Effect of Continuous Plant Culture and Soil Fumigation on Soilborne Plant Pathogens and on Growth of Tomato Transplants

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ABSTRACT

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A 4-yr field test was conducted in southern Georgia to study population changes of selected plant pathogenic fungi and nematodes associated with repeated transplant culture and to determine the feasibility of using general purpose soil fumigants in tomato transplant production. There was no evidence that repeated tomato transplant culture consistently increased populations of soilborne plant pathogens except that root galling caused by *Meloidogyne incognita* increased during the first 3 yr of the test. Annual fumigation with some chemicals significantly increased plant vigor and yield of marketable plants during 3 of the 4 yr. The best chemical treatments also decreased populations of potential soilborne pathogens and increased survival of tomato seedlings grown in the greenhouse in treated soil from field plots. Methyl bromide was most effective in increasing vigor and yield, reducing populations of potential plant pathogens, and increasing survival of tomato seedlings in greenhouse bioassay tests. Methyl bromide applied once did not significantly increase plant vigor or yield or decrease populations of fungal plant pathogens during the 3 years after treatment. Metham decreased populations of potential pathogens, increased survival of seedlings in greenhouse bioassay tests, and improved yield during 2 yr. Spring applications of DD-MENCS and spring and winter applications of sodium azide increased vigor and yields during some years, but were less effective than methyl bromide and metham in reducing populations of soil organisms and in increasing seedling survival in bioassay tests. Reinfestation of fumigated fields and chemical phytotoxicity apparently are major problems that must be overcome to improve the usefulness of general purpose fumigants.

Additional key words: *Lycopersicon esculentum*, *Pythium* spp., *Fusarium* spp., *Rhizoctonia solani*.

Approximately 700 million tomato transplants are produced annually in southern Georgia for shipment to the northern United States and Canada (9). Until recently, diseases caused by soilborne fungi and nematodes were minimized by growing plants on newly cleared land and by moving to new sites before major disease problems developed (3). The use of previously cropped land for transplant production in recent years has increased the incidence of several soilborne disease problems (6, 8, 9). Presently, most tomato transplants are produced on nonfumigated land. However, transplant growers and their customers alike are interested in using general purpose fumigants to control soilborne plant pathogenic fungi and nematodes. Little information is available on the use of these fumigants for vegetable transplant production in the southern United States. This paper reports the results of a 4-yr study to determine the effect of continuous culture of tomato transplants without soil fumigation, or with single or annual applications of general purpose fumigants, on the populations of selected soilborne plant pathogens, and on the growth and yield of transplants.

MATERIALS AND METHODS

Field plots (5.5 m × 10.7 m) were first established in the spring of 1974 on a Fuquay loamy sand. The plots were located near Tifton on a soil typical of the soil types being used for transplant production. Peanuts were produced on the land during 1973. Treatments were: (i) methyl bromide [Dowfume MC-2, 490 kg/hectare (ha)], applied under a 102-μm (4-mil) polyethylene film in a single application (1974) or annually (1974-1977); (ii) metham (sodium methyl dithiocarbamate, Vapam, 748 liters/ha) applied annually as a drench in 6,500 liters of water; (iii) DD-MENCS (20% methyl isothiocyanate + 80% 1,2-dichloropropane, 1,3-dichloropropene and related chlorinated hydrocarbons, Vorlex, 327 liters/ha), injected annually; (iv) sodium azide (NaN_3, granular) applied to the soil surface annually in the winter (135 kg/ha) or spring (34 kg/ha) and incorporated into the top 15-cm soil layer with a tractor-mounted rotary tiller; and (v) control (no chemical). Each year, all treatments except methyl bromide and the winter application of sodium azide were applied in March or April, 3 to 5 wk before seeding, and were sealed into the soil immediately after chemical application with approximately 1.3 cm of water applied by sprinkler irrigation. Methyl bromide was applied 7 to 14 days before seeding and the polyethylene film was removed 3 to 4 days after application. All spring treatments were applied when soil moisture and temperature were suitable for chemical activity. Sodium azide for the winter treatment was incorporated during the November-January period when soil conditions were suitable for application. Treatments were arranged in a randomized complete block design with four replications, each consisting of three beds. All beds were aerated at least once with a rotary tiller before seeding.

Tomato (*Lycopersicon esculentum* Mill. 'Chico III' in 1974, 'Dorchester' in 1975 and 1976, and 'Libby 2981' in 1977) was seeded (98-120 seed/m) in four rows 0.35 m apart on each bed with a Planet Jr. (1974) or Stanhay seeder (1975-77) during late April. The seedbed was fertilized annually with approximately 55, 47, and 44 kg/ha of N, P, and K, respectively, applied as complete fertilizer at planting 2.5 cm under the seed in an 8-cm-wide band. Additional N, as $CaNO_3$, was applied as needed during the growing season to promote normal vegetative growth. Diphenamid (N,N-dimethyl-2, 2-diphenyl acetamide, 4.5 kg/ha) was used for weed control. Plants were grown according to recommended cultural practices and plant height was regulated by scheduled clipping with a rotary mower (4). Maneb (manganese ethylenebisdithiocarbamate, Manzate D, 2.24 kg/ha) or chlorothalonil (tetrachloroisophthalonitrile, Bravo 6F, 2.3 liters/ha) and carbaryl (1-naphthylmethylcarbamate, Sevin 80%, 0.8 kg/ha on young seedlings and 1.6 kg/ha on older seedlings) were applied at 7- to 10-day intervals for the control of foliage pathogens and insects. Methomyl {*S*-methyl-N-[(methylcarbamoyl)oxy] thioacetimidate, Lannate 90%, 0.56 kg/ha} was used as needed to control lepidopterous insects.

Generally, soil samples were collected with a soil sampling tube (40 cores from the top 20 cm to form a composite sample) from the center bed of each plot before and after treatment in the spring and again at transplant harvest and were assayed for plant parasitic nematodes and selected plant pathogenic fungi. Populations of *Pythium* spp. were determined on modified Kerr's medium (2); *Fusarium* spp. on Nash and Snyder's medium (11); *Rhizoctonia solani* Kühn with Ko and Hora's selective medium (7) in 1974-1975 and by a colonization method (12) with tablebeet seed as the bait in 1976-1977; and nematodes by a modified centrifugal-flotation method (5). In 1975-1977 bioassays for fungal pathogens also were made under greenhouse conditions by planting nontreated Marion tomato seed in soil from the treated and nontreated plots. Four pots (10-cm diameter) were filled with soil from each plot, seeded with 75 seed/pot, and placed on a greenhouse bench. Isolations were made from representative damped-off seedlings to determine the organisms present. Surviving plants were counted after 14 to 21 days. In the field, plants were rated for vigor about midseason on a 1 to 5 scale: 1 = plants small, chlorotic, and nonvigorous; and 5 = plants large, dark green, and vigorous. As plants reached marketable size, a random 1.8-m length of row from the center bed of each three-bed plot was harvested, the plants graded as either marketable or culls, and counted. In 1974 two harvests were made, one before clipping and another 3 wk later, after four clippings. The nonclipped yield was taken to give an indication of the treatment effects since smaller, less vigorous plants in nontreated plots may reach marketable size later if larger more vigorous plants are controlled by clipping. Clipping is used by growers to hold plants in the field when markets are not available and also to increase uniformity of plant size (4). At harvest, plants were removed from each plot and were rated for damage caused by root-knot nematodes [*Meloidogyne incognita* (Kofoid and White) Chitwood] on a 1-5 scale: 1 = no galling, 2 = 1-25, 3 = 26-50, 4 = 51-75, and 5 = 76-100% of roots galled.

TABLE 1. Vigor indices of tomato transplants grown in nonfumigated field plots and in field plots treated with general fumigants during 1974-1977[a]

	Plant vigor index[b]				
Soil treatment	1974	1975	1976	1977	Mean
Methyl bromide, 490 kg/ha, each spring	4.0 wx[c]	4.3 w	5.0 x	3.8 z	4.3 w
Methyl bromide, 490 kg/ha, one application (1974)	4.3 wx	2.8 yz	1.5 z	2.3 z	2.7 z
Metham, 748 liters/ha, each spring	4.8 w	5.0 v	1.5 z	4.0 z	3.8 wx
DD-MENCS, 327 liters/ha, each spring	4.0 wx	3.3 xy	3.5 y	3.3 z	3.5 xy
Sodium azide, 34 kg/ha, each spring	3.7 xy	3.8 wx	3.3 y	2.8 z	3.4 xy
Sodium azide, 135 kg/ha, each winter	...[a]	3.5 x	3.5 y	3.8 z	3.3 xy
Check (no treatment)	3.0 y	2.5 z	1.3 z	3.0 z	2.5 z

[a]Fumigant treatments were applied to the same plots annually except where methyl bromide was applied only once in 1974. The sodium azide winter treatment was not applied before the 1974 test so no value is given for that treatment.

[b]Based on a 1 to 5 scale: 1 = plants small, chlorotic, and nonvigorous; and 5 = plants large, dark green, and vigorous.

[c]Each value is the mean of four replications of three beds each. Values in column followed by the same letter are not significantly different as determined by Duncan's multiple range test ($P = 0.05$).

After transplant harvest, all plots were planted to corn (*Zea mays* L. 'Apache') in 1974 and soybean [*Glycine Max* (L.) Merr. 'Bragg'] in 1975 and 1976 to simulate a crop sequence that might be followed by a transplant grower.

RESULTS

Vigor and yield of marketable plants were significantly lower in nontreated plots than in plots treated with various soil fumigants although the results varied among treatments and from year to year (Table 1 and 2). The most striking differences occurred in 1976, when plants in nontreated plots remained markedly stunted during the entire growing season and only 12% were marketable at harvest. No significant differences in yield occurred during 1975 although plants in nontreated plots were generally less vigorous than plants in treated plots. Except for the single application of methyl bromide in 1974, all fumigant treatments significantly increased the average yield of marketable plants over the 4-yr test. The single application of methyl bromide significantly increased plant vigor and yield in 1974, but was ineffective during the subsequent 3 yr of the test. Metham was effective except in 1976 when plants were stunted and yield was low. This inadequate growth response appeared to be due to phytotoxicity. Methyl bromide was the most effective treatment in increasing final plant vigor and yield although plants in this treatment grew slower during the first 3 wk after emergence than those in other treatments. The DD-MENCS and the sodium azide treatments usually increased vigor and yield, but results were more variable than from the methyl bromide and metham (except in 1976) treatments. Yields shown in Table 2 were recorded after plants were clipped several times. Comparison of yields of nonclipped plants (harvested when plants given the most effective treatment reached marketable size) and yields of clipped plants (clipped four times with a rotary mower) in 1974 showed that clipping increased the percent of marketable plants in both treated and nontreated plots (Fig. 1). The latter was especially true in nontreated plots and plots receiving the less effective chemicals. For example, 45 and 81% of plants in nontreated plots were marketable when harvested as nonclipped and clipped plants, respectively, whereas 71 and 93% of plants in methyl bromide-treated plots were marketable when treated similarly. Plots

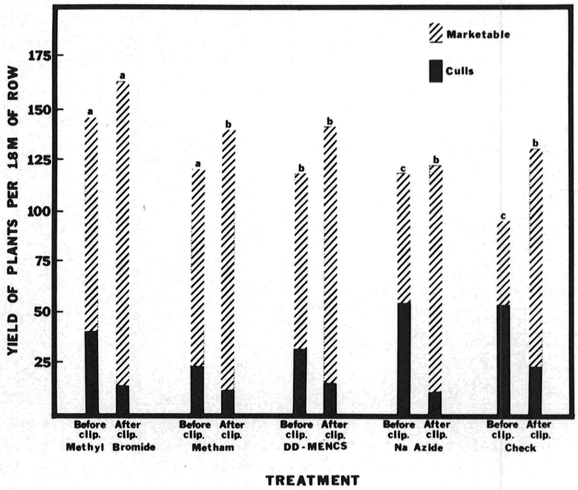

Fig. 1. Yields of tomato transplants grown in nonfumigated and fumigated field plots and harvested before clipping and after four clippings with a rotary mower during 1974. Yields of marketable transplants for a given clipping treatment are not significantly different if followed by a same letter as determined by Duncan's multiple range test ($P = 0.05$).

TABLE 2. Yields of tomato transplants grown in nonfumigated field plots and in field plots treated with general purpose fumigants during 1974-1977[a]

	Clipped plants per 1.8 m of row									
	1974		1975		1976		1977		Mean	
Soil treatment	Mkt. (no.)	Culls (no.)	Mkt. (no.)	Culls (no.)	Mkt. (no.)	Culls (no.)	Mkt. (no.)	Culls (no.)	Mkt. (no.)	Culls (no.)
Methyl bromide, 490 kg/ha, each spring	151 y[b]	12 z	129 z	23 z	149 x	17 z	149 x	10 z	144 w	16 z
Methyl bromide, 490 kg/ha, one application (1974)	139 y	8 z	135 z	21 z	24 z	102 x	107 z	33 z	101 yz	41 x
Metham, 748 liters/ha, each spring	127 z	10 z	122 z	22 z	19 z	77 xy	150 x	14 z	105 y	31 xy
DD-MENCS, 327 liters/ha, each spring	125 z	14 z	123 z	30 z	118 xy	35 yz	134 xy	19 z	125 x	25 yz
Sodium azide, 34 kg/ha, each spring	114 z	10 z	118 z	21 z	131 xy	31 yz	135 xy	26 z	124 x	22 yz
Sodium azide, 135 kg/ha, each winter	...[a]	...	126 z	26 z	103 y	45 yz	112 yz	31 z	113 xy	34 xy
Check (no treatment)	105 z	24 y	122 z	22 z	14 z	107 x	114 yz	22 z	89 z	44 x

[a]Fumigant treatments were applied to the same plots annually except where methyl bromide was applied only once in 1974. The sodium azide winter treatment was not applied before the 1974 spring test. Each value is the mean of four replications of three beds each.

[b]Values in column followed by the same letter are not significantly different as determined by Duncan's multiple range test ($P = 0.05$).

treated with sodium azide, one of the least effective chemicals in 1974, produced 56% marketable plants when harvested as nonclipped plants and 92% marketable plants when harvested as clipped plants.

Populations of soilborne plant pathogens, as measured by laboratory plating methods, ranged from low to moderately high during the 4-yr test period (Table 3 and 4). Populations of *Pythium* spp. in check plots varied from year to year as well as between sampling dates during a given year (Table 3). In 1974 to 1976 there were no

TABLE 3. Populations of *Pythium* spp. in nonfumigated fields plots and in field plots treated with general purpose fumigants and planted to tomato transplants for 4 yr[a]

	Propagules per gram of dry soil[b]							
	After treatment[c]				At harvest[c]			
Soil treatment	1974 (no.)	1975 (no.)	1976 (no.)	1977 (no.)	1974 (no.)	1975 (no.)	1976 (no.)	1977 (no.)
Methyl bromide, 490 kg/ha, each spring	0.0 z[d]	0.6 z	0.0 z	0.4 z	3.0 z	0.5 z	0.8 yz	13.5 z
Methyl bromide, 490 kg/ha, one application (1974)	0.0 z	7.5 z	...	...	1.0 z	2.2 z	7.9 xy	...
Metham, 748 liters/ha, each spring	0.0 z	0.4 z	0.0 z	0.1 z	<0.1 z	0.4 z	0.2 z	1.3 z
DD-MENCS, 327 liters/ha, each spring	0.2 z	15.6 yz	3.2 yz	3.1 z	0.7 z	1.2 z	3.3 yz	3.7 z
Sodium azide, 34 kg/ha, each spring	4.2 y	41.6 x	10.9 yz	6.6 yz	27.0 x	5.3 z	4.4 yz	3.6 z
Sodium azide, 135 kg/ha, each winter	...[e]	25.5 xy	24.1 x	14.9 y	...	8.9 z	6.4 xz	7.5 z
Check (no treatment)	7.7 x	37.3 x	14.5 xy	12.8 y	23.0 xy	3.4 z	12.9 x	9.0 z

[a]Fumigant treatments were applied to the same plots annually except where methyl bromide was applied only once in 1974. The sodium azide winter treatment was not applied before the 1974 test.

[b]Populations were determined on modified Kerr's medium (Hendrix and Kuhlman, Phytopathology 55:1183-1187). Each value is the mean of samples from four replications of three beds each.

[c]Samples were collected 20-25 April (after treatment) and 1-10 June (at harvest) during the test.

[d]Values in each column followed by the same letter are not significantly different as determined by Duncan's multiple range test ($P = 0.05$).

[e]Samples were not taken.

TABLE 4. Populations of *Fusarium* spp. in nonfumigated field plots and in field plots treated with general purpose fumigants and grown in tomato transplants for 4 yr[a]

	Propagules per gram of dry soil $\times 10^3$ [b]							
	After treatment[c]				At harvest			
Soil treatment	1974	1975	1976	1977	1974	1975	1976	1977
Methyl bromide, 490 kg/ha, each spring	0.1 z[d]	<0.1 z	0.2 z	0.1 z	0.8 z	0.3 z	1.7 yz	2.8 z
Methyl bromide, 490 kg/ha, one application (1974)	0.1 z	2.7 xy	...	...	0.2 z	1.6 y	3.0 xy	...
Metham, 748 liters/ha, each spring	0.1 z	0.1 z	1.8 xz	0.2 z	0.5 z	0.3 z	0.8 z	1.3 z
DD-MENCS, 327 liters/ha, each spring	0.1 z	1.9 xy	2.7 xz	2.1 xy	0.4 z	1.5 y	1.2 yz	2.3 z
Sodium azide, 34 kg/ha, each spring	1.2 z	2.6 xy	4.3 x	1.7 yz	1.5 y	1.4 y	2.9 xy	3.5 z
Sodium azide, 135 kg/ha, each winter	...[e]	1.4 yz	0.5 yz	2.7 xy	...	1.6 y	1.1 yz	2.8 z
Check (no treatment)	3.2 y	3.2 x	4.0 xy	3.7 x	3.2 x	1.3 y	3.9 x	4.7 z

[a]Fumigant treatments were applied to the same plots annually except where methyl bromide was applied only once in 1974. The sodium azide winter treatment was not applied before the 1974 test.

[b]Populations were determined on Nash and Snyder's medium (Phytopathology 52:567-572). Each value is the mean of samples from four replications of three beds each.

[c]Samples were collected 20-25 April (after treatment) and 1-10 June (at harvest) during the test.

[d]Values in each column followed by the same letter are not significantly different as determined by Duncan's multiple range test ($P = 0.05$).

[e]Samples were not taken.

significant differences in populations in the various plots before treatment application each spring. In 1977 populations were significantly lower in plots treated the previous year with methyl bromide, metham, or DD-MENCS. Methyl bromide, applied annually, and metham nearly eliminated *Pythium* spp. from the soil each year but some increase or reinfestation occurred by harvest time, most notably in the methyl bromide-treated plots in 1977. Application of DD-MENCS also significantly reduced *Pythium* populations but was generally less effective than methyl bromide and metham. Sodium azide was ineffective in reducing *Pythium* populations. Populations of *Fusarium* also varied greatly among years and sampling dates (Table 4). Populations were not significantly different in the various plots before treatment application each spring. None of the chemical treatments completely eliminated *Fusarium* spp. from the soil although methyl bromide and metham significantly reduced populations in most years. Applications of DD-MENCS and sodium azide gave less consistent results. In some years *Fusarium* populations increased in treated plots between treatment and harvest, indicating that build-up or reinfestation had occurred. Populations of *Rhizoctonia solani*, as determined by laboratory plating methods, were low and variable in most plots throughout the test period and data are not presented. However, limited information suggests that methyl bromide and metham provided an acceptable level of control of this organism. Applications of DD-MENCS and sodium azide also reduced populations. Laboratory and greenhouse tests with soil samples collected at harvest suggested that some reinfestation of treated plots occurred after treatment.

In greenhouse bioassay tests in 1975-1977 seedling survival counts were greatest in soil from methyl bromide (applied annually) and metham-treated plots (Table 5). Applications of DD-MENCS and sodium azide did not consistently increase seedling survival. Marked stand reductions occurred when seed were planted in soil collected at harvest from treated plots. Isolations from damped-off seedlings in the bioassay tests yielded *Pythium* spp., (mainly *P. irregulare* Buis. and *P. aphanidermatum*) (Edson) Fitzp., *Rhizoctonia solani*, *Fusarium* spp., and occasionally *Sclerotium rolfsii* Sacc.

Populations of *Meloidogyne incognita* were rather low throughout the experimental area, but some galling occurred. Numbers of root-knot larvae in the soil were positively correlated with root-gall indices; therefore, only root-gall indices are reported (Table 6). The mean root-gall indices in nontreated plots increased from 1.03 to 3.07 from 1974 to 1976. However, the index then dropped to 1.96 in 1977. Methyl bromide (annual application), sodium azide (135 kg/ha, winter) and DD-MENCS were highly effective in controlling root-knot nematodes. When all years are considered, metham and sodium azide (34 kg/ha, spring) did not give adequate control as certified tomato transplants must be free of galling. Methyl bromide applied once in 1974 provided complete control that year, but galling increased each year thereafter.

DISCUSSION

The production of vegetable transplants free of major diseases is important because pathogens present on southern-grown transplants may be disseminated to other areas of the United States and Canada. Presently, growers consider soilborne fungal and nematode pathogens the greatest threat to the transplant industry as permanent transplant production sites are established on

TABLE 5. Survival of tomato seedlings grown in the greenhouse in soil from nontreated field plots and in soil from plots treated with various soil fumigants during 1974-1977[a]

	Survival[b]					
	After treatment[c]			At harvest[c]		
Soil treatment	1975 (%)	1976 (%)	1977 (%)	1975 (%)	1976 (%)	1977 (%)
Methyl bromide, 490 kg/ha, each spring	81 w[d]	86 y	68 y	41 z	38 z	15 z
Methyl bromide, 490 kg/ha, one application (1974)	63 x	...[e]	...	29 z	25 z	...
Metham, 748 liters/ha, each spring	87 w	81 y	74 y	61 z	47 z	53 y
DD-MENCS, 327 liters/ha, each spring	37 z	57 z	50 z	37 z	22 z	33 yz
Sodium azide, 34 kg/ha, each spring	50 y	65 z	36 z	58 z	11 z	15 z
Sodium azide, 135 kg/ha, each winter	60 x	64 z	32 z	26 z	22 z	12 z
Check (no treatment)	44 yz	48 z	43 z	38 z	32 z	21 z

[a]Fumigant treatments were applied to the same plots annually except when methyl bromide was applied only once in 1974. The sodium azide winter treatment was not applied before the 1974 test.

[b]Each value is a mean of four replications each consisting of four pots seeded with 75 nontreated tomato seed. Counts of surviving seedlings were made after 2 to 3 wk.

[c]Samples were collected 20-25 April (after treatment) and 1-10 June (at harvest) during the test.

[d]Values in each column followed by the same letter are not significantly different as determined by Duncan's multiple range test ($P = 0.05$).

[e]Samples were not taken.

land previously cropped to peanuts, soybeans, and other crops susceptible to several soilborne pathogens (6, 8, 9). General purpose fumigants appeared to offer the greatest potential for controlling several soilborne disease fungi and nematodes that may attack tomato transplants. Earlier tests to evaluate general purpose fumigants for use in tomato transplant production were conducted on land known to be heavily infested with one or more important soilborne plant pathogens (8). It is equally important to know the benefits of fumigants when used as a normal production practice on soils typical of those used by transplant growers since fields with disease problems usually cannot be identified in advance.

Results of the present field tests, laboratory assays, greenhouse bioassays, and of other tests (S. M. McCarter, *unpublished*) indicate that previously-cultivated soils currently used for transplant production contain damaging levels of several plant pathogenic fungi and nematodes that are capable of causing economically important damping-off and root and stem diseases of tomato transplants. Variation of results from year to year in the present tests suggests that soil environmental factors are as important in disease occurrence as the organisms present. Growers are very much concerned about the potential increase of soilborne pathogens with repeated culture of tomato transplants on the same land. There was no strong evidence of an increase in the present test although damage caused by root-knot nematodes increased during the first 3 yr of the test. The population density of nematodes may be markedly altered by different cropping systems (1). For example, Johnson and Campbell (6) reported that a tomato transplant system with a spring crop of transplants followed by fallow reduced populations of root-knot nematodes more than transplants followed by pearl millet, milo, soybean, crotalaria, or pigeon pea. Bragg soybean was used as a summer crop in our test because it has some resistance to root-knot nematodes and is a high-value crop that could fit into a tomato transplant production system. The increase of root-knot nematode damage in nontreated plots in 1976 after a summer soybean crop in 1975 suggests that Bragg soybean is not a suitable crop for rotation with tomato transplants. Initial populations of nematodes and soilborne fungal pathogens were probably lower in our experimental area than in some growers' fields. *Sclerotium rolfsii,* which has caused major problems in some transplant fields in recent years (8, 9), occurred infrequently in our test.

Treatment of field soil with fumigants resulted in a significant increase of vigor and yield in 3 of the 4 yr the test was conducted. The striking response in 1976 and the less impressive but significant responses from some fumigants in 1974 and 1977 indicate that routine fumigation may be warranted. Annual fumigation is needed for maximum effectiveness; a single application of methyl bromide applied once was not adequately effective in later years. We emphasize that our results must be considered only in terms of relative effectiveness of treatments as some reinfestation probably occurred in our small plots that would probably not occur if an entire field were fumigated. We feel, however, that recontamination of fumigated fields through soil and water movement, including irrigation water (13), is a major problem that must be overcome to insure the season-long success of soil fumigation. Phytotoxicity is another problem that must be considered. Some of the chemical treatments used in this test caused stunting of plants during the early part of the growing season in some years although plants usually recovered without permanent damage. An exception to this occurred during 1976 when metham performed poorly and severely stunted plants throughout the growing season. We have no explanation for this response. Tomato transplants are seeded in early spring. Since the less volatile fumigants require a 3 to 4 wk waiting period, soil must be treated when soil temperature and moisture may not be ideal. Phytotoxicity sometimes occurs under these conditions. We feel that soil fumigation during the warmer periods of fall or winter may be the most practical

TABLE 6. Root-gall indices of tomato transplants grown in nonfumigated field plots and in field plots treated with general purpose fumigants during 1974-1977[a]

	Root-gall index[b]				
Soil treatment	1974	1975	1976	1977	Mean
Methyl bromide, 490 kg/ha, each spring	1.00 z[c]	1.00 z	1.00 z	1.00 z	1.00 z
Methyl bromide, 490 kg/ha, one application (1974)	1.00 z	1.14 z	1.88 z	2.00 y	1.51 xy
Metham, 748 liters/ha, each spring	1.00 z	1.20 z	1.72 z	1.00 z	1.23 yz
DD-MENCS, 327 liters/ha, each spring	1.00 z	1.00 z	1.01 z	1.00 z	1.01 z
Sodium azide, 34 kg/ha, each spring	1.00 z	1.19 z	1.05 z	1.00 z	1.06 yz
Sodium azide, 135 kg/ha, each winter	...[a]	1.00 z	1.00 z	1.00 z	1.00 z
Check (no treatment)	1.03 z	1.81 y	3.07 y	1.96 y	1.97 x

[a]Fumigant treatments were applied to the same plots annually except when methyl bromide was applied only once in 1974. The sodium azide winter treatment was not applied before the 1974 test so no root-gall data are given for that treatment.

[b]Based on a 1 to 5 scale: 1 = no galling, 2 = 1-25, 3 = 26-50, 4 = 51-75, and 5 = 76-100% of roots galled.

[c]Each value is a mean of four replications and values in column followed by the same letter are not significantly different as determined by Duncan's multiple range test ($P = 0.05$).

way to overcome some of the phytotoxicity problems since some positive response was obtained by winter treatment with sodium azide. Additional study is needed to determine the performance of the more effective chemicals when applied in the fall or winter before a spring tomato transplant crop (10).

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