shem-Tov*, and D.A. Sullivan. 2008. Effect of plastic tarps over raised-beds and potassium thiosulfate in furrows on chloropicrin emissions from drip fumigated fields. Chemosphere. 72:558–563.
Qin, R., S. Gao, H. Ajwa, D. Sullivan, D., Wang, and B.D. Hanson. 2011**.** Field evaluation of a new plastic film (Vapor Safe™) to reduce fumigant emissions and improve distribution in soil. J. Environ. Qual. 40:1195–1203.
Thomas, J.E., J.J. Van Sickle, L.H. Allen, Jr., J.W. Noling, and D.W. Dickson. 2011. Increasing efficacy and decreasing application rate of Telone C35 with carbonation and low permeable films. p. 76:1–2 *In* Proc. Ann. Int. Res. Conf. on MeBr Alternatives and Emission Reductions, 31 Oct.–2 Nov. San Diego, CA. http://mbao.org/2011/76Thomas.pdf.
U.S. Environmental Protection Agency (USEPA). 2009. Implementation of Risk Mitigation Measures for Soil Fumigant Pesticides. Available at: http://www.epa.gov/oppsrrd1/reregistration/soil_fumigants/#ammendedreds.