Fumigant Alternatives to Methyl Bromide for Polyethylene-mulched Tomato

Salvadore J. Locascio

Horticultural Sciences Department, University of Florida, Gainesville, FL 32611

James P. Gilreath

Gulf Coast Research and Education Center, Bradenton, FL 34203

D.W. Dickson and Thomas A. Kucharek

Entomology and Nematology Department and Plant Pathology Department, University of Florida, Gainesville, FL 32611

J.P. Jones

Gulf Coast Research and Education Center, Bradenton, FL 34203

J.W. Noling

Citrus Research and Education Center, Lake Alfred, FL 33850

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Abstract. Tomato (*Lycopersicon esculentum* Mill.) was grown to evaluate various chemicals as possible alternatives to methyl bromide soil fumigation. Due to a combination of weeds, nematodes, and soil fungi, the use of a broad-spectrum fumigant has been essential for economical tomato production in Florida. Methyl bromide (MBr) and combinations of MBr with chloropicrin (Pic) are the fumigants of choice for most growers using polyethylene mulch culture. In 1991, MBr was allegedly associated with stratospheric ozone depletion. The U.S. Environmental Protection Agency has since mandated a phaseout of MBr for soil fumigation in the United States by the year 2001. At three locations in Florida, alternative soil fumigants were evaluated, including soil injected 98% MBr–2% Pic at 450 kg·ha⁻¹, 67% MBr–33% Pic (390 kg·ha⁻¹), Pic (390 kg·ha⁻¹), dichloropropene + 17% Pic (1,3-D + Pic) at 327 L·ha⁻¹, and metam-sodium (935 L·ha⁻¹). Also, metam-sodium and tetrathiocarbonate (1870 L·ha⁻¹) were applied by drip irrigation. Dazomet (450 kg·ha⁻¹) was surface applied and soil incorporated. Pebulate (4.5 kg·ha⁻¹) was soil incorporated with some treatments. Pic and 1,3-D + Pic treatments provided good to moderate control of nematodes and soil fungi except in one of the six studies, in which nematode control with 1,3-D was moderate to poor. Nutsedge densities were suppressed by addition of pebulate. Tomato fruit yields with 1,3-D + Pic + pebulate and with Pic + pebulate at the three sites ranged from 85% to 114%, 60% to 95%, and 101% to 119%, respectively, of that obtained with MBr treatments. Pest control and crop yield were lower with treatments other than the above pebulate-containing or MBr-containing treatments. These studies indicate that no one alternative pesticide can provide the consistent broad-spectrum control provided by MBr. Chemical names used: trichloronitromethane (chloropicrin); 1,3-dichloropropene (1,3-D); sodium N-methyldithiocarbamate (metam-sodium); sodium tetrathiocarbonate (tetrathiocarbonate); 3,5-dimethyl-(2H)-tetrahydro-1,3,5-thiadiazine-2-thione (dazomet); S-propyl butyl(ethyl)thiocarbamate (pebulate).

Tomato and bell pepper (*Capsicum annuum* L.) are the two most valuable vegetables grown for fresh-market production in Florida (Geuder and Pugh, 1996). During the 1994–95 crop season, tomato was grown on 19,845 ha and had an on-farm value of \$461 million, and

pepper was grown on 8,200 ha with a value of \$189 million. These two crops accounted for 44% of the monetary value of the vegetable industry in Florida with an average value of \$23,200/ha.

Tomatoes require intense management, including the use of broad-spectrum soil fumigants, polyethylene mulch, and adequate rates of fertilizer, irrigation, and pesticides. Before the use of black polyethylene as a mulch for these crops, most production occurred on new land to avoid or minimize competition from various soil pathogens and weeds. In the early 1970s, most Florida growers were using polyethylene mulch and a broad-spectrum fumigant, which resulted in large increases in yield

over that attained without their use. The fumigants of choice, because of their high efficacy and relatively low cost, are methyl bromide (MBr) and MBr–chloropicrin (Pic) combinations. Typical soils where most vegetables are grown in the southeastern United States have serious soilborne pathogens and pests, including plant-parasitic nematodes, fungi, bacteria, and weeds. Lack of control of any one of these can result in a reduction in yield and quality of fruit. Over the past 25 years, MBr and MBr–Pic combinations became the standard fumigants used with polyethylene-mulched vegetables because they were highly efficacious (Overman and Martin, 1978). Methyl bromide is considered one of the most important preplant soil fumigants available (Noling and Becker, 1994).

In 1992, MBr was alleged to contribute to the depletion of the stratospheric ozone layer (Watson et al., 1992). The U.S. Environmental Protection Agency has established regulations that call for a phaseout of MBr in the United States by 1 Jan. 2001 (U.S. Environmental Protection Agency, 1993). Broad-spectrum control of soilborne pests and pathogens to the degree provided by MBr has not been possible with other currently available fumigants (Methyl Bromide Technical Options Committee, 1995). Chloropicrin is effective against many soilborne diseases but is less effective against nematodes than MBr. The nematicide 1,3-D provides control of nematodes but is not an effective soil fungicide or herbicide. Control of purple and yellow nutsedges (*Cyperus rotundus* L. and *C. esculentus* L.) is not provided by either Pic or 1,3-D (Gilreath et al., 1994); however, these nutsedges must be controlled because both species are very serious weed pests that can easily grow through polyethylene mulch and reduce yields (Locascio et al., 1994).

For economic production of tomato, control of soil pathogens and weeds are essential. With the pending loss of MBr, studies were conducted with polyethylene-mulched tomatoes to evaluate other available preplant fumigants or combinations of chemicals as possible alternatives to MBr.

Materials and Methods

Polyethylene-mulched tomato was grown with drip irrigation at two sites on Millhopper fine sands (Grossarenic Paleudults, loamy, siliceous, hyperthermic) near Gainesville, Fla., during Spring 1994 and 1995, and near Bradenton, Fla., with seep irrigation on an Eau Gallie fine sand (Alfic Haplaquods, sandy, siliceous, hyperthermic) in Spring and Fall 1994. Sites in Gainesville were at the Horticultural Unit and the Green Acres Research Farm. Fields at the Horticultural Unit were heavily infested with purple and yellow nutsedges, and moderately infested with the root-knot nematode *Meloidogyne incognita* (Kofoid and White) Chitwood and various soil fungi. The Green Acres site was heavily infested with *Meloidogyne arenaria* (Neal) Chitwood race 1, the peanut root-knot nematode. Sites at Bradenton were heavily infested with purple

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nutsedge, moderately to heavily infested with fusarium wilt (*Fusarium oxysporum* Schlecht. f. sp. *lycopersici* (Sacc.) Snyder and Hans. race 3), and lightly infested with the root-knot nematode *M. incognita*. Treatments included six to 12 fumigants applied during the various seasons with treatments arranged in randomized complete-block designs with six replications. Plots were single rows with 0.9-m-wide bed tops with beds spaced 1.8 m apart and 12 m long at Gainesville and 1.5 m apart and 15.4 m long at Bradenton.

After the initial soil preparation, beds at Gainesville were formed and fertilizer (58N–8P–50K kg·ha⁻¹) was applied in the bed along with the specified soil-applied fumigant and herbicide treatments. Black 0.038-mm-thick polyethylene mulch was then applied over the bed top. Double-wall drip tubing (Chapin Twinwall, Watertown, N.Y.), with emitters spaced 23 cm apart and a flow rate of 62 mL·min⁻¹, was placed 7.5 to 10 cm from the bed center under the mulch for application of water, fertilizer, and fumigants. Postplant fertilizer (144N–130K kg·ha⁻¹ as NH₄NO₃ and KCl) was applied with the irrigation water in 10 weekly applications. At Bradenton, fertilizer (34N–20P–37K kg·ha⁻¹) was applied to the soil and then a prebed was formed. Herbicide and fumigant treatments were applied and a final bed was formed and pressed with fertilizer (247N–284K kg·ha⁻¹) applied in two bands 30 cm from each side of the plant row immediately before application of the polyethylene mulch (black mulch in the spring and white mulch in the fall). Drip tubing identical to that used in Gainesville was placed in appropriate plots 10 cm from the west side of the bed center to allow delivery of drip-applied fumigants. The crop was irrigated with a semi-enclosed, subsurface irrigation system.

Soil fumigants at labeled rates were injected with three chisels per bed spaced 30 cm apart at a depth of 15 to 20 cm. Injected treatments were 98%–2% MBr–Pic (450 kg·ha⁻¹), 67%–33% MBr–Pic (390 kg·ha⁻¹), Pic (390 kg·ha⁻¹), and 1,3-D + 17% Pic (327 L·ha⁻¹). Pebulate (for nutsedge control) was applied on the bed surface and incorporated 15 to 20 cm deep with a roto-tiller before the fumigants were injected. Dazomet (440 kg·ha⁻¹ from a 92% formulation) and metam-sodium (300 L·ha⁻¹ from a 32% formulation) were applied on the bed surfaces and immediately incorporated. At the Horticultural Unit site, dazomet also was incorporated and then watered into the soil with 6 mm depth of water before mulch application. Metam-sodium (300 L·ha⁻¹) and tetrathiocarbonate (1870 L·ha⁻¹) were applied through two drip tubes spaced 30 cm apart per bed at Gainesville, and one drip tube at Bradenton. Tomato was transplanted into the treated soil 3 weeks after fumigant application. Two additional applications of tetrathiocarbonate (187 L·ha⁻¹) were made through the drip irrigation system during the crop growth period at Gainesville and Bradenton.

Tomato plants were set 0.5 m apart in the bed at all sites. ‘Sunny’ tomato was transplanted in 1994 on 4 Apr. at the Horticultural

Unit and on 6 Apr. at Green Acres. ‘AgriSet 761’ transplants were set on 28 Mar. 1995 at the Horticultural Unit and on 29 Mar. 1995 at Green Acres. ‘Sunbeam’ plants were transplanted on 7 Mar. 1994 and ‘Sunny’ plants were set on 18 Oct. 1994 at Bradenton. Drip irrigation was supplied at 0.75 times pan evaporation throughout both seasons at Gainesville. Subsurface irrigation was continuous at Bradenton to maintain a water table at 46 cm from the bed surface. Tomato plants were pruned by removal of the two lower branches and staked. Foliar insecticides and fungicides were applied weekly beginning 3 weeks after transplanting.

Tomato roots were assessed for the presence of fungi in mid-June of each season at the two Gainesville sites. One typical-appearing, randomly selected tomato plant and root system in each plot was removed from the field. The plants were brought to the laboratory where the soil was washed off the roots. Roots from each plant were excised and placed in an individual container where they were surface-disinfected with a 10% solution (v/v) of bleach (5.25%) for 1 min. Roots were then rinsed twice with sterile distilled water. Three clumps of roots, each weighing 0.25 to 0.35 g, from each plant were placed on acidified potato dextrose agar within each of three petri dishes. Beginning 2 d after plating and up to 9 d after plating, the incidence of all fungi associated with each root clump was assessed. At Bradenton, *Fusarium* wilt race 3 infected plants were enumerated weekly.

After harvest, six plants per plot were collected for assessment of nematode galling of the root system at Gainesville and all of the plants per plot were assessed at Bradenton. A galling index of 0 to 10 was used with 0 = 0 galls, 1 = <10% of roots galled, 2 = 20%, ..., 10 = 100% of the roots galled (Barker et al., 1986).

Counts of emerged nutsedge plants growing through the polyethylene mulch were made ≈8 weeks after transplanting in an area of 0.095 m². Counts were made on the drip-tubing side of the plots at the Horticultural Unit. At Bradenton, nutsedge plants that emerged through the mulch film were counted in four randomly selected areas on each side of the plant row in each plot and numbers per plot were averaged.

Fruit were harvested twice at the mature green stage and graded into marketable size categories of extra-large, large, and medium fruits by U.S. grade standard (U.S. Dept. of Agriculture, 1976). Data were subjected to analysis of variance with treatment means separated by Duncan’s multiple range test (SAS, 1995).

Results and Discussion

Marketable fruit yield. Marketable yields of fruit were influenced by fumigant treatments in all seasons and at all locations (Table 1). Fruit yields were higher than control values and statistically similar among treatments with MBr98-2, MBr67-33, Pic + pebulate, and 1,3-D + Pic + pebulate, except at the 1994 Green

Acres site, where the pebulate-containing treatments did not perform as well as the two MBr treatments. During the 1994 fall study at Bradenton, yields with all fumigant treatments were similar and significantly higher than with no fumigant. At the two Gainesville sites, marketable yields varied from intermediate to no higher than the no fumigant treatments with Pic, 1,3-D + Pic, dazomet, dazomet + pebulate, metam-sodium, and metam-sodium + pebulate.

Relative fruit yield with the two MBr treatments was designated as 100% at each site. At the Horticultural Unit site in 1994, relative yields with the Pic + pebulate and with the 1,3-D + Pic + pebulate treatments were 86% and 85%, respectively, and in 1995 they were 114% and 102%, respectively. At Green Acres, relative yields with the two pebulate-containing treatments in 1994 were 60% and 77%, respectively, and in 1995 were both 95%. At Bradenton, relative yields with these two treatments ranged from 101% to 119% during the spring and fall seasons, respectively. In contrast to the fair to excellent production obtained with the two pebulate-containing treatments at the Horticultural Unit in 1994, relative yields were 60% to 70% with Pic, 1,3-D + Pic, dazomet, and metam-sodium drip applied, 45% with soil applied metam-sodium, 47% with tetrathiocarbonate, and 40% with no treatment. Similarly, at Bradenton, yields were reduced with alternative fumigants alone, but where pebulate was combined with fumigants other than metam-sodium in Spring 1994, yields were equal to that with MBr–Pic-containing treatments.

Control of soil fungi. Three predominant pathogenic fungi, *Rhizoctonia solani* Kuhn, *Macrophomina phaseolina* Tassi (Goidanich), and *Fusarium solani* (Mart) Sacc. (emend Snyder and Hans.), were recovered from tomato roots at the two Gainesville sites. Both *R. solani* and *M. phaseolina* are reported as pathogens of tomato (Jones et al., 1991). At Gainesville, the total numbers of colonies of these three fungi isolated from roots were significantly reduced by MBr98-2 and MBr67-33 in all studies, by five of six treatments with Pic alone and Pic + pebulate, and by four of seven treatments with 1,3-D + Pic and 1,3-D + Pic + pebulate, as compared with no treatment (Table 2). Dazomet, metam Na, and tetrathiocarbonate treatments did not significantly reduce the number of fungal colonies recovered. Use of Pic alone or in combination with 1,3-D reduced total fungal counts in nine of the 13 treatments. Pic is generally regarded as being more potent than MBr, but in these studies, treatments with MBr (98-2 and 67-33) provided higher consistency for reducing fungal infections than did those with Pic without MBr (2% Pic). At Bradenton (plots were infested with *Fusarium* wilt race 3), use of all fumigants significantly reduced the percentage of plants infected.

Nematode control. At the Horticultural Unit site, root-knot nematode galling indices were significantly lower with soil treatments of MBr98-2, MBr67-33, and 1,3-D + Pic alone and + pebulate than with no fumigant treatment (Table 3). Galling indices were interme-

Table 1. Marketable fruit yield of tomato as influenced by various fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Marketable yield (t·ha ⁻¹) ^z					
		Gainesville				Bradenton	
		Horticultural Unit		Green Acres		Spring	Fall
		1994	1995	1994	1995	1994	1994
Nontreated		20.1 f ^y	20 e	26.5 de	25.9 e	2.2 d	17.4 b
MBr-Pic 98-2%	450 kg	50.5 a	44 ab	48.2 a	47.8 a	49.6 a	--- ^x
MBr-Pic 67-33%	390 kg	49.1 a	42 a-c	45.8 a	45.6 a	49.5 a	32.1 a
Chloropicrin (Pic)	390 kg	30.8 c-e	---	34.6 bc	---	26.2 b	---
Pic + pebulate ^w	390 + 4.5 kg	43.0 ab	49 a	28.0 c-e	44.4 ab	---	38.2 a
1,3-D + 17% Pic (C-17)	327 L	34.6 bc	---	33.7 cd	27.4 b	---	---
1,3-D, 17% Pic + pebulate	327 L + 4.5 kg	42.5 ab	44 ab	36.2 b	44.4 ab	50.2 a	34.2 a
Dazomet	440 kg	32.2 cd	---	25.3 e	---	26.9 b	---
Dazomet + 6 mm irrigation	440 kg	30.9 c-e	---	---	---	---	---
Dazomet + pebulate	440 + 4.5 kg	---	36 cd	---	41.2 a-c	---	30.8 a
Metam Na	300 L	22.6 ef	---	30.4 c-e	---	9.3 cd	---
Metam Na + pebulate	300 L + 4.5 kg	---	33 d	---	34.5 cd	23.9 bc	32.3 a
Metam Na (drip)	300 L	32.3 cd	---	29.8 c-e	---	23.1 bc	---
Tetrathiocarbonate (drip)	1870 L	23.7 ef	---	23.8 e	---	3.6 d	---

^zMarketable fruit included size categories with mean mass of extra-large 205 g, large 150 g, and medium 115 g.

^yMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

^xTreatment not applied.

^wPic applied at 375 kg in 1995 at Green Acres.

Table 2. Total fungi infecting tomato roots as influenced by fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Gainesville (total fungal colonies/plant sample) ^z				Bradenton (<i>Fusarium</i> wilt, % plants infected) ^y	
		Horticultural Unit		Green Acres		Spring	Fall
		1994	1995	1994	1995	1994	1994
		1994	1995	1994	1995	1994	1994
Nontreated		11.3 a ^x	14.3 a	8.0 a	15.5 a	40 a	23 a
MBr-Pic 98-2%	450 kg	3.3 d	4.3 c	2.0 b	8.0 bc	0 c	--- ^w
MBr-Pic 67-33%	390 kg	4.8 cd	4.3 c	2.3 b	3.0 c	0 c	0 b
Chloropicrin (Pic)	390 kg	4.3 cd	---	4.3 ab	---	4 c	---
Pic + pebulate ^y	390 + 4.5 kg	4.5 cd	4.3 c	3.0 b	4.0 bc	---	0 b
1,3-D + 17% Pic	327 L	5.0 b-d	---	5.3 ab	8 bc	---	---
1,3-D + 17% Pic + pebulate	327 L + 4.5 kg	2.8 d	3.8 c	4.0 ab	3.5 c	4 c	0 b
Dazomet	440 kg	10.0 ab	---	2.7 b	---	4 c	---
Dazomet + 6 mm irrigation	440 kg	10.3 a	---	---	---	---	---
Dazomet + pebulate	440 + 4.5 kg	---	8.7 a-c	---	7.0 bc	---	0 b
Metam Na	300 L	11.3 a	---	4.0 ab	---	8 bc	---
Metam Na + pebulate	300 L + 4.5 kg	---	6.8 c	---	3.3 c	4 bc	0 b
Metam Na (drip)	300 L	6.5 a-d	---	3.3 b	---	20 b	---
Tetrathiocarbonate (drip)	1870 L	8.8 a-c	---	8.0 a	---	12 bc	---

^zTotal fungi infecting tomato roots included *Rhizoctonia solani*, *Macrophomina phaseolina*, and *Fusarium* spp.

^yPlants infected with *Fusarium oxysporum* f. sp. *lycopersici*.

^xMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

^wTreatment not applied.

^yPic applied at 375 kg in 1995 at Green Acres.

Table 3. Nematode gall rating of tomato roots as influenced by fumigants at three locations during 1994 and 1995.

		Nematode gall index ^z				
		Gainesville				Bradenton
Treatment	Rate/ha	Horticultural Unit		Green Acres		Spring
		1994	1995	1994	1995	1994
Nontreated	4.5 a ^y	5.3 a	8.9 ab	8.9 a	2.8 ab	
MBr-Pic 98-2%	450 kg	1.0 b	0.2 c	4.1 e	1.1 c	0.2 b
MBr-Pic 67-33%	390 kg	1.2 b	0.4 c	3.6 e	1.4 c	0.2 b
Chloropicrin (Pic)	390 kg	4.3 a	---	8.5 ab	---	0.2 b
Pic + pebulate ^w	390 + 4.5 kg	3.5 a	0.9 c	8.7 ab	5.8 b	---
1,3-D + 17% Pic	327 L	1.2 b	---	6.3 cd	0.2 b	
1,3-D. 17%Pic + pebulate	327 L + 4.5 kg	1.0 b	0.5 c	6.6 cd	2.6 c	0.8 b
Dazomet	440 kg	3.2 ab	---	7.4 bc	---	2.0 ab
Dazomet + 6 mm irrigation	440 kg	3.9 a	---	---	---	---
Dazomet + pebulate	440 + 4.5 kg	---	2.1 bc	---	3.5 c	---
Metam Na	300 L	3.2 ab	---	9.0 ab	---	4.4 a
Metam Na + pebulate	300 L + 4.5 kg	---	3.9 b	---	7.9 b	2.2 ab
Metam Na (drip)	300 L	3.8 a	---	4.9 de	---	2.8 ab
Tetrathiocarbonate (drip)	1870 L	4.2 a	---	9.7 a	---	3.4 ab

^zRoot-knot gall indices 0-10 with 0 = no galls, ..., 10 = 100% of root system galled.

^yMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

^xTreatment not applied.

^wPic applied at 375 kg in 1995 at Green Acres.

diate with dazomet + pebulate, and with metam-sodium + pebulate, but were significantly lower than with no fumigant treatment. In 1994, Pic and Pic + pebulate had no significant effect on galling index. At Green Acres in both seasons, root-knot nematode galling indices were reduced most consistently with MBr treatments. Moderate nematode control was provided with 1,3-D + Pic alone or with added pebulate and with metam Na (drip applied) in 1994. Nematode control was similar to that with the no fumigant treatment with Pic, Pic + pebulate, dazomet, metam Na, and tetrathiocarbonate. At Bradenton, nematode counts were low even with the nonfumigated treatments, and root galling indices were not significantly affected by treatment.

Nutsedge control. Nutsedge was a major weed pest at the Horticultural Unit in Gainesville and at the Bradenton site where densities were heavy and very heavy, respectively. At Gainesville, counts of emerged nutsedge seedlings were made ≈ 8 weeks after transplanting tomato (Table 4). Nutsedge population densities were higher on the drip tubing side of the bed than on the opposite and drier side of the bed (data not shown). Nutsedge counts with no treatment on the tubing side of the bed near the end of the two seasons were 30 and 16 plants per 0.1 m², respectively (Table 4). Nutsedge counts during 1994 were low (number in parenthesis) per 0.1-m² area with MBr 98-2 (7), MBr 67-33 (9), Pic + pebulate (11), and with 1,3-D + Pic + pebulate (15). Counts were higher with Pic (22) and 1,3-D + Pic (34). Nutsedge control was poor with the other treatments and emerged numbers were similar to those obtained with no treatment. During the 1995 season, nutsedge counts per m² averaged 3 with the two MBr treatments, 4.5 with the pebulate-containing treatments, and 16 with no treatment. During the Spring 1994 study at Bradenton, the combination of 1,3-D + Pic + pebulate and metam-sodium + pebulate provided nutsedge control as good as that obtained with either MBr 98-2 or MBr 67-33. Nutsedge control with other treatments was poor. In the Fall 1994 study, the combination of pebulate with each of the alternative fumigants provided nutsedge control equal to that obtained with the MBr treatments.

Marketable fruit yield correlated negatively with nutsedge number, root-knot nematode galling indices, and total fungal colonies in roots. In these studies, two treatments, Pic + pebulate, and 1,3-D + Pic + pebulate, suppressed nutsedge, nematode galling, and total fungi comparable to the suppression provided by the standard MBr treatments in most studies.

Data from these studies indicate that multiple pests adversely affect tomato production and that the initial level of these pests influences the degree of control obtained by the

Table 4. Nutsedge growing through polyethylene mulch on tomato beds as influenced by fumigants at three locations during 1994 and 1995.

Treatment	Rate/ha	Nutsedge (plants/0.1 m ²)			
		Gainesville		Bradenton	
		Horticultural Unit		Spring	Fall
		1994	1995	1994	1994
Nontreated		30 a-c	16 a ^a	53 ab	22 a
MBr-Pic 98-2%	450 kg	7 e	2 c	8 d	---
MBr-Pic 67-33%	390 kg	9 e	4 c	4 d	1 b
Chloropicrin (Pic)	390 kg	22 b-d	---	60 ab	---
Pic + pebulate ^a	390 + 4.5 kg	11 e	2 c	---	6 b
1,3-D + 17% Pic	327 L	34 a	---	66 a	---
1,3-D. 17% Pic + pebulate	327 L + 4.5 kg	15 de	3 c	5 d	7 b
Dazomet	440 kg	31 ab	---	37 c	---
Dazomet + 6 mm irr.	440 kg	25 a-c	---	---	---
Dazomet + pebulate	440 + 4.5 kg	---	3 c	---	6 b
Metam Na	300 L	32 a	---	56 ab	---
Metam Na + pebulate	300 L + 4.5 kg	---	10 b	7 d	5 b
Metam Na (drip)	300 L	22 cd	---	51 b	---
Tetrathiocarbonate (drip)	1870 L	33 a	---	54 ab	---

^aMean separation by Duncan's multiple range test, $P \leq 0.05$

^bTreatment not applied.

^cPic applied at 375 kg in 1995 at Green Acres.

fumigants. Although no one pesticide provided the broad-spectrum and consistent control provided by MBr, a combination of chemicals did provide similar control in some studies. Pest control and fruit yields were lower with dazomet, metam Na, and tetrathio-carbonate treatments than with the MBr treatments. Where high populations of nutsedge were present, pebulate provided partial control of this weed and, when combined with 1,3-D + Pic or Pic, resulted in sufficient plant growth to obtain 85% to 100% of the yield produced with MBr. In studies where nematodes and fungi populations were high and not adequately controlled, relative yields with Pic + pebulate and with 1,3-D + Pic + pebulate were as low as 60% of that produced with the MBr treatments. With the high cost to produce tomato, this level of yield would not be adequate for long-term sustainable production. For these alternative fumigants to be acceptable, factors that influence the inconsistent control of nematodes and soil fungi at some sites must be determined. Later work at Green Acres indicated that nematode control with 1-3 D + Pic was enhanced by deeper injections to 20 to 30 cm (data not shown) as compared to the 20-cm depth used in the present study. Additional studies on the influence of fumigant rate and placement should provide enhanced control of these pests.

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