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Efficacy of dimethyl disulfide and metam sodium combinations for the control of nutsedge species

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ABSTRACT

Dimethyl disulfide (DMDS) is a methyl bromide alternative with good to excellent nutsedge control when mixed with chloropicrin (Pic). Combining fumigants is a common practice to improve pest control spectrum, however, the use of Pic is restricted in some countries. In order to determine the legitimacy of replacing Pic in DMDS:Pic combinations, a low and high rate of metam sodium (MNa) was used alone and in combination with DMDS and were compared to a single rate of DMDS alone and in combination with Pic to determine their efficacy against nutsedge species and impact on muskmelon yield. All DMDS combinations resulted in lesser nutsedge populations than MNa alone and the non-treated control. MNa applied alone, even under totally impermeable film, was not enough to control nutsedge species. DMDS combinations also provided greater nutsedge control than DMDS applied alone at seasons end. Furthermore, MNa applied concurrently with DMDS may have the potential to replace DMDS:Pic combinations without losing efficacy on nutsedge species in geographies where the use of Pic is restricted.

1. Introduction

For more than 5 decades, methyl bromide was used by vegetable and fruit producers across the globe for the control of soil-borne pathogens, weed species, and nematodes (USDA ERS, 2000). As a result of its high vapor pressure, MBr could quickly reach pests at substantial depths due to the rapid expansion throughout the soil profile (Eshel et al., 1999). The high vapor pressure of MBr also allows it to dissipate from the soil quickly, enabling producers to plant crops into the previously fumigated soil only days after treatment without the threat of crop loss due to phytotoxicity.

The Montreal Protocol on Substances that Deplete the Ozone Layer sanctioned the phase-out of MBr as a consequence of the role it plays in the depletion of the stratospheric ozone layer (US EPA, 2014). The ban has forced vegetable producers to use alternative fumigants that are often more expensive and less efficacious, leading to higher input costs, increased pest incidence, and subsequently, decreased yield and profits.

Nutsedge species are exceptionally troublesome in plasticulture due to the strong midrib and sharp leaf tip that allows it to penetrate plastic mulch. Yield loss due to nutsedge competition can be significant. Previous research has shown yield loss due to purple nutsedge (*Cyperus rotundus*) in tomato and pepper to be as high as 51% and 73%, respectively (Gilreath et al., 2005; Morales-Payan et al., 1997). Yellow nutsedge (*Cyperus esculentus*) competition in watermelon resulted in yield loss of 98% (Buker et al., 2003). Leaf morphology of nutsedge species compounded with the ineffectiveness of methyl bromide alternatives to control nutsedge makes nutsedge control a primary factor to consider in fumigant research (Devkota et al., 2013; Santos et al., 2007).

Current alternatives used by vegetable producers include fumigants such as, 1,3-dichloropropene (1,3-D), chloropicrin (Pic), and metam sodium (MNa). When used singly, these and other fumigants are often considerably less efficacious than MBr. In order to increase the spectrum of control, fumigants are commonly combined or co-applied with each other (Noling et al., 2013). For example, dimethyl disulfide (DMDS) and Pic applied alone resulted in marginal nutsedge control, however when combined, nutsedge control increased significantly and was not significantly different than MBr combined with Pic (MacRae and Culpepper, 2006). Both Pic and 1,3-D are weak on sedge species, but when combined, provide good control, especially when used with totally impermeable film (TIF) (Stevens et al., 2016). Unfortunately, Pic cannot be used in some countries and has been shown to significantly increase the soil persistence of DMDS, up to 54 days post-fumigation (Stevens and Freeman, 2017). All fumigants currently registered in the U.S. have lower vapor pressures and boiling points than MBr which limits their distribution through the soil profile and can contribute to reduced or inconsistent efficacy. Recent work has demonstrated that the intentional placement of fumigants in close proximity to target pest

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organisms can improve efficacy (Jacoby et al., 2015; Noling et al., 2015). This strategy may prove effective with other fumigants where placement is targeted to the portion of the soil profile where pest species are most likely to arise from.

DMDS has proven to be one of the more promising fumigants for control of nutsedge species (McAvoy and Freeman, 2013a). One study reported DMDS controlling nutsedge populations as well as MBr, resulting in similar or greater pepper yields (Culpepper et al., 2006). Olson and Rich (2007) found that DMDS controlled yellow nutsedge as well as MBr, while 1,3-D resulted in nutsedge populations similar to a non-treated control. Unfortunately, DMDS has a pungent sulfur odor that can be detected by the human nose at very low concentrations and can require lengthy plant-back periods, especially when mixed with Pic (Stevens and Freeman, 2017). It is unclear how well DMDS performs without the addition of Pic, but some preliminary data indicates nutsedge control is reduced without Pic (Freeman, unpublished data). This could be critical for its adoption, especially for weed control in areas where Pic use is restricted or prohibited.

Another chemistry used for pre-plant soil fumigation is MNa, which generates the biocide methyl isothiocyanate (MITC) as the primary metabolite and active agent (Thongsinthusak, 2000). In 2007, MNa was the third most used pesticide in the world with 50–55 million pounds of active ingredient used (Grube et al., 2011). Many producers use MNa because it is cost effective. Despite its popularity among vegetable producers, MNa has provided inconsistent results against nutsedge species and pathogenic fungi. One study reported poor nutsedge control with MNa resulting in 32–56% control, compared to 100% control with MBr (Locascio et al., 1997). Another study reported unacceptable control of nutsedge species by MNa when applied alone, with control increasing by 12% with the addition of Pic (Unruh et al., 2002). Alternatively, Gilreath and Santos (2004) found that MNa controlled nutsedge populations as well as MBr. Like other currently available fumigants, MNa does not move readily through the soil profile. It has been shown to be effective against nutsedge but its erratic performance may result from a lack of contact or proximity to target organisms.

In order for a fumigant to be effective, it must contact the pest in adequate concentration for an adequate period of time (Munnecke and Van Gundy, 1979). To increase efficacy, fumigants are often used in conjunction with a plastic mulch, or film. Applying fumigant under plastic mulch increases the retention of fumigant, thereby increasing efficacy. Two of the more commonly used films are low- and high-density polyethylene. These films consist of a single layer of polyethylene and are relatively easy to deploy and inexpensive, therefore, producers prefer to use them over newer films (Santos et al., 2012). Virtually impermeable film (VIF) and TIF are more advanced films with less permeability to fumigants. Both VIF and TIF are multi-layer films produced by coextrusion, either with a layer of polyamide or, as with TIF, a layer of ethyl vinyl alcohol to impart superior fumigant retention (Fennimore and Ajwa, 2011). As a result of its low permeability, TIF is the only film that can be used in conjunction with DMDS in Florida due to odor issues (US EPA, 2015). It has been demonstrated that fumigants use rates can also be reduced when used with TIF without compromising efficacy (McAvoy and Freeman, 2013a, 2013b; Qin et al., 2011; Stevens et al., 2016).

The goal of this research is to determine the efficacy of DMDS used alone, in combination with MNa or Pic, and MNa alone against nutsedge species and their impact on muskmelon yield. The rationale behind this research is to determine whether or not MNa has the potential to replace Pic in DMDS:Pic combinations due to use restrictions on Pic in some areas.

2. Materials and methods

During the spring of 2016 and spring 2017, experiments were conducted at the North Florida Research and Education Center in Quincy, Florida. Soil type for spring 2016 was Dothan-Fuquay complex sandy loam. Soil type for spring 2017 was Norfolk loamy fine sand. Soil was cultivated to a depth of 25 cm before fumigation, fertilized according to soil test results, and had a moisture content of ~75% at fumigation. Treatments were applied using a single row combination bed press with three back-swept shanks spaced equidistantly across the bed width. Each shank was equipped with two release ports, one 10 cm below the bed surface and one 20 cm below the bed surface. The following treatments were applied singly; 374 L/ha of 79:21% DMDS:Pic (Paladin:Pic) (w/w) (Tri-Est Ag, Tifton, GA), 318 L/ha of 100% DMDS (Paladin) (Tri-Est Ag, Tifton, GA), and 372 and 468 L/ha of MNa (Vapam) (AMVAC Chemical Corporation, Los Angeles, CA). Both rates of MNa were applied singly using the top ports on the dual port shanks. DMDS:Pic and DMDS were released through the bottom ports, 20 cm below the raised bed surface. 318 L/ha of pure DMDS was also applied simultaneously with 372 L/ha of MNa or 468 L/ha of MNa, DMDS was deployed through the bottom ports and MNa was deployed through the top ports. Also included was a non-treated control. Bed dimensions were 76 cm wide and 20 cm high. Fumigant was deployed under 0.03175 mm thick white-on-black Total Blockade® TIF (Berry Plastics Corporation, Evansville, IN) with the black side showing. Black mulch is used in the spring to increase soil temperature. Irrigation was provided through trickle tubing the deployed concurrently with the mulch. Experiments were arranged in a randomized complete block design with four replications. Plots were 30.5 m long with between-row spacing of 1.8 m. Fumigant applications occurred on March 10, 2016 and February 28, 2017.

Purple (*C. rotundus*) and yellow (*C. esculentus*) nutsedge shoots that had emerged through the mulch were counted at 30, 60, and 90 days after treatment (DAT) in the planting area of 10.4 m in the center of each experimental plot, except for the spring 2016 trial which was only counted 60 and 90 DAT due to negligible nutsedge density 30 DAT. No other weed species were present.

Trials were planted when the plant-back interval had been reached (Anonymous, 2014, 2010), April 8, 2016 and March 22, 2017, at which point a single row of 'Athena' muskmelon (*Cucumis melo* L.) (Syngenta Seeds, Boise, ID) seedlings were transplanted into the field. Plant spacing was 50.8 cm, allowing for 20 plants per plot. Muskmelon were harvested at appropriate intervals. Yield data collected was fruit count and total weight. Average air temperature at 60 cm during the spring 2016 and 2017 trials was 20.48 °C and 19.25 °C, respectively. Average soil temperature at a depth of 10 cm for spring 2016 and 2017 was 21.15 °C and 20.32 °C, respectively.

Data were analyzed using SAS version 9.4 (SAS Institute, Inc., Cary, NC). Nutsedge population data were analyzed using the PROC MIXED procedure, square root transformed, and analyzed using repeated measures analysis ($\alpha = 0.05$). Yield data were analyzed using the PROC GLM procedure and subjected to one-way ANOVA. Treatment means determined to be significantly different were separated using Tukey's honestly significant difference at $P < 0.05$.

3. Results and discussion

Nutsedge population data was collected at 30 DAT only during the spring 2017 experiment. The data show that all treatments containing DMDS resulted in significantly lower nutsedge populations than MNa applied alone and the control. When MNa was applied alone, it resulted in nutsedge populations lower than the control, however, they were higher than all DMDS treatments.

Due to there being no interaction between treatment and season, spring 2016 and spring 2017 nutsedge population data were combined. At 60 DAT, 374 L/ha DMDS:Pic, 318 L/ha DMDS + 468 L/ha MNa, and 318 L/ha DMDS + 372 L/ha MNa showed significantly lesser nutsedge populations than the control and both MNa treatments with 2.07, 4.07, and 3.99 shoots/m^2, respectively, but were similar to 318 L/ha DMDS (Table 1). Also at this interval, 318 L/ha DMDS had lesser nutsedge population than the control, but was similar to all other treatments. At