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Effects of Midas® on Nematodes in Commercial Floriculture Production in Florida

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Abstract: Cut flower producers currently have limited options for nematode control. Four field trials were conducted in 2006 and 2007 to evaluate Midas® (iodomethane:chloropicrin 50:50) for control of root-knot nematodes (*Meloidogyne arenaria*) on *Celosia argentea* var. *cristata* in a commercial floriculture production field in southeastern Florida. Midas (224 kg/ha) was compared to methyl bromide:chloropicrin (98:2, 224 kg/ha), and an untreated control. Treatments were evaluated for effects on *Meloidogyne arenaria* J2 and free-living nematodes in soil through each season, and roots at the end of each season. Plant growth and root disease were also assessed. Population levels of nematodes isolated from soil were highly variable in all trials early in the season, and generally rebounded by harvest, sometimes to higher levels in fumigant treatments than in the untreated control. Although population levels of nematodes in soil were not significantly reduced during the growing season, nematodes in roots and galling at the end of the season were consistently reduced with both methyl bromide and Midas compared to the untreated control. Symptoms of phytotoxicity were observed in Midas treatments during the first year and were attributed to Fe toxicity. Fertilization was adjusted during the second year to investigate potential fumigant/fertilizer interactions. Interactions occurred at the end of the fourth trial between methyl bromide and fertilizers with respect to root-knot nematode J2 isolated from roots and galling. Fewer J2 were isolated from roots treated with a higher level of Fe (3.05%) in the form of Fe sucrate, and galling was reduced in methyl bromide treated plots treated with this fertilizer compared to Fe EDTA. Reduced galling was also seen with Midas in Fe sucrate fertilized plots compared to Fe EDTA. This research demonstrates the difficulty of reducing high root-knot nematode population levels in soil in subtropical conditions in production fields that have been repeatedly fumigated. Although soil population density may remain stable, root population density and disease can be reduced.

Key words: Celosia argentea, floriculture, iodomethane, methyl bromide, root-knot nematodes, management, *Meloidogyne arenaria*, Midas®.

The continuing phase-out of methyl bromide in developed countries is nearing its completion date, with current preplant applications allowed only under Critical Use Exemptions (CUE), which must be requested on an annual basis, with continuing reductions in allocations each year (USEPA, 2009). Currently, cut flower producers have limited alternatives to broadcast fumigation with methyl bromide for nematode, soilborne pathogen, and weed control, and face some unique problems with regard to employing alternative fumigants. Problems include the proximity of many production fields to developed areas, the lack of registered herbicides for these crops, and the need to control volunteers from previously grown varieties (Rosskopf et al., 2009b). Root-knot nematodes (*Meloidogyne* spp.) are one of the primary pests in cut flower production historically controlled with methyl bromide. The wide host range of root-knot nematodes, combined with the great diversity of cut flower varieties produced, and the lack of known resistance, renders some control tactics, such as the use of crop rotation or resistant varieties, ineffective.

Iodomethane has shown potential as an alternative to methyl bromide for control of several important pests in cut flower production (Kokalis-Burelle et al., 2006; Rosskopf et al., 2006, 2007, 2008, 2009b), and has recently been registered for use as Midas® (iodomethane: chloropicrin, Arysta LifeScience Corp., Cary, NC). The objective of this research was to evaluate Midas for effects on parasitic and free-living nematode population levels in soil, and for control of root-knot nematodes (*Meloidogyne arenaria*) on celosia over multiple cropping cycles.

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Materials and Methods

Field trials were conducted in 2006 and 2007 in a commercial floriculture production field in southeastern Florida infested with root-knot nematode, *Meloidogyne arenaria*. Soil type at the site was an Oldsmar fine sand. Two cropping cycles were evaluated each year for a total of four tests, with fumigant applications prior to each test. The crop, *Celosia argentea* var. *cristata*, commonly known as cockscomb, is highly susceptible to *M. arenaria*. Treatments included an untreated check, Midas 50:50® (http://www.cdms.net/LDat/ld8FK004.pdf) applied at 224 kg/ha (200 lb/A), and methyl bromide:chloropicrin (98:2) applied at 224 kg/ha (200 lb/A). The reduced rate of methyl bromide (224 kg/ha) applied under virtually impermeable film (Klerk's Plastic Products Manufacturing, Inc., Clarksburg, SC) was found to be comparable to the grower standard in two previous trials (Rosskopf, unpublished). Fumigants were applied to a depth of approximately 29 cm through 6 shanks spaced at approximately 30 cm. All plots were covered with metalized mulch (Canslit, Inc., Montreal, Quebec, Canada) immediately after fumigation. Beds were 1.8 m wide by 30.5 m long. Treatments were applied to planting beds, which were immediately covered with plastic mulch. Treatments were replicated four times and arranged in a randomized complete block design. Plastic mulch was removed 15 days after fumigation and celosia cultivar Chief Rose (VIS Seed Company Inc., Arcadia, CA) was seeded five days later. Standard crop management practices were employed by the grower and included foliar fungicides and insecticides, and fertilizers. Fertilizer application during the first two growing seasons was a standard 6N-6P-6K (nitrogen-phosphorus-potassium) with Fe oxide (0.66%). Following the onset and identification of what appeared to be Fe toxicity symptoms in the Midas treated plots during the second season, this fertilizer was discontinued and calcium nitrate was applied for the remainder of the season. Fertilization was modified in the second year of the study in order to determine if there was an interaction between fertilizer and fumigant. In the 2007 spring and fall field trials, the iodomethane-treated blocks remained in the same locations as in the two previous field seasons. All fumigant main plots were split into two fertilizer treatment subplots. Both fertilizers were formulated as 10N-4P-10K, but one contained a higher level of Fe (3.05%) in the form of Fe sucrate (fertilizer A) and one contained Fe EDTA (0.08%) (fertilizer B).

Data on soil nematode population levels, gall ratings, and plant growth parameters were collected from four meter-long sample areas within each replication. Nematode levels in soil were assessed immediately before fumigation, and at approximately 2, 10, and 16 weeks after fumigation. Ten soil cores were taken to a depth of approximately 40 cm in each plot using a 1.75-cm internal diameter soil probe and combined. A 100-cm^3 subsample was used for nematode extraction. Nematodes were extracted from both soil and roots using the Baermann funnel technique and were identified as *Meloidogyne* spp. and free-living (microbivorous and predatory) nematodes. Gravid females were extracted from roots and identified as *M. arenaria* based on enzyme phenotypes using the Phast system (GE Healthcare Bio-Sciences Corp., Piscataway, NJ) (Esbenshade and Triantaphyllou, 1985; 1990). At 16 weeks after fumigation, plants were destructively sampled. Roots were evaluated for galling and nematodes were extracted from roots. After the final harvest, plants were removed from the soil and plant growth measurements, including top weight and root weight were recorded. Roots were also rated for galling and root condition. Root condition was used as a general indicator of root disease and was assessed using a subjective scale of 0 to 4 with 0 = 0% to 20% discolored roots, 1 = 21% to 40%, 2 = 41% to 60%, 3 = 61% to 80%, and 4 = 81% to 100%. Root galling was assessed using a root gall index based on a scale of 0 to 10, with zero representing no galls and 10 representing severe (100%) galling (Bridge and Page, 1980).

Data analysis: For Spring 2006, the data from one plot was dropped due to insufficient application of fumigant. All other data were analyzed with mixed models analysis of variance using the PROC MIXED procedure in SAS for either a randomized complete block (2006) or a split-plot (2007) design (http://www.ats.ucla.edu/stat/sas/library/SASExpDes_os.htm#SPD(RCBD,RCBD)f). Calculations for mean separations in 2007 were performed by the macro designed by Saxton (1998) and are reported as significant at $P \leq 0.05$.

Results

At the initiation of the research in January 2006, pre-fumigation soil population levels of *M. arenaria* were high, with no differences among treatment areas (Table 1). Also, no differences were detected in population levels of free-living nematodes in the treatment areas (Table 1). Following fumigation in February 2006, Midas reduced all nematode levels compared to the untreated control (Table 1), however, by midseason, all soil nematode levels had rebounded, and no differences were observed among treatments (Table 1).

At crop harvest in May, population levels of both *M. arenaria* and free-living nematodes were higher in the methyl bromide treated soil than in untreated soil (Table 1). The late resurgence in *M. arenaria* J2 isolated from soil, however, was not reflected in higher numbers of J2 isolated from roots, or increased galling (Table 2). Both Midas and methyl bromide reduced *M. arenaria* J2 isolated from roots and galling compared to the untreated control. However, only root systems from Midas treated soil were larger than those from the untreated control (Table 2). Because Midas plots had slightly greater galling than methyl bromide this increase in weight may be attributable to increased galling.

In fall 2006, pre-fumigation soil nematode levels were lower than in the spring trial and again did not differ among treatment areas (Table 3). Fumigation did not reduce *M. arenaria* J2 in soil in August or September (Table 3). At harvest in fall 2006, plants in methyl bromide-treated plots had lower soil population levels of

Table 1. Nematodes/ 100 cm^3 soil – Spring Trial 2006.

Pre-fumigation (12 January)	*M. arenaria* J2/ 100 cm^3 soil	Free-living nematodes #/ 100 cm^3 soil
Untreated Control	185.1[1]	7.4
Methyl Bromide	181.5	5.5
Midas	141.9	3.7
Post-fumigation (9 February)		
Untreated Control	102.1	31.2 a[1]
Methyl Bromide	56.7	11.3 b
Midas	34.0	4.2 b
Midseason (23 March)		
Untreated Control	87.2	27.6
Methyl Bromide	87.9	54.6
Midas	81.9	32.0
Harvest (12 May)		
Untreated Control	62.2 b	150.3 b
Methyl Bromide	119.1 a	234.6 a
Midas	102.7 ab	194.2 ab

[1] Means within the same column and date with no letter, or with the same letter, are not significantly different according to LSD at $P \leq 0.05$.

TABLE 2. Nematodes/g root and disease at end of season (18 May) – Spring Trial 2006.

	M. arenaria J2/g root	Free-living nematodes #/g root	Root Weight (g)	Gall rating[1]
Untreated Control	12.2 a[2]	28.1	6.3 b	1.6 a
Methyl Bromide	4.4 b	21.1	11.6 ab	0.1 b
Midas	3.5 b	17.0	13.8 a	0.6 b

[1] Gall rating scale (1-10) where 1 = no galling and 10 = root system completely galled (Bridge and Page, 1980).
[2] Means with no letter or with the same letter are not significantly different according to LSD at $P \leq 0.05$.

M. arenaria J2 than the untreated control plots (Table 3). As in the previous season, the unpredictable response of *M. arenaria* J2 in soil during this cropping cycle was not indicative of population levels isolated from roots at the end of the season, nor of plant growth (Table 4). Both fumigants reduced root-knot nematodes and free-living nematodes isolated from roots at the end of the season, and both reduced galling compared to the untreated control (Table 4). Although Midas was superior to methyl bromide in reducing galling, methyl bromide increased root and shoot weight in coparison to Midas (Table 4).

Before the second year of field trials began, untreated control plots from the previous two seasons were switched with plots previously treated with methyl bromide to reduce weeds in the untreated areas, while Midas treated plots remained in the same location. Interestingly, pre-fumigation numbers of *M. arenaria* in soil were highest in the untreated control plots (previously methyl bromide plots) (Table 5). Midas plots, which remained in the same location throughout the course of all reported experiments, had higher numbers of free-living nematodes at the end of the season. No differences in root-knot nematode population levels were detected in soil at any sample time during this season (Table 5).

TABLE 4. Nematodes/g roots and disease at end of season – Fall Trial 2006.

	M. arenaria J2/g root	Free-living nematodes #/g root	Shoot weight (g)	Root weight (g)	Root disease[1]	Gall rating[2]
Untreated Control	89.8 a[3]	104.3 a	44.9 c	11.3 b	3.1	5.5 a
Methyl Bromide	8.3 b	9.0 b	119.0 a	18.7 a	2.6	4.3 b
Midas	22.8 b	18.0 b	95.0 b	11.8 b	3.1	3.3 c

[1] Root disease rating: 0 = no disease, clean, white roots, 4 = total disease, discolored, rotted roots.
[2] Gall rating scale (1-10) where 1 = no galling and 10 = root system completely galled (Bridge and Page, 1980).
[3] Means with no letter or with the same letter are not significantly different according to LSD at $P \leq 0.05$.

As in the previous two seasons, *M. arenaria* J2 isolated from roots in both fumigant treatments were lower than in roots from the untreated control (Table 6). Galling and root disease were also lower with both fumigants, and root weight was increased (Table 6). Methyl bromide was superior to Midas for improving root health and weight in this trial (Table 6). There were no significant differences between fertilizers and no interactions among fumigants and fertilizers for any of the parameters measured during this crop cycle.

In fall 2007, pre-fumigation soil nematode population levels were low for root-knot nematodes and did not differ among treatments (Table 7). Also, there were no differences in free-living nematode levels among treatments before fumigation (Table 7). As in the previous trial, no differences in *M. arenaria* J2 levels in soil were

TABLE 3. Nematodes/ 100 cm^3 soil – Fall Trial 2006.

Pre-fumigation (21 July)	*M. arenaria* J2/100 cm^3 soil	Free-living nematodes #/100 cm^3 soil
Untreated Control	8.5[1]	72.8
Methyl Bromide	52.5	134.7
Midas	12.8	85.0
Post-fumigation (16 August)		
Untreated Control	78.0	0.0
Methyl Bromide	68.0	0.0
Midas	96.4	0.0
Midseason (20 September)		
Untreated Control	48.2	2.8
Methyl Bromide	70.9	1.4
Midas	80.1	7.8
Harvest (26 October)		
Untreated Control	99.2 a	145.3
Methyl Bromide	44.6 b	82.9
Midas	65.9 ab	96.4

[1] Means within the same column and date with no letter, or with the same letter are not significantly different according to LSD at $P \leq 0.05$.

TABLE 5. Nematodes / 100 cm^3 soil – Spring Trial 2007.

Pre-fumigation (25 January)	*M. arenaria* J2/100 cm^3 soil	Free-living nematodes #/100 cm^3 soil
Untreated Control	341.6 a[1]	340.2
Methyl Bromide	92.1 b	164.4
Midas	163.0 b	589.7
Post-fumigation (15 February)		
Untreated Control	65.2	146.0
Methyl Bromide	12.8	239.6
Midas	36.9	260.8
Midseason (5 April)		
Untreated Control	14.2	131.1 b
Methyl Bromide	31.9	219.0 a
Midas	8.5	194.9 ab
End of season (17 May)		
Untreated Control	12.0	143.2 b
Methyl Bromide	56.0	148.8 b
Midas	54.6	312.6 a

[1] Means within the same column and date with no letter, or with the same letter, are not significantly different according to LSD at $P \leq 0.05$.

TABLE 6. Nematodes /g roots (25 May) – Spring Trial 2007.

	M. arenaria J2/g root	Free-living #/g root	Root weight (g)	Gall rating[1]	Root disease[2]
Untreated Control	1215.8 a[3]	700.0 a	2.5 b	5.5 a	1.3 a
Methyl Bromide	20.5 b	21.5 b	12.7 a	3.0 b	0.0 b
Midas	46.6 b	37.7 b	9.6 a	3.7 ab	0.3 b

[1] Gall rating scale (1-10) where 1 = no galling and 10 = root system completely galled (Bridge and Page, 1980).
[2] Root Disease Rating: 0 = no disease, clean, white roots, 4 = total disease, discolored, rotted roots.
[3] Means with no letter or with the same letter are not significantly different according to LSD at $P \leq 0.05$.

detected for the remainder of the growing season following fumigation (Table 7).

Significant interactions occurred among soil treatments and fertilizer for nematodes isolated from roots and root galling at the end of the season (Table 8). With the high iron fertilizer (fertilizer A), there were no differences among soil treatments for the number of *M. arenaria* J2 isolated from roots, but there was a significant reduction in galling with both fumigants compared to the untreated control. With the fertilizer containing lower amounts of iron EDTA (fertilizer B), more *M. arenaria* J2 were isolated from roots in both fumigant treatments, but there was no difference in galling among treatments (Table 8). Significantly more J2 were isolated from subplots treated with the lower iron content fertilizer in methyl bromide fumigated main plots compared to the fertilizer containing higher levels of iron, and galling was higher in both methyl bromide and Midas treated main plots fertilized with lower iron levels compared to higher levels. No interaction among soil treatment and fertilizer occurred with respect to root weight or root disease. As in previous trials, both fumigants increased root weight and decreased root disease at the end of the season compared to the untreated control (Table 8).

TABLE 7. Nematodes/ 100cc soil – Fall Trial 2007.

Pre-fumigation (3 August)	*M. arenaria* J2/100 cm^3 soil	Free-living nematodes No./100 cm^3 soil
Untreated Control	1.4[1]	193.5
Methyl Bromide	1.4	158.0
Midas	1.4	103.5
Post-fumigation (31 August)		
Untreated Control	0.0	51.0
Methyl Bromide	0.0	25.5
Midas	0.0	28.3
Midseason (12 October)		
Untreated Control	0.0	93.6 b
Methyl Bromide	0.7	143.9 a
Midas	0.0	97.8 ab
Harvest (23 November)		
Untreated Control	17.0	221.1
Methyl Bromide	20.5	159.5
Methyl Iodide	29.8	189.2

[1] Means within the same column and date with no letter, or with the same letter, are not significantly different ($P \leq 0.05$) (Saxton, 1998).

DISCUSSION

Successful nematode control with alternative fumigants is dependent on understanding how these compounds move through soil, affect nematodes in soil throughout the season, and how plants respond to nematodes at the end of the season. The difference in physical properties between Midas and methyl bromide required that application methods be modified to optimize results with Midas. Methyl bromide's high vapor pressure allows for rapid and thorough distribution through soil, enhancing its effectiveness as a fumigant, while Midas has a lower vapor pressure requiring more precise application techniques (Rosskopf et al, 2009). The similar efficacy and consistency of Midas compared to methyl bromide for reducing population levels of nematodes in soil was somewhat unexpected due to the lower vapor pressure and reduced movement of Midas through soil. However, the primary ingredient in Midas (iodomethane) is highly toxic (California Department of Pesticide Regulation, 2009) and this may compensate for reduced rates of soil movement in Midas.

Many ornamental growers use broadcast fumigation applied to flat (not bedded) land, and employ commercial fumigators for the application. The preference for use of broadcast fumigation is due to increased efficacy due to an increase in area treated, and the need to treat around infrastructure such as shade enclosures used for production of many cut-flower crops. In addition, the density with which the ornamental crops are seeded or transplanted also necessitates the use of full field fumigation. Current labeling for Midas allows the application of the material under standard films, but the allowable rates may be more effective if applied under a highly retentive film. The film used in these studies had approximately twice the retention of methyl bromide compared to a standard flat fumigation film, but is not comparable to a virtually impermeable film (VIF). Application of Midas at a slightly reduced rate of 196 kg/ha (175 lb/A) under VIF may provide enhanced control such as that seen with MB under VIF (Gilreath et al., 2005). The difficulty joining VIF sheets together to accomplish full field fumigation has been addressed with the use of new materials applied on small acreage, but this approach has not been validated on larger acreage (Rosskopf, personal observation). In the trials presented here, the selection of the Canslit metalized film was based on the observation that some growers had success with utilizing the material in full field fumigation and in smaller scale field trials, and its use allowed for a rate reduction of methyl bromide (Rosskopf et al, 2007).

These experiments document the response of nematodes in fumigant treated compared to non-treated soil in the same commercial field, over multiple seasons and

TABLE 8. Nematodes isolated from roots and root disease incidence (16 November) - Fall Trial 2007.

	M. arenaria nematodes J2/g root		Free-living nematodes No./g root		Gall rating[1]			
Fertilizer:	A[3]	B	A	B	A	B	Root weight (g)	Root disease[2]
Untreated	23.7[4]	14.1	131.3	97.1	7.2 a	6.3	9.6b	3.4 a
Methyl bromide	15.2*	38.3	59.6	92.1	4.2 b*	6.0	13.4a	3.2 b
Midas	22.0	33.7	74.2	85.3	5.0 b*	5.9	13.4a	3.0 b

[1] Gall rating scale (1-10) where 1 = no galling and 10 = root system completely galled (Bridge and Page, 1980).
[2] Root Disease Rating: 0 = no disease, clean, white roots, 4 = total disease, discolored, rotted roots.
[3] Fertilizer treatments applied to subplots. Both fertilizers were formulated as 10N-4P-10K, but one contained a higher level of Fe (3.05%) in the form of Fe sucrate (fertilizer A) and one contained Fe EDTA (0.08%) (fertilizer B).
[4] Means with no letter or with the same letter are not significantly different ($P \leq 0.05$) (Saxton, 1998).
* Means differ between fertilizer A and fertilizer B for this treatment and variable. LSD ($P \leq 0.05$) value for *M. arenaria* J2/g root for fertilizers in methyl bromide plots was 19.0. LSD ($P \leq 0.05$) value for gall rating for fertilizers in methyl bromide and Midas treated plots were 0.9 and 0.8 respectively.

fumigant applications under subtropical conditions. Nematode population levels in soil were highly variable and somewhat unreliable in predicting disease incidence at the end of the season. Although numbers of nematodes in soil were sometimes not significantly reduced, or rebounded during the growing season, numbers of nematodes in roots and galling at the end of the season were consistently reduced to the same degree with methyl bromide and Midas compared to the untreated control. Interactions occurred between fumigants and fertilizers resulting in increased galling and nematode population levels in roots at the end of the fourth trial. Specifically, interactions occurred between methyl bromide and fertilizers with respect to *M. arenaria* J2 isolated from roots and galling. Fewer J2 were isolated from roots treated with a higher level of Fe (3.05%) in the form of Fe sucrate, and galling was reduced in methyl bromide plots treated with this fertilizer compared to Fe EDTA. Reduced galling was also seen with Midas in Fe sucrate fertilized plots compared to Fe EDTA. Research to determine the nature of this fertilizer/fumigant interaction is on-going.

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