Chemical Control of Nematodes and Soil-borne Plant-Pathogenic Fungi on Cabbage Transplants[1]

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Abstract: Six general-purpose fumigants and one fungicide were applied by different methods and evaluated for control of nematode-fungus complexes on cabbage grown for transplant production. All chemicals reduced populations of nematodes and soil-borne fungi but varied greatly in effectiveness. Methyl bromide + chloropicrin (98% methyl bromide + 2% chloropicrin) (MBR-CP gas), DD + methyl isothiocyanate (DD-MENCS), methyl bromide + chloropicrin (67% methyl bromide + 31.75% chloropicrin) (MBR-CP gel), and chloropicrin were more effective than sodium methyl dithiocarbamate (metham), pentachloronitrobenzene (PCNB), and potassium N-hydroxy-methyl-N-methyldithiocarbamate (Bunema) against *Meloidogyne incognita.* Populations of *Pythium* spp. and *Fusarium* spp. were reduced markedly by all treatments except PCNB. Plant growth, uniformity, and yield were greater when nematodes and fungi were controlled. *Key Words: Brassica oleracea,* root-knot nematodes.

Southern Georgia is a major production area for cabbage transplants to be shipped to other areas for head production. The production of cabbage and other transplants has been on newly cleared land to avoid plant-parasitic nematodes and pathogenic fungi (5). More recently, a scarcity of uncropped land suitable for transplant production, coupled with a need to increase yields and improve plant-size uniformity, has forced growers to establish permanent production sites on previously cultivated land. That change has increased the incidence of diseases caused by nematodes and soil-borne pathogens. Cabbage seedlings can be attacked by soil-borne organisms at any stage of development. Young seedlings damp-off and die rapidly. Older seedlings may develop stem canker (wire stem), in which injury is confined chiefly to a sloughing off of the primary cortex or is confined to the outer layers of the periderm (20). Because of those problems, interest has increased in soil treatment with general-purpose fumigants. One prerequisite for a permanent transplant-production system is seedbeds relatively free of nematodes, pathogenic fungi, and weeds. Greater yields and size uniformity would facilitate mechanical harvest. To aid such development, we evaluated 14 treatments involving six general-purpose fumigants and one fungicide for control of nematodes and soil-borne fungi pathogenic on cabbage.

MATERIALS AND METHODS

Tests were conducted in the summers of 1975 and 1976 in a field (85% sand, 8% clay, 7% silt) naturally infested with several species of nematodes and fungi, at the Coastal Plain Experiment Station, Tifton, Georgia. After land preparation in July, soil beds were prepared and the soil treatments were applied by various methods. Treatments were: 1) MBR-CP (98% methyl bromide + 2% chloropicrin) released with hand applicators at 490 kg/ha under 102-μ (4-mil) black polyethylene film; 2) chloropicrin (trichloronitromethane) injected into the soil at 137 or 327 liters/ha; 3) MBR-CP gel (67% methyl bromide + 31.75% chloropicrin) injected at 280 kg/ha; 4) DD-MENCS (20% methyl isothiocyanate + 80% 1,2-dichloropropane, 1,3-dichloropropene, and related chlorinated hydrocarbons) injected at 327 liters/ha; 5) metham (sodium methyldithiocarbamate) applied at 374 or 748 liters/ha as a drench in 6,500 liters of water, as a drench at 748 liters/ha in 6,500 liters of water and incorporated into the top 15 cm of soil with a tractor-driven rototiller, or as 748 liters/ha injected into the soil; 6) PCNB (pen-

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tachloronitrobenzene) as a drench at 45 kg/ha in 6,500 liters water; 7) Bunema (40% potassium N-hydroxy-methyl-N-methyldithiocarbamate; Buckman Laboratories, Memphis, Tennessee) at 374 liters/ha as a drench in 6,500 liters of water, as a drench and incorporated or injected into the soil; and 8) control (no chemical treatment). All chemical injections were made 15-20 cm deep with a tractor-mounted fumigator with injection chisels 20 cm apart. Beds were reshaped and the soil surface pressed firm simultaneously with chemical injection. All incorporated treatments were made with a tractor-powered rototiller, mixing the chemical in the top 15 cm of soil. Additionally, all chemicals except MBR-CP gas, which was applied under polyethylene, were sealed into the soil by about 1.3 cm of water applied with a sprinkler irrigation system immediately after chemical treatment. All chemicals except MBR-CP and PCNB were applied 2-3 weeks before seeding. MBR-CP was applied 9-10 days before seeding, and the polyethylene cover was removed 5-6 days after chemical application. PCNB was applied as a drench 9 days after seeding. All plots were aerated with a tractor-powered rototiller 5–6 days before seeding. Treatments were arranged in a randomized complete block design with four replications, each consisting of a single bed (1.83 x 12.2 m).

Cabbage (*Brassica oleracea* var. *capitata* L. 'Round Dutch') was seeded (79/m) with seed tapes in eight rows 0.18 m apart on 13 August 1975 or with a Stanhay seeder (197 seeds/m) in four rows 0.36 m apart on each bed on 19 August 1976. Seedbeds were fertilized with N, P, and K, respectively at 67, 58, and 56 kg/ha, applied on the soil surface and incorporated into the top 15-cm soil layer immediately before planting. Plants were side-dressed with calcium nitrate 3 wk after seeding, N at 34 kg/ha in 1975 and 17 kg/ha in 1976. DCPA (dimethyl tetrachloroterephthalate) was applied at 11.2 kg/ha for weed control at seeding. Sprinkler irrigation was used as needed to promote seed germination and plant growth.

Soil was assayed for plant-parasitic nematodes and soil-borne fungi at planting and also 30 days after planting. Twenty cores (2.5 × 15 cm) of soil were collected from the center rows of each plot and mixed thoroughly. For nematode assay, a 150-cm^3 soil aliquant was processed by a centrifugal-flotation method (6). About 1.5 liters of soil was also collected for assay of selected fungi and for greenhouse bioassay tests. Fungi from 2–5 g of moist soil were assayed on selective media. Populations of *Pythium* spp. were determined on modified Kerr's medium (4), *Fusarium* spp. on Nash and Snyder's medium (13), and *Rhizoctonia solani* with Ko and Hora's medium (7). *Pythium* spp. and *Fusarium* spp. were expressed as propagules/g of oven-dried soil, and *Rhizoctonia solani* as percentage of soil plugs yielding the organism. The remaining soil was placed in 10-cm clay pots in a greenhouse, and cabbage was planted (four pots with 75 seed/pot). Percent survival of seedlings was recorded 21 days after seeding.

One month after seeding, plant growth in field plots was rated on a scale of 1 to 5, from poor to excellent. Cabbage plant yields were recorded as the number of seedlings/m row. Plant uniformity was based on the percent of total yield that was marketable. At harvest, plant roots were indexed for root-knot damage according to the following scale: 1 = no galls; 2 = 1–25%; 3 = 26–50%, 4 = 51–75%; and 5 = 76–100% roots galled.

RESULTS

Nematodes: Populations of *Meloidogyne incognita* (Kofoid & White) Chitwood, *Trichodorus christiei* Allen, *Criconemoides ornatus* Raski, and *Helicotylenchus dihystera* Cobb (Sher) were distributed uniformly in the experimental areas before chemical treatment, but only *M. incognita* increased in number as the tests progressed. There was a positive correlation (r = 0.36*) between numbers of *M. incognita* larvae in the soil and root-gall indices at harvest. Therefore, only root-gall indices are reported (Table 1). Root-gall indices were lower in plots treated with chloropicrin, MBR-CP, and DD-MENCS than in untreated plots in 1975 and 1976. Also in 1976, metham (injected), MBR-CP gel, and Bunema (injected) reduced root-gall indices. Metham, regardless of application method, was less effective than chloropicrin, MBR-CP, DD-MENCS, and MBR-CP gel in controlling root-knot nematodes. Control of

TABLE 1. Effect of soil chemical treatments on root-gall indices, growth, and yield of cabbage transplants.

Treatment/rate[u]/ application method[v]	Root-gall index[w]		Growth index[x]		Number plants/m row			
					1975		1976	
	1975	1976	1975	1976	Marketable	Culls	Marketable	Culls
Metham/374 l/dr	2.29 a[y]	—[z]	2.5 c	—	36 a-c	19 ab	—	—
Metham/748 l/dr	1.92 ab	1.10 ab	3.4 b	4.0 a	46 a	14 a-c	49 a	9 b
Metham/748 l/dr-inc	1.65 bc	1.39 a	2.9 b	3.7 a	47 a	8 c	50 a	5 b
Metham/748 l/inj	1.70 bc	1.06 b	3.5 b	4.5 a	42 ab	12 a-c	56 a	7 b
Chloropicrin/137 l/inj	1.01 d	—	4.4 a	—	44 a	7 c	—	—
Chloropicrin/327 l/inj	—	1.04 b	—	4.7 a	—	—	56 a	7 b
MBR-CP/490 kg/pol	1.00 d	1.00 b	3.8 ab	4.2 a	50 a	9 c	46 a	7 b
MBR-CP gel/280 kg/inj	—	1.00 b	—	4.5 a	—	—	53 a	6 b
DD-MENCS/327 l/inj	1.00 d	1.00 b	4.5 a	3.7 a	44 a	9 c	41 a	8 b
PCNB/45 kg/dr	1.31 cd	—	2.6 bc	—	25 c	22 a	—	—
Bunema/374 l/dr	—	1.30 ab	—	4.0 a	—	—	53 a	4 b
Bunema/374 l/dr-inc	—	1.38 a	—	3.7 a	—	—	54 a	7 b
Bunema/374 l/inj	—	1.06 b	—	4.2 a	—	—	50 a	4 b
Control (no chemical)	1.70 bc	1.39 a	2.0 c	1.7 b	30 bc	16 a-c	26 b	15 a

[u]Per hectare

[v]dr = drench; inc = incorporated; inj = injected; pol = under polyethylene.

[w]1–5 scale: 1 = no galls; 2 = 1-25%; 3 = 26-50%; 4 = 51-75%; and 5 = 76-100% roots galled.

[x]1–5 scale: 1 = plants small, chlorotic, nonvigorous; and 5 = plants large, dark-green, and vigorous.

[y]Numbers followed by the same letter are not significantly different according to Duncan's multiple-range test; P = 0.05.

[z]Treatment not evaluated.

nematodes was greater from injection of Bunema than from application as a drench or incorporation.

Populations of soil-borne fungi: The fungi most common in the soil from field plots were *Pythium irregulare, P. ultimum, P. aphanidermatum, F. solani, F. oxysporum,* and *F. roseum.* Numbers of propagules/g soil of *Pythium* spp. and *Fusarium* spp. were reduced by all chemical treatments except PCNB in 1975 (Table 2). *Rhizoctonia solani* was reduced by all chemical treatments except metham injected, chloropicrin, MBR-CP, and DD-MENCS.

In 1976, populations of *Pythium* spp. and *Fusarium* spp. at planting were significantly reduced by all chemical treatments except Bunema injected, and *R. solani* was reduced by all soil treatments (Table 2). Populations of *Pythium* spp. and *Fusarium* spp. increased in most plots after planting. At harvest, populations of *Pythium* spp. were reduced by all chemical treatments, and populations of *Fusarium* spp. and *R. solani* were reduced by all treatments except metham injected, Bunema incorporated, and Bunema injected.

Plant growth and yield: Plant growth, uniformity, and yield of transplants were greatest when populations of *M. incognita* and soil-borne fungi were reduced to low levels by soil fumigation (Table 1). Average growth responses of plants were lower in untreated plots than in treated plots in 1975, except plots treated with metham (374 liters/ha) and PCNB, and in all treated plots in 1976. Plants in plots treated with PCNB were stunted throughout the study. There was an inverse relation between populations of *Pythium* spp. and plant growth ($r = -0.64^{**}$), uniformity ($r = -0.39^{*}$) in field tests, and percent seedling survival ($r = -0.53^{**}$) in the bioassay tests. The relation was similar between *Fusarium* spp. and plant growth ($r = -0.59^{**}$), uniformity ($r = -0.51^{**}$), number of marketable transplants ($r = -0.45^{*}$) in the field, and percent seedling survival ($r = -0.55^{**}$) in bioassay tests. In addition, there was an inverse relation between plant growth and root-gall indices ($r = -0.48^{*}$). Plant uniformity, based on percent of marketable transplants, was highest in plots treated with metham (drench or incorporated), chloropicrin, MBR-CP, and DD-MENCS in 1975, and metham (drench or incorporated), MBR-CP gel, Bunema drench, and Bunema injected in 1976. Plant uniformity was in-

TABLE 2. Populations of selected soil fungi in control plots and plots treated with general-purpose fumigants.

Treatment/rate[v]/ application method[w]	Soil collected: At planting 1975 — Genera of soil fungi[x]: *Pythium* (ppg)	*Fusarium* (ppg)	*Rhizoctonia* (%)	At planting 1976 — Genera of soil fungi: *Pythium* (ppg)	*Fusarium* (ppg)	*Rhizoctonia* (%)	At harvest 1976 — Genera of soil fungi: *Pythium* (ppg)	*Fusarium* (ppg)	*Rhizoctonia* (%)
Metham/374 l/dr	6 b[y]	3,394 bc	2 b	—[z]	—	—	—	—	—
Metham/748 l/dr	1 b	1,425 d	1 b	0 b	56 b	0 b	1 c	1,200 c	0 b
Metham/748 l/dr-inc	1 b	2,513 cd	1 b	0 b	356 b	0 b	1 c	1,856 c	1 b
Metham/748 l/inj	8 b	2,031 cd	10 a	1 b	750 b	2 b	2 c	4,431 ab	3 ab
Chloropicrin/137 l/inj	1 b	1,444 d	8 ab	—	—	—	—	—	—
Chloropicrin/327 l/inj	—	—	—	1 b	294 b	0 b	1 c	2,625 bc	1 b
MBR-CP/490 kg/pol	4 b	863 d	7 ab	0 b	131 b	0 b	1 c	1,375 c	1 b
MBR-CP gel/280 kg/inj	—	—	—	1 b	113 b	2 b	1 c	1,031 c	1 b
DD-MENCS/327 l/inj	1 b	1,281 d	3 ab	0 b	225 b	1 b	1 c	1,106 c	0 b
PCNB/45 kg/dr	65 a	4,538 ab	2 b	—	—	—	—	—	—
Bunema/374 l/dr	—	—	—	0 b	338 b	1 b	3 c	2,906 bc	0 b
Bunema/374 l/dr-inc	—	—	—	1 b	1,050 b	2 b	13 b	4,650 ab	2 ab
Bunema/374 l/inj	—	—	—	7 a	2,719 a	6 b	14 b	5,069 a	3 ab
Control (no chemical)	75 a	5,750 a	10 a	11 a	2,719 a	15 a	33 a	5,500 a	4 a

[v]Per hectare
[w]dr = drench; inc = incorporated; inj = injected; pol = under polyethylene.
[x]*Pythium* populations were determined on modified Kerr's medium, *Fusarium* on Nash and Snyder's medium, and *Rhizoctonia* by Ko and Hora's method expressed as percentage of soil plugs yielding the organism. ppg = propagules per gram of dry soil.
[y]Numbers followed by the same letter are not significantly different according to Duncan's multiple-range test; P = 0.05.
[z]Treatment not evaluated.

versely related to root-gall indices (r = –0.54**) in 1975.

Stepwise regression analyses indicated that the variation in plant uniformity in the field in 1975 was caused 29% by root-gall indices and 43% by root-gall indices plus the number of *Fusarium* spp. propagules in the soil. In 1976, 49% of the variation in plant growth ratings was caused by the number of *Pythium* spp. propagules in the field soil at harvest, root-gall indices, and the number of *R. solani* in the soil at seeding. Variation in average plant vigor ratings in the field was attributed 27% to root-gall indices plus the number of *Pythium* spp. propagules in the soil, and 49% to root-gall indices plus the number of *Pythium* spp. propagules in the soil plus numbers of stubby-root and ring nematodes in the soil.

The number of marketable transplants increased in 1975 in all treated plots except those treated with metham (374 liters-drench and metham injected) and PCNB, and in 1976 in all treated plots. In 1975 the number of marketable transplants was related inversely to the number of *Fusarium* spp. propagules/g soil (r = –0.45*), and in 1976 the number of marketable transplants was related inversely to the number of *Pythium* spp. propagules/g at seeding (r = –0.30*) and at harvest (r = –0.38*) and to *R. solani* at seeding (r = –0.43*).

Bioassay: Seedling survival was lower in untreated soil in greenhouse studies, in 1975, than in soil treated with metham (748 liters/ha) drench, metham plus incorporation, chloropicrin, MBR-CP, or DD-MENCS (Table 3). In 1976 more seedlings survived in soil collected at planting from all treated plots except those treated with Bunema incorporated and Bunema injected, than from untreated soil. In field soil collected at harvest, more seedlings survived in soil treated with MBR-CP and DD-MENCS than in untreated soil. Isolations from seedlings that damped-off or had root rot yielded cultures of *P. irregulare, P. ultimum, P. aphanidermatum, F. oxysporum, F. solani,* and *R. solani. Fusarium* spp. caused 30% and 38% of the variation in percent survival of seedlings under greenhouse conditions in 1975 and 1976, respectively.

TABLE 3. Percent cabbage seedlings that survived from 300 seeds planted in treated and untreated field soil under greenhouse conditions.[x]

Treatment/rate[v]/ application method[w]	Year and soil collection time		
	1975	1976	
	Harvest	Planting	Harvest
Metham/374 l/dr	13 cd[y]	–[z]	–
Metham/748 l/dr	57 a	54 a	36 a-c
Metham/748 l/dr-inc	46 ab	61 a	36 a-c
Metham/748 l/inj	18 cd	30 bc	37 a-c
Chloropicrin/137 l/inj	27 c	–	–
Chloropicrin/327 l/inj	–	45 b	36 a-c
MBR-CP/490 kg/pol	41 b	60 a	48 ab
MBR-CP gel/280 kg/inj	–	41 a-c	32 a-c
DD-MENCS/327 l/inj	46 ab	47 ab	55 a
PCNB/45 kg/dr	12 d	–	–
Bunema/374 l/dr	–	48 ab	26 bc
Bunema/374 l/dr-inc	–	23 cd	18 c
Bunema/374 l/inj	–	14 d	21 c
Control (no chemical)	12 d	12 d	15 c

[v]Per hectare

[w]dr = drench; inc = incorporated; inj = injected; pol = under polyethylene.

[x]Soil samples were collected from treated and control plots in the field. Cabbage seed (75 per pot) were planted in four 10-cm clay pots. Survival counts were made after 21 days.

[y]Numbers followed by the same letter are not significantly different according to Duncan's multiple-range test; P = 0.05.

[z]Treatment not evaluated.

DISCUSSION

In the coastal plain of Georgia, cabbage is direct-seeded for production of transplants in February-March and in July-August, which are respectively shipped for a spring-and-early-summer crop and a fall-and-winter crop. In the late summer, soil temperatures 1–2 cm deep (even with daily sprinkler irrigation) are commonly 30–39 C (17). High soil temperatures are known to increase seedling damage by *R. solani, F. oxysporum, F. solani,* and *Sclerotium rolfsii* (18, 19). Also, high-temperature *Pythium* spp., such as *P. aphanidermatum* and *P. myriotylum,* cause severe damping-off in numerous crops in the coastal plain (10). During our tests, the average maximum soil temperatures 5 cm deep in 1975 and 1976 were respectively 37 C and 35 C. Thus, the temperature was very favorable for damage by several soil-borne pathogens that attack cabbage.

Work on chemical control of cabbage seedling diseases has involved the use of nematicides and specific fungicides (16, 18, 21). We were particularly interested in the effectiveness of general-purpose fumigants rather than specific pesticides on the control of nematode-fungus complexes in permanent production sites. Our results indicate that certain general-purpose fumigants control these complexes on cabbage transplants and that their performance is affected by the rate and method of application. Root-knot-nematode-free cabbage is required to meet transplant certification standards (1). MBR-CP, DD-MENCS, and MBR-CP gel were most effective in controlling nematodes in these studies.

Metham and Bunema were most effective when applied as a drench with a water seal, respectively at 748 liters and 374 liters/ha. We reported similar results with metham for control of *S. rolfsii* on tomato transplants (9). Metham was more effective for fungus control in our tests than has generally been reported by others (5); however, our method of application was different. We believe that drench application of these pesticides was more effective than soil incorporation and injection because the drench provided a greater concentration of chemical in the top 6 cm of soil, where fungi are most active (2, 18).

In our tests, MBR-CP, chloropicrin, MBR-CP gel, and DD-MENCS were effecttive in controlling soil-borne fungi. Both MBR-CP and chloropicrin have been reported to be highly effective against several soil-borne fungi (3, 11, 12, 14, 15). DD-MENCS was only moderately effective in controlling southern blight and early blight of tomato transplants (8, 9).

Even though our results are encouraging, only MBR-CP, DD-MENCS, and MBR-CP gel completely controlled root-knot nematodes and reduced populations of *Pythium* spp., *Fusarium* spp., and *R. solani*. Even so, their use in cabbage-transplant production is precluded at present by the laborious application technique and hazards in using MBR-CP, and the large amounts of the other chemicals required. Since DD-MENCS and MBR-CP gel do not require polyethylene covers after chemical application and cover removal before seeding, they appear most promising for control of nematode-fungus complexes. In fields where soil-borne fungi are primary pathogens and root-knot nematodes are absent or below damaging levels, metham as a drench at 748 liters/ha should give adequate control of root diseases.

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