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FUMIGANT ALTERNATIVES TO METHYL BROMIDE FOR MANAGING NEMATODES AND WEEDS IN SNAPDRAGON

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Abstract. **Effect of several soil fumigants on plant-parasitic nematodes, weeds, and snapdragon (*Antirrhinum majus* L.) production were evaluated in a commercial site in southeast Florida in 2002-03. Treatments consisted of methyl bromide (98%) + chloropicrin (2%), metam sodium, metam sodium + chloropicrin, and a nontreated control. All fumigant treatments reduced ($P < 0.05$) weed populations compared to the nontreated control. Stubby-root nematode (*Paratrichodorus* spp.) numbers were reduced initially by the soil fumigants, but recovered after 5 months. Root-knot nematode (*Meloidogyne* spp.) levels were low, variable, and not affected ($P > 0.10$) by treatment. Heights of plants in nontreated plots were stunted compared to plants in fumigated plots, and more plants were lost (8.7%) from nontreated plots than from fumigated plots (2.1%). The number of cut flowers harvested from nontreated plots was 7.0% lower than the harvest from plots treated with methyl bromide + chloropicrin. In most instances, the performance of the alternative fumigants, metam + chloropicrin or metam alone, was similar to that of methyl bromide + chloropicrin.**

Florida ranks second among U.S. states in ornamental crops, including foliage plants, bedding plants, and cut flowers, with a total production value of $743 million in 2001 (Florida Agricultural Statistics Service, 2002). Many ornamental crops are produced in containers, but some, such as caladium (*Caladium* × *hortulanum* Birdsey) and certain cut flowers, are produced directly in the field (Gilreath et al., 1999; McSorley and Wang, 2002). While field production is economical, crops may be exposed to nematodes, weeds, and other soilborne problems. Currently, soilborne pest problems are managed by fumigation with methyl bromide, a chemical that is facing increasing restrictions and impending phase-out (McMillan and Bryan, 2001; Obenauf, 2002). Much work on chemical alternatives to methyl bromide has been conducted on vegetable crops (Obenauf, 2002), but the need for alternatives is critical on floral and other ornamental crops as well (Gilreath et al., 1999; McSorley and Wang, 2002).

Many flower crops are susceptible to problems with root-knot nematodes (*Meloidogyne* spp.) (Goff, 1936). These include a number of species that are commonly grown for cut flower production, such as snapdragon (*Antirrhinum majus*

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L.), lisianthus (*Eustoma grandiflorum* [L.] Cass.), sunflower (*Helianthus* spp.), and gladiolus (*Gladiolus* spp.) (McSorley and Wang, 2002). While there is potential for managing root-knot nematodes on some floral crops such as salvia (*Salvia* spp.) through the use of resistant cultivars (McSorley and Frederick, 2001), resistant cultivars in many flowers species are unknown or not widely available. Therefore, the need for chemical methods for managing root-knot nematodes remains a priority.

The objective of the research presented here was to evaluate the efficacy of several common fumigant alternatives to methyl bromide for managing nematodes and weeds in floral production. Snapdragon was used as a test crop due to its well-known susceptibility to root-knot nematodes (Goff, 1936; Tarjan, 1952).

Materials and Methods

The research was conducted at a commercial cut flower production site in Martin County, Fla., during 2002-03. Soil at this site consisted of 96% sand, 1% silt, and 3% clay. Four treatments were established in a randomized complete block design with four replications: methyl bromide + chloropicrin, metam sodium, metam sodium + chloropicrin, and nonfumigated control. Individual plots were 3.2 m wide × 13.7 m long (10.5 ft × 45 ft). Methyl bromide (98%) + chloropicrin (2%) was injected in broadcast fashion over each appropriate plot at a rate of 504 kg ha^{-1} (450 lbs/acre). Metam sodium was drenched on the soil surface at 701 L/ha (75 gal/acre) and rototilled to a depth of 20-30 cm (8-12 in). In the plots receiving the metam + chloropicrin treatment, chloropicrin was injected at 168 kg ha^{-1} (150 lbs/acre) immediately after the metam sodium application and rototilling was complete. All treatments were applied by a commercial applicator (Hendrix and Dail, Inc., Palmetto, Fla.) on 21 Aug. 2002. Immediately after treatment applications were completed, all plots (including controls) were covered with clear plastic sheeting, which remained in place until 4 Sept. Following removal of the plastic, two beds, with centers 1.5 m (5 ft) apart, were formed within each plot area.

Plugs with small (1-2 cm tall) snapdragon seedlings were planted at a rate of 120 plants per 1.0 m of bed on 30 Sept. (replications 1 and 2) and 23 Oct. (replications 3 and 4). Several different cultivars of snapdragon were used, as is typical in commercial production to provide a range of colors and maturity. Replication 4 was planted with 'Pot Pink', replication 3 with 'Pot Ivory', replication 2 with a mixture of 'Pot Ivory' and 'Pot Pink', and replication 1 with a mixture of 'Pot "Pink' and 'Rocket White'. The crop was fertilized, irrigated, and maintained according to standard grower practices. Cut flower harvest began in December and extended into April, depending on cultivar and planting date. Flower stems were cut about 3-5 cm (1-2 in) above ground level at peak bloom. Shoot regrowth from the base can sometimes provide a second cutting from the same plant.

A section of one bed, 7.6 m (25 ft) long, was used for data collection within each plot. Soil samples for nematode analysis were collected 5 times during the growing season. On each sampling date, a single soil sample consisting of 6 soil cores (2.5 cm [1 in] diameter × 20 cm [8 in] deep) was collected from each plot. In the laboratory, nematodes were extracted from a 100-cm^3 (0.2 pt) soil subsample using a standard sieving and centrifugation procedure (Jenkins, 1964). Plant-parasitic nematodes extracted were identified and counted. On 9 Oct. and 14 Nov., all weeds were counted per 7.6-m bed. Weeds were removed from each bed by the grower following the November evaluation. Data on plant performance were collected periodically throughout the growing season. These included plant heights of 10 plants per plot, number of plants blooming per m of bed, and number of plants that had been harvested per m of row from each plot.

Nematode data, weed data, and final harvest data were analyzed by analysis of variance (ANOVA) followed by mean separation using Duncan's new multiple range test (Freed et al., 1991). Because different cultivars and planting dates were used, it was not possible to directly analyze plant height data across the entire experiment. Plant heights in fumigated plots were standardized relative to nontreated controls of the same cultivar and planting date by the formula:

(Height in treated - height in control)/(height in control) × 100%

Data for the three fumigant treatments were then compared over the entire experiment by ANOVA (SAS Institute, Inc., 1985). One replication of the experiment was planted uniformly with the cultivar Pot Ivory (replication 3). In this case, heights of 10 plants from each of the 4 treatments (including control) in that replication were compared directly by ANOVA. In this way, a limited but direct comparison was possible among heights of plants in control plots and those in plots with the fumigant treatments. A similar analysis was performed on plant height data from replication 4, which had been planted uniformly to 'Pot Pink.'

Results and Discussion

Pigweed (*Amaranthus* spp.) and goosegrass (*Eleusine indica* [L.] Pers.) were the most common weeds present in this site (Table 1). Other weeds present, but at very low population levels, included purslane (*Portulaca oleracea* L.), bermudagrass (*Cynodon dactylon* [L.] Pers.), sida (*Sida acuta* Burm.), nightshade (*Solanum* spp.) black medic (*Medicago lupulina* L.), crabgrass (*Digitaria* spp.), nutsedge (*Cyperus* spp.) and dichondra (*Dichondra repens* J. R. Forst. & G Forst.). Pop-

Table 1. Effect of soil fumigation treatments on weeds in snapdragon test, fall 2002.

Treatment	Weeds per 7.6 m of row		
	Pigweed	Goosegrass	Total weeds
	9 Oct.		
Methyl bromide + CP[z]	0.25 b[y]	0.50 b	1.25 b
Metam sodium + CP	0.75 b	0.50 b	1.50 b
Metam sodium	0.25 b	0.25 b	0.50 b
Control	3.25 a	10.50 a	16.25 a
	14 Nov.		
Methyl bromide + CP	0.75 b	3.75 b	4.75 b
Metam sodium + CP	1.00 b	2.00 b	3.75 b
Metam sodium	0.25 b	1.00 b	2.00 b
Control	15.75 a	19.50 a	37.00 a

[z]CP = chloropicrin.
[y]Data are means of 4 replications. Means in columns for each sampling date followed by the same letter are not different ($P < 0.05$) according to Duncan's new multiple range test.

ulation levels of weeds, especially pigweed, increased from October to November. All of the fumigant treatments were effective in suppressing weeds on both sampling dates (Table 1). There were no differences ($P > 0.10$) among the three fumigant treatments in their performance against weeds. After the 14 Nov. evaluation, all weeds were manually removed by the grower to minimize future impact on the crop.

Stubby-root (*Paratrichodorus* spp.) and root-knot (*Meloidogyne* spp.) were the dominant plant-parasitic nematodes at this site (Table 2). Stubby-root nematode population levels were initially reduced by the soil fumigants, but recovered by January. The ability of stubby-root nematodes to recover following soil fumigation is well-known (Weingartner et al., 1983), making them difficult to control by this method. Stubby-root nematode populations in all plots peaked in January or February, and then declined later in the season as the snapdragon plants deteriorated following harvest. Stubby-root nematodes are not considered a major pest of flower crops, however little or no information is available on their impact on snapdragon or other floral crops.

Root-knot nematode, the key nematode pest of snapdragon, occurred at low population levels throughout the growing season (Table 2). Although there was a tendency toward greater numbers of root-knot nematodes observed in nonfumigated control plots, this trend was not significant ($P > 0.10$), and no significant impact of soil fumigants on root-knot nematode populations was observed throughout the experiment. Root-knot nematode populations were highly variable among replications.

Because several different snapdragon cultivars were used in this experiment, it is not meaningful to make direct comparisons of plant height across the entire experiment. However, by comparing the height of plants in a fumigated plot with the height of plants in the corresponding control plot of the same cultivar, it is possible to assess the performance of the fumigant treatments relative to the controls. For example, at 1.5 months after planting, the height of plants in plots treated with methyl bromide + chloropicrin was 131% of the height of plants in corresponding control plots (Table 3). At 1.5 months after planting, the heights of plants in fumigated plots were 28-46% greater than in control plots, but there were no significant differences ($P > 0.10$) among the three fumigant treatments (Table 3). At 2.5 months, the heights of plants in fumigated plots were only 8-18% greater than those in control plots, indicating some recovery of plants in control plots. In replication 3 (planted with 'Pot Ivory') and replication 4 (planted with 'Pot Pink'), the same snapdragon cultivar was used throughout the entire replication. When the heights of 10 plants from each treatment were compared within each of these replications, the advantage of fumigation treatment was apparent, especially in the 5 Dec. sampling (Table 4). On that date, plants of the cultivar Pot Ivory were 32.7% taller and 'Pot Pink' plants were 66.7% taller in plots treated with methyl bromide + chloropicrin than in nonfumigated control plots (Table 4). On 5 Dec., 'Pot Ivory' plants treated with metam alone were taller than those treated with methyl bromide + chloropicrin. In general, the differences in height between plants in control plots and those in treated plots decreased as the season progressed (Table 4). It is likely that the adverse impact of weeds on plant growth was greater earlier in the season, since weeds were removed from all plots (including controls) in mid-November.

Significantly ($P < 0.01$) more plants were harvested from fumigated plots than from control plots (Table 5). The number of plants harvested from control plots was 7.0% less than the harvest from plots treated with methyl bromide + chloropicrin. There were no differences ($P > 0.10$) among the three

Table 2. Effect of soil fumigation treatments on nematodes in snapdragon test, 2002-03.

Treatment	Nematodes per 100 cm^3 soil				
	9 Oct.	14 Nov.	15 Jan.	19 Feb.	10 Apr.
			Stubby-root nematodes		
Methyl bromide + CP[z]	0 b[y]	1.5 ab	47.8	84.5	6.0
Metam sodium + CP	0 b	0.2 b	43.2	84.5	9.8
Metam sodium	0 b	0.2 b	13.0	20.8	14.5
Control	13.2 a	3.5 a	55.8	20.2	8.2
			Root-knot nematodes		
Methyl bromide + CP	0	0	0.2	0	0
Metam sodium + CP	0	0	0	0	0.2
Metam sodium	0	0	0	0	3.0
Control	0	0.2	11.8	9.8	2.5

[z]CP = chloropicrin.
[y]Data are means of 4 replications. Means in columns for each nematode followed by the same letter are not different ($P < 0.10$) according to Duncan's new multiple range test. No letters in column indicate no significant effect at $P < 0.10$.

Table 3. Effect of soil fumigant treatments on plant heights of snapdragon at 1.5 and 2.5 months after planting.

Treatment	Plant height as % of control[z]	
	1.5 months	2.5 months
Methyl bromide + CP[y]	131[x]	108
Metam sodium + CP	128	114
Metam sodium	146	118

[z]Computed as (height of plants in treated plot - height of plants in control plot)/(height of plants in control plot) × 100%; height measurements were means of 10 plants per plot.
[y]CP = chloropicrin.
[x]Data are means of 4 replications. No differences among treatments at $P \leq 0.10$.

Table 4. Effect of soil fumigation on plant heights of two snapdragon cultivars, planted 23 Oct. 2002.

Treatment	Plant height (cm)		
	5 Dec.	15 Jan.	19 Feb.
-		Cultivar: Pot Ivory	
Methyl bromide + CP[z]	13.8 b[y]	55.1 a	93.1 ab
Metam sodium + CP	15.7 b	59.0 a	95.1 a
Metam sodium	19.2 a	61.6 a	89.1 b
Control	10.4 c	54.6 a	94.5 a
		Cultivar: Pot Pink	
Methyl bromide + CP	15.5 a	47.0 a	78.7 a
Metam sodium + CP	15.5 a	42.0 ab	75.4 a
Metam sodium	14.6 a	37.6 b	74.5 a
Control	9.3 b	41.4 b	63.6 b

[z]CP = chloropicrin.
[y]Data are means of 10 plant measurements. Means in columns for each cultivar followed by the same letter are not different ($P < 0.05$) according to Duncan's new multiple range test.

Table 5. Effect of soil fumigation on snapdragon plant production, 10 Apr. 2003.

Treatment	Harvested plants per m of row	Missing plants per m of row	Regrowth plants with blooms (per m)
Methyl bromide + CP[z]	117.8 a[y]	2.2 b	7.2 a
Metam sodium + CP	118.0 a	2.0 b	8.2 a
Metam sodium	116.8 a	3.2 b	5.2 a
Control	109.6 b	10.4 a	3.1 a

[z]CP = chloropicrin.
[y]Data are means of 4 replications. Means in columns followed by the same letter are not different ($P < 0.01$) according to Duncan's new multiple range test.

fumigant treatments in number of plants harvested. More plants (8.7% of total) were lost from control plots over the season than from fumigated plots (2.1% of total plants) (Table 5). Typically, some regrowth occurs from the base of harvested plants, and it is possible to obtain a second cutting from plants that had been harvested earlier. However, the number of plants with regrowth that had bloomed and was suitable for second harvest was generally low and not affected by the treatments (Table 5).

Losses in control plots were probably less than anticipated. One reason may be that the site had been fumigated annually with methyl bromide for several years, perhaps resulting in low pest pressure. The relatively low numbers of root-knot nematodes are consistent with this idea, and overall weed populations, averaging up to 4.9 plants per m of bed in control plots, are not particularly high. The dominant weeds present however, are large plants that can crowd and impact establishment of young snapdragon seedlings. Based on the data presented here, it is likely that loss of plants and stunted heights in control plots were due to impact of early-season weed growth in these plots. However, these losses were minimized as well, since weeds were removed in November, allowing some recovery of plants in control plots. If weeds, particularly a spreading weed like goosegrass, were not managed, then losses would likely have been much greater.

Under the conditions of this test, the efficacy of methyl bromide + chloropicrin and the two alternative fumigant treatments was similar in terms of crop production and management of weeds and nematodes. Based on these data, choice of one of the these fumigants could be based on cost and convenience rather than an efficacy. However, these treatments should be evaluated in additional tests over time. It is possible that prior use of methyl bromide in this site may have benefitted all treatments. It is not clear how fumigation for several seasons with methyl bromide may compare with several seasons of fumigation with an alternative fumigant.

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