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Evaluating Surface Seals in Soil Columns to Mitigate Methyl Isothiocyanate Volatilization

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1. Introduction

The banning of methyl bromide (MeBr) as a pre-plant soil fumigant due to its implication as an ozone depleting substance, has led to increased interest in finding alternative soil fumigants to replace MeBr (United States Environmental Protection Agency [USEPA], 2009). One of the promising alternatives for certain crops is methyl isothiocyanate (MITC). Several MITC generating compounds, such as metam sodium®, metam potassium®, and dazomet® are being used to control a wide variety of fungal pathogens, weeds, and nematodes in soils. The physiochemical characteristics of MITC are significantly different than that of MeBr, such as that its effectiveness in regards to dissipation and movement in the soil is altered by multiple factors, such as soil type, texture, and soil moisture content. The largest challenge to soil fumigation is the prevention of fumigant loss to the atmosphere and especially to the nearby communities and homes adjacent to farm land. Rapid off-gassing or non-target release of the fumigant to the atmosphere can lead to poor pesticide performance and ineffective pest control. To combat this problem that is common to all soil fumigants currently on the market, various methods have been employed to reduce chemical off-gassing. A few of these methods are tarping the soil surface immediately following chemical application with high density polyethylene plastic, incorporation of organic matter to the soil surface to absorb the fumigant, or altering chemical formulations. Another method of reducing fumigant loss can be applying a surface water application as a means of sealing the soil surface to prevent chemical volatilization. On-farm field scale studies have been performed to evaluate all of these methods to better evaluate the potential for reducing fumigant loss to the atmosphere. However, field-scale studies are expensive to perform, and experimental error is challenging to control and replicate due to diurnal temperature fluctuations, varying soil physical properties, and air current differences. Thus, the volatilization loss in one study will not represent the typical fumigant loss from site to site. A more controlled laboratory environment is needed to more adequately predict fumigant loss under specific conditions. Laboratory-scale columns can be used to study soil fumigant release from soils under a wide array of conditions and under controlled

circumstances. The aim of this study was to evaluate the amount of water applied to the surface of a specific soil type to reduce MITC volatilization in soil columns. Furthermore, evaluating the impact of various soil physical properties have on MITC loss is important, such as varied soil type, soil bulk density, organic matter additions and various MITC generating compound formulas have on MITC loss and mitigation. In short, the results of these studies will summarize the effectiveness of the use of soil columns to adequately assess MITC loss at the laboratory scale as a tool to predict chemical fate prior to the expense of large-scale on-farm studies.

1.1 History of fumigants

Soil fumigants are commonly used in high-value horticultural crop production to control soil originating pests such as plant-parasitic nematodes, soil-borne pathogens, insects and weeds. The intrinsic volatility of a fumigant is essential for a chemical to disperse laterally and vertically throughout the soil profile in order to control soil-borne diseases. Fumigants are typically applied via shank/chisel injection directly into the soil. After being applied, the fumigants quickly change into a gaseous phase whereby it is dispersed within the soil and results in pest control. Many compounds are classified as soil fumigants, with various rates of efficacy, with MeBr considered the most effective broad-spectrum pest control fumigant due to its high efficacy level. MeBr was one of the most widely used soil fumigants until, under the Montreal Protocol; it was officially phased out in 2005 as an ozone depleting compound (USEPA, 2009). MeBr is still used in developing countries, but must be phased out by 2015 (United States Government Printing Office [USGPO], 2005).

In effort to meet the challenge to find a suitable replacement for MeBr that has similar efficacy capabilities for crop protection a concentrated effort of research and funding has occurred. Although these studies on alternative fumigants to MeBr have been occurring for approximately two decades, there is still no fumigant replacement as effective in almost all soil types like MeBr. Currently there are still several instances where MeBr can be used; such as critical use exemptions (CUE), quarantine and pre-shipment (QPS), and emergency exemption (EE). However, these uses are highly restricted and subjected to strict regulation. In recent years, there has been a movement to find alternatives to MeBr that are as effective but less harmful to the atmosphere and environment. While this has proved a formidable challenge to scientists, there are several fumigants used in agriculture today that are effective under specific soil and cropping conditions. Table 1 shows the five most used soil fumigants in the United States.

1.2 Methyl bromide

MeBr has been the most effective soil fumigant for most soil borne pathogens and pests since it was introduced as a pesticide in 1932. Due to its harmful effects on the atmosphere as an ozone depletor, MeBr production has been phased out in most developed and developing countries in accordance with the Montreal Protocol (USEPA, 2009). MeBr can still be used under critical use and emergency exemptions but its use is strictly regulated by state and governmental agencies.

MeBr is a volatile gas at room temperature and 1 atm pressure and can be produced commercially or by plants and algae (National Pesticide Information Center [NPIC], 2000).

MeBr is a odorless, gaseous chemical above 4°C that is highly toxic to humans and vertebrate animals that can result in death under acute exposure. Thus, commercial formulations of MeBr include a certain percent of chloropicrin (tear-gas) added to act as a warning agent to indicate presence of MeBr to prevent overexposure. MeBr is applied under pressure as a liquid using shank injection into the soil, usually in conjunction with covering the soil with plastic tarps to suppress and prevent volatilization loss of the gas to the atmosphere (Papiernik et al., 2001; Wang et al., 1997). The gas then diffuses through soil pores and cracks and allows for control of soil borne pests and pathogens.

Rank	Fumigant	Formulations	Application	Amount Used per Year
1	Metam sodium/ Metam potassium	Liquid, soluble concentrate	Shank injection, chemigation	51-55 million lbs/ 1-2 million lbs (2002)
2	Methyl bromide	Pressurized gas	Shank injection, hot gas	14.76 million lbs (2007)*
3	Chloropicrin	Liquid, pressurized gas, pressurized liquid, emulsifiable concentrate	Shank injection, drip irrigation	10 million lbs (2007)
4	1,3- Dichloropropene	Liquid	Soil injection, deep drip irrigation	40,420 lbs (1998 estimate)
5	Dazomet	Granule, pellet, liquid, water soluble solids	Spreader	15,000 lbs (2003)

*Critical use exemption and emergency exemption usage
(USEPA, 2009).

Table 1. Top five most commonly used soil fumigants in the United States.

1.3 Methyl bromide alternatives

While no fumigant has proven as effective as MeBr for the control of soil-borne pests and pathogens, the reasons why the four most widely used fumigant alternatives are currently in use today are discussed below.

1.3.1 Metam sodium and metam potassium

Metam sodium (MS) is among the most widely used soil fumigant available for use (USEPA, 2008b; Sullivan et al., 2004). MS and metam potassium (MK) are broad-spectrum soil fumigants and are also used in sewers, drains, and ponds to control weeds and roots (USEPA, 2008b). MS is a sodium salt formulation of methyldithiocarbamate which breaks down into the active ingredient methyl isothiocyanate (MITC) when injected into the soil. MK is a potassium salt of N-methyldithiocarbamate and breaks down into MITC similarly

to MS. MITC is a volatile gas used for soil borne pest control, it is mobile and water soluble. While it has minimal effects on impacting ozone, it does have potential as a groundwater contaminant (El Hadiri et al., 2003). Because of its relative ease in water solubility it can be used in chemigation applications and it leaves no residue on food crops (Noling and Becker, 1994). MS and MK are applied via shank injection and chemigation into the soil as a liquid.

1.3.2 Chloropicrin

Chloropicrin (trichloronitromethane) is a common fumigant used to control fungi, insects and nematodes. It is used as a pre-plant soil fumigant, warning agent and in wood treatment (USEPA, 2008a). It is a volatile gas that does not have a significant impact on ozone depletion. However it does have the potential to be a groundwater contaminant. Chloropicrin is also commonly mixed with another fumigant to increase the fumigants effectiveness (Shaw & Larson, 1999). It is shank injected into the soil or can be applied via chemigation.

1.3.3 1,3–Dichloropropene

1,3-dichloropropene (1,3-D) is a volatile gas used for the control of nematodes, fungi, insects and weeds (USEPA, 1998). 1,3-D is commonly applied as a pre-plant soil fumigant for many crops. It is considered by many to be one of the more important soil fumigant replacements for MeBr (Noling & Becker, 1994). It is typically shank injected into the soil, after which a soil sealing method is required to prevent off-gassing. 1,3-D is mobile and persistent and has the potential for groundwater contamination (USEPA, 1998). It has been estimated that 1,3-D emission loss to the atmosphere can range from 30 to 60% of the total amount applied to the soil (Gan et al., 1998a, 1998b; Gan et al., 2000b)

1.3.4 Dazomet

Dazomet is another MITC generating compound used in pathogen control. It is a broad spectrum soil fumigant used in controlling weeds, nematodes and fungi. It also has applications as a material preservative, as a biocide, and in wood treatment. It is most commonly sold and is applied in a granular form through spreaders.

1.4 Preventing emmissions of soil fumigants

Common methods used to reduce fumigant emission loss (off-gassing) to the atmosphere include using polyethylene (PE) tarps, other improved plastic barrier films, use of clear PE films for soil solarization (Chase et al., 1998; Gamliel et al., 1997; Nelson et al., 2000), soil amendment additions, drip application (Ajwa et al., 2002; Schneider et al., 1995), and surface water sealing. The on-farm fumigant emission reduction practice most readily used is the covering of the soil with PE plastic films. Emission of MeBr can still be extensive regardless of PE film use, therefore, improved formulations of high density polyethylene (HDFE) films or ‘virtually impermeable films (VIF) that have lower permeability to MeBr have been investigated and used at the farm level (Wang et al., 1997). Many of these films are of high cost and limit their use in commercial production for crops that do not supply a high economic return to the grower. Various chemical additions have also been used in film

formulations that may further suppress the volatilization loss of fumigants through PE, HDFE and VIFs.

Clear PE films have been used in locations such as Florida to suppress noxious weeds, such as purple and yellow nutsedge, and nematode populations. This practice of using clear plastic films can create a natural greenhouse effect and heating the upper soil rooting depth to temperatures that kill soil-borne pests, nematodes, or burns the foliage of weeds, but the pest control efficacy of this practice is limited and unpredictable making it an unreliable cultural practice for most growers (Chase et al., 1998). Incorporation of organic matter or fertilizer amendments into the soil surface in concert with PE film use have also been employed to lower fumigant emissions. Enhanced degradation of the fumigant 1,3-D have been observed after soil incorporation of organic matter (Dungan et al., 2001) and ammonium thiosulfate by chemical reactions with 1,3-D (Wang et al., 2001; Gan et al., 2000a).

Drip fumigation integrates the use of soil fumigant chemical application within drip irrigation lines. To achieve success, drip fumigation requires that the fumigant is diluted in water below its solubility or carried in conjunction with an emulsifier and dispersed throughout the rooting depth of crops by water through the dripline. In crops and soils where drip irrigation lines are utilized, drip fumigation has the potential to use lower fumigant rates than shank injection (Ajwa et al., 2002; Gan et al., 1998b), while reducing the amount of labor needed to apply the fumigant where drip lines are pre-installed (Schneider et al., 1995).

Another form of soil surface sealing is the application of water to act as a barrier to soil fumigants volatilization from the soil surface (Gan et al., 1998a, 1998b). Soil surface sealing with water application is used to change the chemical exposure within the soil being fumigated. Additional water can prolong the amount of time that MITC remains exposed to soil-borne pathogens, extending the efficacy of the chemical. There have been many studies that have shown reduced fumigant volatilization from the soil surface after irrigation water has been applied immediately following fumigant application. Results have been promising for lowering fumigant off-gassing whether the water was applied in a single event or in an intermittent method following soil fumigant application. The use of water seals is impractical for many of the highly volatile, low water soluble fumigants, such as MeBr and chloropicrin. These compounds will typically escape too quickly from the soil surface as they rapidly convert from the liquid to gaseous phase after application. Water seals are generally applied via overhead sprinkler systems, which do not apply water fast enough to prevent the gaseous fumigant's release into the atmosphere. Therefore, surface water seals typically work best for soil fumigants that have greater water solubility and will stay in solution longer before transformation into its volatile form, like MS and other MITC generating compounds (Simpson et al., 2010).

2. Field and laboratory methods

When dealing with volatile chemicals such as soil fumigants, both laboratory and field scale experiments are needed to estimate and measure off-gassing in a wide variety of conditions and situations. While field scale studies are of the utmost importance, they are labor intensive, and require more time and expense in order to test experimental

variations. Laboratory, bench-scale experiments can be an inexpensive, fast way to test theories and experimental methods before performing larger scale field studies (Gan et al., 2000b).

2.1 Field methods

Most fumigants are used in conjunction with tarps to seal the surface of the soil and prevent off-gassing of the chemical, thus allowing more time for the pest control properties of the fumigant to occur. For on-farm field scale water seal investigations it typically requires shank injection of soil fumigants into the soil followed by irrigation of the soil surface to create the surface water seal. A challenge for growers to implement this into practice is the fact that they must set out standing pipe in the field equipped with sprinkler heads and risers prior to soil fumigation. The conversion of the chemical into a gaseous phase generally occurs too quickly not to have this done in advance, furthermore human fumigant exposure becomes a high risk if working in the field after application. Irrigation lines in the field can restrict blanket soil fumigant applications throughout the entire site, as pipe may limit where tractors can drive. Despite these challenges, surface water seals have been accomplished at the on-farm level with promising results for fumigant suppression (Sullivan et al., 2004). A limiting factor that makes field-scale studies challenging, is that they are typically good for that site only, and seldom reflect the potential fumigant loss for other locations that have different soil types and physical characteristics. Soils are highly variable systems, and small changes in organic matter content, soil water content, temperature, bulk density, and the fraction of sand, silt and clay will alter fumigant behavior (Dungan et al., 2001).

2.2 Laboratory methods

The use of stationary, bench-scale soil columns has been shown to a reliable means of estimating the emission potential of soil fumigants under many different soil conditions and soil types (Gan et al., 2000b). Artificial soil profile conditions under a controlled environment can be created and manipulated to more quickly assess fumigant behavior under restricted conditions. In many ways, these conditions can provide data that is less costly and cumbersome than field-scale conditions, and yet give appropriate estimates of fumigant loss comparable to that observed from field trials.

The following describes the experimental conditionals and results of one such soil column study aimed at determining the proper amount of water needed to best suppress MITC release from a sandy loam soil after MS application.

2.2.1 Experimental setup

To simulate a soil profile in laboratory scale studies, stainless steel soil columns were constructed. The soil columns constructed were 60 cm high with a 10 cm I.D. as shown in Fig.1a. Gas sampling ports were installed and spaced 10 cm apart located at soil depths of 15, 25, 35, 45, and 55 cm down the length of the soil columns. All gas sampling ports were sealed with Swagelock® fittings and septa to create an air tight environment to prevent gas leaking. A sandy clay loam soil (fine-loamy, mixed, hyperthermic Typic Ochraqualfs), used to pack the soil columns, and was collected from an area not previously exposed to soil

fumigants. Soil was air dried and sieved to 2.0 mm, then brought to 8% moisture with distilled water. Each column was packed to a bulk density of 1.5 g cm^{-3}. A headspace sampling chamber was attached to the top of the soil column in order to collect gas samples and to apply a uniform water seal through a microjet spray sprinkler attached to the inside of the chamber. The upper chamber was sealed to the lower column using aluminum air-conditioning duct construction tape to preserve an airtight chamber. To promote airflow through the chamber, two holes were drilled on opposite sides of the headspace chamber, one with access to outside airflow and the other attached to a vacuum source. Charcoal tubes were connected to the ends of each port to act as filters to collect any volatile MITC that was released during the study. The vacuum airflow rate was maintained at 150 +/- 10 mL min^{-1} from the 1mmHg vacuum source.

Fig. 1a. Soil columns with charcoal filters.

Fig. 1b. MS injection at 15 cm soil depth.

MS was applied to the soil columns via simulated soil drip fumigation by injecting the fumigant in the center of the soil through a side port located 10 cm below the soil surface (Fig. 1b). The MS was applied at a rate of 420 g L^{-1} EC (Vapam® 42; Amvac Chemical Corp., Los Angeles, CA) with 112 mL of distilled water, thus MS was diluted in water sufficient to simulate a 1.3 cm chemigation event. The equivalent amount of MITC applied to each column was 121.2 mg. Additional water application through the microjet spray sprinkler located inside the top of the soil column cap to simulate water seals of 0, 1.3, 2.5 and 3.8 cm applied to the soil surface and this was performed immediately following the injection of MS in order to prevent chemical off-gassing. Each treatment was replicated in triplicate for statistical analysis.

2.2.2 Chemical analysis

Analysis of MITC can be done in many ways. Gas chromatography (GC) with flame ionization detector (FID) was used in this research, but other detectors such as electron capture detectors and nitrogen phosphorus detectors can be used in MITC analysis for greater sensitivity.

After MS was applied to each column, air samples were taken at predetermined times from the side ports along each column. MITC concentrations within the soil air space were determined by filling a gas-tight syringe with 250 µL of air and injecting it into the GC-FID. The charcoal filters attached to the columns were sealed and replaced every 4 to 8 hours

(Fig. 2a) to ensure that no MITC was escaping undetected. These filters were then frozen until analyzed. To determine the amount of MITC volatilized from the soil surface, each glass charcoal filter tube was broken and the charcoal dispensed into 10-mL headspace sampling vials (Fig. 2b).

Fig. 2a. Charcoal filters replaced periodically.

Fig. 2b. Charcoal filter extracted into vials.

Afterwards, 5 mL of organic solvent (methanol) was used to extract the MITC off the charcoal, the vials were immediately cap sealed, then shaken (Fig. 3a) overnight in the dark, as it was determined in a preliminary trial that 12 h was sufficient time to extract over 99% of all MITC from the charcoal. Charcoal was placed on the counter for 2 h to allow it settle to the bottom of the vial. 1-mL of the solvent supernatant was then extracted and transferred to 2-mL GC vials (Fig. 3b), and a GC syringe was used to extract the solvent from small GC vials (Fig. 3c) followed by injection into the GC for MITC analysis by FID (Fig. 3d).

Fig. 3a. Vials shaken to extract MITC.

Fig. 3b. Transfer of solvent to small GC vial.

Fig. 3c. Syringe extraction of solvent.

Fig. 3d. Injection of solvent into GC for analysis.

3. Results of water seal column study

The movement of MS within soil systems can be described in regards to its partitioning from the liquid phase into the gaseous phase after transformation to MITC. For analytical simplicity, only MITC was within the gaseous phase was analyzed during this study, although MITC does partition in water as well. The amount of MITC volatilized was monitored over time after MS chemical injection in two parts: 1) the soil-air movement of MITC within the soil column profile, and 2) the flux of MITC evolved from the soil surface.

3.1 Soil air movement of MITC

The distribution of MITC within the soil-air space within the soil profile was measured at periodic times, but only data from 0.3, 1, 2, 3 and 5 days after treatment (DAT) are displayed here for simplicity (Fig. 4a-d). As expected, the soil columns that did not receive additional water to the soil surface (0-cm water seal) had rapid release of the fumigant after application (Fig. 4a) because of a lack of a barrier film of water to restrict MITC volatilization. This is evident by the bulk of MITC located at the 20 cm soil depth within hours after application (0.3 DAT). Although the MS was applied at the 10-cm injection port, the bulk of the chemical moved down the soil profile as apparent by the bulk MITC concentration located at the 20 cm soil depth 0.3 DAT. This was due to the total initial amount of water applied with the diluted MS solution and a lower fumigant amount near the 10 cm soil depth of the column. The highest level of MITC was observed 1.0 DAT at the 10 cm soil depth, indicating that the majority of the fumigant was moving upward throughout the soil column. Thereafter the amount of MITC within the soil-air phase progressively decreased each DAT (Fig. 4a).

Similar to the 0-cm water seal treatment, the 1.3-cm water seal treatment had MITC distributed in a like manner, with the highest amount of MITC observed at the 10 cm sampling depth 1.0 DAT (Fig. 4b). However, the concentration level of MITC observed within the soil profile was higher than that of the 0-cm water seal treatment at sampling times after chemical application. This indicates that although the water seal amount was low (1.3 cm) it is sufficient to restrict and delay the volatilization loss of MITC. This is apparent by MITC levels 2 to 3 times greater within the soil-air phase 2.0 and 3.0 DAT at the upper 30 cm soil sampling depths when compared to the no water seal treatment (Fig. 4b).

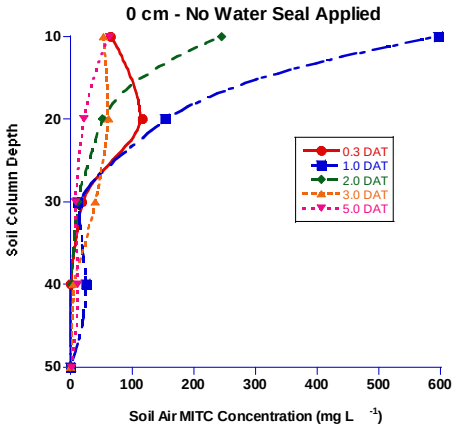

Fig. 4a.

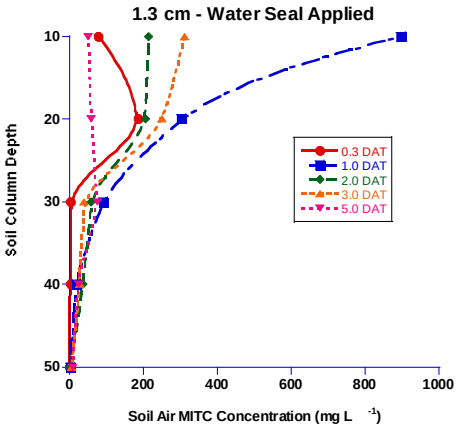

Fig. 4b.

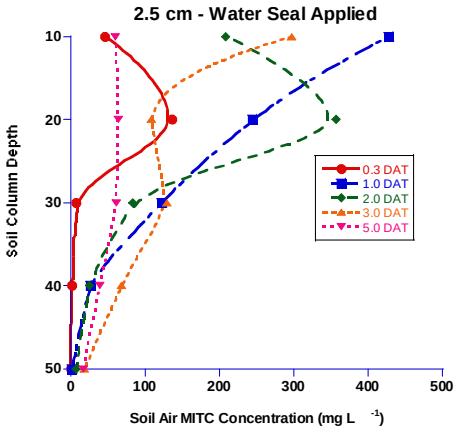

Fig. 4c.

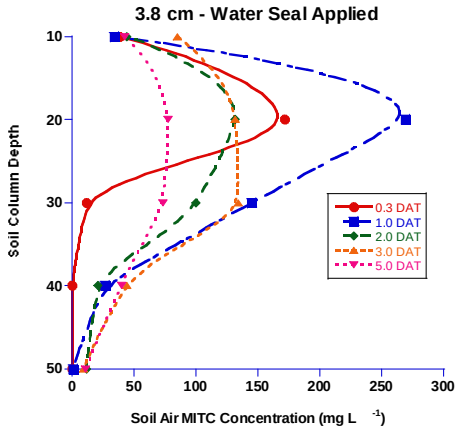

Fig. 4d.

Fig. 4. MITC distribution in soil airspace throughout the soil profile of columns over time (DAT=days after treatment, or after injection of metam sodium at 10-cm column depth); data shown represent the mean of three replications for each water seal treatment [0-cm (4a), 1.3-cm (4b), 2.5-cm (4c), and 3.8-cm (4d) water seal application depth].

The real impact of the water seal treatment at suppressing MITC volatilization was observed in the 2.5-cm water seal treatment (Fig. 4c). This is especially apparent when looking at the level of MITC over time at the 10 cm soil depth. The concentration of MITC at the 10 cm soil depth was lower 1.0 DAT for the 2.5-cm than the 0-cm and 1.3-cm water seal treatments (Fig. 4a-c), suggesting a restriction in the volatilization loss of MITC through the soil surface. Furthermore, the bulk amount of MITC resided at the 20 cm soil depth for a longer period of time after chemical application when compared to the lower water seal treatments, allowing

the MITC to distribute vertically throughout the soil column with MITC concentrations observed at the 50 cm by 5.0 DAT (Fig. 4c).

Application of a 3.8-cm water seal resulted in the longest retention of MITC within the soil profile, along with the greatest suppression of MITC from the soil surface as evident by low MITC soil-air phase levels at the 10 cm soil depth up to 5.0 DAT (Fig. 4d). The extra water applied to the soil surface in the 3.8-cm treatment moved the MS further down the soil profile resulting in high MITC concentrations at both the 20 and 30 cm soil depths 1.0 to 5.0 DAT. The higher water amount within the soil profile was confirmed at the end of the study as soil moisture levels were higher at the 25 cm soil depth of the 3.8-cm than the 2.5-cm water seal treatments (data not shown).

3.2 Soil surface flux of MITC

The highest amount of MITC volatilized through the soil surface was observed from soil columns with no (0-cm) water seal applied after MS application (Fig. 5). The greatest MITC flux was observed within the initial 36 h after chemical application and decreased over time thereafter. A similar trend was observed for the 1.3-cm water seal treatment, but the amount of MITC evolved was substantially less than that from the 0-cm treatment. The lowest amount of MITC flux observed occurred from both the 2.5-cm and 3.8-cm water seal treatments, with the 2.5-cm treatment releasing slightly more MITC by 120 h after MS application.

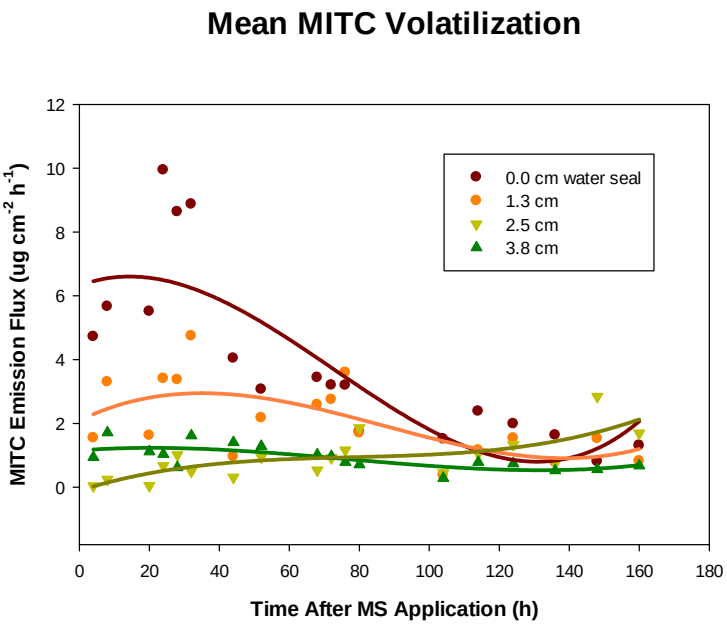

Fig. 5. The mount of MITC volatilized and captured on charcoal filters over time. Data represents mean of three replicates per water seal treatment.

In order to determine to total amount of MITC volatilized from the surface of the soil columns, cumulative MITC levels were calculated and plotted (Fig. 6). In this respect it is easily apparent that the highest MITC emissions occurred from soil columns without a water seal treatment. But more importantly, for soil columns that received additional surface water irrigation, total MITC volatilization decreased with increasing water seal depth (Fig. 6a). The total mean MITC volatilization loss from the 0-, 1.3-, 2.5- and 3.8-cm water seal treatments was respectively 24, 14, 9 and 6% of the total initial MITC applied (Fig. 6b). The highest variability in MITC loss was observed in the low to no water seal treatments, suggesting that neither of these treatments would be acceptable for suppressing MITC fumigant loss from soils. Whereas a low amount of variability (small error bars) was observed for the higher water seal treatments, with no statistical difference in total MITC loss (Fig. 6b).

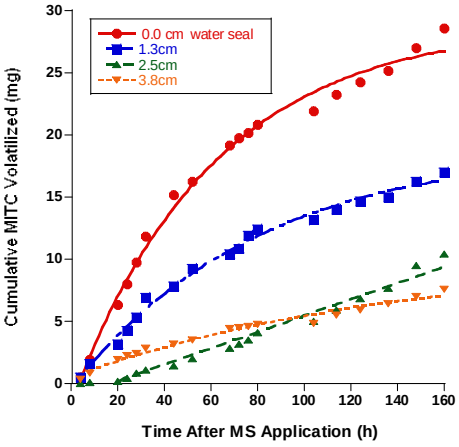

Fig. 6a. Mean MITC emitted from soil columns.

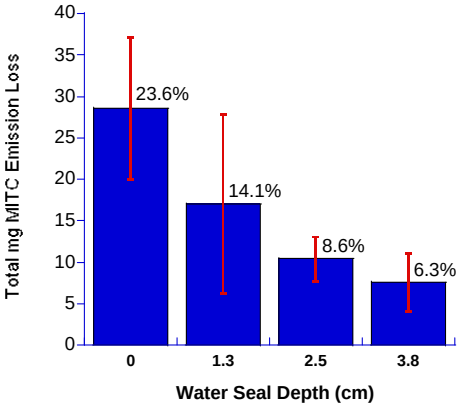

Fig. 6b. MITC release ± std error mean.

Fig. 6. Total cumulative MITC evolved from soil columns as captured on charcoal filters.

4. Conclusion

These findings illustrate how effective bench-scale soil column studies are at assessing the volatilization potential of MS after varying surface water seal treatments. Keeping in mind that this study represents specific and restricted conditions, it does provide a good estimate of the proper water seal depth needed for a sandy clay loam soil type. Although a 3.8-cm water seal led to the least amount of fumigant loss, it is recommended that a 2.5 -cm water seal be applied in the field for similar soil types. This is suggested due to the fact that applying large amounts of water can significantly alter chemical behavior by further diluting the MS to a level below the critical threshold for MITC to be effective for pest control. Furthermore, in areas where water tables are high, adding too much water via supplemental overhead irrigation may lead to groundwater contamination and result in other environmental concerns. The 2.5-cm water seal application suppressed MITC volatilization to level statistically equivalent to that of the 3.8-cm treatments and therefore, it is a good practice to reduce fumigant emissions to the atmosphere while minimizing

excessive chemical movement beyond the crop rooting depth. On-farm field investigations will be needed to back up these laboratory scale findings to provide confirmation that the suppressive loss of MITC is ultimately achievable.

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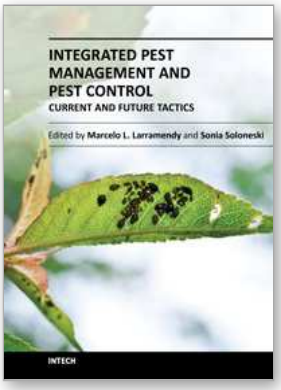

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Integrated Pest Management is an effective and environmentally sensitive approach that relies on a combination of common-sense practices. Its programs use current and comprehensive information on the life cycles of pests and their interactions with the environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means and with the least possible hazard to people, property, and the environment.

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