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Soil persistence of dimethyl disulfide combined with chloropicrin after repeated applications

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ABSTRACT

Applying pre-plant soil fumigation is a commonly used practice in plasticulture production systems to control some weed species, bacteria, and pathogenic fungi that can cause damage to high value crops such as cut flowers and vegetables. Since the phasing out of methyl bromide, growers have been seeking an alternative that has similar broad spectrum efficacy. Dimethyl disulfide (DMDS) alone or combined with chloropicrin (Pic) has proven to be effective against pathogens and has the potential to become a widely used pre-plant soil fumigant. The results show that the addition of Pic significantly increases the soil persistence of DMDS when compared to pure DMDS under totally impermeable film (TIF). Dissipation of pure DMDS during the fall application was quicker during the spring application. The dissipation curve exhibited by DMDS:Pic in the fall was not typical of this mixture. It is unclear if this trend is a result of the sequential applications.

1. Introduction

The use of fumigants is imperative in many locations for the continuation of successful fruit and vegetable production. The ban on the use of methyl bromide in fruit and vegetable production has led to the utilization of older chemistries, for example, chloropicrin (Pic) and 1,3-dichloropropene, and development of novel compounds, such as dimethyl disulfide (DMDS) for soil fumigation to control various pests including weeds, insects nematodes, fungi, and bacteria (Noling et al., 2013). While some of these chemicals are extremely efficacious, many come with a host of problems for producers including reduced efficacy, odor issues, and increased input costs compared to historical use of methyl bromide (Samtani et al., 2010; Santos et al., 2006).

Perhaps one of the more troublesome problems associated with many of the methyl bromide alternatives is the prolonged planting interval, particularly when high barrier mulch, such as virtually impermeable film and totally impermeable film, is used (Ajwa et al., 2003; McAvoy et al., 2010). In order for a fumigant to be effective, it must move throughout the soil profile and persist long enough for sufficient pest contact and dissipate from the soil in a timely manner (Gamliel and Triky-Dotan, 2009). Planting seeds or transplants into soil that has high fumigant concentrations can lead to phytotoxicity, which often results in lower yielding plants or even plant death. Some fumigant labels will specify the planting interval based on soil temperatures.

Soil diffusion is affected by many chemical characteristics of the fumigant such as vapor pressure, boiling point, water solubility, and Henry's constant (Munnecke and Van Gundy, 1979; Ruzo, 2006). Due to its high vapor pressure and low boiling point, methyl bromide had the advantage of dissipating quickly from the soil, allowing for a relatively short planting interval, whereas the alternatives have comparatively lower vapor pressures and don't move through the soil as rapidly (Munnecke and Van Gundy, 1979). Dissipation of a fumigant can also depend on factors not directly associated with the chemical properties of the fumigant. Microbial activity, soil pH, moisture content, and organic matter content can also affect persistence of a fumigant (Munnecke and Van Gundy, 1979; Ruzo, 2006). Due to the various mechanisms that affect the dissipation rate of a fumigant, its fate can vary depending on the cropping system, soil type, and environmental conditions at the time of application.

Due to the absence of several chemistries with acceptable efficacy that are available to producers, many are using the same active ingredient on the same soil year after year. It has been documented that the repeated application of some fumigants can lead to increased dissipation, also known as accelerated degradation (AD), and reduced efficacy (Gamliel and Triky-Dotan, 2009). Accelerated

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degradation due to repeated applications is well known for several pesticides and is associated with increased soil microbial populations that are able to use the active ingredient as its sole energy source, however, the phenomenon is less known for soil fumigants (Arbeli and Fuentes, 2007; Gamliel and Triky-Dotan, 2009).

Accelerated degradation of pesticides can be both beneficial and detrimental, depending on the situation. While an increase in degradation can lead to reduced planting intervals, it can also translate into decreased efficacy of the pesticide (Arbeli and Fuentes, 2007; Gamliel and Triky-Dotan, 2009; Triky-Dotan et al., 2008). The list of herbicides, insecticides, nematicides, and fumigants that undergo accelerated degradation has been collected and continues to grow (Arbeli and Fuentes, 2007). Accelerated degradation of 1,3-dichloropropene has been studied in Florida and the Netherlands (Lebbink et al., 1989; Smelt et al., 1989a, 1989b; Verhagen et al., 1996). The effect of repeated applications of metam-sodium and the production of methyl isothiocyanate (MITC) have also been studied (Smelt et al., 1989a; Verhagen et al., 1996). Smelt found that the transformation of MITC was much faster in soils that had been previously treated versus soil that had never been treated (Verhagen et al., 1996). Several different soil types were fumigated with MITC and over the course of three years, all soils exhibited accelerated degradation of MITC (Smelt et al., 1989a).

It is currently unknown whether the repeated application of pure DMDS or DMDS with the addition of Pic undergoes accelerated degradation in a field setting. Pic is a soil fumigant that is commonly used in conjunction with other fumigants to increase the spectrum of control against soil-borne fungal pathogens, beyond what each could achieve if used alone (Anonymous, 2010; MacRae et al., 2010). It is also unknown whether the addition of Pic to DMDS increases the soil persistence. Therefore, it is the objective of this study to determine the effect of repeated application of DMDS and DMDS:Pic on dissipation.

2. Materials and methods

Four field experiments were conducted at the North Florida Research and Education Center (NFREC) in Quincy, Florida during the spring and fall of 2014 and 2015. Soil type in the field used for these experiments was Dothan-Fuquay complex consisting of loamy fine sand. Soil was cultivated to a depth of 25 cm before each fumigation event and had a moisture content of ~70%. 318 L/ha of 100% DMDS (Paladin) (TriEst Ag Group, Tifton, GA) and 374 L/ha of 79:21% DMDS:Pic (Paladin:Pic) (w/w) (TriEst Ag, Tifton, GA) was shank applied using a single row combination bed press with bed dimensions 76 cm wide and 20 cm high with three swept back shanks 28 cm apart. Fumigant was released 20 cm below the raised bed surface and white-on-black Vaporsafe® (Raven Industries Inc., Sioux Falls, SD) polyethylene mulch with 0.02794 mm thickness was deployed concurrently with fumigant in the fall experiments and black Vaporsafe® mulch of the same thickness in the spring experiment. Black mulch is used in the spring to raise soil temperatures, while white-on-black is used in the fall, allowing soil temperatures to remain constant. Plots were 30.5 m long with row spacing of 1.8 m with four rows per plot. The experimental set up was a randomized complete block design with four replications. Fumigant applications were made in the same plot as the previous treatment, with the same treatment, therefore treatments were superimposed in the same plots and replications for all field trials. This was accomplished by placing flags at the corner of each outside bed to ensure fumigant was applied in the same general area as the preceding application. Fumigant was applied on May 19, 2014 and July 23, 2014 and on March 4, 2015. Due to a rain event, the fall 2015 application was split with DMDS:Pic being applied on July 2nd and pure DMDS applied one week later on July 9th.

Fumigant persistence data was collected using a MiniRAE 3000 photoionization meter with a 9.8-eV lamp (RAE Systems, San Jose, CA) that measures volatile organic compounds (VOCs) in the air. The lamp utilized detects DMDS, but is not sensitive to Pic, therefore readings obtained from the soil were DMDS. A particle filter was attached to prevent soil particles from entering the meter. Intermittent VOC measurements were taken to determine when fumigant began to dissipate from the soil to concentrations below the meters maximum concentration. The MiniRAE 3000 has a maximum detection concentration of 1000 ppm DMDS. When fumigant reached readable concentrations, measurements were taken every other day until readings were at concentrations that are acceptable for planting. All VOC readings were taken in the afternoon on days when sampling occurred. Measurements were taken equidistant from the bed middle and shoulder. A wooden dowel rod with a diameter of 1.3 cm was inserted vertically into the bed to a depth of 15.2 cm. The MiniRAE probe was immediately inserted into the headspace once the wooden dowel rod was removed. The particle filter creates a seal with the mulch and readings were recorded when concentrations stabilized or reached a peak before decreasing. Four subsamples were taken in each of the two middle rows of each experimental plot. Once measurements were taken, polyethylene tarp tape (BAC Industries Inc., Minneapolis, MN) was used to cover the hole, preventing further fumigant escape.

Additional measurements were taken from separate sampling holes. Soil temperature under the plastic was measured using a S-TMB-M002 12-bit Temperature/RH Smart Sensor (Onset Computer Corp., Bourne, MA) that was attached to a HOBO micro station data logger that recorded and stored temperature values. The sensor was in the soil at a depth of 1.3 cm and recorded temperature every 30 s, averaging measurements every 2 min.

The persistence data were combined by days after treatment and the means were analyzed. Statistical differences between treatments were determined by analysis of variance by day after treatment (DAT) at $P < 0.05$.

3. Results and discussion

3.1. Spring 2014

Average daily minimum soil temperature during this experiment was 24.2 °C. The DMDS:Pic treatment in this experiment persisted in the soil for a longer period of time than the pure DMDS treatment (Fig. 1).

The Paladin® label states that for soil temperatures 21.7 °C and higher, the planting interval is 21 days after the application is complete (Anonymous, 2014). The planting interval is based on the average daily minimum soil temperature and not fumigant concentration, however, another study used concentration to determine the planting interval, as a high fumigant concentration can cause phytotoxicity in seedlings and transplants (McAvoy and Freeman, 2013). The mixture of DMDS and Pic persisted in the soil at a higher concentration than is allowed for planting to occur until more than 36 DAT. Pure DMDS had dissipated from the soil and was at a low enough concentration for planting to occur after 27 DAT. All sampling dates revealed significant treatment differences with the exception of 17 DAT.

The addition of Pic increases the soil persistence of DMDS significantly more than if pure DMDS was applied alone. The increase in persistence of DMDS:Pic resulted in potentially phytotoxic concentrations of fumigant in excess of 36 DAT, which for many producers is unacceptable. The concentration of pure DMDS began to drop after 17 DAT and were at an acceptable planting level after