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Efficacy of Metam Sodium Under Drip and Surface Spray Application in Florida Tomato Production

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ABSTRACT

The most effective soil fumigant for the past 40 years for preplant chemical control of nematodes, weeds, and fungal pathogens in Florida vegetable production has been methyl bromide (MBr). Unfortunately, MBr has been implicated in depletion of stratospheric ozone, and is slated to be banned in the United States. A possible alternative replacement to MBr is metam sodium (MS, sodium N-methyl dithiocarbamate). However, previous field trials have reported inconsistent pest-pathogen control efficacy. The objective of the present study was to compare the effectiveness of MS applied via drip irrigation versus surface spray application followed by soil incorporation on pest-pathogen control and tomato (*Lycopersicon esculentum* Mill.) production. Two field tests were conducted at the Plant Science Research and Extension Unit, Citra, Florida to compare these MS application methods to conventional MBr soil fumigation. The average total marketable tomato yield from pre-plant MBr fumigation from the two field trials was 79,800 kg ha^{-1}. Control plots resulted in significantly lower yields than that of MBr, ranging from 15,900 to 53,700 kg ha^{-1}. Although total yields from MS fumigation was not significantly different than that of MBr, total marketable yields were suppressed with 64,000 kg ha^{-1} under drip irrigation and 70,800 kg ha^{-1} under surface sprayed MS fumigation practices followed by soil incorporation. Results from these studies show the difficulty in pest-pathogen control for MS use in Florida sandy soils, as root-knot nematode and nutsedge weed problems continued to hinder tomato crop production relative to yields observed under MBr shank soil fumigation.

RESUMEN

El fumigante de suelo mas efectivo durante los últimos 40 años en Florida para el control químico presiembra de nemátodos, malezas, y hongos patógenos en hortalizas ha sido el bromuro de metilo (BrM). Desafortunadamente, el BrM se ha relacionado con la disminución del ozono estratosférico y se ha enlistado para prohibirse en los Estados Unidos. Un posible substituto alternativo para el BrM es el metano de sodio (MS, ditiocarbamato N-metil de sodio). Sin embargo, experimentos previos en campo han indicado inconsistencia en la eficacia para el control de los patógenos y plagas. El objetivo de este estudio fue comparar la efectividad de la aplicación de MS vía irrigación por goteo contra la aplicación por asperjado en la superficie del terreno seguida de incorporación de suelo, sobre la producción y el control de plagas y patógenos en tomate (*Lycopersicum esculentum* Mill). Se realizaron dos experimentos de campo en la Unidad de Investigación y Extensión Botánica en Citra, Florida para comparar estos métodos de aplicación con el método convencional de fumigación de suelo. El promedio del rendimiento total del tomate comercializable en los dos experimentos de campo fumigado con BrM fue 79,800 kg ha^{-1}. Las parcelas testigo presentaron rendimientos significativamente mas bajos que aquellos del BrM, que variaron de 15900 a 53,700 kg ha^{-1}. Aunque los rendimientos totales de la fumigación con MS no fueron significativamente diferentes que las de BrM, los rendimientos comercializables fueron menores obteniéndose 64,000 kg ha^{-1} bajo condiciones de irrigación por goteo y 70,800 kg ha^{-1} con la aplicación por aspersión en la superficie seguida de incorporación de suelo. Los resultados de estos estudios mostraron la dificultad para controlar plagas y patógenos con el uso de MS en los suelos arenosos de Florida, donde el nemátodo nodular de la raíz y las malezas continúan disminuyendo los rendimiento de la cosecha de tomate en comparación con los rendimientos observados con la fumigación del suelo con BrM.

Additional index words: methyl bromide alternatives, drip fumigation, pest control

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The most effective control for nematodes, weeds, and fungal pathogens has been soil fumigation using methyl bromide (MBr). Although MBr is an effective pesticide, it may be harmful to human health and the environment by potentially causing the depletion of stratospheric ozone (U. S. Environmental Protection Agency, 1993; Yung et al., 1980). The bromine atom is about 60 times more potent than chlorine at destroying stratospheric ozone by effectively converting ozone to oxygen (Anonymous, 1998; Yagi, et al., 1995). Due to this fact, the production of MBr was scheduled to end in the USA by 2005 (Hileman, 2004). Because of the apparent future loss of MBr, other soil fumigants are being investigated as potential replacements. Some of the more common alternative fumigants are 1,3-dichloropropene; chloropicrin (trichloronitromethane); and methyl isothiocyanate (MITC) generating compounds (Locascio, et al., 1997); while iodomethane (methyl iodide) is another possible alternative that is being developed but has not yet received registration by the U.S. Environmental Protection Agency).

Vegetable production in Florida and California has relied heavily on the use of MBr for well over 35 years for pest management and yield stability. Most preplant soil fumigant use in the U.S. occurs in these two states for tomato, strawberry, pepper, ornamentals, nurseries, grapes and melon production (Ristaino and Thomas, 1997; Wilhelm and Paulus, 1980). Unless satisfactory alternatives for MBr are found, the National Biological Impact Assessment Program concluded that its loss will result in a serious negative economic impact on agriculture in the U.S. Current estimates of yield losses are estimated to range from 13 to 25% depending on the crop (Subbarao, 2002). In regions of California and Florida where pre-plant MBr fumigation is performed land is of premium value and to make farming profitable requires a continuous production of high-value cash crops. Tomato is one such high-value crop where repetitive MBr soil fumigation provides large economic benefits on relatively small acreage (Chellemi, et al., 1994; Noling, 1997).

Metam-sodium (sodium N-methyl dithiocarbamate) has been used as a stand-alone fumigant in Florida tomato and California strawberry production, and is a potential replacement to MBr (Noling and Becker, 1994). Metam-sodium (MS) applied to soil quickly degrades to MITC, a volatile gas with broad spectrum control activity against weeds, plant-parasitic nematodes, oomycota, and various plant-pathogenic fungi (Kreutzer, 1963). The behavior of MS and MITC has been extensively investigated (Trout and Ajwa, 1998), but inconsistent efficacy has been reported in many parts of the U.S. (Gan, et al., 2000). Even though MS is a registered fumigant and available on the market, growers are hesitant to use it widely due it's unreliable reputation. Metam sodium is a water soluble chemical that is not very mobile in soil and typically requires careful mechanical placement or exact delivery with water to the treatment zone to achieve effectiveness. Infiltration of MS into the soil from overhead sprinkler systems or through drip irrigation lines are some of the more commonly used water deliver methods (Trout and Ajwa, 1999). Application of MBr to soil is typically done by injecting the chemical directly into the soil, where shank-mounted tubes are pulled through the soil at 20-30 cm depth followed by covering the bed with polyethylene (PE) film (Nelson, et al., 2000). Targeted application of MS to the soil by shank injection is also possible, but because MITC has a much lower vapor pressure than that of MBr the gas moves only a short distance from where it is injected. This often leads to inconsistent pest-pathogen control due to inadequate movement of MITC in the soil pore space (Ajwa, et al., 2002). The poor lateral dispersion of MS, especially in sandy soils of the southeast, require increased focus on cultural practices and chemical delivery systems that can provide pest-pathogen control similar to that obtained under conventional MBr use.

The objective of this research was to evaluate the effectiveness of two different preplant soil fumigation methods of applying MS in the field on pest-pathogen control and tomato production. One method of application involves the spraying of MS over the soil surface followed immediately by soil incorporation and covering with polyethylene mulch. The second method involves MS applied through drip irrigation lines, in a process known as drip fumigation. The effectiveness of these MS treatment methods is compared against typical shank injected application of MBr.

MATERIALS AND METHODS

This study was conducted during the spring of 2003 at the University of Florida, Plant Science Research and Education Unit at Citra, Marion County, FL. The experimental area was previously covered with trees and grass, and used as grazing land until 1999. Afterwards, the experimental site became infested with purple nutsedge (*Cyperus rotunda* L.) and yellow nutsedge (*C. esculentus* L.) and a mixed population of nematode species, *Meloidogyne incognita* (root-knot nematode, RKN), *M. arenaria*, and *M. javanica*. This site was selected for soil fumigant evaluation studies using MBr and MS in preplant tomato production due to the extensive pest-pathogen pressure. The soil was an Arredondo fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleudult) with 950, 30, 20, and 15 g kg^{-1} sand, silt, clay, and organic matter, respectively, and slightly acidic (pH 6.5) to a depth of 1 to 2 m.

Two field sites were designated as: 1) the North field site, and 2) the South field site, according to their location at the research farm. Each field site was approximately 0.53 ha in size, and the two field sites were adjacent to each other, separated by a distance of 5 m. The North and South field sites were arranged in a randomized complete block design with each field site consisting of 10 replicated blocks with 5 rows per block. The five rows per block contained randomized treatments, including an untreated (non-fumigated) control treatment in one row, MBr shank fumigation in one row, and MS fumigation in 3 rows. Thus, at both the North and South fields there were a total of 10 untreated control and 10 MBr treatments, and 30 MS treatments per site. The higher number of MS treated plots was included in the study to better evaluate the effectiveness of applying MS through drip irrigation lines vs. soil incorporated surface spray methods. Pre-plant soil fumigation was performed on the North field site on 19 February 2003, and the South field site was fumigated on 11 March 2003. A pre-plant fertilizer, 6% N -17% P_2O_5 -16% K_2O

at a rate of 934 kg ha^{-1} (56N-70P-124K kg ha^{-1}), was applied using a drop spreader over a 0.9 m bed width and incorporated into the top 0.3 m soil. Post-transplant fertilization of tomato plants through drip lines was performed weekly for 10 weeks using a mixture of 16.8 kg N ha^{-1} as NH_4NO_3 and 7.6 kg K ha^{-1} as KCl for a season total of 224N-159P_2O_5-241K_2O (224N-70P-200K) kg ha^{-1}. Row spacing between beds was 0.9 m (1.8 m bed center to bed center), and each raised bed (0.9 m wide x 12.2 m long x 0.23 m high) was shaped and covered with 0.038 mm black polyethylene plastic (PE) film immediately following soil fumigant application. Two thin-walled Chaplin (Watermatics, Watertown, NY) drip tubes (0.3 m emitter spacing and flow rate of 1.9 L min^{-1} per 30 m) were installed per bed, and tubes spaced 0.3 m apart and 0.15 m from the center of each bed.

The day prior to chemical treatments, beds were irrigated with 2.5 cm water to raise the moisture level to enhance chemical movement within the bed. In February, pre-plant chemical treatments included: 1) MS broadcast surface sprayed over the top of the bed; and 2) MBr shank applied via 3 chisels spaced 0.3 m apart and 0.2 m deep into the raised bed and immediately covered with black PE film. The surface spray treatment was done by applying MS in a 1.83-m wide band followed immediately by a Kennco powerbedder (Kennco Manufacturing, Inc., Ruskin, FL) to rototill the fumigant into the soil and shape a raised bed. A second tractor, which followed, pulled a Kennco mini-combo superbedder to reshape and cover the bed with PE film. In March, pre-plant chemical treatments included: 1) MS applied via 2 drip irrigation lines per bed; and 2) MBr shank applied as previously described. The chemical rate for MBr treatments was 390 kg ha^{-1} applied as 67% MBr + 33% chloropicrin. The February MS treatment was applied at the recommended rate of 700 L ha^{-1}, whereas, the March drip application was inadvertently applied at higher rate of 880 L ha^{-1}. The MS source (Metam CLR®, 42% metam sodium) was supplied by The Metam Sodium Task Force. These chemical treatments were compared against untreated raised beds (no chemical treatment) covered with PE mulch.

On 15 March (spray on MS, North field site) and 30 March (drip MS, South field site) twenty five ‘Florida 47’ tomato (*Lycopersicon esculentum* Mill.) seedlings were transplanted per bed at a spacing of 0.45 m. Tomato fruit from the February fumigated plots were harvested on two harvest dates, 5 June and 16 June 2003. Tomato fruit from the March fumigated plots were only harvested once on 18 June 2003. The fruit were sized on a commercial grader, and fruit weight recorded separately for extra large, large, and medium. Culls were discarded. After harvest, a total plant count was taken on 19 June 2003 by evaluating the number of live plants remaining per row. Twelve tomato plants per row were dug out of the ground and visually rated for RKN gall damage on 19 June 2003. A visual rating index of 0 to100 was subjectively created based on a scale of 0 = no galling, 10 = 10% galled, …, 100 = 100% galled root system (Barker, et al., 1986). Weed pressure was evaluated visually over the growing season, with final nutsedge weed density counts taken using a 0.25 m^2 template on the west side of the raised beds on 24 June 2003.

Meterological data collection. An on-site meterological station recorded air temperature fluctuations throughout the two studies, with 12-28ºC in February and 13-29ºC in March. Soil surface temperatures were also recorded with February soil temperature ranging 13-22ºC (2.5 cm depth, grass covered soil) and March temperature ranging 17-33ºC (2.5-18.0 cm depth, bare soil). Thus, February and March air and soil temperature readings during the two study periods were of similar temperature range.

Data analysis. A separate statistical analysis was performed for the North and South locations as the total amount of MS applied in these field sites was significantly different at the start of fumigant application. Data were subjected to analysis of variance (ANOVA) using the general linear model procedures of SAS (SAS Institute, Cary, NC). Treatment means were separated using Duncan’s multiple-range test (Freund and Little, 1981).

RESULTS AND DISCUSSION

MS surface spray evaluation. Tomato yields for the February fumigation for surface spray incorporation of MS were compared to MBr and untreated soil treatments. Total marketable tomato yield was significantly lower ($P \leq 0.05$) in untreated rows compared to MBr and MS fumigated soils as shown in Table 1. Total tomato yield from untreated plots was approximately 18% (15,900 kg ha^{-1}) of that from MBr-treated plots (87,500 kg ha^{-1}). Fruit yields from control plots were significantly lower in all marketable size classes (extra large, large, and medium sized fruit) compared to those tomato from MBr injection and MS surface spray plots (Table 1).

Total marketable tomato yield for soils surface sprayed with MS were not statistically different from traditional MBr treatment. However, on average marketable yields in all tomato size classes were lower than yields obtained from MBr treated plots (Table 1). Total marketable yields for MS (70,800 kg ha^{-1}) surface spray treatments were approximately 81% that of MBr (87,500 kg ha^{-1}) treatments.

The lower average yield from MS treated compared to MBr fumigated soils do not appear to be related to an increased number of dead plants. This is evident as tomato plant count results are very similar and not statistically different from one another in all treatments (Tables 1, 2). Therefore, another mechanism or pest-pathogen is most likely the cause for variation among treatments. Weed pests can cause substantial tomato crop yield suppression. Yellow and purple nutsedge weed pressure was found to be intense (8 to 9 times that observed under MBr treatment) throughout this study as evident by weed counts from the MBr (1,000 weeds ha^{-1}) treated plots being significantly lower ($P \leq 0.05$) than both the untreated (9,100 weed ha^{-1}) and MS (8,200 weeds ha^{-1}) surface spray treated plots (Tables 1). Weed pressure was greatest within the untreated plots, but MS surface spray plots did not control nutsedge any better than the control treatment. Obviously weed densities of this magnitude result in reduced nutrient and water availability to the crop and may possibly result in increase plant pathogen problems that can contribute to lower crop yield.

Another common pathogen in Florida sandy soils is RKN. Root galling was significantly reduced by the MBr treatment but not by MS treatments (Table 1). Root systems from MBr

Table 1. Effect of metam-sodium (MS) applied via surface spray treatments on plant growth, weed and root-knot nematode management on marketable tomato (cv. Florida 47) yield in a field trial at the Plant Science Unit, Citra, FL. Spring 2003.

					Marketable Tomato Yield (kg/ha x 1000)			
Treatment	Rate/ha	# Plants/ha[1]	% Galling[2]	#Weeds/ha[3]	Extra Large	Large	Medium	Total
Untreated	-	21.1 a	66.3 a	9.1 a	4.3 b	4.7 b	6.9 b	15.9 b
MBr [4]	390 kg	21.1 a	2.9 b	1.0 b	31.3 a	27.3 a	28.9 a	87.5 a
MS [5]	700 L	21.1 a	47.4 a	8.2 a	24.9 a	23.3 a	22.6 a	70.8 a

Shown are means of ten replications for Untreated and MBr treatments, and thirty replications for MS treatment.
Means within a column followed by a common letter are not different according to Duncan's multiple-range test ($P \leq 0.05$).
[1]Average number of tomato plants per ha (x 1000).
[2]Average percentage galling on 12 plants per bed was subjectively rated based on a scale of 0 = no galling, 10 = 10% of root system galled, …, 100 = 100% of the root system galled (Barker, et al., 1986).
[3]Average number of nutsedge plants per ha (x 1000) that penetrated through the mulch were counted in a 25 x 25-cm square on the west side of the bed.
[4]Applied with 3 chisels spaced 30-cm apart, 20-cm deep into a preformed 90-cm wide bed, 23-cm tall.
[5]Applied in 183-cm wide band (spray) over flat soil surface and immediately pulled into a 90-cm wide bed, 23-cm tall, with a Kennco power bedder; applied 19 February 2003 on the North field site.

Table 2. Effect of metam-sodium (MS) applied via drip fumigation treatments on plant growth and root-knot nematode management on marketable tomato (cv. Florida 47) yield in a field trial at the Plant Science Unit, Citra, FL. Spring 2003.

				Marketable Tomato Yield (kg/ha x 1000)			
Treatment	Rate/ha	# Plants/ha[1]	% Galling[2]	Extra Large	Large	Medium	Total
Untreated	-	18.8 a	61.5 a	11.1 a	19.9 b	22.7 b	53.7 b
MBr[3]	390 kg	20.2 a	2.2 b	14.7 a	26.9 a	30.5 a	72.1 a
MS[4]	880 L	18.8 a	38.3 ab	11.7 a	24.7 ab	27.6 ab	64.0 ab

Shown are means of ten replications for Untreated and MBr treatments, and thirty replications for Met-Na treatment. Means within a column followed by a common letter are not different according to Duncan's multiple-range test ($P \leq 0.05$).
[1]Average number of tomato plants per ha (x 1000).
[2]Average percentage galling on 12 plants per bed was subjectively rated based on a scale of 0 = no galling, 10 = 10% of root system galled, …, 100 = 100% of the root system galled (Barker, et al., 1986).
[3]Applied with 3 chisels spaced 30-cm apart, 20-cm deep into a preformed 90-cm wide bed, 23-cm tall.
[4]Applied via 2 drip lines/bed spaced ca. 30-cm apart; applied 11 March 2003 on the South field site.

treated soils were approximately 3% galled in comparison to 47% and 66% galled in MS and untreated soils, respectively. The lack of pathogen control observed in the surface sprayed MS treatment suggests that this application method to Florida's sandy soils will not adequately prevent crop loss by a common plant pathogen like RKN or a weed pest like nutsedge.

MS drip fumigation. Total marketable tomato yields of MS drip treatments were slightly lower in the March, than in the February treated fields. [This may be due to the fact that February fumigated fields were harvested twice in comparison to March treated fields only receiving a single harvest event.] Although this disparity exists between the number of harvest events, similar trends in yield among treatments were observed in both the February and March field studies (Tables 1, 2). Total yield from non-fumigated control plots (53,700 kg ha^{-1}) in Table 2 showed significantly lower ($P \leq 0.05$) tomato fruit than MBr plots (72,100 kg ha^{-1}). However, total yields from MS drip fumigated plots were not statistically different ($P > 0.05$) from MBr-treated plots (Table 2), but average marketable yields were still lower in the MS drip-applied soils (64,000 kg ha^{-1}) than the MBr treatments (72,100 kg ha^{-1}). Slight differences in marketable size fruit classes were observed in the MS drip fumigation study with no statistical differences between treatments for the extra large fruit size category (Table 2). In all other marketable size classes and total marketable yield, MS applied via drip irrigation lines resulted in yields that were intermediate that of MBr and untreated soils (not statistically different at the P = 0.05 level).

Variation within the total number of live plants at harvest did not affect treatment effects on yields. This is evident by live plant numbers not being significantly different from each other, although plant numbers ranged from 18,800 in untreated soils and MS-treated beds to 20,200 plants ha^{-1} in MBr-treated soil (Table 2). Once again, this may suggest that dead plants were not the major contributing factor for observed tomato yield differences among treatments.

Insufficient pest-pathogen control in the untreated and MS drip fumigated plots is the reason for lower average tomato yields. Nutsedge weed counts were not taken after the March fumigation treatments, but visual assessments were noted. Dr. Don Dixon (nematologist, University of Florida) noted from in-field observations that, "nutsedge growth on the drip test site was very eradic, as MS suppressed nutsedge for about 3-4 weeks before it ripped through the plastic mulch and out of the soil." Thus, long term nutsedge control was not accomplished using MS drip applications as similarly observed when MS was applied using surface spray treatments. Data was collected on RKN root galling and pathogen control evaluations were able to be performed on MS drip application. Untreated soils resulted in significantly ($P \leq 0.05$) higher galled tomato root systems than MBr treated soil (Table 2). Tomato root galling from soil treated with MS via drip irrigation (38% galled) was not statistically different ($P > 0.05$) than that observed under MBr (2%) and control (62%) treatments. The lack of pathogen control in both the untreated and MS drip fumigated soils would cause the average lower yields displayed in these studies.

CONCLUSIONS

This research confirms the dilemma facing farmers to find a viable replacement for MBr in Florida tomato production. Applying MS either by drip irrigation or by surface spray application followed by soil incorporation led to very erratic field pest-pathogen control. Some MS treated areas exhibited good weed and RKN control while other areas had intense weed problems and 100% RKN galling of tomato roots. A suitable method for applying MS in Florida's deep sandy soils that will adequately provide season long RKN control has not yet been found. Results from the drip fumigation studies showed that even applying MS at a rate 1.25 times higher than the recommended label rate is still insufficient to control nutsedge growth and RKN. In some situations during this study, we observed more galling in tomato roots where MS was used than in the untreated control plots. Recommended label rate for MS under surface spray application resulted in average tomato yields 81% that of standard MBr shank injection. Application of MS at a higher rate through drip lines still resulted in suppressed yields with an average marketable tomato yield of 89% of that produced under MBr fumigation. It appears that when MS is used as an alternative to MBr, additional herbicide and nematicide chemical control will be necessary in Florida soils to adequately suppress RKN and nutsedge proliferation and to reach yields equivalent to standard MBr fumigation. In the absence of soil fumigation total marketable tomato yields ranged from 18 to 74% of yields under MBr use, further demonstrating the continual need for field trials focusing on finding an adequate replacement for MBr in Florida horticulture crop production.

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