FUMIGANT ALTERNATIVES TO METHYL BROMIDE IN NORTH FLORIDA U.S.A. TOMATO PRODUCTION[1]

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ABSTRACT

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Four field trials were conducted on loamy fine sand soils in northern Florida U.S.A. to determine efficacy of soil fumigant alternatives to methyl bromide for control of root-knot (*Meloidogyne* spp.) and reniform (*Rotylenchulus reniformis*) nematodes in tomato. Tests were conducted with commercially available fumigants and arranged in randomized complete block designs containing five or six replications. Fumigants and combinations varied but generally included 1,3-dichloropropene (1,3-D), methyl bromide (Mbr), and chloropicrin (Pic). Chemicals were applied on 0.91-cm-wide raised beds formed in 1.8-m-wide rows. Black polyethylene mulch, drip irrigation, and trellising were used in the tomato production system. Data collection in these tests included fruit yield, root gall indices, and reniform nematode soil population densities. Mbr and Mbr + Pic generally resulted in greatest reduction in root galling and reniform nematode populations in these tests. The 1,3-D + Pic and Pic alone treatments, however, approximated Mbr treatments in yield but varied somewhat in nematode control. These data indicated that soil treatments with 1,3-D + Pic or Pic may be used as chemical alternatives to Mbr, but appropriate rates of these materials should be further explored.

Key words: chloropicrin, dichloropropene, *Lycoperscion esculentum*, *Meloidogyne* spp., methyl bromide, reniform nematode, root-knot nematode, *Rotylenchulus renifromis*, Telone, tomato.

RESUMEN

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Cuatro ensayos de campo fueron llevados a cabo sobre francoso-arena fina en Florida, USA para determinar la eficacia de alternativas de fumigantes al bromuro de metilo para controlar nemátodos agalladores (*Meloidogyne* spp.) y el nemátodo reniforme (*Rotylenchulus reniformis*) en tomate. Se hicieron ensayos con fumigantes comerciales, organizados según el diseño de bloques completos hechos al azar conteniendo cinco o seis replicaciones. Los fumigantes y sus combinaciones variaban, pero incluían en general 1,3 dicloropropano (1,3-D), bromuro de metilo (MBr) y chloropicrina (Pic). Los químicos fueron aplicados sobre banquetas elevadas de 0.91 cm de anchura formadas en hileras de 1.8 metros de anchura. Una cobertura de polietileno negro y riego por goteo y enrejado fueron usados en el sistema de producción de tomate. Colección de datos en estos ensayos incluye cosecha de fruto, índices de agalladuras en las raíces, y densidades de poblaciones del nemátodo reniforme en el suelo. Mbr y Mbr+Pic generalmente resultaron en la mayor reducción de agalladuras en las raíces y poblaciones del nemátodo reniforme en estos ensayos. Sin embargo, los tratamientos de 1,3-D+Pic y solamente Pic eran similares en el efecto sobre la cosecha de frutos, pero variaban algo en el control de nemátodos. Estos datos indican que el tratamiento del suelo con 1,3-D + Pic o solamente Pic se pueden usar como alternativas químicas a Mbr, aunque se debería investigar más el uso de cantidades apropiadas de estos materiales.

Palabras clave: cloropicrina, dicloropropano, *Lycopersicon esculentum*, *Meloidogyne* spp., bromuro de etilo, nemátodo reniforme, nemátodo agallador, *Rotylenchulus reniformis*, Telone, tomate.

INTRODUCTION

Fresh market tomato (*Lycopersicon esculentum* Mill.) is an important vegetable crop in Florida U.S.A. During the 1999-2000 season, the crop was grown on over 17 000 ha and valued at over U.S. $418 million (Anonymous, 2000a). The production system almost universally practiced by growers in Florida is an intensively managed raised-bed system that includes soil fumigation, polyethylene mulch, drip or seepage irrigation, and trellising. This system produces yields that can exceed 60 MT/ha and has been in use for over 25 years (Overman and Martin, 1978). The application of the fumigant, methyl bromide (Mbr), sometimes with mixtures including chloropicrin (Pic), to control soilborne pests is a critical component of this production system (Noling and Becker, 1994). However, Mbr is scheduled for phaseout in the United States in 2005 (Anonymous, 2000b). A number of chemicals, combinations, and their rates have been tested as replacements for Mbr and some of these include 1,3-dichloropropene (1,3-D), Pic, metam sodium, and dazomet (Locascio *et al.*, 1997; Gilreath *et al.*, 1998; Rich *et al.*, 2003).

Plant-parasitic nematodes are a serious pest problem in northern Florida vegetable and agronomic production systems (Dunn and Noling, 1997). The major nematode problems include three *Meloidogyne* spp. (*M. arenaria*, *M. incognita*, and *M. javanica*) and *Rotylenchulus reniformis.* The widespread use of Mbr in fresh market tomatoes has substantially reduced damaging nematode populations in Florida tomato production areas. This is expected to dramatically change with the loss of Mbr. Potential chemical replacements have been reported from the central and southern tomato production areas of Florida and mainly include combinations of 1,3-D and Pic (Locasio *et al.*, 1997; Gilreath *et al.*, 1998). These tests, however, were conducted on deep sandy soils while tomato production in northwest Florida is on heavier soil types that include clay subsoil. Additionally, *R. reniformis* is widely present in northern Florida but limited in distribution in other Florida tomato production areas. The tests reported herein were conducted to determine performance of potential chemical alternatives to methyl bromide under edaphic and climatic conditions of the northern Florida production area.

MATERIALS AND METHODS

Four field trails were conducted at the University of Florida North Florida Research and Education Center, Quincy, FL, U.S.A. in an loamy fine sand soil (78% sand, 14% silt and 8% clay). The sites contained varying levels of root-knot (mainly *Meloidogyne javanica*) and reniform (*Rotylenchulus reniformis*) nematodes. The trials contained 4-8 fumigant treatments arranged in a randomized complete block design. Before fumigation, soil was moldboard plowed and double-disced in early March for the Spring trials and early July for the single Fall trial. Fertilizer was applied modified broadcast at the rate of

196-61-196 of N-P_2O_5-K_2O kg/ha in the Spring trials and at a rate of 131-40-131 of N-P_2O_5-K_2O kg/ha in the Fall trial and disc-incorporated. Treatments included Mbr, Pic, Mbr + Pic, 1,3-D, and 1,3-D + Pic, all at varying application rates, and nontreated controls (Tables 1-4). Fumigant applications were made using nitrogen gas as the propellant through a flow meter system. Unless otherwise noted, application of the chemicals was made with a single row bed press through 3 chisels spaced 30 cm apart on a 0.91-cm-wide raised bed (within 1.8-m-wide rows) and injected to 25 cm deep. Polyethylene mulch (1.25-mil) and double wall drip tubing were laid concurrently with chemical applications. Black polyethylene mulch was used in the Spring trials and white mulch in the Fall trial. In all trials, tomatoes were transplanted 51 cm apart in the row. Root galling indices were determined at the end of harvest on four plants in each plot and estimated using a 0-10 scale where 0 = no root galling and 10 = 100% of the root system galled. Additionally, six soil cores (2.5 cm diam.) to 25 cm deep were collected from each plot in tests infested with *R. reniformis*. Soil was processed with a modified centrifugation-flotation technique and vermiform stages of reniform nematodes counted (Jenkins, 1964). All fruit harvested from plots were separated by grade on a standard tomato grading line. Fruit was sized into medium, large and extra-large categories, weighed and small fruit was discarded. Data were analyzed with ANOVA and means separated with Duncan's multiple range test.

Spring 1997

The experiment contained five replications, and individual plots were single rows, 13.7 m long. Fumigants were applied on 4 March, and plots were transplanted to 'Agriset 761'on 24 March. Fruit harvests were made on 16 June, 26 June and 7 July from the center 12 plants of each plot. On 11 July, tomato plants were excavated from each plot and root gall assessments conducted. Soil samples for reniform nematode extraction were collected the same day.

Fall 1998

The experiment contained five replications, and individual plots were single rows, each 13.7 m long. Fumigants were applied on 4 August 1998, and 'Equinox' tomatoes were transplanted on 14 August. Fruit harvests were made on 9 November and 17 November from center 12 plants of each plot. Soil samples for nematode analysis were collected and root galling assessments were made in each plot on 24 November.

Spring 1999

The experiment contained six replications of single row plots, each 11.9 m long. On 26 February, 1,3-D + 17% Pic treatments were injected using a broadcast rig with 9 chisels spaced 30 cm apart (treatment width was 3.0 m with the center 1.8 m used) to a depth of 30 cm. Chemical treatments were applied on 12 March. 'FL 47' tomatoes were transplanted on 24 March, and harvests were made from the center 8 plants in each plot on 15 and 24 June. Soil samples for reniform nematode population assessment and root galling were made as stated previously on 6 July.

Spring 2001

The experiment contained six replications of single row plots, each 10 m long. Fumigants were applied on 14 March. 'BHN 444' tomatoes were transplanted on 9 April, and harvests were made from the

Table 1. Effect of fumigant treatment on root gall index, reniform nematode population densities and marketable yield of 'Agriset 761' tomatoes, Spring, 1997.

Treatment	L or kg/ha formulation[w]	Root gall index[x]	No. reniform/ 100 cm^3 soil	Fruit wt. (mt/ha)	
				Extra-large	Total[y]
Mbr 98% + 2% Pic	448 kg	0.6 bcz	0 d	53.9 ab	66.8 ab
Mbr 67% + 33% Pic	392 kg	0.1 c	660 b-d	56.4 ab	71.1 ab
Pic alone	392 kg	2.1 ab	1 005 bc	61.1 a	78.3 a
1,3-D + 35% Pic	112 L	2.2 ab	483 cd	49.2 ab	63.3 b
1,3-D + 35% Pic	168 L	2.9 a	1 194 a-c	49.9 ab	64.4 b
1,3-D + 35% Pic	224 L	0.8 bc	545 cd	54.4 ab	71.3 ab
1,3-D + 17% Pic	187 L	1.3 a-c	967 bc	51.6 ab	65.8 ab
1,3-D + 17% Pic	234 L	1.6 a-c	678 b-d	51.7 ab	63.9 b
1,3-D + 17% Pic	280 L	0.8 bc	500 cd	46.1 b	61.5 b
1,3-D + 17% Pic	327 L	1.5 a-c	586 cd	52.7 ab	65.7 ab
Control	—	3.0 a	2 039 a	48.1 b	65.7 ab

[w]Chemical rates listed are broadcast equivalent but only one-half of the area (in-bed) was treated.
[x]Root gall index based on a 0-10 scale where 0 = no galling and 10 = dead plants due to extensive galling.
[y]Total fruit weight was the sum of medium, large and extra-large grades.
[z]Column means followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

center 8 plants in each plot on 25 June and 9 July. Root galling assessments were made in each plot on 13 July.

RESULTS

Spring 1997

Root gall indices were reduced significantly over the nontreated control by the two Mbr treatments, the 1,3-D + 35% Pic at 224 L/ha and 1,3-D + 17% Pic at 280 L/ha treatments (Table 1). Reniform nematode population densities were highest in the nontreated control and were significantly higher than in all other treatments except 1,3-D + 35% Pic at 168 L/ha. Highest yield of extra-large fruit was produced by the Pic alone treatment, but it was only greater than the 1,3-D + 17% Pic at 280 L/ha and the control. Highest total yield was also with the Pic alone treatment which was significantly higher than the 1,3-D + 35% Pic treatments at 112 and 168 L/ha, and 1,3-D + 17% Pic treatments at 234 and 280 L/ha but not higher than the control.

Fall 1998

Highest root gall indices were in the nontreated control and 1,3-D + 35% Pic at 224 L/ha, and these were significantly higher than both Mbr treatments,1,3-D + 17% Pic at 327 L/ha, and Pic (Table 2). Reniform nematode population densities were highest in the Pic treatment and were significantly higher than all other treatments including the nontreated control. Lowest reniform nematode populations

Table 2. Effect of fumigant treatment on root gall index, reniform nematode population density and marketable yield of 'Equinox' tomatoes, Fall, 1998.

Treatment	L or kg/ha formulation[w]	Root gall index[x]	No. reniform/ 100 cm^3 soil	Fruit wt. (mt/ha)	
				Extra-large	Total[y]
1,3-D + 35% Pic	280 L	2.65 ab[z]	788 bc	40.1 a	51.2 a
Pic alone	336 kg	0.80 bc	1 817 a	39.4 a	51.1 a
1,3-D + 35% Pic	327 L	2.30 abc	486 cd	35.7 a	49.3 a
Mbr 67% + 33% Pic	392 kg	0.10 c	276 d	38.3 a	49.3 a
1,3-D + 17% Pic	327 L	0.40 c	66 d	37.8 a	49.1 a
Mbr 98% + 2% Pic	448 kg	0.15 c	182 d	37.0 a	48.4 a
1,3-D + 35% Pic	224 L	3.95 a	1 267 b	33.9 a	47.4 a
Control	—	3.85 a	812 bc	26.6 b	35.2 b

[w]Chemical rates listed are broadcast equivalent but only one-half of the area (in-bed) was treated.
[x]Root gall index based on a 0 -10 scale where 0 = no galling and 10 = dead plants due to extensive galling.
[y]Total fruit weight was the sum of medium, large and extra-large grades.
[z]Column means followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

were found in both Mbr treatments and the 1,3-D + 17% Pic treatment at 327 L/ha. All chemical treatments produced significantly higher yields of extra-large fruit and total yield than the nontreated control. No yield differences were found among chemical treatments.

Spring 1999

Reniform nematode populations were highest in the nontreated control and were significantly higher than the 1,3-D + 17% Pic treatments at 112 and 168 L/ha and the Mbr + 33% Pic treatment (Table 3). The 1,3-D + 17% Pic treatment of 112 L/ha produced the highest yield of extra-large and total yield but was only greater than the 1,3-D + 35% Pic treatment at 168 L/ha.

Spring 2001

Root gall indices were significantly reduced by all treatments compared to the control (Table 4). The Mbr + Pic and the 1,3-D + Pic treatments reduced gall ratings greater than the 1,3-D alone. The Mbr + 33% Pic and 1,3-D + 35% Pic increased yield of extra large tomatoes as compared to the control. Total fruit yield was increased in all treatments except in the 1,3-D alone.

DISCUSSION

Mbr + 2% Pic, Mbr + 33% Pic and the higher rates of 1,3-D + Pic resulted in the greatest reduction in root galling from *Meloidogyne* spp. in these tests. The higher rates of 1,3-D + Pic generally provide comparable reductions in root galling compared to the standard Mbr + 2% Pic and Mbr + 33% Pic treatments. Pic alone showed good efficacy in one test and poor reductions in root galling in a second test. The lower rates of 1,3-D and 1,3-D + Pic produced variable and generally more root galling as compared to both the Mbr

Table 3. Effect of fumigant treatment on reniform nematode population densities and marketable yield of 'FL 47' tomatoes, Spring 1999.

Treatment	L or kg/ha formulation[x]	No. reniform/100 cm^3 soil	Fruit wt. (mt/ha)	
			Extra-large	Total[y]
1,3-D + 17% Pic	112 L	1 014 b[z]	58.1 a	66.1 a
1,3-D + 17% Pic	140 L	1 143 ab	56.0 ab	64.9 ab
1,3-D + 17% Pic	168 L	895 b	53.9 ab	61.8 ab
Mbr 67% + 33% Pic	382 kg	598 b	50.1 ab	59.1 ab
1,3-D + 35% Pic	168 L	1 419 ab	48.2 b	55.9 b
Control	—	2 374 a	50.3 ab	57.1 ab

[x]Chemical rates listed are broadcast equivalent but only one-half of the area (in-bed) was treated.
[y]Total fruit weight was the sum of medium, large and extra-large grades.
[z]Column means followed by the same letter are not significantly different (P ≤ 0.05) according to Duncan's multiple range test.

formulations. Similarly, postharvest reniform nematode population densities were reduced by treatments with Mbr and higher rates of 1,3-D + Pic as compared to the control. The relative nematicidal effectiveness and use rates of the chemicals agrees with those of others (Ingham *et al.*, 2000); Lamberti *et al.*, 1998, Locasio *et al.*, 1997).

Significant yield increases were observed among chemical treatments compared to the control in three of the four tests. Average yield differences across trials and among treatments generally mirrored

Table 4. Effect of fumigant treatment on root gall index and marketable yield of 'BHN 444' tomatoes, Spring, 2001.

Treatment	L or kg/ha formulation[x]	Root gall index[x]	Fruit wt. (mt/ha)	
			Extra-large	Total[y]
1,3-D + 17% Pic	327 L	0.97 c[z]	19.7 bc	35.3 a
1,3-D + 35% Pic	327 L	1.42 c	26.1 ab	37.5 a
Mbr 67% + 33% Pic	392 kg	1.75 c	28.1 a	36.9 a
1,3-D alone	224 L	4.94 b	17.5 c	31.8 ab
Control	—	9.29 a	15.8 c	20.7 b

[w]Chemical rates listed are broadcast equivalent but only one-half of the area (in-bed) was treated.
[x]Root gall index based on a 0-10 scale where 0 = no galling and 10 = dead plants due to extensive galling.
[y]Total fruit weight was the sum of medium, large and extra-large grades.
[z]Column means followed by the same letter are not significantly different (P ≤ 0.05) according to Duncan's multiple range test.

root gall ratings and reniform nematode population densities. Due to the high value of the tomato crop, even apparently small yield differences, are important since the crop value can exceed U.S. $25 000/ha (Anonymous, 2000a).

Data from these tests indicate that the higher rates of 1,3-D + Pic performed similarly to the standard Mbr treatments for nematode control and tomato yield enhancement. The Pic alone treatment approximated the Mbr treatments in yield but not in nematode control. These results with Pic are similar to those found in tobacco, where it was suggested that suppression of soil-borne fungi may have enhanced yield (Rich and Whitty, 1999). The 1,3-D + Pic or Pic alone at higher rates are currently the most viable chemical alternatives to Mbr for tomato production in northern Florida soils and environment (Rich *et al.*, 2002). Further study of rates under higher nematode infestation levels similar to those in Test 4 are needed.

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