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FIELD VALIDATION OF 1,3 DICHLOROPROPENE + CHLOROPICRIN AND PEBULATE AS AN ALTERNATIVE TO METHYL BROMIDE IN TOMATO[1]

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Abstract. **Seven experiments were conducted on grower farms during the fall of 1996 and spring 1997 to validate results of smallplot research with 1,3 dichloropropene + chloropicrin (Telone C-17) and pebulate as an alternative to methyl bromide soil fumigation in fresh market tomato (*Lycopersicon esculentum* Mill.) production in Florida and to assess the potential for assimilation of that combination treatment into commercial production practices. Plot size ranged from 3 to 5 acres. Pebulate was sprayed on the soil surface and incorporated within 10 minutes of application with either a rototiller, a disk or a field cultivator (s-tine harrow with crumbler bars), with the exception of one test where it was incorporated with bedding disks. In most trials it was incorporated immediately after application with a field cultivator. 1,3 dichloropropene + chloropicrin (17% by weight) was applied through three chisels per row with the fumigant placed 8 inches deep in the 24 to 36 inch wide beds. Fumigant application occurred anywhere from 20 minutes to 2 days after pebulate application with the more common time frame being within 1 hour of pebulate application. Methyl bromide (67%) + chloropicrin (33%) was applied at 350 lb/acre and served as the standard to which the alternative treatment was compared. Each test was monitored for presence of soilborne diseases, nematodes, and weeds. Yield data were collected either from 20 plant subplots or as field-run production on a bins (1,000 lb) per roll of mulch basis.**

Soilborne pest control was as effective with the alternative treatment as with methyl bromide and yields were similar, except where pebulate was incorporated with bedding disks. Purple nutsedge (*Cyperus rotundus* L.) only was present in sufficient numbers to provide an indication of control level in two experiments and root-knot nematode (*Meloidogyne* spp.) was not a major factor in any study. Incidence of soilborne diseases was quite low in all locations.

Introduction

Considerable research has been conducted in Florida over the past 4 years to identify soil fumigants which might serve as replacements for methyl bromide in tomato production (Gilreath et al., 1994; Jones et al., 1995; McMillan et al., 1996; McSorley and McGovern, 1996). None of the available fumigants was effective against sedge weeds; therefore, research was conducted to find herbicides which could be integrated into a soil fumigation program to control weeds, principally yellow (*Cyperus esculentus* L.) and purple nutsedge (*C. rotundus* L.). Results of these studies identified pebulate as the most suitable herbicide to use in such a program and a combination of 1,3 dichloropropene and chloropicrin was determined to be the most effective replacement for methyl bromide for control of soilborne diseases and nematodes in tomatoes grown in flatwoods soils (Gilreath et al., 1994; Jones et al., 1995). Research also demonstrated that pebulate must be incorporated thoroughly in the soil to the depth of the bed to provide good weed control. The pebulate label specifies that thorough incorporation is a must and recommends either a rototiller or tillage in two passes at right angles with either a disk or a harrow. Most research involved incorporation of pebulate with a tractor-powered rototiller. A study reported last year demonstrated that when combined with bed preparation with a commercial bedder, a single uni-directional pass with a disk or a field cultivator (s-tine harrow with crumbler bars) provided adequate incorporation of pebulate to achieve good nutsedge control (Gilreath et al., 1996). Since this was a new system for tomato growers to adopt, experiments were conducted on commercial farms to determine if the efficacy seen in small plots would hold up in a commercial setting and to identify and assess any physical limitations or problems associated with the adoption of the combination of a mixture of 1,3 dichloropropene and chloropicrin and pebulate herbicide.

We were particularly interested in any limitations we might encounter in the use of pebulate since it represented an extra step in the field preparation process.

Materials and Methods

Seven experiments were conducted on commercial tomato farms in west central and southwest Florida during the fall of 1996 and the spring of 1997. One experiment involved cherry tomatoes, while the others focused on standard, large fruited fresh market tomatoes. The alternative fumigant program, consisting of 1,3 dichloropropene + chloropicrin (Telone C-17, DowElanco, Indianapolis, IN) and pebulate herbicide (Tillam, Zeneca Ag Products, Willmington, DE), was compared to the grower's standard rate of methyl bro-

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mide (350 lb./acre) in plots ranging from 3 to 5 acres in size. In most cases the alternative fumigant plot was surrounded on both sides by methyl bromide treated areas.

Pebulate (4 lb/acre) was sprayed on the soil surface with a tractor mounted, boom sprayer and incorporated approximately 4 to 6 inches deep within 10 minutes of application with either a rototiller, a disk, or a field cultivator (s-tine harrow with crumblerbars), with the exception of one test wherein it was incorporated in a bed-over technique with bedding disks. In most trials it was incorporated immediately after application with a field cultivator. In all cases, it was applied either just before or just after application of starter fertilizer and prior to formation of the initial rough bed (false bed) and fumigant application. The application volume ranged from 20 to 40 gal/acre with most applications in the 25 gal/acre range. All fumigant applications were made with the grower's standard fumigation rig, most being Kennco (Kennco Mfg., Ruskin, FL) units, utilizing nitrogen gas as the propellant and the typical flow meter system. The alternative fumigant, 1,3 dichloropropene + chloropicrin (17% by weight), was applied at 35 gal/acre through 3 chisels per row with the fumigant placed 8 to 10 inches deep in the 2 to 3 ft wide beds spaced 5 to 6 ft apart. Methyl bromide + chloropircrin (33%) mixtures were applied at 350 lb/acre in the same fashion to soil which had not received pebulate. Fumigant application occurred anywhere from 20 minutes to 2 days after pebulate application with the more common time frame being within 1 hour of pebulate application.

Tomatoes were grown using either seepage or drip irrigation with standard commercial practices, including stakes and polyethylene film mulch. Cultivars varied with location and season but included 'Solamar' (3 tests), 'Solar Set' (2 tests), 'Sunpride' (1 test), 'Agriset 761' (1 test), and 'DNAP94478' for the cherry tomato test. Each test was monitored for the presence of soilborne diseases, nematodes, and weeds and yield data were collected, either from the actual field harvest (fall 1996 and spring cherry tomato tests) or from 20 plant subplots arranged in a paired t test and replicated 6 to 8 times (spring 1997 tests). Fruit were harvested by commercial pickers at the typical mature green stage of development with the number of harvests per season determined by market conditions. Fruit were graded by quality and size in the spring 1997 experiments (subplots), whereas results in fall 1996 are reported as the number of field bins (1,000 lb) per roll of mulch film (2400 ft).

Plots were monitored for the presence of weeds and visible symptoms of soilborne diseases during the season. Plants were excavated at the end of the crop season to examine for root-knot nematode galling. Galling severity and incidence were evaluated using a standard 0 to 8 severity scale and percentage for incidence in studies where root-knot galling was observed. All data were analyzed using a paired t test analysis of variance.

Results and Discussion

Tomato plant height was reduced slightly in some experiments with application of pebulate and 1,3 dichloropropene + chloropicrin (Table 1), but only in one experiment was the growth reduction that noticeable. Plants were quite stunted for the first half of the season at the Myakka farm where the pebulate was incorporated with bedding disks. Bedding disks tend to fold soil into a bed rather than provide thorough mixing and it is believed that this resulted in a concentrated layer of pebulate into which the tomato roots were attempting to grow, thereby restricting root growth until enough herbicide had degraded to no longer impede root development. No difference in plant height was observed at Ruskin in the fall nor at Ruskin, Naples, or Plant City in the spring (data not reported). Other than a slight reduction in plant height, tomato plants generally looked as vigorous in the 1,3 dichloropropene treated rows as in the methyl bromide treated ones, with the exception of those at Myakka in the fall of 1996 (data not reported).

Tomato production in the fall of 1996 reflected the growth data in that some delay in crop maturity was observed (Table 2). At the Bradenton site where the pebulate was incorporated more thoroughly with a field cultivator, fruit production was the same in the first harvest with the two fumigant programs, but harvest of the 1,3 dichloropropene + chloropicrin treated area was delayed for the second harvest because the grower felt the crop was about 4 days behind the methyl bromide treated plants in maturity. This resulted in slightly higher yields of fruit with the 1,3 dichloropropene treatment in the second harvest and lower yields in the third. Total fruit production for the season was the same with the two fumigant programs at this site. Yields were greatly reduced in the first harvest where pebulate was incorporated with bedding disks at the Myakka site. The second harvest followed the first by

Table 1. Effect of soil fumigation program on tomato plant height in selected experiments at various times after planting. 1996 and 1997.

	Height in inches			
Fumigant	Myakka - fall 20 days	Bradenton - fall 42 days	Bradenton - spring 64 days	Ruskin - spring 102 days
Methyl bromide	14 a[z]	25 a	41 a	33 a
1,3 Dichloropropene + Chloropicrin with Pebulate	8 b	21 b	37 b	31 a

[z]T-test, 0.05 probability level.

Table 2. Effect of soil fumigation program on tomato production at 3 locations in the fall of 1996.

	Number of 1,000-lb bins per 2400 ft roll of mulch			
Fumigant	First harvest	Second harvest	Third harvest	Season total
	Bradenton - field cultivator			
Methyl bromide	5.9[z]	5.8	6.6	18.3
1,3 Dichloropropene + Chloropicrin with Pebulate	5.9	6.6[y]	5.8	18.3
	Myakka - bedding disks			
Methyl bromide	8.0	5.0	5.5	18.5
1,3 Dichloropropene + Chloropicrin with Pebulate	5.0	8.0	2.0	15.0
	Ruskin - grove disk			
Methyl bromide	7.4	6.3	—	13.8
1,3 Dichloropropene + Chloropicrin with Pebulate	8.0	4.2	—	12.2

[z]No statistical analysis was performed because the treatments were not replicated.
[y]Harvest of plots treated with the alternative fumigant was delayed 4 days due to slower maturation of the fruit.

Table 3. Effect of soil fumigation program on tomato production at Bradenton in the spring of 1997.

Fumigant	Number of 25-lb cartons per acre 5 × 6	6 × 6	6 × 7	Marketable	Cull
			First harvest		
Methyl bromide	812 a[z]	259 a	64 a	1133 a	27 a
1,3 Dichloropropene + Chloropicrin with Pebulate	1100 a	256 a	54 a	1410 a	21 a
			Second harvest		
Methyl bromide	342 a	320 a	538 a	1200 a	6 a
1,3 Dichloropropene + Chloropicrin with Pebulate	430 a	375 a	259 a	1063 a	10 a
			Third harvest		
Methyl bromide	202 a	107 a	174 a	483 a	37 a
1,3 Dichloropropene + Chloropicrin with Pebulate	243 a	78 a	126 a	448 a	35 a
			Season total		
Methyl bromide	1356 a	687 a	776 a	2819 a	70 a
1,3 Dichloropropene + Chloropicrin with Pebulate	1772 a	707 a	442 a	2921 a	64 a

[z]T test, 0.05 probability level.

about 10 days at which time more fruit was produced in the area treated with 1,3 dichloropropene + chloropicrin and pebulate but less was produced in the third harvest, leading to a reduction in yield for the season with the alternative treatment. It is believed that if the third harvest had been delayed, there may not have been so much disparity in yields. At the Ruskin site the first harvest was greater with 1,3 dichloropropene but considerably less in the second harvest and for the season overall. Fruits were not picked a third time at Ruskin because the grower could not get sufficient labor to harvest the crop in a timely fashion. Most likely yields would have

Table 4. Effect of soil fumigation program on tomato production at Ruskin in the spring of 1997.

Fumigant	Number of 25-lb cartons per acre 5 × 6	6 × 6	6 × 7	Marketable	Cull
			First harvest		
Methyl bromide	403 a	307 a	207 a	918 a	102 a
1,3 Dichloropropene + Chloropicrin with Pebulate	380 a	211 b	136 a	728 b	108 a
			Second harvest		
Methyl bromide	192 a	269 a	376 a	837 a	100 a
1,3 Dichloropropene + Chloropicrin with Pebulate	263 a	361 a	528 a	1152 a	165 a
			Season total		
Methyl bromide	593 a	576 a	586 a	1755 a	202 a
1,3 Dichloropropene + Chloropicrin with Pebulate	643 a	572 a	664 a	1880 a	273 a

[z]T test, 0.05 probability level.

Table 5. Effect of soil fumigation program on tomato production in Naples in the spring of 1997.

Fumigant	Number of 25-lb cartons per acre 5 × 6	6 × 6	6 × 7	Marketable	Cull
			First harvest		
Methyl bromide	344 a[z]	249 a	175 a	766 a	235 a
1,3 Dichloropropene + Chloropicrin with Pebulate	377 a	265 a	177 a	820 a	148 a
			Second harvest		
Methyl bromide	148 a	191 b	196 a	534 a	94 a
1,3 Dichloropropene + Chloropicrin with Pebulate	173 a	221 a	214 a	606 a	80 a
			Season total		
Methyl bromide	492 a	439 b	370 a	1299 a	328 a
1,3 Dichloropropene + Chloropicrin with Pebulate	550 a	486 a	391 a	1462 a	228 b

[z]T test, 0.05 probability level.

been more closely equal for the third harvest had there been one, and total yields might have been quite similar.

There were no differences in tomato yield in the subplots at Bradenton during the spring of 1997 (Table 3); however, there were more large (6 × 6) and marketable fruit picked in the first harvest at Ruskin where methyl bromide was applied (Table 4). This effect was not repeated in the second harvest or for the season total.

Few differences in yield were observed at Naples during the spring of 1997 (Table 5). More large (6 × 6) fruit were produced with 1,3 dichloropropene + chloropicrin and pebulate in the second harvest and for the season total than were produced with methyl bromide, but there was no difference in fruit production for any other category or for the total production of marketable fruit. Fewer culls were produced with 1,3 dichloropropene + chloropicrin and pebulate over the course of the season.

Cherry tomatoes were harvested six times during the spring of 1997 (Table 6). No differences were noted in fruit production for any harvest date or for the season total.

There were very few weeds in plots at any location in either season and no differences in weed control were observed, except at Naples and Plant City. Pebulate combined with 1,3 dichloropropene + chloropicrin provided better purple nutsedge (*Cyperus rotundus* L.) and sweet clover (*Melilotus alba* Desr.) control than methyl bromide at Naples (Table 7). Nutsedge was not controlled in the row middles by the broadcast, pre-bed application of pebulate, suggesting that most of the pebulate treated soil was moved into the bed. Also, the uniform presence of nutsedge in the row middles demonstrates that nutsedge was uniformly distributed throughout the test area.

Nutsedge control in the cherry tomatoes at Plant City was not affected by treatment; however, control of eclipta (*Eclipta alba* (L.) Hassk.), grasses (*Digitaria ciliaris* (Retz.) Koel.) and *Eleusine indica* (L.) Gaertn.), and pigweed (*Amaranthus* spp. L) was better with methyl bromide (Table 8). It is believed that the poor control of these weeds which are included on the pebulate label is due to the fact that the seed did not be-

Table 6. Effect of soil fumigation program on cherry tomato production during six harvests and for the season total at Plant City in the spring of 1997.

Fumigant	Number of 14-lb flats per acre						
	5 May	8 May	10 May	13 May	17 May	21 May	Total
Methyl bromide	213[z]	543	409	540	794	630	3154
1,3 Dichloropropene + Chloropicrin with Pebulate	211	533	380	637	850	790	3400

[z]No statistical analysis was performed because the treatments were not replicated.

Table 7. Effect of soil fumigation program on weed control and incidence of fusarium wilt at Naples in the spring of 1997.

Fumigant	Number of plants per row			
	Nutsedge in bed	Nutsedge in middle	Clover in bed per row	Number of wilt plants
Methyl bromide	8.0 a[z]	65 a	71 a	1.9 a
1,3 Dichloropropene + Chloropicrin with Pebulate	0.4 b	63 a	27 b	1.0 b

[z]T test, 0.05 probability level.

Table 8. Effect of soil fumigation program on weed control at Plant City in the spring of 1997.

Fumigant	Number of plants per row			
	Nutsedge	Eclipta	Grass	Pigweed
Methyl bromide	38 a[z]	0 b	0 b	0 b
1,3 Dichloropropene + Chloropicrin with Pebulate	36 a	2 a	2 a	10 a

[z]T test, 0.05 probability level.

gin to germinate until after the herbicide had dissipated to a level below which it was not effective against these species.

Fusarium wilt (*Fusarium oxysporum* Schlecht. f. sp. *lycopersici*) infected plants were observed at most of the experimental sites but never in sufficient numbers to determine any difference in control between fumigant programs, except at Naples where there were fewer infected plants in the area treated with 1,3 dichloropropene + chloropicrin (Table 7). Although the difference was significant, the extent of the difference was not great enough to attach much practical importance to it.

Rootknot nematode infested plants were not observed at any site except Plant City where cherry tomatoes were planted in the spring immediately following a fall crop of cherry tomatoes. Although rootknot galling was observed on the roots of the fall crop, there were no rootknot nematodes recovered in soil samples collected prior to application or in the middle of the spring season (Table 9). The amount of rootknot nematodes observed in soil samples collected at the end of harvest was not high and there was no difference between the two fumigant programs. About 18% of the plants examined from areas treated with 1,3 dichloropropene + chloropicrin had galls on their roots compared with less than 1% from methyl bromide treated areas; however, the severity of root galling was quite low with both treatments and there was no difference between treatments.

Overall, the combination of pre-bed, broadcast application of 4 lb/acre of pebulate herbicide and injection of 35 gal/acre of a mixture of 1,3 dichloropropene + chloropicrin (17%) into the bed provided weed, disease, and nematode control as good as methyl bromide. Some reduction in tomato plant height was observed along with delay in crop maturity by as much as one week in some experiments. The height reduction was only about 4 inches in most cases and this is not considered serious since growers often top plants due to excessive growth. The delay in crop maturity could be an important consideration due to differential value of fruit over time and this potential delay must be considered by the grower when he schedules his plantings. It appears that tomato production would remain the same with the alternative herbicide/fumigant program; however, the greater incidence in rootknot nematodes on tomato roots at Plant City suggests that there may be potential for a greater resurgence in rootknot nematodes if the field was double-cropped. Additional research is underway to investigate this possibility and to determine methods to minimize any potential effect it may have on subsequent double crops.

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Table 9. Effect of soil fumigation program on rootknot nematode control at Plant City in the spring of 1997.

Fumigant	Number of nematodes per 100 cc soil			Root gall severity (0 to 8 scale)	Root gall incidence (%)
	Pre-application	Midseason	Post-harvest		
Methyl bromide	0 a	0 a	0 a	0.1 a	0.1 b
1,3 Dichloropropene + Chloropicrin with Pebulate	0 a	0 a	8 a	0.9 a	17.5 a

[z]T test, 0.05 probability level.