Revised Guidance for Data Collection and Submission of Soil Fumigant Field Studies

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Objective:

The Department of Pesticide Regulation (DPR) uses results from soil fumigant field studies to characterize emission rates (flux) and to develop mitigation measures to minimize exposure of bystanders to off-site air concentration of soil fumigants. This document provides updated general guidance for data collection and specifies the type of data required from flux studies in order for DPR to consider the submitted study data. This document supersedes DPR's previous General Guidance for Conducting Fumigant Studies document (Sanders 2005).

1. Introduction

Fumigant use results in some loss of the fumigant from the injection site into the surrounding environment. DPR has implemented mitigation measures specific to registered fumigants to minimize both the loss of the fumigant into the environment and the impact of the unavoidable loss of the fumigant on bystanders. While the underlying basis for mitigation measures is similar across all fumigants, specific measures vary from fumigant to fumigant depending upon a fumigant's level of concern (LOC) and use practices. For registered fumigants, most of these measures are under continual review and improvement as new data is collected. DPR may require registrants of new fumigants to submit field monitoring studies as part of the registration process. These studies need to adequately characterize expected air concentrations and other environmental parameters so that DPR can reliably use them together with computer simulation modeling to examine alternative scenarios and mitigation measures designed to keep exposures below the LOC.

Field studies are routinely conducted to measure air concentrations associated with the application of a fumigant and are used – in part – as a basis for mitigation measure development. However, field monitoring studies possess their own limitations and drawbacks, including: (1) they tend to provide air concentrations at a specific monitored time and location, (2) conducting them can be time consuming, and (3) they are relatively expensive to conduct. As a result, only a limited number of treatments and replicates may be conducted to account for variability in application size, rate, and time, meteorological conditions, and other factors in these types of studies. To address these limitations, DPR uses field data in conjunction with computer modeling to estimate off-site air concentrations associated with fumigant emissions and to develop appropriate mitigation measures. Some features in field study design are intended to improve the fidelity of the modeling. Once mitigation measures are developed, DPR uses permit conditions and statewide regulations, among other methods, to implement those mitigation measures. DPR seeks a uniform approach in the evaluation of different fumigants and strives for consistency and reproducibility in determining mitigation measures.

DPR uses various modeling approaches to develop flux profiles and mitigation measures for soil fumigants. Some of these have changed since the release of DPR's previous soil fumigant field study guidance (Sanders 2005), including: [1] adoption of the AERMOD model, replacing ISCST3 as the preferred air dispersion model; and [2] use of the HYDRUS model to develop flux profiles when field study data are inadequate to represent all the application scenarios. In part due to these changes, DPR has established new guidelines that any submitted soil fumigant

field study data must meet for DPR to accept and use it. This document provides details of the required soil fumigant field study data parameters. These parameters include application site information, meteorological data, terrain data, surface characteristics, soil characteristics, and air monitoring results.

2. Data submission

DPR requires that all submitted soil fumigant field studies include at a minimum the following information:

2.1. Field geometry

The exact lengths and directions of the field must be accurately measured. The exact directions and locations are critical for properly interpreting wind direction data. Coordinates and dimension of the field's corners and edges should be drawn on a digitally formatted map like Google Earth or through the use of Geographic Information Systems (GIS) and submitted to DPR as an ASCII text file (tab-delimited or comma-separated value format) or in a spreadsheet format like MS Excel.

A "minimum distance" between a study site and any adjacent fumigation site is required to ensure that cross-contamination does not occur. Generally, when a study site is four acres or smaller, the minimum distance between the study site and any adjacent fumigation sites must be at least ½ mile.

2.2. Application parameters

The method of application, shape, exact dimensions of the vertical cross-section of the soil profile, and the application depth (i.e., injection point) must be carefully described and submitted as a diagram. Table 1 shows a template for required data about the fumigation application. Figure 1-A shows an example for a typical bed application. The submitted diagram must clearly indicate the bed/row height, sides, furrows, depth of injection or depth of drip application (chemigation), and location of sprinklers, if applicable.

For injection applications, the shapes, angles, dimension, locations of implements, and the number of sprayers per shank must be diagramed, photographed, and described in detail. If using a camera for visual presentation, the photo must have a clear contrast so it can be seen in both color and black-and-white formats. All the dimensions must be annotated on the picture.

Table 1. A template for required data about the fumigant application.

Application start time	Application end time	Area of field	Total amount applied	Comments
DD/MM/YYYY HH:MM	DD/MM/YYYY HH:MM	ac (or ha)	lb (or kg)	

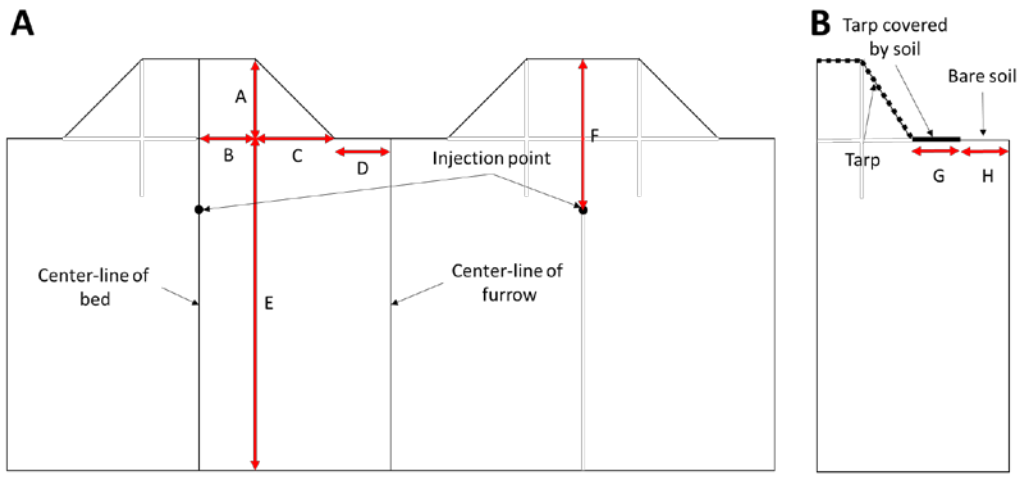

Figure 1. An example of vertical cross-section of soil profile from application site for bed application. The recommended length for "E" is 125 cm.

For tarped applications (bed or broadcast), the tarp name, manufacturer, lot number, thickness, and type of tarp should be provided. Additionally, DPR encourages submittal of a small tarp sample (i.e., 1 ft. by 1 ft.) collected from the tarp roll for evaluation purposes. The width of the tarp roll and length used for the application area also need to be reported. A cross-sectional diagram illustrating the tarped area, tarped area covered with soil, and un-tarped area for bed application (e.g., drip and shank) must be submitted to DPR (See. Fig. 1-B as an example for bed application). If glue was used to connect any portion of the tarp, the glue line width as well as the exact ratio between solid tarp and glued tarp area must be determined and submitted.

For chemigation, the presence and locations of any surface liquid (pooling or puddling) during the application period must be recorded. Pooling of applied material immediately upwind of air samplers can significantly affect the air sampling results. Characteristics of the irrigation system, including the number of driplines per bed, distance between and depth of driplines, pressure, valves, and mechanisms for controlling the injection flow, if any are used must be described as shown in the template provided (Table 2). Additionally, if electronically controlled injection mechanisms are used, the calculated application rate must be compared to the rate obtained by weighing cylinders. Sufficient documentation required to confirm any of the above calculations should be submitted for verification purposes.

The product formulation must be clearly specified including the percent of active ingredient present. The quantity of applied material must be accurately measured. This typically requires weighing cylinders before and after application to accurately measure the amount applied to the field. In addition, amounts left in the lines or purged should be noted.

Table 2. A template for required data specific for chemigation application method

Irrigation start time	DD/MM/YYYY HH:MM	
Chemigation start time	DD/MM/YYYY HH:MM	
Chemigation end time	DD/MM/YYYY HH:MM	
Irrigation end time	DD/MM/YYYY HH:MM	
Total applied water	in (or cm)	
	ft^3 (or m^3)	
Total applied fumigant	lb (or kg)	
Number of driplines per bed	(-)	
Distance between driplines	in (or cm)	
Depth of dripline	in (or cm)	
Distance between dripline's emitters	in (or cm)	
Discharge of each emitter	l/h (or gpm)	
Temperature of water	^oC	

2.3. Irrigation

Irrigation is used to raise the soil water content to values specified in the product label. It is also used as a sealing technique to reduce the emission of fumigant from soil. Table 3 shows a template for required data about irrigation events. Information should be provided for each irrigation event during the field monitoring study and preceding the field monitoring study as part of the field preparation.

Table 3. A template for required data about irrigation events

Irrigation purpose	# of event	Irrigation start time	Irrigation end time	Irrigation method	Applied water	Temperature of water
		DD/MM/YYYY HH:MM	DD/MM/YYYY HH:MM	(-)	in (or cm)	^oC
Preparation	1					
	2					
	…					
Water seal	1					
	2					
	…					
Other	1					
	2					
	…					

2.4. Placement of air samplers

The exact locations of air samplers relative to the field must be accurately measured. Location of sampling points (off-site and on-site) should be drawn on a digitally formatted map like Google Earth or by using a Geographic Information System (GIS) and submitted for review. Additionally, all the information (longitude and latitude) should be submitted as an ASCII text file or in a spreadsheet format like MS Excel. Photographs of the sampling setup are required. Air samplers should be placed away from trees and obstacles such as buildings and structures. The distance from the obstacle to the sampler inlet must be at least 2.5 times the height that the obstacle protrudes above the inlet. The sampling media and the inlet tubing must be shielded from the sun to avoid or minimize the photo-degradation.

2.4.1. Off-site air samplers

Off-site air sampling is required in cases where the Back-Calculation method is used for flux estimation. It is also required during the fumigation period, unless fumigant is applied through drip chemigation system. In the latter case, the sampling time must coincide with the application time. Atmospheric conditions are normally very dynamic and complex and, as a result, associated parameters such as wind speed and direction can significantly change from one hour to another. Therefore, an essential element of designing the placement of air samplers is that a representative number of sampling points exist downwind from the field edge irrespective of wind direction. In other words, the cluster of sampling locations should create a ring around the field. Figure 2-A shows an exemplary design of off-site sampling (circles and stars) and on-site mast (cross) locations for a circular, a square and a rectangular field. Because of the variation of wind direction during any monitoring period, air samplers should be evenly spaced from the edge of the field.

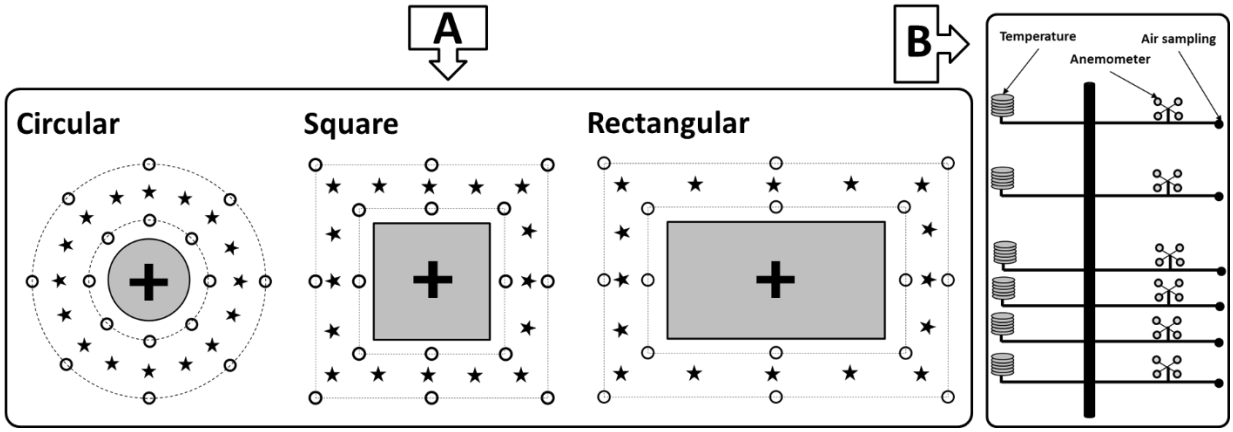

Figure 2-A: Schematic of air-sampling location designs that include the minimum of 16 sampling locations (circles), addition sampling locations (stars), and the location of the on-site sampling mast (cross). 2-B: Schematic of the on-site sampling mast for Aerodynamic or Integrated Horizontal Flux showing the air sampling tube, anemometer, and shielded temperature sensor at different heights. Shapes and markers are in different scales.

In case of using Back-Calculation method to estimate the fumigant emission flux, the application site size should be at least 2 acres to provide enough area to accurately assess off-site emissions. While a circular shaped field is desirable because it has a similar fetch regardless

of wind direction, square and rectangular fields may also be used. When fields are rectangular, the length to width ratio should not be greater than five and air samplers should be placed in approximate proportion to the side lengths. The type of field to be used in the study should be included in the study protocol and discussed with DPR prior to initiating the field study.

For application sites between 2 to 4 acres, a minimum of 8 off-site air samplers (inner ring of circle markers in Fig. 2-A) is required. DPR highly encourages considering additional sampling locations to enhance the confidence in estimated flux using back-calculation method. For application sites exceeding 4 acres, a minimum of 16 off-site air samplers (circle markers in Fig. 2-A) is required. Placement distances for the off-site air samplers should be based on the range of air concentrations expected at the downwind air samplers over the course of the study and the minimum detection limit, which may depend on the length of the sampling interval. Low wind speed or calm conditions can produce uniform concentrations around the edge of the field and thus affect the quality of air samples (concerning their use for modeling purposes) if the off-site air samplers are located too close to the field. Therefore, off-site air samplers should generally be close enough to detect positive concentrations when downwind, but not so close as to be adversely affected by low wind speed plume meander or diffusion during calms. DPR is available to provide insight on the placement of the samplers to ensure proper placement and to ensure that DPR can use the collected air concentrations. Off-site air samplers should be on a mast at height of approximately 1.5 m.

2.4.2. On-site air samplers

The on-site air sampling is required when flux estimation methods such as Aerodynamic Profile and Integrated Horizontal Flux are used. Flux profiles (time series of fumigant emission rate) estimated using these approaches should be accompanied by period(s) of off-site air concentrations. Specifically, at a minimum, the initial 24 hours following an application should be sampled using off-site air samplers with sampling frequencies of at least every 6 hours. DPR recommends submitting off-site air concentrations for the first 72 to 96 hours along with the data determined from the Aerodynamic Profile or Integrated Horizontal Flux methodologies. An on-site sampling mast is used to measure profiles of wind speed, air temperature, and pesticide air concentrations. The on-site sampling mast should include a minimum of 5, but preferably 6 sampling heights within the first 300 cm (e.g., 30, 60, 100, 120, 200, and 300 cm). Figure 2-B shows an exemplary design of an on-site sampling mast for Aerodynamic or preferably Integrated Horizontal Flux that includes air sampling tubes, anemometers, and shielded temperature sensors. It should be noted that the “cup anemometer” was used for illustration only and use of best available anemometer (i.e., sonic anemometer) is highly recommended.

In case of using Aerodynamic Profile or Integrated Horizontal Flux to estimate the fumigant emission flux, the application site size should provide enough fetch distance to accurately assess emission of fumigant. The on-site sampling height to fetch distance ratio of 1:100 can be used as a rule of thumb for Aerodynamic Profile. In case of Integrated Horizontal Flux, an application site of one acre may be deemed sufficient by DPR.

2.5. Air sampling intervals and total duration

In order to evaluate the background concentration of the fumigant in ambient air, an air sample should be collected prior to the start time of study.

Commencement of air monitoring should coincide with the beginning of the pesticide application. The application period should be a separate air sampling interval, which means samples should be collected immediately at the conclusion of the pesticide application. In order to capture the time and magnitude of peak flux, DPR suggests following a non-uniform sampling interval scheme that consists of a greater sampling interval frequency in the hours/days following the pesticide application, followed by a gradual decrease in sampling frequency until the end of the study. Table 4 shows the suggested sampling interval scheme for both off-site and on-site samplers. Atmospheric stability and turbulence change considerably from day to night. Therefore, sampling periods in Table 4 might be revised such that night monitoring is separate from day monitoring.

Start and stop times, as well as air volumes, must be recorded for each sample in a sampling interval. A complete (both on-site and off-site) sample-change-out within 30 minutes is optimal. Shorter sampling intervals (e.g., 2 to 6 hours) should be used when the peak flux/air concentrations are expected. Airflow measurements must be taken on calibrated equipment and the measurements should be within 10% of the target flow in order for the samples to be considered valid. Analytical aspects of air sampling for field samples should be validated prior to initiation of the field study.

Total duration of air sampling must be at least 14 days, or three times longer than the time to achieve peak concentrations, or until the flux declines to one-tenth of the peak flux, whichever is longer. Thus, the air sampling results should clearly demonstrate that the peak concentrations have been captured and the flux has substantially declined. A rule of thumb is that a 21-day sampling period is sufficient. This prescription may be modified if air concentrations during and after tarp removal are being sampled.

Table 4. Suggested sampling interval scheme when both off-site and on-site sampling are conducted.

Off-site and on-site sampling					
Time period	Application period	Day 1-2	Day 3-4	Day 5-10	Day 11 - 21
Sampling intervals	Start to end of application	Maximum of 4 hours	Maximum of 8 hours	Maximum of 12 hours	Maximum of 24 hours

2.6. Meteorology

Irrespective of the methodology used for estimation of emission rate, the following meteorology data is required. In addition to national and state meteorological databases, on-site instrumentation is required. A distance within 2 to 50 m of the treated area should be used for on-site measurements. The meteorological station should be located away from structures,

berms, trees, or other variations on the surface that might influence monitoring parameters. Table 5 provides a detailed list of the information DPR requests for a meteorological dataset and indicates which information is essential or recommended. DPR recommends the meteorological data be recorded at the highest possible frequency for the instrumentation used (sub-minute recordings are highly recommended) but at a minimum must include 5-minute averages. These measurements must be provided in an electronic format, as either an ASCII file or a spreadsheet file. Wind direction information must specify whether the frame of reference is true north or magnetic north in order to properly align wind direction with the geometry of the field and air sampler location design. Degree of cloudiness on an hourly basis is necessary. Site information must be provided including a diagram of the area around the study site showing buildings, berms, roads, towers, structures, trees, and adjacent crops, etc.

Table 5. A list of the information DPR requests for a meteorological dataset that specifies which information is essential or recommended.

Input data	Level of requirement	Comments	Averaging period
Cloud Cover	Essential	Report total and opaque cloud cover in tenths where zero is clear sky and 1 is overcast.	1 h
		If cloud cover is not available, two vertical measurements of temperature (typically at 2 and ≥10 m), and a measurement of solar radiation at a 2-m height can be substituted.	Every 5 seconds measurement, 10 min averaged
Wind Speed and Direction	Essential	Monitor wind speed and direction at a height ≥10 m. An additional height measurement at 2 m is highly recommended.	Every second measurement, 10 min averaged
Ambient (Dry Bulb) Air Temperature	Essential	Monitor temperature at a 2-m height. An additional measurement at a height of ≥10 m is highly recommended.	Every 5 seconds measurement, 10 min averaged
Morning Sounding	Essential	Obtain a full morning upper air sounding from the closest available station. Global upper air data in FSL format is available online from the NOAA Earth System Research Laboratory (ESRL) Radiosonde Database at http://esrl.noaa.gov/raobs/	
Precipitation	Essential	Precipitation data is used for characterization of surface moisture (categorizing for Bowen Ratio); hourly data beginning five days prior to the study should be provided.	10 min measurement
Net Radiation	Highly Recommended	Net Radiation is used to characterize the energy balance in the Planetary Boundary	Measure every 5 seconds, 10 min averaged

		Layer and on-site measurement is highly recommended.	
Sigma-W	Highly Recommended	Standard deviation of vertical wind speed is an important parameter. If available it adds great value to the input data. The recommended height is between 2 and 10 m.	Every second measurement, 10 min averaged
Sigma-Theta	Highly Recommended	Standard deviation of wind direction is an important parameter. If available it adds great value to the input data.	Every second measurement, 10 min averaged

2.7. Soil texture, bulk density, and organic carbon

Irrespective of the methodology used for estimation of emission rate, the following soil properties data is required. A minimum of eight locations should be selected for undisturbed soil core sampling for soil texture analysis, bulk density, and organic carbon. Each field should be divided into four quadrants and two locations per quadrant should be randomly selected. A minimum of 3 sampling depths should be considered. The recommended sampling depths are 5, 15, and 35 cm, which represent 3 soil layers of 0-10, 10-30, and 30-50 cm. Bulk density samples should be taken (within 24 hours) before and at the end of study. Table 6 shows a template for required data about soil texture, bulk density, and organic carbon at different depths and different locations. A protocol describing the methodology used to determine each of the above properties must be submitted to DPR.

Table 6. A template for soil texture, bulk density, and organic carbon data at different depths and different locations.

Location	Depth	Sand	Silt	Clay	Bulk density	Organic carbon
	(cm)	(%)	(%)	(%)	(g cm^{-3})	(%)
#1	0-10					
	10-30					
	30-50					
…..						
#8	0-10					
	10-30					
	30-50					

2.8. Soil water content

Irrespective of the methodology used for estimation of emission rate, the following soil moisture data is required. Soil cores (undisturbed) collected for bulk density (section 2.7) should also be analyzed to measure volumetric soil moisture. The temporal changes in soil moisture also provide valuable information; therefore, collecting such data is required. Installing soil moisture sensors should follow the same arrangement as described for

undisturbed soil core sampling (i.e., 4 quadrants, 2 random locations per quadrant, and 3 depths of 5, 15, and 35 cm per location). Tables 7 and 8 show a template for required data for soil water content measured by cores and sensors, respectively. The averaging time period of recording the soil water content data for chemigation and any scenario that includes water application (e.g., water seal) should be 5 minutes or less. In case of no irrigation, a one-hour averaging time period would be sufficient.

Table 7. A template for soil water content (measured by soil core) at different depths and different locations.

Depth (cm)	unit	Location #									
		Before fumigation DD/MM/YYYY HH:MM					At the end of study DD/MM/YYYY HH:MM				
		1	2	3	4	5	1	2	3	4	5
5	$g\ g^{-1}$										
	$cm^3\ cm^{-3}$										
15	$g\ g^{-1}$										
	$cm^3\ cm^{-3}$										
35	$g\ g^{-1}$										
	$cm^3\ cm^{-3}$										

Table 8. A template for required data about soil water content (measured by sensor) at different depths and different locations.

Date and time	Location#1 Depth#1	……	Location#8 Depth#3
DD/MM/YYYY HH:MM	$cm^3\ cm^{-3}$		$cm^3\ cm^{-3}$

2.9. Soil temperature

Irrespective of the methodology used for estimation of emission rate, the following soil temperature data is required. The flux of fumigant from the ground to the atmosphere is highly correlated to soil temperature; thus, continuous measurement of soil temperature at depths 5, 10, and 50 cm at a minimum of 4 locations is required. The exact monitoring depth (e.g., 5 cm) for soil temperature should be reported. Do not report the temperature depths in the format of range such as 0 to 10 cm. Table 9 shows a template for reporting the required data for soil temperature.

DPR also requires monitoring the temperature at soil surface under the tarp with a temperature sensor. The sensor (minimum of 4 different locations) should be placed inside a shield (e.g., white PVC pipe attached to a T-fitting) to block direct sunlight while not in contact with the body of the shield. The shield should allow a free exchange of air within the vicinity of tarp and soil surface. The shielded sensor can be placed on the ground below the tarp. The tarp above the sensor cannot be covered by soil or any other object like tape.

The averaging time period of recording the soil temperature data for chemigation and any scenario that includes water application (e.g., water seal) should be 5 minutes or less. In case of no irrigation, a one-hour averaging time period would be sufficient. A protocol describing the arrangement of temperature sensors in the soil and in the vicinity of tarp and soil surface should be submitted to DPR for review prior to the study.

Table 9. A template for required data about soil temperature at different depths and different locations.

Date and time	Location#1 Depth#1	……	Location#4 Depth#4
DD/MM/YYYY HH:MM	^{o}C		^{o}C

3. References

Sanders, J. D. 2005. General guidance for conducting fumigant field studies. Department of Pesticide Regulation.