Using Irrigation and Organic Amendment to Reduce Fumigant Emissions

Project No.: **08-AIR5-Gao**

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Objectives:

The ultimate goal of this project is to develop effective, economical and environmentally sound methods to minimize fumigation emissions for *Prunus* and other perennial crop production systems that require pre-plant soil fumigation. The specific objective is to determine the effectiveness of irrigation and composted dairy manure incorporation into surface soil in comparison with other treatments on emission reductions from soil fumigation.

Interpretive Summary:

Achieving low emissions from soil fumigation will allow continued availability of fumigants to growers by minimizing environmental impact and meeting air quality standards. Methods that are effective, economically feasible and environmentally sound are the most desirable. The objective of this study was to determine the effectiveness of an organic soil amendment, composted dairy manure, which is a readily available and inexpensive, on emission reductions in comparison with other treatments. A field trial was conducted in a sandy loam soil in the San Joaquin Valley Agricultural Sciences Center (SJVASC), California in fall 2008. Emissions of 1,3-dichloropropene (1,3-D) was measured from various treatments over shank injection of Telone® II. Surface treatments included a high application rate of composted dairy manure (49.4 Mg ha^{-1} or about 20 tons per acre) that was compared to a bare-soil control, post-fumigation intermittent water seals, and plastic tarps including standard high density polyethylene

(HDPE) film and a low permeable tarp as virtually impermeable film (VIF). The data were also compared to lower incorporation rates (12.4 and 24.7 Mg ha^{-1}) of composted dairy manure in a previous trial. Results showed that none of the manure application rates effectively reduced fumigant emissions. Water seals reduced more emissions than manure treatments although the effect was greater on emission peak flux than cumulative loss. The VIF demonstrated continuously effective emission reduction (>95%) and glue joints did not present problems in the field to reduce the tarp effect. The VIF can effectively reduce emissions as well as improve efficacy. The information should be considered by various commodities and regulatory agencies in identifying effective practices to minimize emissions from soil fumigation.

Materials and Methods:

A field trial was conducted from September 24 through October 8, 2008 at the USDA-ARS SJVASC at Parlier, California. The soil was Hanford sandy loam (coarse-loamy, mixed, superactive, nonacid, thermic Typic Xerorthents). During the trial, the daily maximum, minimum and average air temperature was in the range of 23.7–35.8, 9.2–18.2 and 16.8–24.2^{o}C, respectively.

To evaluate effect of manure incorporation and irrigation treatments on emission reduction from soil fumigation, the following treatments were applied and tested in three replicates:

1. Control
2. Manure incorporation to surface soils at 49.4 Mg/ha (~20 ton/ac)
3. Water seals (25 mm water sprinkler applied immediately after fumigant injection followed by 4 mm water at 24 and 48 h, respectively)
4. HDPE tarp from both continuous sheet and glue joints
5. VIF tarp from both continuous sheet and glue joints

Composted dairy manure was obtained from Valley Soil & Forest Products (Reedley, CA). The application rate was based on fresh weight with an average water content of 37.2%. The manure material was spread evenly over the soil surface prior to fumigation and was incorporated into surface (0-15 cm) soils with a disc and roller operation following fumigant application. The incorporation was restricted to surface soils with the intent that the organic material would react with fumigants only near the soil surface without reducing fumigant concentrations in subsurface soils. This application rate was about 2 to 4 times of the previously tested rates (12.4 and 24.7 Mg ha^{-1}) (Gao et al., 2009). Three other treatments were included as comparisons and they were tested in previous trials with varying results. In particular, there has been inconclusive information regarding the effectiveness of VIF on emission reduction due to the potential damage to the film during field installation and concerns about the gluing technique. Thus this trial included testing the plastic sheet glue joints for both HDPE and VIF materials. The HDPE tarp (1-mil or 0.025-mm thickness) was obtained from Tyco Plastics (Princeton, NJ) and VIF was Bromostop VIF (0.025-mm thickness) from Bruno Rimini Corp (London, UK).

Telone® II (containing *cis*- and *trans*-1,3-D isomers) was shank applied at a target rate of 380 kg ha^{-1} (33.7 gallons per acre). The application was done by TriCal, Inc.

(Hollister, CA) with the equipment and gluing materials and techniques that are used in commercial fields. The actual application rate varied among treatment plots with an average of 408±117 kg ha^{-1}. Emissions of both 1,3-D isomers were sampled for two weeks following fumigant injection. The sampling was carried out using dynamic flux chambers that used charcoal sampling tubes (ORBO™-32 Standard Charcoal Tubes, Supelco, Bellefonte, PA) to trap/adsorb the fumigants. The information regarding the dynamic flow-through flux chambers was reported in Gao et al. 2008. The samples were later extracted and analyzed for the fumigant isomers using gas chromatography with micro electron capture detector (µECD). Reported data is the sum of 1,3-D isomers. In addition, fumigant concentration in the soil-gas phase (up to 90 cm depth) over time, residual fumigant in soil and soil water content at the end of the trial were measured. Sampling and analysis procedures were similar to those reported in Gao et al. 2009.

Results and Discussions:

Emission flux

Figure 1 shows the average emission flux from various surface soil treatments. The manure treatment at the high rate of 49.4 Mg ha^{-1} did not demonstrate an emission reduction effect compared to the control and it actually gave the highest emission rate within 48 h among all treatments. The emission rates in the control were lower than the manure treatments but had large variations that resulted in no significant difference between the two treatments. After 48 h, the manure treatment showed lower average emission rates than the control. The data may indicate that at least manure incorporation into surface soils even at such a high rate may not be effective in reducing emissions when emission rates were extremely high, i.e., immediately following fumigant injection. The water seals gave lower emission rates than the control and the manure treatment in the first 48 h when irrigation was applied and showed no differences from the manure treatment after 3 days, but were continuously lower than the control. With variations in the first few days, the HDPE tarp gave lower emission rates than most other treatments except the VIF tarp. The VIF tarp gave the lowest emission rates at all times, with the highest average rates of 2 µg m^{-2} s^{-1} compared to >50 µg m^{-2} s^{-1} from the control (>95% reduction).

Emission rates followed apparent diurnal patterns (**Figure 1**), i.e., highest early afternoon and lowest early in the morning. After the emission peak, however, emission flux decreased dramatically with time for all treatments. By the end of the monitoring period, the emission fluxes were at or below 0.5 µg m^{2} s^{-1} for all the treatments.

Cumulative emission loss

The cumulative emission loss for 1,3-D over the 2-week monitoring period was shown in **Table 1**. The highest emission losses were from the control (42% of total applied with a large standard deviation of 17%) and the manure treatment (50%) that were followed by water seals (34%) and HDPE tarp (22-24%). The lowest emission loss was from the VIF tarp (<2%). Statistical analysis indicates that only the differences in the cumulative emission loss between the VIF tarp and all other treatments are significant (α=0.05) as well as that between the HDPE tarps and the manure treatment.

Manure incorporation at the high rate of 49.4 Mg ha^{-1} did not illustrate the emission reduction effect. Lower manure application rates of 12.4 and 24.7 Mg ha^{-1} were tested in a previous year's field trial that did not reduce emissions either compared to the control (Gao et al., 2009). It was suspected that the higher emission loss from the manure treatment might be due to a potentially decreased bulk density in surface soil from the high rate of manure incorporation that may have resulted in the higher emission rates when emission was high, i.e., immediately following fumigant injection. Kinetic factors for the reaction between organic materials and fumigants may also have played a role and resulted in lower emission rates compared to the control at later times. The role of manure in reducing emissions is based on the organic materials which can enhance degradation of fumigants both biologically (enhancing microbial activity) and chemically as well as through sorption processes. Although laboratory studies showed that composted manure or other organic materials can degrade fumigants and reduce emissions effectively, these field data did not illustrate the effectiveness of manure incorporation on emission reductions, at least in the soil/environmental conditions tested in these two field trials. These results indicate that organic material type, application methods and rate, and particularly the interaction between several important factors under field conditions bear further understanding for identifying the optimum organic amendment conditions to minimize fumigant emissions.

Water seals (post-fumigation irrigation) had been shown to effectively reduce emissions especially in reducing emission flux that is directly related to potential exposure risks to workers and by-standers. This effect is again illustrated in the first few days when irrigation was applied; but fumigant emission increased after this period of time which reduced its effect on reduction of cumulative loss. The HDPE tarp has been shown ineffective in reducing 1,3-D emissions in relatively dry soils and at high temperatures. In some tested conditions including this field trial, lower emissions were observed from the HDPE tarp compared to the control. This is most likely associated with relatively moist soil conditions and/or cooler temperatures.

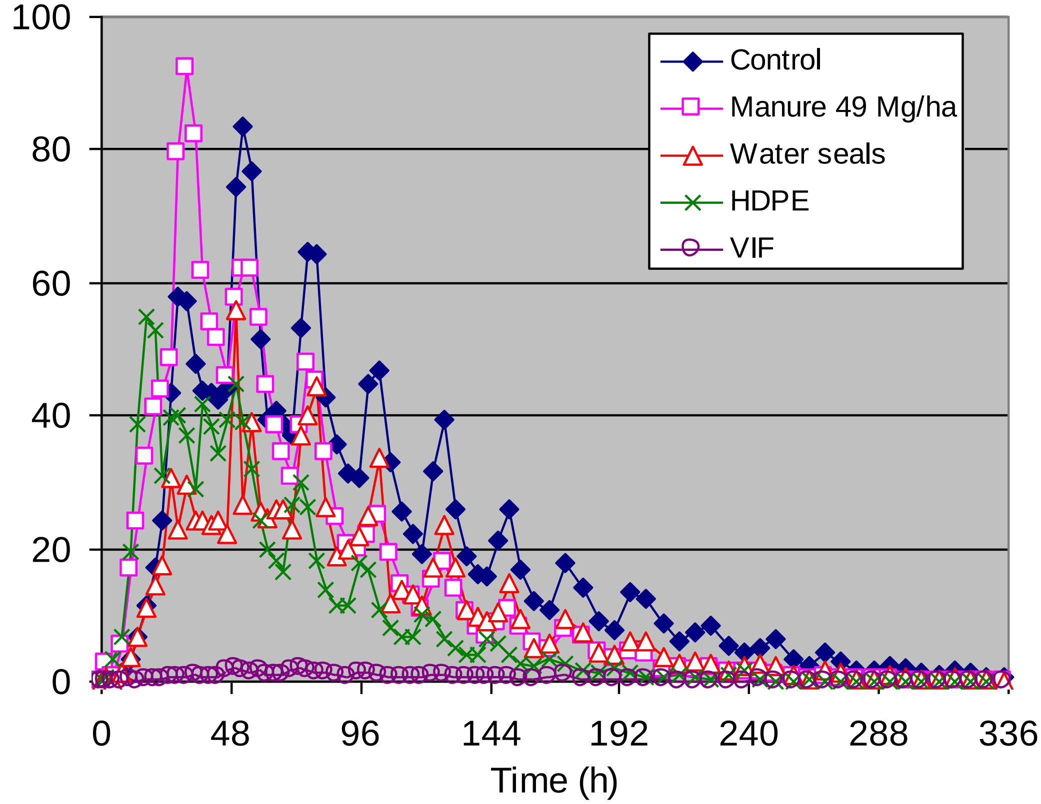

Figure 1. Effects of surface treatment on emission flux of 1,3-dichloropropene (1,3-D). Plotted data are averages of three replicates. Error bars are not given for the legibility of the figure. Manure, composted dairy manure; Water seals, intermittent irrigation with sprinklers (25 mm at 0 h, 4 mm at 24 h and 4 mm at 48 h); HDPE, high density polyethylene film; VIF, virtually impermeable film.

Table 1. Cumulative emission loss of 1,3-dichloropropene from 2008 field trial

Treatment†	Emission loss (% of applied)
Control	42.4 (±17.0)
Manure at 49.4 Mg ha^{-1}	50.5 (±10)
Water seals	33.6 (±6.8)
HDPE (continuous sheet)	21.6 (±6.5)
HDPE (glue joints)	23.9 (±15.1)
VIF (continuous sheet)	1.4 (±1.0)
VIF (glue joint)	1.9 (±2.4)

† Manure, composted dairy manure; Water seals, intermittent irrigation with sprinklers (25 mm at 0 h, 4 mm at 24 h and 4 mm at 48 h); HDPE, high density polyethylene; VIF, virtually impermeable film

Effect of tarps on emission reduction

Plastic tarping has been used as a physical barrier to minimize fumigant emissions. The effectiveness of the tarp on emission reduction depends largely on the properties of the tarp. Polyethylene film such as HDPE had been used to control emissions effectively for methyl bromide, but was not effective in reducing emissions of alternative fumigants, especially 1,3-D, as demonstrated from a number of studies. In a few cases, however, the HDPE tarp did result in lower emissions compared to bare soil control when relatively moist soil conditions were produced. Attention has been shifted to low permeable films such as VIF because this type of film demonstrated great potential in reducing emissions, especially in laboratory and small field plot tests. In large field applications, however, results have been inconclusive. The concerns have been that VIF film can be easily damaged during field installation due to stretching. VIF film also suffers from inadequate glue materials or gluing techniques that might not seal the sheet joints well. With this in mind, we measured emissions from the tarps including the continuous sheet (non-glue areas) and the glue joints. The results indicate that although it took longer for the glue joints to dry for VIF than HDPE (based on visual observation in field); there were no differences in emission flux (**Figure 2**) or cumulative loss (**Table 1**) between measurements from the continuous sheet and the glue joint areas. Emissions from the glue joint areas for both HDPE and VIF tarp varied similarly as those from the continuous sheet (**Figure 2**). The HDPE tarp gave more than 10 times higher emission loss than VIF tarp (**Figure 2, Table 1**), which has been observed from a couple of previous field trials that measured emissions from shank injection of Telone products. These data indicate that VIF is effective in minimizing fumigant emissions when the tarp can be installed successfully in the field.

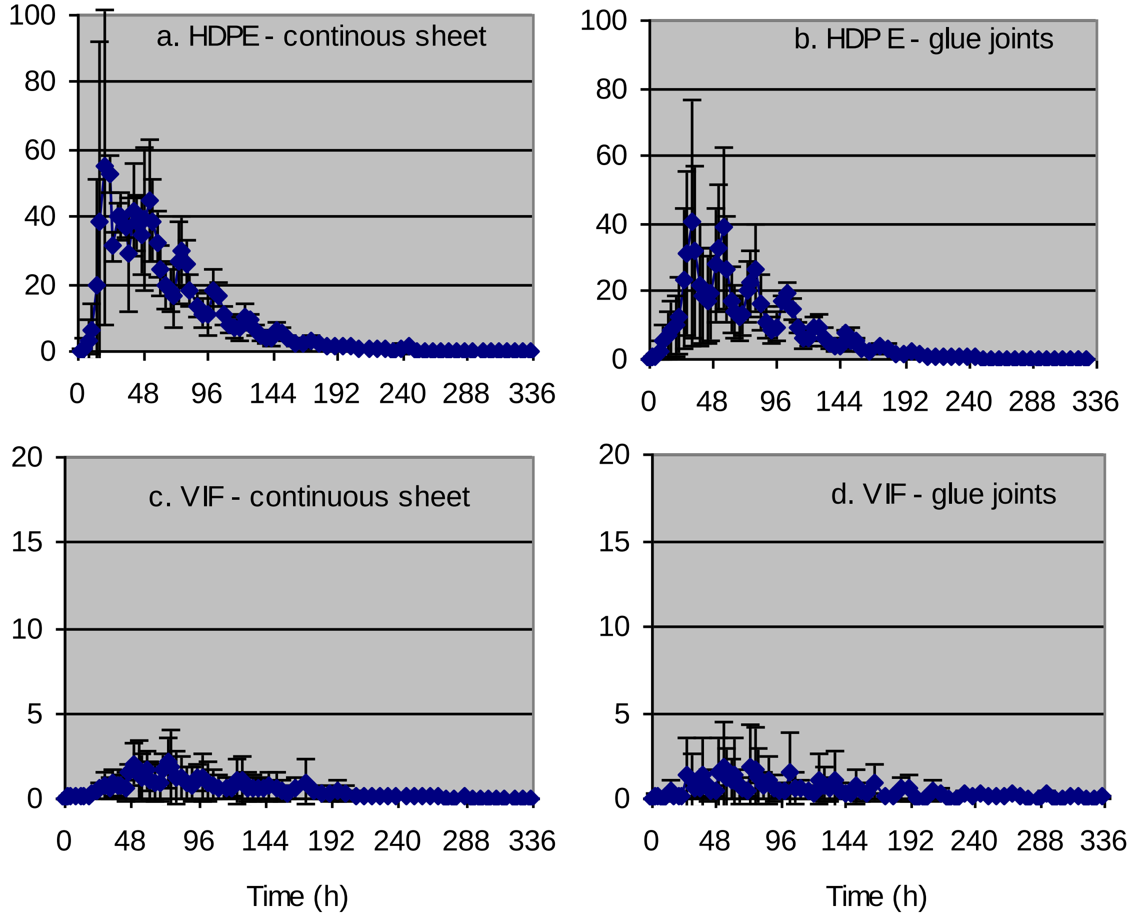

Figure 2. Emission flux of 1,3-dichloropropene (1,3-D) measured over plastic tarp continuous sheet and glue joints. Error bars are standard deviation of the average (n=3). HDPE, high density polyethylene film; VIF, virtually impermeable film.

Soil-gas fumigant concentration change.

Bare soil, HDPE tarp (data not shown), and post-fumigation water seals usually result in a similar pattern of gaseous fumigant concentration profile over time after fumigant injection (**Figure 3**), i.e., highest near injection depth and very low at deeper depths and near soil surface. These were due to the high volatility of soil fumigants and subsequent emission loss once fumigants reach the soil surface. The VIF tarp previously illustrated its ability to retain higher fumigant concentration immediately under the tarp as compared to the HDPE tarp; but the VIF tarp's ability to retain relatively higher gaseous fumigant concentrations in the whole soil profile was uncertain. Data from this field trial and a trial in the previous year are given in **Figure 4,** which shows that the VIF tarp retained a more uniform concentration profile (from 5 cm to 90 cm depth) especially at or after 24 h of fumigant application. Although the absolute concentrations for the VIF tarp in this trial appeared much lower than that from the control and water seals treatments, this may be affected to some extent by the actual amount of fumigant injected at the monitoring spot. For example, a similar concentration near the injection depth was expected at 6 or 12 h following fumigant injection for all treatments; but the fact that VIF tarp had a much lower concentration than the control may indicate the nonuniform applications. Nevertheless, the improvement on uniform fumigant distribution in soil profile by the VIF can be significant because it can improve overall efficacy in soil profile rather than providing most control at certain depths and poor control at surface or lower depths as in the case of the control or water seals treatments based on the gaseous fumigant concentration data (**Figure 3**). The effect of low permeable tarps on achieving uniform fumigant distribution in the soil profile deserves further investigations as the monitoring of soil gaseous fumigant changes was done in one plot only in each trial.

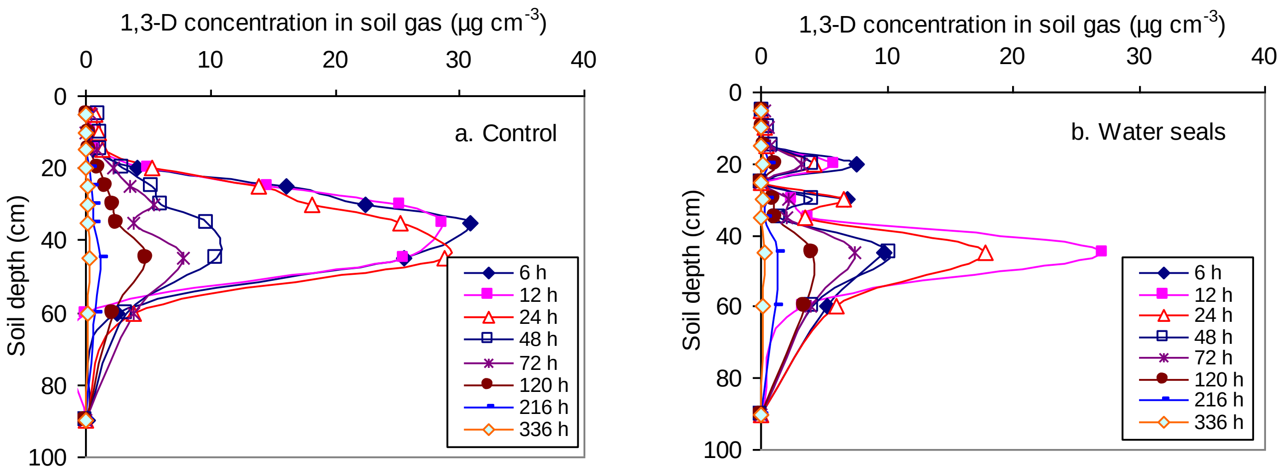

Figure 3. Change of soil gaseous fumigant concentration over time from bare-soil control and water seals treatments.

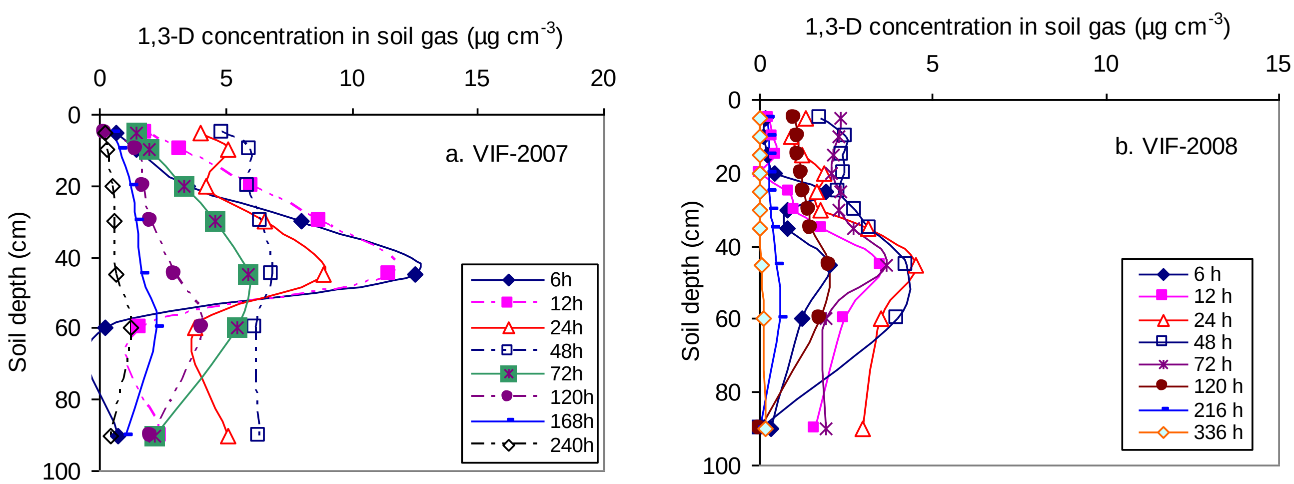

Figure 4. Change of soil gaseous fumigant concentration over time in virtually impermeable film (VIF) tarped soil profile from two field trials conducted in 2007 and 2008, respectively.

Soil water content and residual fumigants.

The soil water content (**Figure 5a**) ranged from 30 to > 60% of field capacity (FC was 17%, w/w). The field was irrigated prior to fumigation and the surface soil water content prior to fumigation was estimated around 40-45% of FC or greater. Evaporation and percolation resulted in drier surface over time. Residual fumigants (**Figure 5b**) were higher in surface soils due to the high volatility of soil fumigants and the high clay or organic matter content in surface soils. These assumptions have been supported by a number of previous studies. The residual fumigant concentrations under the VIF tarp was almost double that of all other treatments at the surface soil (0-10 cm) as well as much higher concentrations at 20-30 cm depth for the tarped and irrigated soils than the bare soils. The soil samples were collected when the tarp was still in place. There were no differences in the lower depths (at or below 30 cm) between the treatments where the overall concentrations were very low (<0.05 mg kg^{-1}).

Calculated residual total amount of fumigants in soil profile ranged from 0.3 to 0.5% of initially applied. The difference between total applied and the measured emission loss (1-51%), gaseous fumigants (0.1%), and the residual fumigants were attributed to degradation that ranged from about 50% in the bare soil to 98% from the VIF tarp treatments.

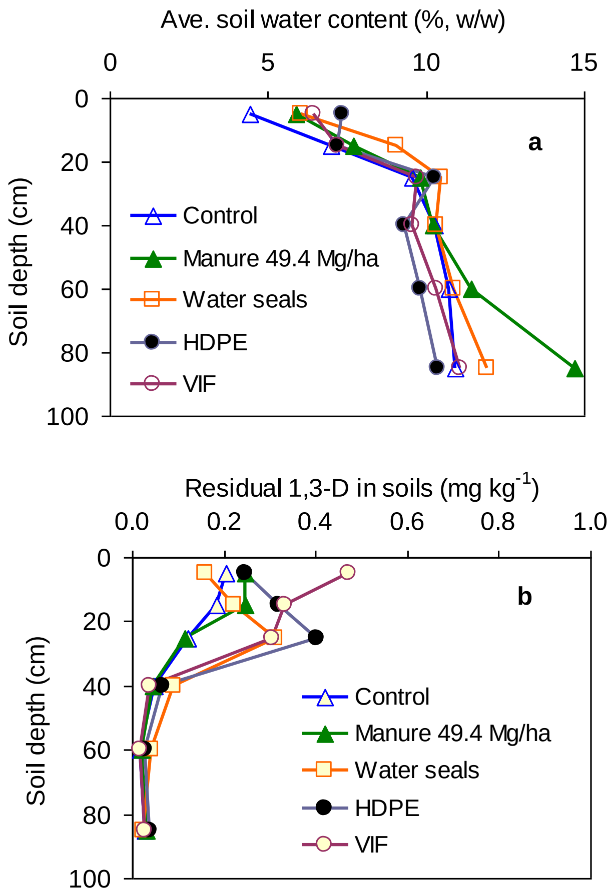

Figure 5. **(a)** Soil water content and **(b)** residual fumigants at the end of field trial (two weeks after fumigant application) in 2008.

Recent Publications:

Gao, S, D. Wang, T. Pflaum, R.Qin, B. Hanson, G. Browne, H. Ajwa, and S. Yates. 2008. Dynamic flux chamber systems for fumigant emission measurements. Ann. Int. Res. Conf. on MeBr Alternatives and Emission Reductions, San Diego, Nov. 11-15, 2008. p. 21-1 to 21-4. http://www.mbao.org/2008/Proceedings/mbrpro08.html.

Gao, S., R. Qin, B.D. Hanson, N. Tharayil, T.J. Trout, and D. Wang. 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.

Qin, R., S. Gao, D. Wang, B.D. Hanson, T.J. Trout, and H. Ajwa. 2009. Relative effect of soil moisture on emissions and distribution of 1,3-dichloropropene and chloropicrin in soil columns. Atmospheric Environment. 43:2449–2455.

McDonald, J.A. S. Gao, R. Qin, B.D. Hanson, T.J. Trout, and D. Wang. 2009. Effect of water seal on reducing 1,3-dichloropropene emissions from different soil textures. J. Environ. Qual. 38: 712-718.