Dispersion, Dissipation, and Efficacy of Methyl Bromide-Chloropicrin Gas vs. Gel Formulations on Nematodes and Weeds in Tifton Sandy Loam[1]

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Abstract: Dispersion, dissipation, and efficacy of gas and gel formulations of methyl bromide-chloropicrin (202, 269, 336, and 403 kg/ha) on nematodes and weeds on tomato were studied in field plots. Concentrations of methyl bromide and chloropicrin 4 hr after soil treatment were greater at a depth of 15 cm than at 30, 45, or 60 cm. The concentrations of both chemicals decreased with lower doses, greater depths, and longer times after application. The gel formulation was more persistent than the gas formulation at both 336 and 403 kg/ha at depths of 30 and 45 cm, especially 24 and 36 hr after chemical application. Plant growth and yield were improved when nematodes and weeds were controlled. *Key Words:* multiple pest control.

Nurseries and field soils frequently need fumigation to prevent infection of plants by soilborne pathogens. Methyl bromide (MB) has been used commercially to control soilborne plant-pathogenic fungi for about 30 yr. Fumigation with MB stimulates growth of plants primarily because it eliminates soilborne pests (3). However, stunting of certain crop plants grown in MB-fumigated soils has been observed repeatedly in several countries (4).

Gas and gel formulations of methyl bromide-chloropicrin (MBC) are available, but no information is available on the movement and dissipation of the gel formulation. Such knowledge would assist understanding of plant growth stimulation and the stunting problem following fumigation. This study was done to: 1) measure the movement and dissipation of MBC in a Coastal Plain soil; and 2) study the influence of MBC on nematodes and weeds.

MATERIALS AND METHODS

Field plots were established in March 1977 on Tifton sandy loam (75% sand, 10% silt, 15% clay) naturally infested with *Meloidogyne incognita* (Kofoid & White) Chitwood, *Macroposthonia ornata* (Raski) de Grisse, *Paratrichodorus* (N.) *minor* (Allen) Siddiqi, and weeds (nutsedge, *Cyperus esculentus;* common bermudagrass, *Cynodon dactylon;* and Florida pursley, *Richardia scabra*). Soil pH was 6.2 when chemicals were applied. The soil contained approximately 1.0% organic matter (wet

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oxidation) and had a bulk density of 1.5–1.6 g/ml. Each experimental plot was a single bed of 1.8 × 15.2 m. Fertilizer (1120 kg/A, 4-8-12, N-P-K) was broadcast and incorporated into the soil with a disk harrow. After land preparation, trifluralin (0.56 kg/ha) was incorporated in the top 5-cm soil layer in all plots with a tractor-powered rototiller. A set of stainless-steel capillary probes (1.6 mm diam) terminating at depths of 15, 30, 45, and 60 cm were installed in each plot. Each probe was fitted with a rubber septum aboveground to allow withdrawal of air samples from the respective depths. Treatments were: 1) MBC gas (Terr-O-Gas 67, 67% methyl bromide, and 31.8% chloropicrin); 2) MBC gel (Terr-O-Gel 67, 67% methyl bromide, and 30.75% chloropicrin), each applied at 202, 269, 336, and 403 kg/ha; and 3) untreated control. Treatments were arranged in a randomized complete block design with three replications. Soil chemical treatments were injected 15 to 20 cm deep with a tractor-drawn applicator with chisels 30 cm apart. Each chemical treatment was applied on the hour to expedite collection of gas samples. All plots were covered with black polyethylene (38 μm thick) immediately after chemical application.

The gas samples were analyzed by a Hewlett-Packard Model 5840 gas chromatograph (GC) using a flame ionization detector (FID). The gas samples were injected through an automated gas sampling valve with a 0.5-ml sample loop onto the analytical column. The column used was aluminum, of 0.64 cm × 0.91 m, packed with 20% DOW II on 80/100-mesh chromosorb W HP. The temperatures of injection port, oven, and detector were respectively 90, 85, and 125 C; the carrier gas was nitrogen at 50 ml/min. The retention time of methyl bromide was 0.67 minutes. Calibrations with pure methyl bromide gave a straight-line response from concentrations of 920 to 13,350 ppm in air.

The plastic cover was removed from all plots on 25 April (37 days after chemical application), and 4 days later all plots were planted with tomato, *Lycopersicon esculentum* Mill. cv. Campbell-28, 56 cm apart in rows 1.8 m apart and 15.2 m long. All plants were sidedressed with 560 kg 4-8-12, N-P-K on 16 May, and were sprinkler-irrigated with about 1.3 cm water per application on 29 April, 5 and 20 May, and 17, 21, and 22 June.

Initial and final plant stands were recorded on 2 June and 27 July. Plant growth indices were recorded on 2 June. All fruit was hand-harvested on 23 and 29 June and 5, 11, 14, and 21 July, and recorded as marketable or cull, on the basis of size. Only marketable yield data are presented.

Soil samples for nematode assays (20 2.1 × 20-cm cores to form a composite sample) were collected from the root zone on 18 April, 5 May, and 21 July. Each composite sample was mixed thoroughly, and a 150-cm^3 aliquant was processed by the centrifugal-flotation method (2) to separate nematodes from the soil.

Two plants from each plot were dug on 2 June and rated for damage caused by *M. incognita,* on a 1–5 scale. After the final harvest, all plants were uprooted and rated for galls.

Percent weed control and composition, based on a visual estimate for each weed species, were recorded 4 weeks after planting.

RESULTS

Tables 1 and 2 give the concentrations (μg/g) of methyl bromide and chloropicrin at various depths and time intervals after soil treatment. Both concentrations 4 hr after treatment were greater at a depth of 15 cm than at 30, 45, or 60 cm. The concentrations generally decreased with lower doses, greater depth, and longer times after application. The gel formulation at 403 kg/ha gave higher concentrations ($P = 0.05$) of methyl bromide 15 cm deep after 24 and 36 hr, 30 cm deep after 24 and 36 hr, and 45 cm deep 36 and 48 hr after application than did comparable gas formulation treatments. The trend was similar for the gel formulation at 336 kg/ha 30 cm deep at 24 and 36 hr and 45 cm deep at 24, 36, and 48hr. Concentrations of methyl bromide at 202 and 269 kg/ha were greater ($P = 0.05$) 15 cm deep at 36 hr for gas than for gel. The concentrations of chloropicrin 15 cm deep 4 hr after application of the gas formulation at 269 kg/ha were greater ($P = 0.05$) than the concentration in the comparable gel-formulation treatment.

TABLE 1. Influence of dose, depth, and time after application on concentrations of methyl bromide in soil.

Methyl bromide-chloropicrin treatment		Concentration (μg/g)																			
		15-cm depth					30-cm depth					45-cm depth					60-cm depth				
Formulation[a]	Rate (kg/ha)	4 hr	12 hr	24 hr	36 hr	48 hr	4 hr	12 hr	24 hr	36 hr	48 hr	4 hr	12 hr	24 hr	36 hr	48 hr	4 hr	12 hr	24 hr	36 hr	48 hr
Control	—	0.12	0.07	0.04	0.02	0.01	0.04	0.06	0.01	0.02	0.00	0.14	0.04	0.05	0.06	0.02	0.03	0.15	0.06	0.00	0.02
Gas	202	22.70	5.23	2.21	2.21	0.57	18.20	7.84	1.98	1.73	0.38	7.21	5.04	3.73	1.89	1.32	1.58	2.71	3.23	2.38	1.91
Gas	269	26.87	6.65	2.77	2.77	0.82	14.91	6.75	4.52	2.47	1.44	2.52	5.50	4.50	3.22	2.36	1.82	3.23	2.10	3.16	2.48
Gas	336	36.38	6.73	1.99	1.08	0.74	25.92	8.89	4.19	2.23	1.05	9.62	4.54	4.36	3.03	2.14	2.30	4.30	4.02	3.12	2.33
Gas	403	51.57	10.34	3.13	1.64	1.14	39.93	6.22	4.17	3.19	2.00	20.32	10.80	8.50	2.63	1.76	3.40	5.50	6.65	3.59	2.28
Gel	202	3.02	1.64	0.54	0.09	0.05	3.29	2.01	0.97	0.45	0.25	1.19	1.55	1.03	0.76	0.45	0.45	0.86	0.86	0.77	0.52
Gel	269	6.50	3.23	1.63	0.72	0.44	6.44	4.21	2.27	1.21	0.77	2.72	2.96	2.14	1.49	0.95	0.78	1.30	1.41	1.20	0.87
Gel	336	37.75	6.13	3.46	1.88	1.13	23.42	10.55	8.05	4.55	2.88	10.68	9.81	7.80	5.67	4.05	3.27	6.98	6.79	5.97	4.15
Gel	403	49.95	11.99	6.60	2.83	1.48	41.45	13.39	9.15	5.41	3.17	16.77	15.85	9.34	4.98	4.38	2.98	7.83	8.18	4.03	4.01
	LSD 0.05	22.30	4.87	3.01	0.99	ns	15.84	ns	3.66	1.89	1.41	ns	6.07	2.70	1.98	1.76	ns	3.98	2.98	3.26	2.48
	LSD 0.01	30.83	6.74	0.00	1.37	ns	21.82	ns	5.04	2.60	1.95	ns	8.39	3.75	2.73	2.42	ns	0.00	4.12	0.00	0.00

[a]Gas = 67% methyl bromide and 31.8% chloropicrin; gel = 67% methyl bromide and 30.75% chloropicrin.

TABLE 2. Influence of dose, depth, and time after application on concentrations of chloropicrin in soil.

Methyl bromide-chloropicrin treatment		Concentrations (μg/g)																			
		15-cm depth					30-cm depth					45-cm depth					60-cm depth				
Formulation[a]	Rate (kg/ha)	4 hr	12 hr	24 hr	36 hr	48 hr	4 hr	12 hr	24 hr	36 hr	48 hr	4 hr	12 hr	24 hr	36 hr	48 hr	4 hr	12 hr	24 hr	36 hr	48 hr
Control	—	0.32	0.00	0.00	0.03	0.04	0.06	0.01	0.05	0.03	0.05	0.03	0.15	0.12	0.04	0.24	0.09	0.31	0.00	0.09	0.40
Gas	202	5.40	1.05	0.20	0.04	0.12	0.90	0.49	0.22	0.08	0.05	0.53	0.33	0.24	0.02	0.12	0.62	0.03	0.41	0.04	0.08
Gas	269	11.18	1.55	0.65	0.04	0.00	0.36	0.15	0.22	0.13	0.00	0.59	0.06	0.41	0.03	0.00	0.20	0.00	0.04	0.00	0.00
Gas	336	7.35	0.96	0.29	0.15	0.00	0.63	0.85	0.54	0.17	0.00	0.36	0.07	0.32	0.11	0.00	1.08	0.15	0.45	0.16	0.00
Gas	403	9.98	2.71	0.65	0.31	0.00	2.08	0.00	0.70	0.40	0.00	1.04	0.35	0.98	0.20	0.06	0.39	0.14	0.45	0.11	0.15
Gel	202	0.13	0.14	0.00	0.00	0.00	0.50	0.09	0.20	0.06	0.11	0.15	0.29	0.47	0.11	0.69	0.06	0.05	0.11	0.03	0.10
Gel	269	1.57	0.29	0.45	0.06	0.24	0.43	0.08	0.04	0.00	0.03	0.11	0.00	0.02	0.00	0.00	0.45	0.22	0.45	0.06	0.15
Gel	336	7.72	1.04	0.72	0.21	0.28	1.45	0.51	0.13	0.38	0.77	0.30	0.08	0.31	0.11	0.16	0.64	0.14	0.38	0.02	0.72
Gel	403	15.75	2.20	0.77	0.20	0.31	2.87	0.72	0.66	0.15	0.23	0.72	0.29	0.23	0.11	0.14	0.51	0.18	0.27	0.04	0.25
	LSD 0.05	6.25	1.61	ns	0.19	ns	1.73	ns	ns	0.25	0.29	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	LSD 0.01	8.68	—		—		—			—	0.41										

[a]Gas = 67% methyl bromide and 31.8% chloropicrin; gel = 67% methyl bromide and 30.75% chloropicrin.

Initial and final plant stands were not affected by the chemical treatments; however, the visual growth ratings were higher ($P = 0.05$) in treated plots (except gel formulation at 202 and 403 kg/ha) than for untreated plots (Table 3).

All gas treatments increased yield of marketable fruit over the control, whereas only the 269-kg/ha gel treatment increased yields over those of the control (Table 3). No significant differences in yield occurred between similar rates of the gas and gel formulations, except at 202 kg/ha, where the gas increased yield but the gel did not. Treatments did not influence the percent of total yield that was of marketable quality.

The numbers of *P. minor, M. incognita* and *M. ornata* were low, erratic, and not significantly ($P = 0.05$) different in plots on 18 April (pretreatment). Numbers of *P. minor* and *M. ornata* remained low in all plots on 5 May, and were below detectable levels in all treated plots on 21 July. The numbers of *M. incognita* were higher in untreated plots than treated plots. In soil samples collected after the final harvest, *M. incognita* in treated plots was present only in plots treated with the gel formulation at 202 kg/ha (data not shown).

Root-gall indices of plants were lower ($P = 0.05$) for treated plots than for controls (Table 3). Galls were not found on roots of plants on 2 June and 27 July from treated plots, except those treated with the gel formulation at 202 kg/ha. Only a trace of galling was found on 27 July on roots from plots treated with the gel formulation at 269 kg/ha.

Weed control was acceptable in all treated plots (Table 4). Percent weed control was similar with the gas and the gel formulations.

DISCUSSION

Growers consider nematodes and soilborne pathogenic fungi the greatest threat to vegetable production in the southeastern USA, since production sites are established on land previously cropped to corn, soybeans, peanuts, and other crops susceptible to several soilborne pathogens (5). Most of these pathogens inhabit the upper 30-cm soil layer (1). The degree of nematode control in our experiment was related to the concentrations of methyl bromide and chloropicrin 15 and 30 cm deep 4 hr after chemical application.

Control of soilborne pathogenic fungi may possibly account for much of the growth and yield increase associated with our experimental treatments. We did not attempt to measure the control of soilborne pathogenic fungi or bacteria; however, Munnecke et al. (7) accurately determined the dose responses of several fungi to methyl bromide fumigation in soil under controlled laboratory conditions.

Van Gundy et al. (8) reported comparable data for certain nematodes. In

TABLE 3. Influence of methyl bromide-chloropicrin on tomatoes.

Treatment: Formulation[a]	Treatment: Rate (kg/ha)	Growth index[b] Jun. 2	No. plants/plot Jun. 2	No. plants/plot Jul. 27	Root-gall indices[c] Jun. 2	Root-gall indices[c] Jul. 27	Yield (metric ton/ha)
Control	—	3.0 d[d]	25	21	3.25 a	4.33 a	2.80 c
Gas	202	4.4 abc	26	22	1.00 c	1.00 c	4.37 ab
Gas	269	4.5 ab	25	21	1.00 c	1.00 c	4.00 ab
Gas	336	4.8 a	24	22	1.00 c	1.00 c	4.73 a
Gas	403	4.8 a	26	23	1.00 c	1.00 c	4.13 ab
Gel	202	3.5 cd	25	22	1.75 b	2.16 b	2.78 c
Gel	269	4.1 abc	26	22	1.00 c	1.08 c	4.49 ab
Gel	336	4.5 ab	26	23	1.00 c	1.00 c	3.79 abc
Gel	403	3.8 bcd	26	23	1.00 c	1.00 c	3.53 bc

[a]Gas = 67% methyl bromide and 31.8% chloropicrin; gel = 67% methyl bromide and 30.75% chloropicrin.
[b]1–5 scale: 1 = poor growth, and 5 = excellent growth.
[c]1–5 scale: 1 = no galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% roots galled.
[d]Values followed by the same letter indicate groupings of treatments that do not differ significantly at the 5% level of probability according to Duncan's multiple-range test. No letter indicates nonsignificance.

TABLE 4. Effect of methyl bromide-chloropicrin on weed control on tomatoes.

Treatment		Weed control (%)[b]	Percent composition of weed population		
Formulation[a]	Rate (kg/ha)		Nutsedge[c]	Bermudagrass[d]	Broadleaf weeds[e]
Control	—	0	78	4	18
Gas	202	95	50	0	50
Gas	269	95	83	0	17
Gas	336	99	90	0	20
Gas	403	97	56	0	44
Gel	202	92	68	0	32
Gel	269	86	60	0	40
Gel	336	94	65	0	35
Gel	403	99	38	0	62

[a]Gas = 67% methyl bromide and 31.8% chloropicrin; gel = 67% methyl bromide and 30.75% chloropicrin.
[b]Based on a visual estimate of percent ground cover in each plot.
[c]*Cyperus esculentus.*
[d]*Cynodon dactylon.*
[e]Florida pursley (*Richardia scabra*).

their studies, *M. incognita* in soil exposed to flowing 600 ppm methyl bromide became progressively less motile during 38 hr; infectivity (tomato bioassay) remained high for 30 hr and then decreased sharply.

Our data indicate that, at a depth of 30 cm, the gel formulation at 336 and 403 kg/ha was more persistent than the gas formulation 24 and 36 hr after application. The gas formulation gave higher concentrations than the gel formulation at 202 and 269 kg/ha. The greater concentrations, and possibly an "overkill" of mycorrhizal fungi (4), might account for the lower yields at the higher doses from gel-treated plots than from gas-treated plots.

The acceptable control of nematodes and weeds with both formulations of methyl bromide-chloropicrin at 269 kg/ha indicate that that dose seems adequate for Coastal Plain soils. In soils with nematode-fungi complexes, however, greater doses may be required to control certain soilborne fungi (6). Our data indicate that methyl bromide gel can be used to control nematodes and weeds in tomato production.

LITERATURE CITED

1. BRODIE, B. B. 1976. Vertical distribution of three nematode species in relation to certain soil properties. J. Nematol. 8:243-247.

2. JENKINS, W. R. 1964. A rapid centrifugal-flotation technique for separating nematodes from soil. Plant Dis. Rep. 48:692.

3. MAW, G. A., and R. J. KEMPTON. 1973. Methyl bromide as a soil fumigant. Soils and Fertilizers. Commonwealth Bur. Soils, Tech. Commun. 36:41-47.

4. MENGE, J. A., D. E. MUNNECKE, E. L. V. JOHNSON, and D. W. CARNES. 1978. Dosage response of the vesicular-arbuscular mycorrhizal fungi Glomus fasiculatus and G. constrictus to methyl bromide. Phytopathology 68:1368-1372.

5. McCARTER, S. M., C. A. JAWORSKI, and A. W. JOHNSON. 1978. Effect of continuous plant culture and soil fumigation on soilborne plant pathogens and on growth of tomato transplants. Phytopathology 68:1475-1481.

6. MUNNECKE, DONALD E., JAMES L. BRICKER, and MARTIN J. KOLBEZEN. 1978. Comparative toxicity of gaseous methyl bromide to ten soilborne phytopathogenic fungi. Phytopathology 68:1210-1216.

7. MUNNECKE, D. E., B. J. MOORE, and ABU-EL-HAJ. 1971. Soil moisture effects on control of Pythium ultimum or Rhizoctonia solani with methyl bromide. Phytopathology 61:194-197.

8. VAN GUNDY, S. D., D. MUNNECKE, J. BRICKER, and R. MINTEAR. 1972. Response of Meloidogyne incognita, Xiphinema index and Dorylaimus sp. to methyl bromide fumigation. Phytopathology 62:191-192.