



**Department of Pesticide Regulation
Environmental Monitoring Branch
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**STUDY #285: SOIL SAMPLING AND DYNAMIC MONITORING OF
TEMPERATURE, SOIL MOISTURE, HUMIDITY, AND PRESSURE DURING
BEDDED FUMIGANT APPLICATIONS OR BROADCAST FUMIGANT
APPLICATIONS**

October 2013

I. INTRODUCTION

The Air Program within the Environmental Monitoring Branch has made steady progress in development and validation of the Hydrus 2D/3D model for use as a supplemental tool for estimating flux density from the application of fumigants. Under contract with the model's author, DPR has obtained and tested modifications to the Hydrus 2D/3D model for facilitating simulation of fumigant volatilization. These modifications include (1) temperature dependent boundary layer thickness, which simulates temperature affect upon tarp permeability (2) ability to simulate tarp removal during mid-simulation (3) ability to simulate two different volatilization boundary conditions reflecting a tarped and untarped field, such as in drip irrigation fumigations, where furrows between tarped beds are bare (4) technical modifications which make it easier to use and extract fumigant-related information from the model (Spurlock et al., 2010).

After the modifications were implemented and tested, sensitivity of the Hydrus2D/3D model was examined (Spurlock et al., 2013a). The sensitivity depended on the gross system being modeled. For example, for tarped, broadcast applications, the soil diffusive resistance and tarp permeability resistance in series dominated flux density. Maximum 6-h flux densities were most sensitive to tarp permeability activation energy while cumulative fluxes were most sensitive to the permeability of the tarp. These conclusions were different for the bedded, drip method of fumigant application. In the drip case, soil hydraulic properties played a relatively more important role and the resulting flux density was a complex interplay of tarp permeability, fumigant/water penetration into the profile and volatilization from the untarped surfaces (Spurlock et al., 2013a).

DPR has also sought to validate the Hydrus 2D/3D model with respect to estimating flux (Spurlock et al., 2013b). A broadcast, tarped study in the southern Central Valley of California provided such an opportunity with three similarly treated fields. Field 1 was used for calibration of Hydrus 2D/3D to estimate tarp field permeability, Koc and

degradation. These calibrated values from Field 1 were then used in cold simulation for the other two fields. Results were generally within a factor of 2. For technical reasons, this was not a 'true' validation since the 'measured' flux values are themselves based on modeling and use of measured air concentrations. Nonetheless, the Hydrus-modeled flux densities compared reasonably well to the 'measured' flux densities and until direct means for measuring field flux density are available, this approach is the closest one can get to field validation of such a model.

Recent use of the Hydrus 2D/3D model to estimate possible effects of deeper applications, strip applications and increased post application irrigations on flux density has resulted in additional focus on the issue of variability in Hydrus 2D/3D flux density estimates (Spurlock, 2013). The regulatory unit for fumigant restrictions is generally the applied field. If soil conditions just prior to fumigant application were known for a large number of fields, what amount of variability would result in Hydrus2D/3D simulations based on that variability, all other factors being equal? Towards that end, DPR is conducting a study of field conditions immediately prior to fumigation and the resulting impact on modeled flux densities (Johnson, 2013). Quantifying this variability will provide a statistical context for Hydrus2D/3D estimates.

Studies described in this protocol will help 'validate' the Hydrus 2D/3D model with respect to future drip fumigation or broadcast fumigation studies. Drip fumigation is distinct from broadcast fumigation because of the much greater role of water, its movement through the soil convectively transporting the fumigant in the liquid phase and its impact on fumigant diffusion in the gas phase by reducing soil air-filled porosity. Gaining confidence in the Hydrus2D/3D model for drip fumigation will enlarge the range of conditions for which we have confidence in Hydrus 2D/3D. Also, further broadcast study validations will add to our confidence in simulation of that type of application. This protocol was originally drafted with respect to a specific drip study: Ajwa et al. (2013) in which two identical fields drip fields received an application of 1,3-dichloropropene and chloropicrin. However, we have modified that protocol to include broadcast applications and to be more generic. The intent in this protocol is to describe procedures for a suite of soil sampling procedures and instrumental measurements which provide important information for conducting and evaluating Hydrus 2D/3D flux study simulations.

For drip studies a component of the desirable input information is detailed soil information, as well as detailed moisture, humidity, temperature, and pressure information beneath the tarp in the beds, as well as in the furrows between the tarps. We believe that it is important to compare the Hydrus2D/3D model predictions to other measurable parameters in addition to the flux in order to gain confidence in the ability of the model to correctly predict water movement, temperature as well as dynamic movement of the fumigant. For broadcast studies, detailed soil information, soil moisture, humidity, temperature and pressure information beneath the tarp are also important.

It is the aim of this protocol to describe procedures which will provide a detailed picture of the soil characteristics within the bed for drip studies or in the field for broadcast studies, the initial soil water conditions preceding fumigation, and the dynamic temperature, moisture, humidity and pressure conditions during the monitoring period. In

addition, soil samples will be taken in order to measure the soil water retention function in the laboratory. These measurements will support the modeling effort.

II. OBJECTIVES

Disturbed and Undisturbed Soil Sampling

The undisturbed soil sampling (soil cores) is designed to capture the state of the bed or field soil conditions immediately prior to fumigation, in order to provide realistic and site specific initial conditions for the HYDRUS2D/3D modeling effort. Two key parameters needed are initial soil moisture and bulk density. An additional parameter is the particle density, which is used with the bulk density to calculate the saturated water content (assuming equivalent to total voids or porosity) as follows:

$$\theta_{sat} = 1 - \frac{\rho_{bd}}{\rho_{pd}}$$

where θ_{sat} is the saturated water content (cm^3/cm^3), ρ_{bd} is dry bulk density (g/cm^3) and ρ_{pd} is the particle density (g/cm^3). Particle density for a mineral soil is usually estimated at $2.65 \text{ g}/\text{cm}^3$ (Freeze and Cherry, 1979). In addition, disturbed soil sampling will be performed for texture analysis. The term ‘disturbed’ means that the sample is not taken in a known volume and is acquired as a bulk sample, which may be composited with other samples.

In-situ Soil and Under Tarp Air Physical Parameters Monitoring

Beds in drip studies or a small side plot for broadcast studies will be instrumented in order to monitor moisture, temperature, humidity and air pressure during the study. These dynamic measurements will be used in the modeling effort to help validate the Hydrus 2D/3D model.

III. PERSONNEL

This study will be conducted by Environmental Scientist, Atac Tuli under the direction of Research Scientist III, Bruce Johnson and under the general supervision of Pam Wofford, Senior Environmental Scientist. Questions concerning this monitoring project should be directed to Atac Tuli at 916-324-4264 email at Atac.Tuli@cdpr.ca.gov.

Other key personnel include:

Project Leader – Atac Tuli

Research or Senior Scientists – Bruce Johnson and Frank Spurlock

Project Supervisor: Pam Wofford

Project Staff: EM Staff

Laboratory Analysis: Fabio Sartori and Staff

Statisticians – Bruce Johnson & Jing Tao

Other: (for Ajwa et al. (2013) - USDA-ARS, Fresno - Suduan Gao; UC Davis, Salinas - Husein Ajwa – other personnel will vary depending on the study)

IV. STUDY PLAN

Location of Study Area

Study areas generally should be located in areas of agricultural production in California.

Measurements and Soil Sampling in Drip Studies

These procedures are approximately similar to those in Johnson (2013). One difference is the flexibility to sample from fewer locations, which is needed for possible time and resource constraints.

Measuring bed geometry. In each field at a series of eight or more random locations amongst the beds, bed geometry measurements should be taken of (1) bed base width, (2) bed top surface width, (3) bed center-to-center distance, (4) bed height, and (5) tuck-in depth (Figure 1). The tuck-in depth is the depth of the tarp buried at the edge of the bed. In addition, as part of the bed geometry, the bed lengths, and number of beds in each field will be recorded, with a diagram showing the location of the blank and treated beds. The irrigation setup should also be drawn and recorded, and/or photographed. Since the blank beds must receive the same amount of water as the treated beds, it is important to note how the irrigation in the separate beds was accomplished. It is also recommended to photograph the beds in order to characterize the general shape, geometry, condition of tarp and furrow configuration.

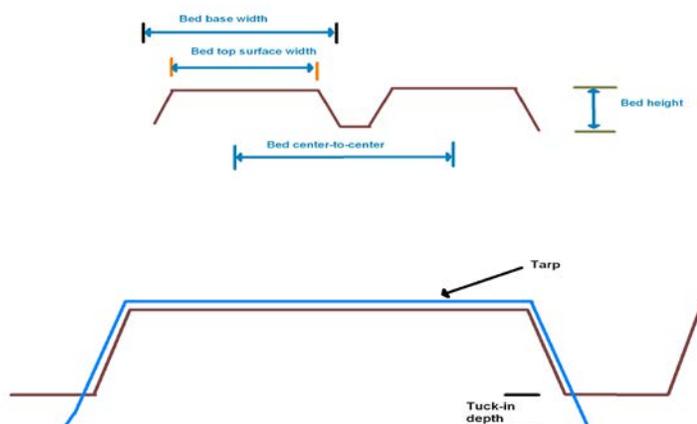
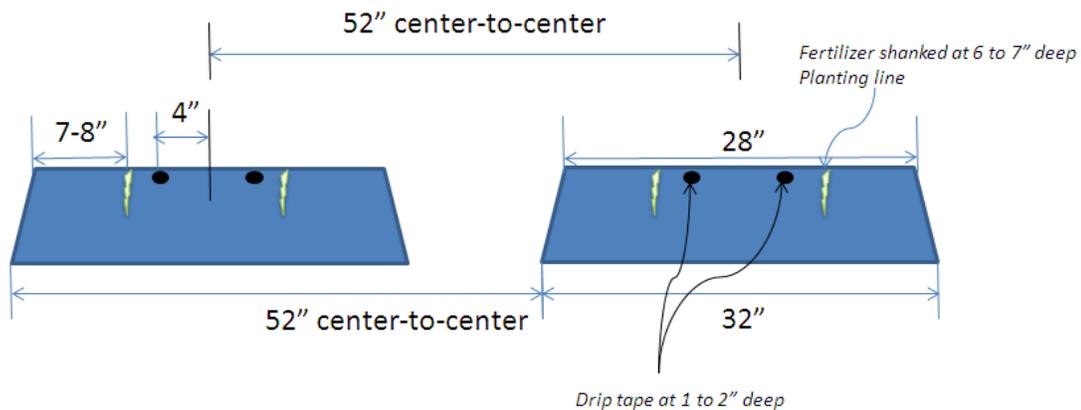


Figure 1. Bed geometry measurements to record at each sampling location.

Selection of locations for soil sampling in drip studies. A feature of the bed formation is the shanking in of fertilizer along two parallel lines, approximately midway between the center of the bed and the edge of the bed. There may be one or two drip lines. Some flexibility will be needed in specific cases as to where to sample within the bed. In any case, notes should be taken describing where the samples were taken. These instructions assume that there will two drip lines placed about 4 inches from the center of the bed (Figure 2). It is anticipated that there will be either 1 or 2 blank beds on each side of the field. These blank beds will be irrigated identical to the treated beds, but will not receive any fumigant. They will receive irrigation during the line testing phase the same as the treated area as well as the same amount during the application. Two of the blank beds will be selected for soil sampling. These beds will be divided into either four or two approximately equal lengths. If time and resources permit, divide the beds into four sections, otherwise divide into two equal sections. Within each bed-section, a random point will be selected which determines where both undisturbed and disturbed soil sampling will take place.



Bed top varies between 27 to 28 inches.

Bed bottom is at least 32 inches.

Beds are made at 52 inches center-to-center (10052 liner bed-ft/acre).

Furrow is 16-18 inches (it should be 20", but plastic burial takes 1 to 2").

Figure 2. Example bed geometry for drip fumigation study (Ajwa, personal communication). Beds are 12 inches high (not shown).

In each transect, samples representative of the 0–10 cm, 10–30 cm, and 30–50 cm depth increments will be collected using a 5-cm diameter by 5.1-cm high stainless steel

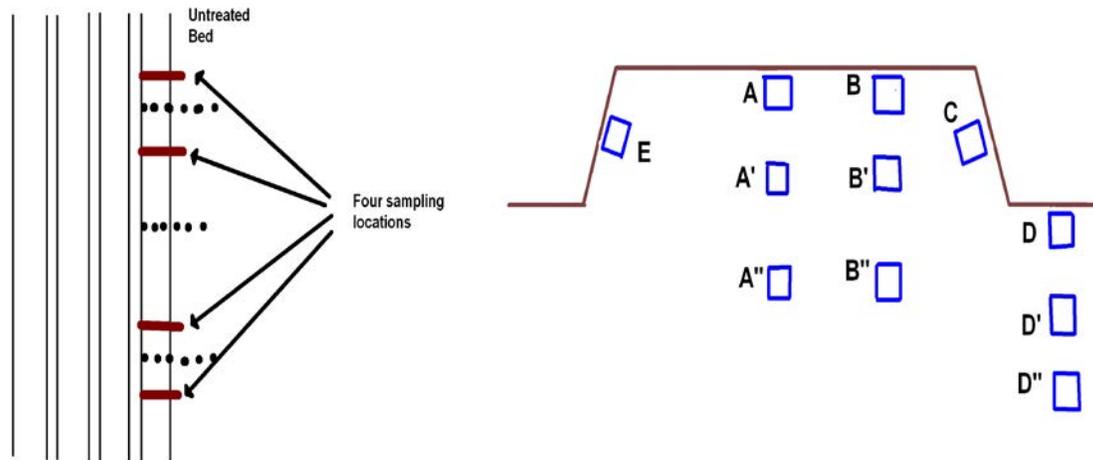


Figure 3. Selection of sampling locations within a bed (left) showing example with four locations in a bed. Alternatively, sampling from two locations by choosing randomly within each equal half. Dotted lines on left represent division of bed into four approximately equal lengths and solid lines are randomly selected sampling locations within each quarter bed. Within-bed and furrow sampling locations using 5 cm rings shown on right.

core in three locations: (1) center of the bed (location A in Fig. 3, right), (2) one-fourth of the distance from center to edge (location B in Fig. 3, right), and (3) center of the furrow (location D in Fig. 3, right). In addition, two samples, one for each side (locations C and E in Fig. 3 right), will be taken perpendicular to the side surface of the bed at about the midpoint representative of the 0-10 cm depth from the tarp surface towards the bed interior.

The horizontal cross-sectional location of the bed samples may need to be varied. For example, if there is a single drip line in the center of the bed, then sample to the side of the drip tape.

The sampling scheme depicted on the right side of Figure 3 results in a total of 11 samples per location (or transect). Thus if 2 locations are used per bed, this results in 22 samples per bed. For sake of illustration, and assuming that there is one field with two beds, each bed sampled at two locations, then there will be 11 samples/location x 2 locations/bed x 2 beds = 44 samples. In order to obtain samples representative of the intended depth zone, the sample should be taken from the midpoint of the depth range that is being sampled (Figure 4). For example, the 0-10 cm range would be sampled from 2.5 to 7.5 cm and the 10-30 cm depth range would be sampled from 17.5 to 22.5 cm deep.

The undisturbed soil samples will be returned to the laboratory and weighed. After returning the undisturbed soil samples to the laboratory, the samples will be saturated in 0.01 M CaCl₂ solution to prevent dispersion in the samples. The saturated hydraulic conductivity and soil water retention characteristics will be determined on a subset of samples using constant head method (Klute and Dirksen, 1986) and pressure chamber method (Klute, 1986), respectively. At the end of the water retention experiment, the samples will be placed into an oven for drying at 105 °C at least 24 hours. The dry bulk density and initial water content will be determined using their oven dry weight.

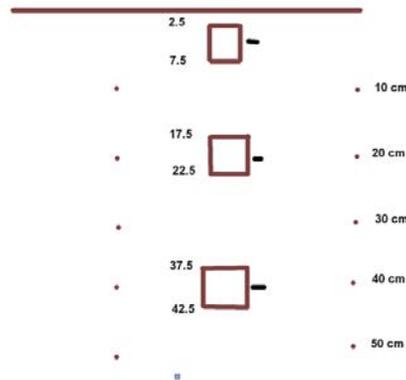


Figure 4. Idealized sampling depths to obtain representative samples from zones: 0-10 cm, 10-30 cm, and 30-50 cm.

Disturbed bulk sampling in drip studies. Disturbed bulk soil samples will also be collected using a 6.7-cm diameter stainless steel soil probe with internal liner and slide hammer from near each of the transects at the center of the bed and representative of the same depth increments. These disturbed bulk samples will be composited by depth increment within the bed (3 composited samples per bed) and by depth increment between beds. Near the location of each of the bed bulk samples, corresponding bulk samples representative of the 0-10, 10-30 and 30-50 cm depths will also be taken from the furrow. As with the bed bulk samples, these samples will be composited by depth within the furrow. For illustration, assume that there is one field with two locations in each of two beds. Then there will be 3 composited by depth samples/bed + 3 composited by depth samples/furrow=6 total disturbed bulk samples per bed/furrow combination. These samples will be composited with the corresponding samples for the other bed/furrow locations for a total of 6 disturbed samples for the field.

The disturbed bulk soil samples will be returned to the laboratory under ice, air dried, and passed through a 2-mm sieve prior to analysis to determine soil particle size analysis, using the hydrometer method (Gee and Or, 2002), and particle density using the volumetric flask method (Flint and Flint, 2002).

Measurements and Soil Sampling in Broadcast Studies

This methodology is nearly the same as the broadcast methodology in Johnson (2013). The main differences are (1) the flexibility to sample at a predetermined 1 or 2 locations within each quadrant, giving a total of 4 or 8 sampling locations for the field and (2) the requirement to sample the soil from a small tarped blank plot near the field. The small tarped plot will later be instrumented for dynamic recording of soil moisture, temperature, relative humidity and pressure. This flexibility is needed because of possible time constraints. The procedures are to divide the broadcast field into four approximately equal quadrants. Within each quadrant one (or two) locations will be randomly selected. At each location three samples will be taken at three depth increments. Each sampling location will be geo-referenced for later comparison to the corresponding USDA NRCS soil maps. On the day before application, soil samples (first set) will be collected using a 5-cm diameter by 5-cm high brass core from each selected location vertically centered within the 0- to 10-, 10- to 30-, 30- to 50-cm depth increments. Assuming sampling at four locations, there will be 4 locations x 3 depths/location = 12 samples collected per field. Near one of the possible two sampling locations within each quadrant, mineral soil samples (second set) will be collected, split, and composited by depth increment over the field using a 6.7-cm diameter stainless steel soil probe with internal liner and slide hammer. This will result in 3 composited samples per field. Two or three additional locations per field may also be sampled to gather a sufficient soil mass for laboratory analyses, if the soil bulk densities of the selected fields are relatively low. Further details on this sampling can be found in Johnson (2013).

Soil sampling from the small tarped side plot. In addition, undisturbed soil samples will be taken from two locations in the small side plot (which will not be fumigated, but will be tarped) This locations will be selected randomly from each half of the plot at the same depths (0-10 cm, 10-30 cm, and 30-50 cm) as in the larger field. In addition, near each location in the small plot, disturbed bulk samples will be taken at each depth and composited from the small plot, giving 3 disturbed bulk samples for texture analysis from the small plot.

The undisturbed bulk density samples from both the field and the small plot will be returned to the laboratory to estimate bulk density and initial soil-water content after drying at 105 °C to constant weight. A subset of these samples may be used for measuring the soil retention curve (Klute, 1986) and saturated hydraulic conductivity (Klute and Dirksen, 1986). This procedure would be performed prior to any oven-drying. The disturbed soil samples will be returned to the laboratory under ice, air dried, and passed through a 2-mm sieve prior to analysis to determine soil particle size analysis, using the hydrometer method (Gee and Or, 2002), and particle density using the volumetric flask method (Flint and Flint, 2002). The remainder of bulk samples after analysis will be archived for future studies. The total of soil sample counts in detailed is given in Appendix 1.

In-Situ Soil and Under Tarp Air Physical Parameters Monitoring in Drip Studies

Several site specific parameters will be monitored simultaneously and continuously during period of study at two locations in the two-non-fumigated beds. These parameters include soil temperature, soil moisture, soil electrical conductivity, temperature, pressure and relative humidity of air between soil surface and tarp (Table 1). The soil moisture measurements will be performed with 5TE sensors from Decagon Devices, Inc. These sensors simultaneously measure volumetric soil moisture, temperature and electrical conductivity. At each field, two non-fumigated beds (blanks) will be assigned for instrumentation (Figure 5A). Each blank bed will receive one instrument cluster. In order to install the instruments, the tarp will be sleeved or minimally cut in a gentle way to avoid making holes in the tarp. After installation, the tarp will be reinstated to its original position or closed with duct tape.

The instrument cluster will consist of 5TE, 12-bit Temperature/Relative Humidity (RH) sensors and pressure transducers, thermocouples connected to EM50R(Decagon Devices, Inc.), HOBO (Onset Computer Corporation), and 21X (Campbell Scientific, Inc.) data loggers, respectively (Figure 5A). At each cluster, the total of five 5TEs connected to the EM50R (sensors connected with Green lines) datalogger will be installed at the center of the elevated bed at depth segments of 0-10 cm (5 cm), 10-30 cm (20 cm), and 30-50 (40 cm) cm at the center of the furrow at depth segments of 0-10 cm (5 cm) and 10-30 cm (20 cm) corresponding one 5TE for each depth segment (Figure 5B). To install 5TE's, a guide hole will be made using a wide auger and 5TE will be installed on the wall of the hole at corresponding depths. The two RH (Blue lines connected to the HOBO data logger in Figure 5) and pressure transducers/Thermocouples (Black/Red lines in Figure 5) will be installed in the air gap between soil surface and tarp covering for measuring relative humidity, changes in pressure relative to barometric pressure, and temperature on the soil surface and air gap at each assigned location. These sensors will be 1 m away from the locations where 5TEs are installed. Every installed 5TEs, RH, and Pressure transducers/Thermocouples connected to EM50R, HOBO and 21X data loggers, respectively, will record data with 10-minute reading intervals. The relative humidity sensor will have additional temperature measurement for ensuring accuracy of the air temperature measurements by thermocouples. The collected data will be transferred via Rm1 radio receiver or direct data logger connection to the computer. The tarp punching will be performed manually in the blank beds where the instrument clusters were installed or at the same time as when the treated beds are hold-punched.

Table 1. Soil and soil surface instrumentation under tarp.

Instrument	Number of sensors at each location	Measured Parameter	Data Logger
5TE	3 in bed 2 in furrow	Soil moisture, temperature, electrical conductivity	EM50R
Pressure Transducer	2	Air Pressure	Datalogger 21X
Thermocouples	2	Temperature	Datalogger 21X
12-bit Temperature/RH sensors	2	Relative Humidity, Temperature	HOBO

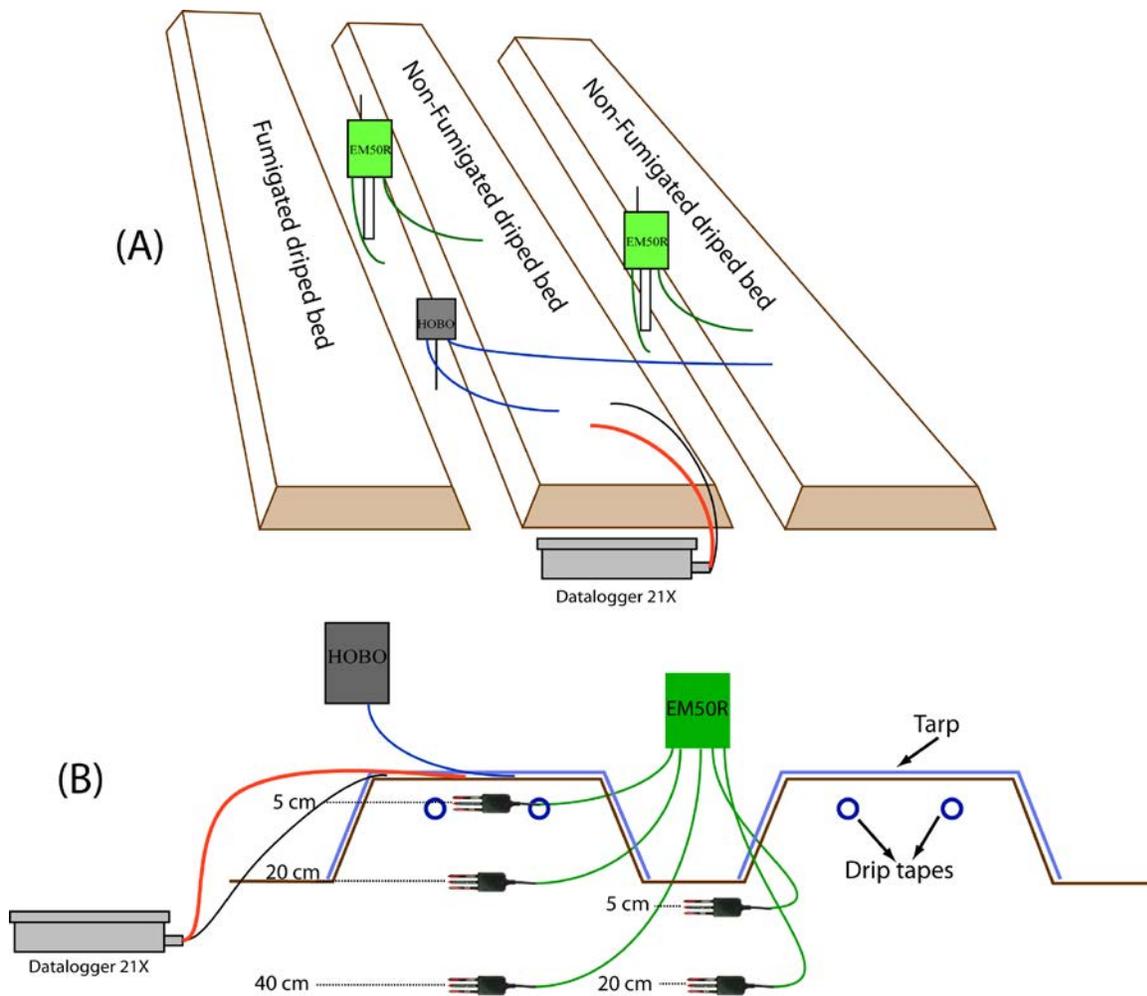


Figure 5. Schematic of installation of soil sensors instruments (A) in two non-fumigated beds and (B) under tarp, in depths of bed and furrow.

In-Situ Soil and Under Tarp Air Physical Parameters Monitoring in Broadcast Studies

Similar to bedded fields, the site specific parameters will be monitored simultaneously and continuously during period of study at two locations in the side plot (non-fumigated but tarped). The size of the side plot will depend on the available area near the treated field. The same parameters will be monitored as those given in Table 1. The schematic of the instrumentation in the small side plot is depicted in Figure 6a whereas cross sectional representation of instrumentation under tarp and soil depths in the side plot is shown in Figure 6b.

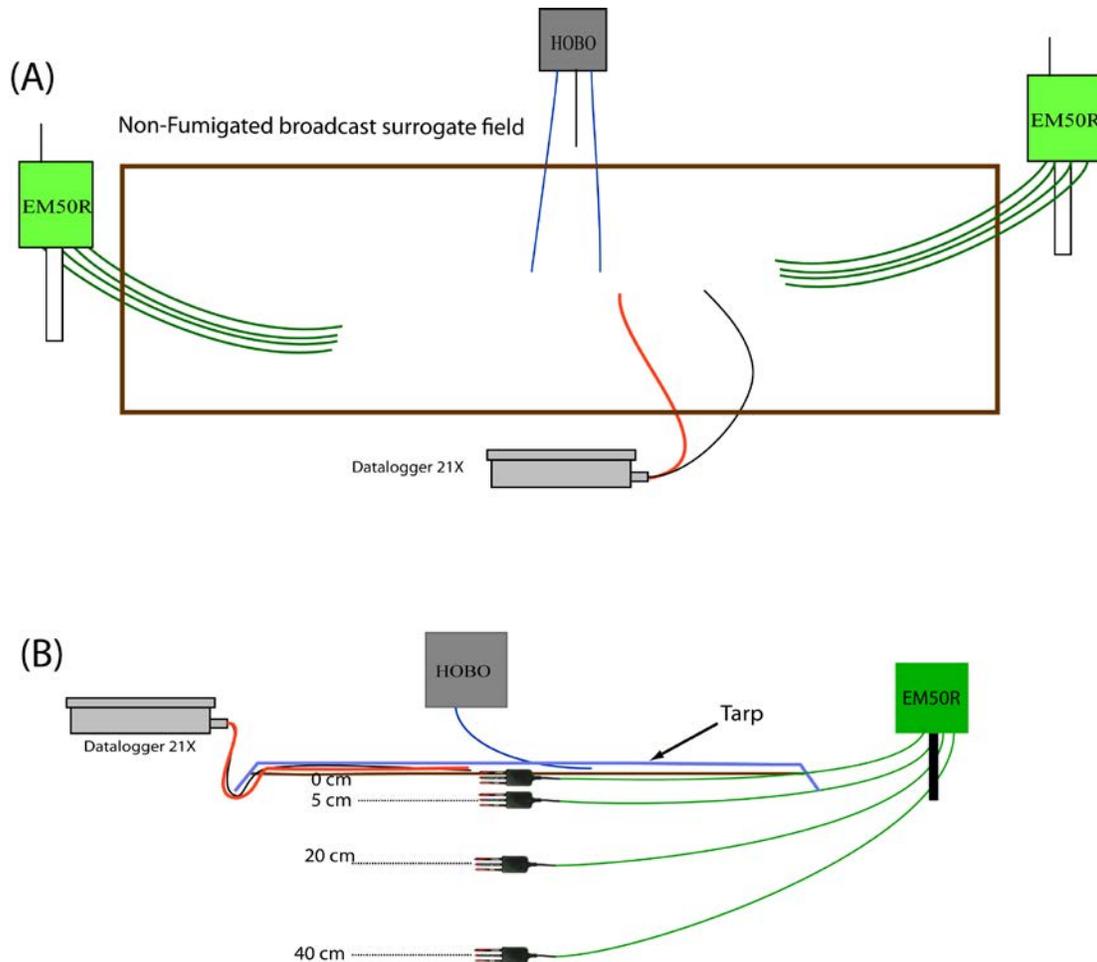


Figure 6. Schematic of installation of soil and other sensors (A) in surrogate plots and (B) under tarp, in depths of surrogate (side) plot.

Data Analysis

Undisturbed soil sampling: The primary statistical focus will be characterizing the distributions of soil moisture, bulk density and saturated water content.

Moisture retention curves will be analyzed on a subset of soil samples to determine the van Genuchten parameters by fitting van Genuchten retention function (van Genuchten, 1980) to the measured retention data (van Genuchten et al., 1991). Whereas the saturated water content (θ_{sat}) will be fixed to its measured value based on dry bulk density and particle density, the parameters; residual water content (θ_r), α and n will be considered fitting parameters to be optimized by the RETC (van Genuchten et al., 1991) software.

Disturbed soil sampling: The texture analysis from the bulk samples will be compared to soil survey data. The particle density variability will also be analyzed.

Physical parameters monitoring: Monitoring results will be graphed and simple summary statistics will be calculated.

V. TIMETABLE

The time table will depend on when studies arise and so approximate time sequences are as follows:

Field study and soil sampling: 1 month

Handling soil samples for physical properties: 4 months

Data analysis and modeling: 4 months

Report Preparation: 4 months

VI. REFERENCES

- Ajwa, H., D. Sullivan, S. Gao, and M. Stanghallini. 2013. Monitoring chloropicrin and 1,3-dichloropropene emissions from drip applications under totally impermeable film: Study Number: 2013HA1, Salinas CA.
- Flint, A.L., and L.E. Flint. 2002. Particle density. *In* J.H. Dane and G.C. Topp (ed.), *Methods of soil analysis. Part 4. Physical methods*, Madison, WI, pp. 229-240.
- Freeze, R. A. and J. A. Cherry. 1979. *Groundwater*. Prentice-Hall, Inc. Englewood Cliffs, New Jersey
- Gee, G.W., and D. Or. 2002. Particle-size analysis. *In* J.H. Dane and G.C. Topp (ed.), *Methods of soil analysis. Part 4. Physical methods*, Madison, WI, pp. 255-293.
- Johnson, Bruce. 2013. STUDY #286: Selected Physical Properties of California Soils Prior to Broadcast or Bedded Fumigation Treatments July 2013. Department of

Pesticide Regulation Environmental Monitoring Branch 1001 I Street, PO Box 4015
Sacramento, CA 95812.

- Klute, A. 1986. Water retention: Laboratory methods. *In* A. Klute (ed.) *Methods of soil analysis*. Part 1. Physical and Mineralogical Methods, Madison, WI, pp. 635-662.
- Klute, A. and C. Dirksen. 1986. Hydraulic conductivity and diffusivity: Laboratory methods. *In* A. Klute (ed.) *Methods of soil analysis*. Part 1. Physical and Mineralogical Methods, Madison, WI, pp. 687-734.
- Spurlock, Frank, Rick Bergin, Atac Tuli and Bruce Johnson. 2010. Memorandum to Randy Segawa on FUMIGANT TRANSPORT MODELING USING HYDRUS: 4. DEVELOPMENT AND TESTING OF MODIFICATIONS TO ENHANCE FUMIGANT FIELD SIMULATIONS dated May 6, 2010.
- Spurlock, Frank. 2013. Effect of chloropicrin application practices on cumulative and maximum chloropicrin flux. Memorandum to Randy Segawa dated March 20, 2013.
- Spurlock, F., J. Šimunek, B. Johnson and A. Tuli. 2013a. Sensitivity Analysis of Soil Fumigant Transport and Volatilization to the Atmosphere. *Vadose Zone J.* doi: 10.2136/vzj2012.0130.
- Spurlock, Frank, Bruce Johnson, Atac Tuli, Suduan Gao, Jing Tao, Fabio Sartori, Ruijin Qin, David Sullivan, Mike Stanghellini and Husein Ajwa. 2013b. Simulation of Fumigant Transport and Volatilization from Tarped Broadcast Applications. *Vadose Zone Journal*. doi:10.2136/vzj2013.03.0056.
- van Genuchten, M.Th. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Soc. Am. J.* 44:892-898.
- van Genuchten, M. Th., F.J. Leij and S.R. Yates. 1991. The RETC code for quantifying the hydraulic functions of unsaturated soils. US Salinity Laboratory, US Department of Agriculture, Agricultural Research Service, Riverside California. EPA/600/2-91/065.

Appendix 1. Detailed soil sample counts.

Broadcast				Drip		
	Bulk density/soil moisture samples (undisturbed samples)		Texture samples (disturbed)		Bulk density/soil moisture samples (undisturbed samples)	Texture samples (disturbed samples)
	Assume 1 location in each quadrant	Assume 2 location in each quadrant				
Quadrants	4	4	4	Blank Beds (untreated)	2	2
Locations in each quadrant	1	2	1	Locations in each bed	2	2
Total Locations	4	8	4	total Location	4	4
#samples at each location	3	3	3	# bed samples at each location	8	3
Total bulk density samples	12	24		total bulk density samples in bed	32	12
Samples composited by depth			3	Net composited texture samples		3
				# furrows near bed sample locations	4	4
Small plot				# samples at each furrow location	3	3
Halves	2	2	2	total samples	12	12
Locations in each half	1	1	1	Total composited samples furrows		3
Total locations	2	2	2	Total bulk density samples beds plus furrows	44	
# samples at each location	3	3	3	Total texture samples beds plus furrows		6
total samples	6	6				
samples composited by depth			3			
total samples larger field plus small plot	18	30				
3 composited samples for larger field and 3 composited samples for small plot			6			