Table 3. Interaction of micronutrients and soil pH on development of Fusarium crown rot of tomato.

Micronutrient amendment	Rate kg·ha[-1]	Soil pH (saturated paste) 4.0	4.9	6.2	7.3
		% diseased plants			
Iron (Fe)	17.0	66 a[z]	33 a	39 b	13 a
Manganese (Mn)	10.0	44 a	28 a	43 b	10 a
Zn (Zn)	19.4	49 a	47 ab	26 a	13 a
Fe+Mn+Zn	17+10+19.4	45 a	75 b	56 b	8 a
None	—	56 a	27 a	6 a	7 a

[z]Mean separation by LSD test at the 0.05 probability level.

in pathogenesis is not understood. Woltz and Jones (1968) reported that Zn and other micronutrients were essential for the growth, sporulation, and virulence of *Fusarium oxysporum* f. sp. *lycopersici*. *Fusarium vasinfectum* Atk. also requires Zn for growth and the production of fusaric acid (Kalyanasundaram and Saraswathi-Devi, 1955). Kalyanasundaram (1954) reported that soil amendments of zinc altered the susceptibility of cotton to *F. vasinfectum*, and Subramanian (1963) induced resistance of pigeon pea, *Cajanus cajan*, to *F. udum* by application of Mn to the soil. The effect of micronutrients on pathogenesis of tomato to *F. oxysporum* f. sp. *radicis-lycopersici* may be upon the host, pathogen, or both. Nevertheless, certain micronutrient treatments added to the medium as EDTA complexes reversed the disease-inhibiting effects of lime ($CaCO_3$) and the concomitant increased medium pH. This supports the hypothesis that an imbalance in micronutrient supply may be the mechanism by which liming retards development of Fusarium crown rot.

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EFFICACY OF 1,3-DICHLOROPROPENE FORMULATIONS FOR CONTROL OF PLANT-PARASITIC NEMATODES ON TOMATO

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Abstract. **Several formulations of 1,3-dichloropropene and chloropicrin were compared with a methyl bromide/chloropicrin formulation for nematode control on tomatoes (*Lycopersicon esculentum* Mill.) grown on a sandy soil in Immokalee, Collier County, Florida, during 1995-96. Numbers of the root-knot nematode (*Meloidogyne incognita* [Kofoid and White] Chitwood) and root galling were lower in 1,3-dichloropropene-treated plots than in nonfumigated control plots, but root-knot nematodes and root galling were absent from plots fumigated with methyl bromide. At harvest, population levels of the stubby-root nematode (*Paratrichodorus minor* [Colbran] Siddiqi) had increased in all plots, regardless of treatment. Numbers of sheath nematodes (*Hemicycliophora* spp.) were low and unaffected by treatment. Formulations of 1,3-dichloropropene were effective in reducing the most serious nematode pest of tomatoes (*M. incognita*), but not below detectable levels. Additional data from future tests are needed to reliably assess the consequences of this level of nematode management.**

Soil fumigation with methyl bromide/chloropicrin formulations is the most commonly-used pre-plant practice for control of soil-borne pests in tomato (*Lycopersicon eculentum* Mill.) production in Florida (Jones et al., 1995). However, the classification of methyl bromide as an ozone-depleting substance and its impending removal by the U.S. Environmental Protection Agency necessitates the development of alternative management strategies, including the use of alternative

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fumigants, for soil-borne pests such as nematodes (Noling and Becker, 1994). A number of alternative fumigant nematicides are currently available, among the oldest of which are the chlorinated C_3 hydrocarbons, 1,3-dichloropropene and 1,2-dichloropropane (Hague and Gowen, 1987).

These chlorinated hydrocarbons have been used for many years for control of nematodes in vegetable crops in Florida (McSorley et al., 1985; Overman and Jones, 1984). In the early 1980s, a formulation of 80% chlorinated C_3 hydrocarbons and 20% methyl isothiocyanate (MS/DD = Vorlex) was as effective as methyl bromide/chloropicrin formulations in reducing galling from root-knot nematodes (*Meloidogyne* spp.) and population levels of several nematode species in soil, in several tests conducted on tomatoes in west central Florida (Overman and Jones, 1984) and southeast Florida (McSorley et al., 1985; 1986). In one test, the methyl bromide/chloropicrin formulation was more effective than MS/DD in reducing soil population levels of the reniform nematode, *Rotylenchulus reniformis* Linford and Oliveira (McSorley et al., 1985). In 1985, Overman (1985) established that 1,3-dichloropropene alone or in combination with 16.5% chloropicrin (C-17) provided levels of control of root-knot nematode juveniles in soil which were similar to that achieved with the older mixture, MS/DD. Subsequently, 1,3-dichloropropene has been used in potato (*Solanum tuberosum* L). production in Florida for control of *Meloidogyne incognita* (Kofoid and White) Chitwood and other nematode pests, but has not been successful against stubby-root nematodes (*Paratrichodorus* spp., *Trichodorus* spp.) (Weingartner et al., 1993; Weingartner and Shumaker, 1990).

More recently, C-17 provided root-knot nematode control similar to that achieved with methyl bromide/chloropicrin formulations (Gilreath et al., 1994; 1996), although methyl bromide/chloropicrin was somewhat better in one case (Jones et al., 1995). The objective of the current experiment was to compare the efficacy of several different formulations of 1,3-dichloropropene and chloropicrin with a methyl bromide/chloropicrin formulation for control of plant-parasitic nematodes in a staked fresh-market tomato crop.

Materials and Methods

A commercial tomato field on Pomello fine sand (95.5% sand, 3.0% silt, 1.5% clay) in Immokalee, Collier County, Florida, was used in this study. The site was chosen based on previously high incidences of Fusarium crown rot and root-knot nematodes. The field was cultivated and wetted prior to bed formation and fumigation. Beds were 81 cm wide with a spacing between beds of 1.8 m. Six different experimental preplant soil treatments were applied: an unfumigated control, methyl bromide/chloropicrin (formulated as Terr-O-Gas 67 = 67% methyl bromide, 33% chloropicrin) at 448 kg ha^{-1}, and four treatments with 1,3-dichloropropene (Telone) formulated by weight with different percentages of chloropicrin. These 1,3-dichloropropene/chloropicrin treatments were: C-17 (17% chloropicrin) at 200 liters ha^{-1}, C-17 at 327 liters ha^{-1}, C-25 at 224 liters ha^{-1}, and C-35 at 259 liters ha. Each soil treatment was replicated four times using single-bed plots 15.2 m long separated by 7.6-m-long buffers between plots, and arranged in a randomized complete block design. Fumigants were applied to the beds by means of a tractor-drawn super-bedder at a depth of 23 cm using three chisels spaced 28 cm apart on 12 Oct. 1995. Beds were mulched with 31-µm black polyethylene mulch immediately following fumigation. Six-week-old transplants of the tomato cultivar Sunny were planted in the beds on 2 Nov. 1995 using a 46 cm in-row spacing. Conventional cultural and pest management practices for staked tomato production in southwest Florida were used, including drip irrigation and fertigation.

A freeze on 7 Feb. 1996 severely damaged all experimental plants and allowed only one premature harvest on 8 Feb. All fruit from 15 plants per plot were harvested regardless of size to obtain an approximation of the potential fruit number which would have resulted from two harvests. On the same date, plants were rated for Fusarium crown rot, although methods and results (McGovern, unpublished) are not reported here.

Soil samples for nematode analysis were collected from each plot on 2 Nov. 1995 (post fumigation, at planting) and 21 Feb. 1996 (end of experiment). Each soil sample consisted of six soil cores (2.5-cm-diameter × 20 cm deep) collected in a systematic pattern from an individual plot using a soil sampling cone (Esser el al., 1965). The cores comprising a sample were mixed and stored in a plastic bag at 10 C for two to three days prior to extraction. Nematodes were then extracted from a 100-cm^3 soil subsample using a modified sieving and centrifugation procedure (Jenkins, 1964). All individual specimens extracted were then identified and counted using an inverted microscope. On the final sampling date (21 Feb.), five plants were removed from each plot, and root systems were rated for galling from root-knot nematodes (*Meloidogyne* spp.) using a 0 to 5 scale, such that 0=0 galls, 1=1-2 galls, 2=3-10 galls, 3=11-30 galls, 4=31-100 galls, and 5=>100 galls per root system (Taylor and Sasser, 1978).

All nematode data (soil counts and root ratings) were analyzed using single degree of freedom orthogonal contrasts (Sokal and Rohlf, 1969) performed using MSTAT-C software (Freed et al., 1988). Three contrasts were examined: 1) methyl bromide/chlorpicrin treatment vs. control; 2) methyl bromide/chloropicrin treatment vs. 1,3-dichloropropene/chloropicrin treatments; and 3) 1,3-dichloropropene/chloropicrin treatments vs. control.

Results

No visible phytotoxicity (plant height reduction, foliar distortion, or chlorosis) resulted from any of the treatments. No significant yield differences among treatments were detected in the premature harvest.

Initial nematode population densities present in this site were very low, and root-knot nematodes (*Meloidogyne*) were

Table 1. Effect of soil fumigation on initial plant-parasitic nematode levels in a site at Immokalee, 2 Nov. 1995 (post fumigation, at planting).

		Nematodes per 100 cm^3 soil	
Fumigant[z]	Rate/ha	Stubby root	Sheath
MB-C	448 kg	0[y]	2.2
C-35	259 liters	0	0.5
C-25	224 liters	0	0
C-17	327 liters	0	0.2
C-17	200 liters	0	3.0
None	—	1.0	0

[z]MB-C = methyl bromide/chloropicrin; C-35, C-25, C-17 = 1,3-dichloropropene/chloropicrin.
[y]Data are means of four replications.

Table 2. Effect of soil fumigation on plant-parasitic nematode levels and root galling on tomato in a site at Immokalee, 21 Feb. 1996 (post harvest).

Fumigant[z]	Rate/ha	Nematodes per 100 cm³ soil			Root gall index[y]
		Stubby-root	Sheath	Root-knot	
MB-C	448 kg	44.5[x]	0.2	0	0.00
C-35	259 liters	66.8	0.8	20.2	0.40
C-25	224 liters	57.8	2.0	3.5	0.05
C-17	327 liters	66.2	12.5	15.0	0.15
C-17	200 liters	43.0	0.2	5.5	0.20
None	—	55.8	2.0	166.0	1.40
Contrasts:[w]					
MB-C vs. none		ns	ns	*	*
MB-C vs. C-35, C-25, C-17		ns	ns	*	ns
C-35, C-25, C-17 vs. none		ns	ns	*	*

[z]MB-C = methyl bromide/chloropicrin; C-35, C-25, C-17 = 1,3-dichloropropene/chloropicrin.
[y]Rated on a 0-5 scale: 0=0 galls, 1=1-2, 2=3-10, 3=11-30, 4=31-100, 5=>100 galls per root system (Taylor and Sasser, 1978).
[x]Data are means of four replications.
[w]Asterisk (*) = significant contrast at $P \leq 0.05$; ns = contrast not significant at $P \leq 0.10$.

not detected at planting (Table 1). Numbers of stubby-root (*Paratrichodorus minor*), sheath (*Hemicycliophora* spp.), and root-knot (*M. incognita*) nematodes increased by the end of the tomato crop (Table 2). Stubby-root nematodes were not controlled by any of the fumigant formulations used, but historically these nematodes are not usually controlled very well by pre-plant soil fumigation on potato, a crop on which stubby-root nematodes are of economic concern (Weingartner et al., 1993). Distribution of sheath nematodes was low and erratic, and showed no pattern with treatment.

On 21 Feb., root-knot nematodes were absent from plots treated with methyl bromide/chloropicrin, in contrast to a mean of 166 per 100 cm³ soil observed in nonfumigated control plots (Table 2). Root-knot nematode numbers across the four 1,3-dichloropropene/chloropicrin treatments averaged only 11 per 100 cm³ soil, significantly lower ($P \leq 0.05$) than the number in control plots, but still greater ($P \leq 0.05$) than the number present in plots treated with methyl bromide/chloropicrin. The root-gall index across the four 1,3-dichloropropene/chloropicrin treatments averaged 0.2, which was not significantly different from the level observed in plots treated with methyl bromide/chloropicrin, but was lower ($P \leq 0.05$) than the mean rating of 1.4 observed in control plots.

Discussion

The present data confirm the efficacy of 1,3-dichloropropene/chloropicrin formulations against root-knot nematodes, as reported in previous studies (Gilreath et al., 1994; 1996; Jones et al., 1995; Overman, 1985). Although numbers of root-knot nematodes in soil following fumigation with 1,3-dichloropropene/chloropicrin were not as low as those following fumigation with methyl bromide/chloropicrin, they were on average <10% of the numbers present in nonfumigated plots. Root-gall indices obtained after fumigation with 1,3-dichloropropene formulations were comparable to those obtained after fumigation with the methyl bromide formulation. The data suggest that 1,3-dichloropropene formulations with chloropicrin may be suitable and only slightly less effective alternatives to methyl bromide/chloropicrin for control of root-knot nematodes.

Nematode control is only one desirable characteristic of an effective multipurpose soil fumigant. Recent work on tomatoes in southern Florida has shown that 1,3-dichloropropene/chloropicrin formulations were also effective against several soil-borne diseases, including Fusarium crown rot, Fusarium wilt, and bacterial wilt (Gilreath et al., 1994; Jones et al., 1995; McGovern et al., 1994; 1995). It appears that formulations of 1,3-dichloropropene and chloropicrin are not as effective as methyl bromide in controlling nutsedge (*Cyperus* spp.) (Gilreath et al., 1994). Comparable efficacy was achieved when 1,3-dichloropropene and chloropicrin were combined with the herbicide pebulate (Gilreath et al., 1994; Jones et al., 1995).

Future tests are needed to assess the economic consequences of the levels of nematode management obtained in the present work and in other studies. Nevertheless, it is possible that 1,3-dichloropropene and chloropicrin could become an adequate fumigant alternative to methyl bromide if use of the latter material is suspended. However, concern about potential environmental effects from 1,3-dichloropropene (Noling and Becker, 1994) could become important if the Florida tomato industry became dependent on a single chemical product once again. For long-term security, it is essential that a variety of control practices, including effective non-chemical alternatives, be developed for integrated management of nematodes and other soilborne pests of this important crop.

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EVALUATION OF PEPPER TOLERANCE TO SELECTED PREPLANT HERBICIDES

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Abstract. **Two studies were carried out at Bradenton, FL and three studies were carried out at Gainesville, FL from 1994 through 1996 to evaluate the tolerance of bell pepper (*Capsicum annuum* L.) to several herbicides applied preplant under polyethylene mulch. Pebulate, napropamide, trifluralin, and lactofen applied preemergence (pre) and preplant incorporated (ppi) did not reduce pepper plant vigor nor shoot biomass in the spring of 1994. Pebulate applied at 2.0 lb/acre pre reduced vigor and yield as compared to pebulate 2.0 lb/acre ppi in the fall of 1994 at Bradenton. Pepper was tolerant to applications of napropamide (2.0 and 4.0) lb/acre, pebulate (2.0, 3.0, 4.0) lb/acre ppi, clomozone (1.0 lb/acre) ppi, metalachlor (1.5 lb/acre) ppi, pendimethalin and trifluralin at 0.75 lb/acre ppi, lactofen (0.5 lb/acre) pre, rimsulfuron, (0.016 and 0.024 lb/acre) and thiazopyr (0.125 and 0.25 lb/acre) pre at Gainesville. Vigor and yield were reduced with applications of EPTC at 3.0 lb/acre ppi and oxyfluorfen at 0.5 lb/acre pre.**

Methyl bromide plus chloropicrin are labeled for use as a preplant fumigant and have been highly effective in controlling nematodes, soilborne diseases, insects, and weeds in mulched pepper production in Florida for the past 20 years. Methyl bromide was listed as a Class I ozone depleting substance on 30 Nov. 1993, and a phase-out date of 1 Jan. 2001 was established under the U.S. Clean Air Act (Section 602). Currently available alternative fumigants to methyl bromide will not adequately control nutsedges nor several broadleaf and grass weeds under Florida cultural conditions. Herbicides will be needed to control these weeds in an alternative production management situation (Stall, 1994).

At the present time, only napropamide has a label for use under polyethylene mulch in pepper production. The label is for a surface application, but it is labeled for preplant incorporated (ppi) application in non-mulched situations. Trifluralin has a label for use in pepper, but has no mention of use with mulch. Clomozone also is labeled for ppi use. Clomozone is relatively volatile and its use under mulch is questionable.

A tolerance has been established for the use of metalachlor in pepper, but the third party label is for directed-shielded applications to pepper row middles. Also, a tolerance is being established for lactofen for row middle use only. EPTC has had a tolerance established on the fruiting vegetable subgroup (tomato, pepper, eggplant) but does not have a label for use, and pebulate is labeled for use on tomato, but does not have a tolerance established to be able to be labeled on pepper (USDA, 1982).

Several other herbicides may be effective under mulch for pepper production. Pendimethelin has been a candidate for IR-4 tolerance establishment in pepper. Oxyfluorfen volatilizes under mulch. Bellinder *et al.* (1993) found that if seven days elapsed between oxyfluorfen application and mulching, residues on the soil surface would be volatilized during that period. When oxyfluorfen was applied, mulch immediately applied, and two to three weeks elapsed before strawberry transplanting, no damage was observed (Stall *et al.*, 1995). This same phenomenon may also apply to clomozone application under mulch.

Rimsulfuron is labeled in a few midwestern states for weed control in potato. Trials in Florida have also shown good tomato tolerance to the herbicide (Bewick *et al.*, 1995). Thiazopyr is also being tested in many vegetable crop situations.

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