Efficacy of Metam-Sodium Applied Through Overhead Sprinkler Irrigation for Control of Soilborne Fungi and Root Diseases of Vegetables

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ABSTRACT

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Metam-sodium was more effective against *Rhizoctonia solani* AG-4 and *Pythium* spp. when applied through overhead sprinkler irrigation than when injected with chisels in a fall experiment and had equal efficacy in spring experiments. There was a linear increase in efficacy when metam-sodium was applied in 1.3 cm of water, and low dosages of 187 to 280 L/ha increased plant stand by an average of 149 and 212%, respectively, in fall crops of turnip, kale, mustard, collard, and spinach. In contrast, metam-sodium was less effective in controlling root diseases and increasing plant stands in spring crops of snap bean, okra, cucumber, tomato, and pepper, and 468 L/ha or more was required for effective disease control. Application of metam-sodium in 2.5 cm of water was more effective in controlling root diseases in deep-rooted vegetables such as okra than in 1.3 cm of water, and applications in 0.6 cm of water were ineffective. Increasing rates of metam-sodium caused a significant linear reduction in populations of *R. solani* AG-4 and AG-2 type 2, *Pythium* spp., *Fusarium* spp., and saprophytic fungi, and applications through irrigation water had greater or equal efficacy to injection with chisels.

Metam-sodium is a broad-spectrum soil fumigant that decomposes rapidly to methylisothiocyanate (MIT). The chemical is effective against numerous soilborne pathogenic fungi and has been used successfully to control many root, tuber, and pod diseases (4,12,14). However, injection of metam-sodium at low dosages (327 L/ha) under film mulch has been less effective than DD-MENCS and methyl bromide-chloropicrin in controlling soilborne pathogens in previous research in Georgia (23). A uniform distribution of MIT in soil is difficult to obtain (7), and recent research indicates that application of metam-sodium through overhead irrigation water may be a more effective way to obtain uniform distribution than by injection with chisels (1,2,4). In the Georgia coastal plain, application of metam-sodium at a constant concentration with 1.3 cm of overhead irrigation water was optimal for controlling soilborne pests and increasing yields of turnip greens, collards, and spinach (16).

Soil fumigation is expensive, but consistent control of soil pests with low dosages would make fumigation more economical for vegetable growers. Root diseases frequently are limiting factors in producing economical yields of high-quality vegetables in the Georgia coastal plain (9,10,18,22,24). Because most vegetable growers routinely use irrigation to prevent drought injury in the sandy soils, this research was initiated to determine the influence of metam-sodium dosages and application methods on control of soilborne pathogenic fungi and root diseases in both spring and fall vegetables.

MATERIALS AND METHODS

This study was conducted under solid-set overhead irrigation on Bonifay sand (loamy, siliceous, Thermic, gross arenicplinthic Paleudult, 93.5, 2.9, and 3.6% sand, silt, and clay). An experiment was run each spring and fall in 1981 and 1982. A split-plot experiment with a randomized complete block design was used. Whole plots were four replicates of chemical treatments, 12.2 × 12.2 m with five raised beds 1.8 m wide. Irrigation was applied by two Nelson Beta II sprinklers 1 m high on opposite corners of each plot. Metam-sodium (Vapam) was injected through irrigation at rates from 94 to 1,870 L/ha with positive pressure pumps in constant amounts with 0.64, 1.27, or 2.54 cm of water. Also, metam-sodium was injected with chisels,

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25 cm apart, 20–25 cm deep, in the first three tests. Controls and chiseled plots were irrigated with 1.27 cm of water immediately after injection.

Metam-sodium was applied in March or April for spring crops and in September for fall crops. Soil temperatures 10 cm deep averaged 21.8, 29.4, 24.1, and 29.1 C for 1 wk after treatment in the four successive spring and fall tests, respectively. Fenamiphos (Nemacur 3, 6.72 kg a.i./ha), alone and with metam-sodium (468 L/ha), was applied in the first test. Subplots were crops planted or transplanted 3–5 wk after treatment. Each crop was in a bed 1.8 × 12.2 m. Crops grown in the spring were snap bean (*Phaseolus vulgaris* L. cv. Eagle), cucumber (*Cucumis sativus* L. cvs. Dasher and Calypso), tomato (*Lycopersicon esculentum* Mill. cv. UC-82B), pepper (*Capsicum frutescens* L. cvs. Yolo Wonder and Pimento), and okra (*Hibiscus esculentus* L. cv. Clemson spineless). Spinach (*Spinacia oleracea* L. cvs. Grandstand and Iron Duke), collard (*Brassica oleracea* var. *acephala* cv. Vates), turnip (*Brassica campestris* L. Rapifera group cvs. Purple Top and Shogoin), mustard (*Brassica juncea* L. cv. Giant Curled), and kale (*Brassica oleracea* var. *acephala* cv. Vates) were grown in fall.

Soil fungi. Soil samples were collected at planting, 10 cores 2.5 cm in diameter × 15 cm deep in each plot. Cores were

Table 1. Populations of fungi in soil treated with metam-sodium and fenamiphos applied through overhead irrigation water and injected with chisels (April 1981)

Treatment	Rate (L/ha)	Application method	*Pythium* spp.[a]	*Rhizoctonia solani* + RLBF[b]	*Fusarium solani*	*Penicillium* spp. + *Paecilomyces* spp.	Total *Phycomycetes*	Total fungi
Metam-sodium	935	Irrigation (0.63 cm)	11	0	50	30,700	0	242,400
		Irrigation (1.27 cm)	0	0	110	25,000	10,000	246,100
		Irrigation (2.54 cm)	1	2	60	23,800	600	112,700
		Chisel	2	2	160	134,000	0	576,800
	468	Irrigation (0.63 cm)	2	0	500	192,300	3,100	511,600
		Irrigation (1.27 cm)	1	0	310	23,200	11,300	135,300
		Irrigation (2.54 cm)	2	0	60	9,400	13,800	569,300
		Chisel	20	2	340	213,000	6,900	425,200
Metam-sodium + fenamiphos[c]	468 ± 18.7	Irrigation (1.27 cm)	3	0	20	8,800	6,900	88,300
Fenamiphos	18.7	Irrigation (1.27 cm)	92	4	300	125,900	7,500	331,300
Control	0	Irrigation (1.27 cm)	82	19	550	105,800	15,000	690,800
Comparisons of interest[d]								
Metam-sodium rate			NS	NS	NS	NS	NS	NS
Chisel vs. irrigation			NS	NS	NS	NS	NS	0.05
Irrigation (linear)			NS	NS	NS	NS	NS	0.05
Metam-sodium + fenamiphos vs. fenamiphos			0.01	0.01	0.01	0.01	NS	0.01
Fenamiphos vs. check			0.01	0.01	NS	NS	NS	0.01
Metam-sodium vs. other			0.05	0.01	NS	NS	0.05	NS

[a] Primarily *P. irregulare*.
[b] Populations of *Rhizoctonia solani* + *Rhizoctonia*-like binucleate fungi are in colony-forming units (cfu)/100 g of oven-dried soil. All other fungi are cfu/g of oven-dried soil.
[c] Metam-sodium is 32.7% a.i.; fenamiphos is 359 g a.i./L.
[d] $P = 0.05$ or 0.01, NS = no significant differences.

Table 2. Populations of fungi in soil and root and stem diseases in vegetables after treatment with metam-sodium through overhead irrigation water or with chisels (March 1982)

Rate (L/ha)	Application method	*Pythium* spp.[a]	*Rhizoctonia solani* AG-4[b]	*Fusarium solani*	Total fungi	Root and hypocotyl disease index[c]			
						Okra	Snap bean	Tomato	Pepper
1,870	Irrigation	1	1	20	167,000	2.4	3.2	2.0	2.6
	Chisel	2	0	40	196,000	3.1	2.8	1.9	3.0
935	Irrigation	4	2	170	307,000	2.9	3.2	1.9	2.9
	Chisel	1	2	270	180,000	4.0	3.3	1.9	3.0
468	Irrigation	3	3	330	376,000	3.4	3.4	2.1	3.1
	Chisel	7	2	340	234,000	3.4	3.2	2.1	3.2
234	Irrigation	6	0	590	331,000	3.4	2.6	2.1	3.1
	Chisel	19	0	460	274,000	3.5	2.6	2.1	3.1
93	Irrigation	26	0	390	252,000	3.4	3.0	2.3	3.0
	Chisel	32	0	290	403,000	3.4	2.6	2.2	3.5
0	Chisel	67	1	240	393,000	3.3	2.6	2.2	3.3
	None	18	1	320	374,000	3.2	2.3	2.1	3.4
Comparisons of interest[d]									
Irrigation vs. chisel		NS	NS	NS	NS	NS	NS	NS	NS
Rates									
Linear		0.01	NS	0.01	0.01	0.01	NS	0.01	0.05
Quadratic		0.01	0.01	NS	NS	NS	0.01	NS	NS
Cubic		0.05	NS	NS	NS	NS	NS	NS	NS

[a] *P. irregulare* and *P. aphanidermatum*.
[b] Colony-forming units (cfu)/100 g of oven-dried soil; all other fungi are cfu/g of oven-dried soil.
[c] Disease index: 1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% root and hypocotyl discoloration and decay; 5 = dead plant.
[d] $P = 0.05$ or 0.01, NS = no significant differences.

divided into depths of 0–7.5 and 7.5–15 cm and mixed, and soil from each depth in each plot was processed separately. A multiple pellet-soil sampler (8) was used to assay soil for *Rhizoctonia solani* and *Rhizoctonia*-like binucleate fungi (RLBF) on tannic acid benomyl agar (TABA) medium (20). Hyphal tips were transferred to PDA and identified.

Soil dilutions in 0.3% water agar were assayed for *Pythium* spp. on pimaricin-ampicillin-rifampicin (PAR) medium (11), for *Fusarium solani* (Mart.) Appel & Wor. and total *Fusarium* spp. on modified PCNB medium (15), and for numerous saprophytic fungi and total fungi on Ohio Agricultural Experiment Station (OAES) medium (25). Populations were expressed as colony-forming units (cfu) per gram of oven-dry soil, except *R. solani* and RLBF were cfu/100 g of oven-dry soil.

Root and hypocotyl diseases. Plants in 1 or 2 m of row (3–35/plot) in selected crops were removed 2–4 wk after planting and rated for disease on a scale of 1–5, where 1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% root and hypocotyl discoloration and decay; 5 = dead plant. Data were taken on all experiments except one. Because of herbicide injury and low winter temperatures, crops were abandoned in the fall of 1981 and replanted. Stand counts were taken two or three times 1–4 wk after planting, and postemergence damping-off was determined. In the spring of 1981, fungi were isolated from roots or hypocotyls of five seedlings in

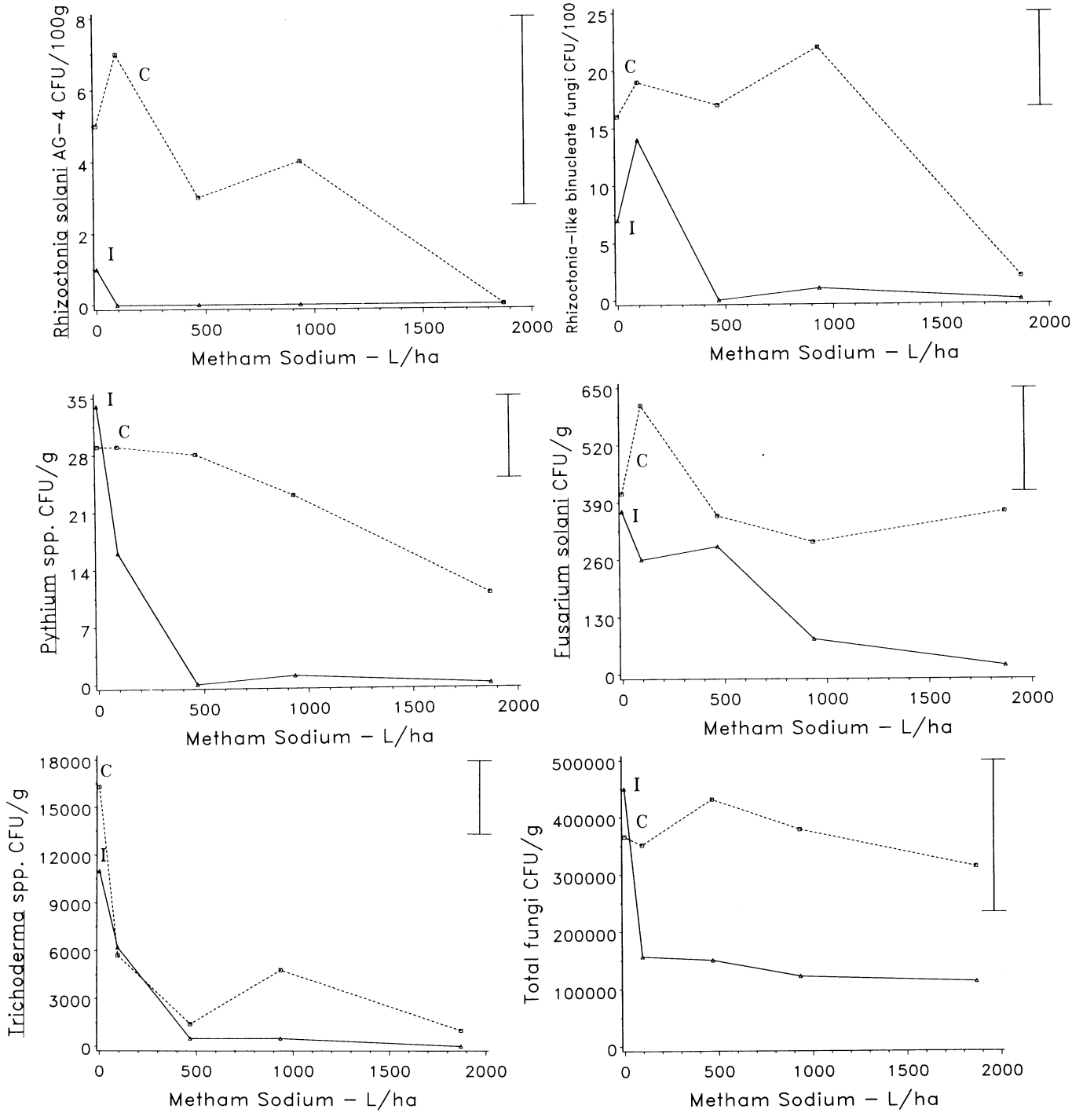

Fig. 1. Populations of different soil fungi with metam-sodium applied at 0, 94, 468, 935, and 1,870 L/ha with chisels or through 1.3 cm of overhead sprinkler irrigation water in September 1981. Bar indicates LSD, $P = 0.05$.

each plot of four, three, and two replicates in snap bean, cucumber, and okra, respectively (total = 495 seedlings). In the spring of 1982, fungi were isolated from lesions on 185 plants from selected treatments. In the fall tests, fungi were isolated from 20 spinach seedlings in 1982 and 480 spinach and collard seedlings in 1982. Crucifer and spinach seedlings were washed in running tap water 30–60 min, blotted dry on sterile filter paper, and incubated on water agar. Root, hypocotyl, or lower stem tissues of other crops were surface-disinfested 30–60 sec in 0.5% NaOCl, rinsed in tap water, blotted dry on sterile filter paper, and incubated on water agar. Hyphal tips were transferred to PDA and identified.

Greenhouse experiments. Numerous anastomosis groups (AGs) of *R. solani* and RLBF are indigenous in soils of the Georgia coastal plain, and many AGs are pathogenic on vegetables (19). Cultures of *R. solani* AG-2 type 2 (three isolates) and AG-4 (four isolates) and CAG-2, CAG-3, and CAG-5 (one isolate of each) were grown on 3% cornmeal-sand (w/w) for 12–13 days. All isolates were from soil or plants in Georgia, and all except CAG-2 were pathogens (19,20). Tifton loamy sand was treated with aerated steam for 30 min at 65–70 C and blended separately with each culture, 1:300 inoculum to soil (v/v). To determine the efficacy of metam-sodium on the different AGs, four plastic cans were filled (9,600 ml) with infested soil of each isolate and drenched with water to raise the soil moisture to the water-holding capacity (about 8%). The following day, one can of each isolate was drenched with a solution of 0, 243, 602, or 1,204 μg/ml a.i. metam-sodium in 624 ml of water, the equivalent of 0, 94, 234, and 468 L/ha in 1.27 cm of irrigation water.

Cans were kept in a greenhouse bench during the winter for 21 days. Soil temperature (av. 10 cm deep) minima and maxima ranged from 5 to 31 C. Three soil cores 2.5 × 15 cm were then removed from each can and composited. Soil 0–7.5 cm deep was kept separate from soil 7.5–15 cm deep. The two samples from each can were assayed on TABA and PAR agar for populations of *R. solani*, RLBF, and *Pythium* spp. Eagle snap bean (10 seeds) and Funks G-4507 corn (five seeds) were planted on opposite sides of each can, grown for 18–19 days, removed, and rated for disease severity. Both crops grew well intercropped.

Vegetables may follow peanut in Georgia, and unharvested peanut pods remaining in soil may serve as a reservoir of inoculum of soilborne pathogens (3). Therefore, a second experiment was conducted to determine the efficacy of metam-sodium on inoculum in peanut debris in naturally infested soil. Soil was collected in January in a field of Tifton loamy sand that had been in peanuts the previous year. The soil with peanut stem and pod debris was mixed with a shovel, then blended with fertilizer (27, 54, and 80 mg/kg, NPK) in a concrete mixer, and pots were filled (9,600 ml). A randomized complete block design with four replicates was used. Metam-sodium drench treatments were 0, 243, 602, 1,204, 2,408, and 4,816 μg a.i./ml in 624 ml of water. Soil temperature (av. 10 cm deep) minima and maxima ranged from 10 to 29 C for 4 wk after treatment. Four weeks after drenching, snap bean and cucumber were planted and grown 25 days. Roots and hypocotyls were then rated for disease, and soil from each pot was mixed and a sample assayed on selective media for *R. solani,* RLBF, *Pythium* spp., and *Fusarium* spp.

Data were analyzed with least squares analysis of variance and general linear models statistical procedures. Various linear comparisons were tested with the *F*-test.

RESULTS

Soil fungi. There were rarely significant differences in populations of fungi 0–7.5 vs. 7.5–15 cm deep, so populations are expressed as average cfu 0–15 cm deep. In the spring, there were no differences between application methods in control of *R. solani*, RLBF, *Pythium* spp., and other soil fungi (Tables 1 and 2). Total populations of fungi were higher with injection than with application through irrigation water in the second but not in the first year. Fenamiphos increased populations of *Pythium* spp., decreased populations of *R. solani* + RLBF and total fungi, and had no effect on populations of other fungi when applied through irrigation water. Metam-sodium + fenamiphos was similar to metam-sodium alone (Table 1).

There were no differences between metam-sodium rates of 468 and 935 L/ha applied through irrigation water in the first spring test, but when rates of 93–1,870 L/ha were used in irrigation water in the second spring test, there was a significant linear effect in reduction of populations of *Pythium* spp., *F. solani*, and total fungi (Table 2). Populations of *R. solani* were low or undetectable in all treatments. Populations of *Pythium* spp. were reduced but not eliminated with metam-sodium at 234 L/ha or more (Table 2).

In the fall, application of metam-sodium through irrigation water reduced populations of all fungi more than injection with chisels (Fig. 1). The effects of rates of metam-sodium from 93 to 1,870 L/ha were both linear and quadratic. Metam-sodium at 468 L/ha reduced populations of *R. solani*, RLBF, and *Pythium* spp. below detectable levels, but 93 L/ha was ineffective (Fig. 1). *F. solani* and saprophytic fungi were not eliminated from soil even with 1,870 L/ha. In the second fall test, low rates (94–468 L/ha) were applied only through irrigation water. There was a significant linear reduction in populations of *R. solani*, but populations of *Pythium* spp. were too low to get efficacy data (Table 3). Populations of *F. solani* and other *Fusarium* spp., saprophytic fungi, and total fungi were not influenced significantly by rates of 94 to 468 L/ha.

Isolations of fungi from roots and hypocotyls. The fungi isolated most frequently (percentage of plants) from roots and lower stems of seedlings of snap bean, cucumber, and okra in the spring plantings were *R. solani* AG-4 (34%), *F. oxysporum* Schlect. (13%), and *Pythium aphanidermatum* (Edson) Fitzp. (8%). *Pythium myriotylum*

Table 3. Control of soilborne pathogens and root diseases of fall vegetables with low dosages of metam-sodium applied through overhead irrigation water (September 1982)

	Populations of fungi in soil			Collard		Spinach	
Rate (L/ha)	*Rhizoctonia solani* AG-4[a]	*Pythium* spp.[b]	*Fusarium solani*	Plants 1.8 m	RHDI[c]	Plants 1.8 m	RHDI
0	2.5	0.5	150	9.6	1.8	4.2	2.0
94	0.4	0.3	150	12.8	1.6	9.2	1.5
187	0.7	1.0	150	13.6	1.4	10.0	1.3
280	0.0	0.3	240	11.9	1.4	15.2	1.5
374	0.0	1.8	320	13.0	1.3	11.6	1.5
468	0.0	0.0	330	13.1	1.4	13.5	1.3
Comparisons of interest[d]							
Rate							
Linear	0.01	NS	NS	0.01	0.01	0.01	NS
Quadratic	NS	NS	NS	0.05	NS	NS	NS
Cubic	NS	NS	NS	0.05	NS	NS	NS
Quartic	NS	NS	NS	NS	NS	NS	NS

[a] Populations of *R. solani* AG-4 are in colony-forming units (cfu)/100 g of oven-dried soil; all other fungi are in cfu/g of oven-dried soil.
[b] *P. irregulare* and *P. aphanidermatum*.
[c] Disease index: 1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% root and hypocotyl discoloration and decay; 5 = dead plant.
[d] $P = 0.05$ or 0.01, NS = no significant differences.

Drechs. and *F. solani* were isolated infrequently (<5%). In the fall, *F. oxysporum, Pythium* spp. (primarily *P. irregulare* Buis.), *R. solani* AG-4, and RLBF CAG-2 and CAG-4 were isolated from spinach seedlings and *R. solani* AG-4, *Pythium* spp., and *F. oxysporum* from collard seedlings.

In May and June 1981, 4–7 wk after planting, fungi were isolated from root or hypocotyl lesions on five plants in all plots of cucumber and in all plots of three and two replications of snap bean and okra, respectively. In cucumber and snap bean, there was a significant linear reduction in the frequency of isolation of *R. solani* AG-4 as dosages increased. In snap bean, the fewest cultures of *R. solani* AG-4 were isolated when metam-sodium was applied in 2.5 cm of water or with chisels. In contrast, in cucumber, the fewest cultures were isolated when metam-sodium was applied in 0.6 cm of water (Fig. 2). Metam-sodium had no effect on the frequency of isolation of *F. solani* or *F. oxysporum* in any crop. The frequency of isolation of *Pythium* spp. was too low to measure differences. In August 1982, 16 wk after planting, isolations were made from roots of 10 okra plants per plot in each replicate of treatments receiving metam-sodium at 0, 468, and 1,870 L/ha through irrigation water. *P. myriotylum, R. solani* AG-4, *F. oxysporum*, and *F. solani* were isolated from 8, 28, 20, and 25% of root lesions in the control plots, from 2, 30, 20, and 30% of the roots in plots treated with metam-sodium at 468 L/ha through irrigation water, and from 0, 2, 10, and 0% of the roots of plants in plots treated with metam-sodium at 1,870 L/ha through the irrigation water, respectively.

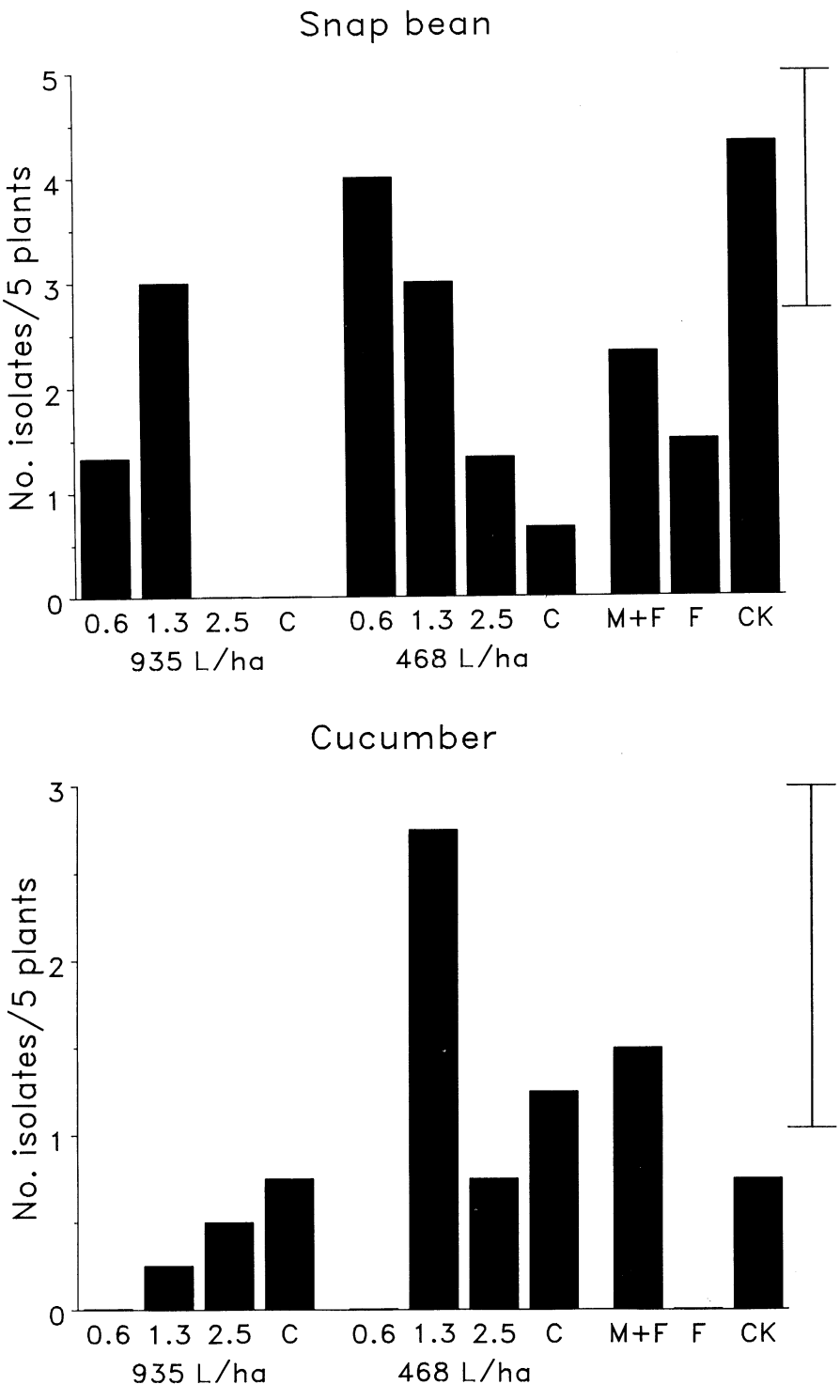

Fig. 2. Frequency of isolation of *Rhizoctonia solani* AG-4 from snap bean and cucumber seedlings grown in soil treated with metam-sodium applied at two rates with chisels (C) or through 0.6, 1.3, or 2.5 cm of overhead sprinkler irrigation water. M = metam-sodium, F = fenamiphos, and CK = control. Bar indicates LSD, $P = 0.05$.

Pathogenicity tests were conducted in a greenhouse in soil heated with aerated steam (70–75 C for 30 min) using cultures grown on 3% cornmeal-sand (w/w). *R. solani* AG-4, *P. myriotylum, P. aphanidermatum*, and *P. irregulare* were all highly virulent on most crops, and CAG-4 and *F. oxysporum* were mildly virulent to avirulent. The wilt pathogen *F. oxysporum* f. sp. *vasinfectum* was not identified in okra.

In the first spring crop, there was a highly significant ($P = 0.01$) linear reduction in the frequency of isolation of *R. solani* AG-4 and a linear increase in the frequency of isolation of *F. oxysporum* as metam-sodium was applied in increased amounts of irrigation water from 6.4 to 25.4 mm. No differences occurred in the frequency of isolation of *Pythium* spp. or *F. solani* in snap bean. In cucumber, there was a significant curvilinear response with metam-sodium rates and irrigation water rates. With 468 L/ha of metam-sodium, *R. solani* was isolated most frequently when 12.7 mm of water was used, but with 935 L/ha, *R. solani* was isolated most frequently when 25.4 mm of water was used (Fig. 2). There were no significant differences in the frequency of isolation of other fungi from cucumber or in any of the fungi from okra.

Root diseases and plant stands. Root and hypocotyl disease severity was reduced slightly with metam-sodium (Tables 2 and 3). In 1981, average plant stands in fall-seeded kale, turnip, mustard, collard, and spinach were increased 149 and 212%, respectively, with metam-sodium applications of 94 and 468 L/ha through irrigation water compared with the control. There was a significant linear increase in plant stands as dosage increased in all crops except mustard, but there were no significant differences between application methods. In 1982, plant stands of crucifers and spinach were increased with low dosages

of metam-sodium with fall applications (Table 3). Metam-sodium treatments had little influence on plant stand in okra, snap bean, cucumber, tomato, and pepper in spring applications. Applications of low dosages (187–280 L/ha) of metam-sodium with 1.3 cm of water were effective in controlling root diseases with shallow-rooted fall vegetables, but applications of 935 or 1,870 L/ha in 2.5 cm of water were required for effective root disease control in okra and snap bean.

Greenhouse experiments. In the first experiment, there was a significant ($P = 0.01$) effect of rate of metam-sodium on populations of *R. solani* and RLBF. Average populations of seven isolates of *R. solani* and four isolates of *Rhizoctonia*-like binucleate fungi were 53, 12, 1.0, and 0.2 cfu/100 g of oven-dry soil with 0, 243, 602, and 1,204 μg/ml, respectively. With the two lower rates of metam-sodium, the efficacy was significantly greater in soil 0–7.5 cm deep than 7.5–15 cm deep, but 1,204 μg/ml was equally effective at both depths.

Root and hypocotyl disease severity and root and mesocotyl disease severity were reduced with metam-sodium treatments (Table 4), and oven-dry weights were increased. Preemergence damping-off was reduced in snap bean, but treatments with metam-sodium did not influence plant stand in corn (Table 4). *R. solani* AG-2 type 2 causes crown and brace root rot in corn, and the number of lesions per plant averaged 2.3, 0.1, 0.6, and 0.2 in untreated soil and soil treated with 243, 602, and 1,204 μg/ml, respectively. *R. solani* AG-2 type 2 was isolated from corn roots and snap bean hypocotyls in untreated soil but not in treated soil. In contrast, *R. solani* AG-4 was isolated from snap bean plants grown in soil treated with 243 and 602 μg/ml of metam-sodium but not from snap bean plants grown in untreated soil or soil treated with 1,204 μg/ml of metam-sodium. CAG-5 was isolated from snap bean plants grown in untreated soil and soil treated with 602 and 1,204 μg/ml but not from plants grown in soil treated with 243 μg/ml.

In the second experiment with a soil from a peanut field, RLBF were not detected with treatments of 243 μg/ml or greater, and *Pythium* spp. and *F. solani* were not detected with treatments of 2,408 μg/ml or greater (Table 5). Root and hypocotyl disease severity was not reduced in snap bean, and high dosages (2,408 and 4,816 μg/ml) slightly increased root and hypocotyl discoloration in cucumber. *P. myriotylum* was isolated from one snap bean hypocotyl in plants grown in soil treated with 243 μg/ml but not in other treatments, and one culture each of RLBF CAG-2 and CAG-3 was isolated from plants grown in soil treated with 243 and 1,204 μg/ml, respectively, but not from other treatments. In contrast, *F. oxysporum* was isolated from roots on hypocotyls of plants grown in all treatments. Only *Fusarium* spp. were isolated from cucumber seedlings. Plant heights declined at 4,816 μg/ml in both crops compared with controls, indicating that the toxicant was still present in soil at planting (Table 5).

DISCUSSION

Application of metam-sodium in 1.3 cm of overhead sprinkler irrigation water gave more consistent control of *R. solani* AG-4, *P. irregulare*, and *P. aphanidermatum* than soil injection with chisels. These pathogens are ubiquitous in soils of the Georgia coastal plain and frequently reduce plant stands and stunt growth of vegetables (18,19,21–24). The pathogens could be isolated frequently from roots of plants and soil in untreated plots or plots treated with metam-sodium at 94 L/ha through overhead irrigation water but less frequently as dosages increased from 187 to 468 L/ha. Our research corroborates other reports on the efficacy of metam-sodium applied through irrigation water (1,2,10).

In greenhouse tests, *R. solani* AG-4 and AG-2 type 2 were controlled with 243 μg a.i./ml (94 L/ha in 1.3 cm of water) in soil 0–7.5 cm deep, but 602 μg/m was required for effective control 7.5–15 cm deep. In soil naturally infested with peanut pods and debris, the equivalent of

Table 4. Plant stand and root disease severity in snap bean and corn in soil infested with *Rhizoctonia solani* and *Rhizoctonia*-like binucleate fungi and treated with metam-sodium in a greenhouse

	Snap bean			Corn		
Rate[a] (μg/ml)	Live plants[b]	RHDI[c]	Foliage oven-dry wt (g)	Live plants	RMDI[d]	Foliage oven-dry wt (g)
0	3.6	3.3	0.67	3.6	1.8	1.2
243	5.4	2.6	1.18	3.8	1.2	1.3
602	5.7	1.9	1.35	4.4	1.2	1.7
1,204	6.4	1.3	1.56	4.0	1.1	1.4
Comparisons of interest[e]						
Linear	0.01	0.05	0.05	NS	0.05	0.05
Quadratic	NS	NS	NS	NS	NS	0.05

[a] Applied as a drench in the equivalent of 1.3 cm water per hectare.
[b] Ten seeds planted per treatment in snap bean and five in corn. Plants were 17 days old at harvest.
[c] Root and hypocotyl disease index: 1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% discoloration and decay; 5 = dead plant.
[d] Root and mesocotyl disease index, same scale as RHDI.
[e] $P = 0.05$ or 0.01, NS = no significant differences.

Table 5. Populations of soil fungi, root and hypocotyl disease severity, and plant growth in field soil treated with metam-sodium in a greenhouse

	Populations in soil[a]							
Rate (μg/ml)	RLBF	*Pythium* spp.	*Fusarium solani*	Total *Fusarium* spp.	RHDI[b] Snap bean	RHDI[b] Cucumber	Height (cm) at 25 days Snap bean	Height (cm) at 25 days Cucumber
0	6	163	650	6,500	4.2	1.0	8.8	31.8
243	0	14	1,030	5,160	3.4	1.2	16.5	34.0
602	0	1	1,070	6,840	3.9	1.0	14.8	34.0
1,204	0	2	1,240	4,710	2.3	1.0	16.5	34.0
2,408	0	0	0	3,470	3.3	1.6	21.5	28.8
4,816	0	0	0	3,100	3.5	1.6	14.2	17.5
Comparisons of interest[c]								
Linear	NS	0.01	0.01	0.05	NS	0.01	NS	0.01
Quadratic	NS	0.01	NS	NS	NS	NS	0.05	NS

[a] Twenty-seven days after treatment, colony-forming units (cfu)/100 g of soil with *Rhizoctonia*-like binucleate fungi (RLBF) and cfu/g with other fungi.
[b] Root and hypocotyl disease index: 1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% discoloration and decay; 5 = dead plant.
[c] $P = 0.05$ or 0.01, NS = no significant differences.

187 L/ha reduced populations of *Pythium* spp. and RLBF to very low levels, but 935 L/ha was required to reduce *Pythium* spp. below detectable levels. Peanut pods (3) and colonized plant debris from other crops harbor *R. solani* AG-4 and AG-2 type 2 and other pathogens. High rates of metam-sodium may be required for disinfestation of soils immediately after incorporation of refuse from a previous crop. However, if the soil is plowed 20–30 cm deep with a moldboard turning plow before treatment with metam-sodium, low rates of 200–400 L/ha through irrigation water may be adequate for growing vegetables with shallow root systems.

Dosages of 187 L/ha or higher were particularly effective in increasing plant stands and reducing root disease severity in fall crops. Average soil temperatures were higher after treatment in the fall than in the spring, and the combination of high soil temperatures plus metam-sodium may have increased control of soilborne pathogens (5,6).

With deep-rooted vegetables such as okra, application of metam-sodium in 2.5 cm of water was more effective in controlling soilborne pathogens than in 1.3 cm of water, and application in 0.6 cm of water was ineffective. Fusarium wilt was not a limiting factor in the production of okra in these tests, but Fusarium wilt is a major pathogen in growers' fields. Metam-sodium was less effective against *Fusarium* spp. than against *R. solani* and *Pythium* spp., and fumigation with metam-sodium may be ineffective with okra. Also, metam-sodium gave poor control of root diseases in snap bean in our tests, and that may have been because of increased root and hypocotyl injury from *F. solani* f. sp. *phaseoli* and *F. oxysporum*.

Metam-sodium induced little or no reduction in populations of saprophytic fungi, including *Trichoderma* spp. Other research indicates metam-sodium may reduce populations of added *Trichoderma* spp. that are effective biocontrol agents but not of indigenous *Trichoderma* spp. (13). Because saprophytic organisms survive in large numbers after fumigation with low dosages of metam-sodium, they may help prevent recolonization of the soil by *R. solani* and *Pythium* spp. (17). We did no research to determine if the fumigation with metam-sodium would be effective for more than one crop of vegetables, but previous research at the Coastal Plain Station showed that fumigations with methyl bromide or DD-MENCS were effective in reducing populations of soilborne pathogenic fungi and nematodes for two or three successive crops (9). Soil fumigation once per year with crop rotations in multicrop systems may be sufficient to control soilborne pathogens and feasible economically in many vegetable production systems.

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