Control of Cylindrocladium Black Rot of Peanut with Soil Fumigants Having Methyl Isothiocyanate as the Active Ingredient

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ABSTRACT

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Metham-sodium and 1,3-dichloropropene (1,3-D) plus methyl isothiocyanate (MIT) were evaluated for control of Cylindrocladium black rot (CBR) of peanut (*Arachis hypogaea*) in naturally infested fields. In three tests (1981–1983), metham-sodium at 36 and 72 kg/ha suppressed disease incidence in peanut cv. Florigiant (CBR-susceptible) by 39 and 85% and increased yields by 536 and 545 kg/ha, respectively. In four subsequent tests (1984–1987), metham-sodium at 36 and 72 kg/ha and 1,3-D at 15.4 kg/ha plus MIT at 7.7 kg/ha reduced disease incidence in Florigiant by 77, 84, and 51% and in NC 8C (CBR-resistant) by 62, 89, and 48%, respectively. The above treatments increased yields of Florigiant by 1,012, 1,032, and 810 kg/ha and of NC 8C by 620, 627, and 550 kg/ha, respectively. Without soil fumigation, NC 8C had 54% less disease and 532 kg/ha more yield than Florigiant. Soil fumigation and planting NC 8C significantly suppressed the buildup of microsclerotial populations of *Cylindrocladium crotalariae* in soil during the growing season compared with planting NC 8C alone or planting Florigiant with or without soil fumigation. Preplant soil treatment with either metham-sodium at 36 kg/ha or 1,3-D at 15.4 kg/ha plus MIT at 7.7 kg/ha followed by planting a CBR-resistant cultivar is recommended for control of CBR in peanut.

Additional keywords: *Calonectria crotalariae*, chemical control, cultivar resistance, groundnut

Cylindrocladium black rot (CBR) of peanut (*Arachis hypogaea* L.), caused by *Cylindrocladium crotalariae* (Loos) Bell & Sobers, was first discovered in Georgia in 1965 (3). Subsequently, CBR has been reported in all peanut-producing areas of the southeastern United States and in Japan, India, and Australia (13). CBR has been a major cause for concern in Virginia, where it was detected in one of every five fields planted in 1979 (20), and new field infestations have continued to be reported annually since that survey. Early attempts to find suitable control measures for CBR included evaluations of several fungicides and certain soil biocides. Soil fumigants containing metham-sodium, methyl isothiocyanate (MIT), chloropicrin, and sodium azide were shown to partially suppress CBR in greenhouse and field trials (2,21). Commercial-use patterns for these materials to control CBR were not developed because of their high cost and the necessity for high rates to control the disease in available commercial cultivars of peanut.

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The development and release of the CBR-resistant cultivar NC 8C in 1982 gave growers their first opportunity to combat CBR in problem fields (24). The incidence and severity of CBR in susceptible and resistant cultivars have been shown to depend on inoculum densities of microsclerotia of *C. crotalariae* in soil, populations of certain nematodes in soil, and soil moisture and temperature (7,16,17). These factors have resulted in some failures of NC 8C to give adequate control of CBR and have sustained the need for more effective measures.

This paper reports the results of field research on control of CBR with soil fumigants and the development of effective, economical strategies for CBR control in Virginia. Preliminary reports have been published (12,15).

MATERIALS AND METHODS

On-farm tests were conducted at different locations annually between 1981 and 1987. Fields had histories of moderate to heavy CBR losses in peanuts and had been cropped in corn-peanut rotations for several years. Each year, land was prepared by moldboard plowing and disking before the planting of peanuts. Soil fumigants were applied in mid-April to early May, when soil temperatures at the 10-cm depth were ≥15 C. Peanuts were planted 12–24 days after application of soil fumigants. Plots consisted of either two or four rows (0.9 m apart and 12.2 m long), planted with approximately 120 seeds per row. A randomized complete block design with four to six replications was used. Except for application of soil fumigants, standard practices for peanut production and management in Virginia were followed each year. Herbicides (metolachlor, alachlor, naptalam [Alanap], bentazon), insecticides (aldicarb, carbaryl, fonofos), and fertilizers (calcium sulfate, boron, manganese) were applied routinely according to recommendations of the Virginia Cooperative Extension Service. Applications of fungicides (either of benomyl plus sulfur or of chlorothalonil) for control of Cercospora leaf spot were made according to guidelines of the Virginia Peanut Leafspot Advisory Program (14).

The commercial soil fumigants evaluated were metham-sodium (Vapam) and 1,3-dichloropropene (1,3-D) plus MIT (Vorlex). Fumigants for row treatment were deposited 15–20 cm deep with two chisels spaced 25 cm apart and 12.5 cm from the center of rows, unless specified otherwise. Chisel shanks were mounted on a tool bar at the front of a power-driven Tilrovator (Ferguson Mfg., Suffolk, VA) with Virginia-type bed shapers. The L-shaped tines of the Tilrovator were operated to a depth of 5.0–7.5 cm. The Tilrovator was used to partially seal the area above fumigant deposition and form beds (10 cm high and 53 cm wide) to mark the location of treated rows. The fumigants were delivered from a stainless-steel tank with a gravity flow regulator having orifice disks to control flow rates. Plowdown applications of metham-sodium were made on 40-cm centers to a depth of 20–25 cm during moldboard plowing. All crop management inputs were made with commercial field implements commonly used in peanut production.

Populations of microsclerotia of *C. crotalariae* and nematodes in soil were assessed by the elutriation and elutriation-centrifugation methods, respectively (5,19). Assays of sieve residues for *C. crotalariae* were made with a sucrose-QT medium (9). Soil samples consisted of 10–14 soil cores (2 cm diam., 15 cm deep) and were collected from within designated rows before soil treatment and approximately 160 days after treatment. Levels of taproot infection were determined by collecting 10–25 taproots at random from replicates of treatments immediately after digging peanuts.

Biopsies to detect root infection by *C. crotalariae* were made by assaying taproot samples on a semiselective isolation medium (18).

The incidence of plants with signs and/or symptoms of CBR was recorded about 12, 16, and 20 wk after planting. Root rot and pod rot severity (16) were evaluated immediately after peanuts were dug. Plots were dug between 145 and 160 days after planting with a commercial digger-inverter and picked with a commercial combine within 5–10 days after digging. Peanuts were then dried to near 10% moisture (w/w), plot weights were recorded, and crop value was determined in accordance with federal-state inspection service methods.

RESULTS

Initial tests of metham-sodium. Field tests from 1981 to 1983 indicated that metham-sodium at 36 and 72 kg/ha gave significant levels of CBR control in fields planted to the CBR-susceptible cultivar Florigiant (Table 1). Disease incidence at harvest was reduced significantly as the rate of metham-sodium was increased. Striking differences between treated and untreated plots were often visible as early as 12 wk after planting. Microsclerotia of *C. crotalariae* in plots before application of treatments ranged from 0.7 to 5.5 per gram of soil. Root biopsy and soil tests indicated that the 72 kg/ha rate of metham-sodium was required to significantly suppress taproot infection and populations of microsclerotia at harvest. The yield response to treatments with metham-sodium was significant at 36 kg/ha but was no greater at 72 kg/ha. The unit value ($/kg) of harvested peanuts was not significantly affected by treatments according to analyses of grade data. Some tests also evaluated metham-sodium at 144 kg/ha, and except for root infection and soil inoculum levels at harvest, the results were not significantly different from treatments with 36 and 72 kg/ha.

Chisel vs. plowdown application. Metham-sodium at 36 kg/ha applied with two chisel shanks 25 cm apart and 12.5 cm from the center rows gave CBR control that was equivalent to plowdown applications at 40-cm intervals and rates of 72 and 144 kg/ha, according to field tests in 1982 and 1983. Yields were improved by all metham-sodium treatments. Although differences in application methods at these rates were not significant, the results indicated that row treatments provided CBR control at reduced rates of chemical and would be more economical.

Row treatment with one vs. two chisels. Applications of metham-sodium at 36 kg/ha with one or two chisels per row were compared for CBR control in Florigiant and NC 8C in 1985 (Table 2). Disease incidence, taproot infection, soil inoculum, and yield data indicated that both application methods were equally effective in CBR control. NC 8C performed significantly better than Florigiant only when metham-sodium was not applied.

Ring nematode (*Macroposthonia* sp.) and northern root-knot nematode (*Meloidogyne hapla* Chitwood) were active parasites of both Florigiant and NC 8C, according to soil assays at harvest. Ring nematode populations at harvest averaged 593 and 455 with treatments using one and two chisels per row, respectively, and were significantly ($P = 0.05$) lower than the 1,854 nematodes per 500 cm^3 in untreated soil. Populations of northern root-knot nematode averaged 762, 497, and 149 juveniles per 500 cm^3 of soil in untreated rows and rows treated with one and two chisels, respectively. Differences in root-knot populations were not significant.

Comparison of metham-sodium and 1,3-D plus MIT. In annual field tests from 1984 to 1987, metham-sodium and 1,3-D plus MIT provided significant control of CBR in both Florigiant and NC 8C (Table 3). Differences in cultivars and their response to soil treatment were visible at 16 wk after planting and were often striking at 20 wk (Fig. 1). Application of 1,3-D plus MIT performed similarly to metham-sodium at 36 kg/ha with NC 8C but tended to be less effective with Florigiant. Increasing the rate of metham-sodium from 36 to 72 kg/ha did not improve CBR control significantly with either cultivar. Populations of microsclerotia of *C. crotalariae* in soil at harvest were suppressed significantly by use of NC 8C and soil fumigation. NC 8C alone or soil fumigation and planting Florigiant did not suppress the buildup of populations of *C. crotalariae* by harvest.

Table 1. Control of Cylindrocladium black rot of peanut with metham-sodium in soil planted to susceptible cultivar Florigiant in three annual field trials from 1981 to 1983

Treatment[t]	Disease incidence[u]	Taproot infection[v]	Soil inoculum (ms/g soil)[w]	Yield (kg/ha)[x]	Value ($/kg)[y]
Untreated control	26.7 a[z]	42.1 a	29.6 a	3,774 b	0.52 a
Metham-sodium					
36 kg/ha	16.4 b	33.7 ab	19.5 a	4,310 a	0.50 a
72 kg/ha	4.1 c	21.2 b	4.5 b	4,319 a	0.50 a

[t] Metham-sodium applied 12–16 days preplant with two chisels placed 12.5 cm on each side of row centers.
[u] Counts in two 12.2-m rows before harvest.
[v] Percent recovery of *Cylindrocladium crotalariae* from 25 taproot samples per replicate at harvest.
[w] Populations of microsclerotia (ms) of *C. crotalariae* before harvest.
[x] Based on weight of peanuts with 8% moisture content.
[y] Determined from a 500-g sample from each plot in accordance with federal-state inspection service methods.
[z] Means of three tests in columns followed by the same letter(s) are not significantly different (LSD, $P = 0.05$). Arcsine transformation of percent data and square root transformation of microslerotia data were made before analyses for statistical significance.

Table 2. Comparison of metham-sodium (36 kg/ha) applied with one vs. two chisels per row for control of Cylindrocladium black rot of peanut in 1985

Cultivar Treatment[u]	Disease incidence[v]	Taproot infection[w]	Soil inoculum (ms/g soil)[x]	Yield (kg/ha)[y]
Florigiant (susceptible)				
Untreated control	10.0 a[z]	19.8 a	17.3 a	3,089 c
Metham-sodium				
One chisel	3.0 b	1.8 b	1.2 b	5,108 a
Two chisels	2.0 b	3.5 b	0.6 b	5,021 a
NC 8C (resistant)				
Untreated control	2.0 b	13.3 ab	26.8 a	4,423 b
Metham-sodium				
One chisel	0.8 b	1.8 b	1.0 b	5,257 a
Two chisels	0.5 b	3.5 b	0.2 b	5,220 a

[u] Metham-sodium applied 19 days preplant with either one chisel centered in row or two chisels placed 12.5 cm on each side of row centers.
[v] Counts in two 12.2-m rows before harvest.
[w] Percent recovery of *Cylindrocladium crotalariae* from 15 taproot samples per replicate at harvest.
[x] Populations of microsclerotia (ms) of *C. crotalariae* before harvest.
[y] Based on weight of peanuts with 7% moisture content.
[z] Means in columns followed by the same letter(s) are not significantly different (LSD, $P = 0.05$). Arcsine transformation of percent data and square root transformation of microslerotia data were made before analyses for statistical significance.

As in early field tests of metham-sodium, soil assays for nematodes at harvest indicated that ring nematode and northern root-knot nematode were active parasites of both cultivars. Soil treatments significantly suppressed numbers of ring nematode but not of northern root-knot nematode. Metham-sodium and 1,3-D plus MIT were equally effective in suppression of ring nematode populations.

DISCUSSION

Metham-sodium is a soil fumigant used to control a wide spectrum of soilborne pests such as weeds, nematodes, fungi, and insects. Because of its highly toxic and nonspecific nature, it must be applied at least 2 wk before planting. Metham-sodium converts rapidly in soil to MIT, which is the bioactive agent (8,23). The efficacy of metham-sodium as a soil fungicide is largely, if not entirely, dependent upon its decomposition to MIT. The maximum theoretical levels of MIT obtainable from metham-sodium at 36 and 72 kg/ha would be 20 and 40 kg/ha, respectively. The actual conversion efficiency of metham-sodium, however, would likely be considerably below these levels. According to conversion studies in a sandy loam at 10 and 20 C, the highest concentration of MIT reached in soil would be about 63 and 71% of the maximum theoretical rate, respectively (23). Based on these figures, a soil treatment for CBR control with metham-sodium at 36 kg/ha would result in MIT levels of 12.6 and 14.2 kg/ha at soil temperatures of 10 and 20 C, respectively. Use of 1,3-D at 15.4 kg/ha plus MIT at 7.7 kg/ha (Vorlex) affords direct delivery of the active ingredient (MIT) for CBR control as well as a well-known nematicide (1,3-D) that might have benefits for suppression of CBR (7).

The results of tests in 1981 and 1982 were used to obtain a special local-need registration for use of metham-sodium at 36 kg/ha (Vapam, 10 gal/acre) as a preplant row treatment to control CBR in Virginia in 1983. Similar approval for use of 1,3-D at 15.4 kg/ha plus MIT at 7.7 kg/ha (Vorlex, 4 gal/acre) was granted in 1986. Growers were advised to use these materials in conjunction with the CBR-resistant cultivar NC 8C. As recommended, the cost of Vapam in 1988 was approximately $133/ha ($54/acre), compared with approximately $163/ha ($66/acre) for Vorlex. With the farm value of Virginia-type peanuts being about 68¢/kg in 1988, the yield response needed to pay the cost for chemicals was 196 kg/ha with Vapam and 240 kg/ha with Vorlex. In tests conducted from 1984 to 1987 (Table 3), the mean yield response of NC 8C to soil treatment was 550 kg/ha with 1,3-D at 15.4 kg/ha plus MIT at 7.7 kg/ha and 620 kg/ha with metham-sodium at 36 kg/ha. Both treatments were significantly better than NC 8C untreated and would result in a gross value increase of $374 to $422/ha at the 1988 farm value of peanuts.

According to a recently reported decision model for use of fumigation and resistance to control CBR (1), expected yields of NC 8C in soils with and without fumigation can be computed from yield and disease incidence in Florigiant. This model projected that planting NC 8C instead of Florigiant in trials from 1984 to 1987 (Table 3) would increase yield an average of 434 kg/ha, whereas the actual increase was 532 kg/ha. The same model projected that the use of NC 8C and metham-sodium at 36 kg/ha instead of Florigiant without fumigation would increase yield in these trials an average of 536 kg/ha, whereas the actual increase was 1,152 kg/ha. Disparities between the predicted and actual yield response may be attributed to the difficulty of making accurate estimates of disease severity on the basis of aboveground symptoms before harvest. The effects of soil moisture and temperature (17), nematodes (7), and inoculum densities (6,10,16) of *C. crotalariae* on disease progress and symptom expression in CBR-susceptible and CBR-resistant cultivars may be additional sources of difficulty in accurately predicting the yield response to inputs for CBR control.

Microsclerotia of *C. crotalariae* are the primary source of inoculum as well as the survival and dispersal units (4,18, 19,22). Inoculum distribution in fields is clustered or in clumps (11), resulting in "hot spots" of disease in infested fields as well as clusters of root infections (10). The mechanism of CBR control by row treatments that employ MIT seems to be a result of soil disinfestation in the zone of seed germination and taproot development. This conclusion is supported by results of the current study and tests in artificially infested soil within microplots (6). Over an entire growing season, infection would be delayed until secondary roots enter the surrounding zone of soil having viable microsclerotia of *C. crotalariae.* Root infections in this zone may result in significant root pruning, although natural defense mechanisms coupled with the onset of plant maturity may minimize any impact before harvest.

Current recommendations for control of CBR include crop rotation with nonlegumes such as corn, control of nematodes, and use of CBR-resistant cultivars (NC 8C or the newly released NC 10C) in combination with soil fumigation with products having MIT as the active ingredient (14). Results of the current study clearly demonstrate that row treatments with products that employ MIT as an active ingredient and the planting of a CBR-resistant cultivar provide economical control of CBR and may prevent the buildup of populations of microsclerotia of *C. crotalariae* in soil during the cropping of peanuts in infested fields. Rotation of peanuts with nonleguminous crops such as corn, coupled with sustained periods of freezing soil temperatures in some winters, can significantly reduce populations of microsclerotia in soil (18). Together, the above management inputs are believed to offer a working solution to the devastating

Table 3. Comparison of metham-sodium (36 or 72 kg/ha) and 1,3-dichloropropene (1,3-D, 15.4 kg/ha) plus methyl isothiocyanate (MIT, 7.7 kg/ha) for control of Cylindrocladium black rot of peanut in annual field trials from 1984 to 1987

Cultivar Treatment[u]	Disease incidence[v]	Taproot infection[w]	Soil inoculum (ms/g soil)[x]	Yield (kg/ha)[y]
Florigiant (susceptible)				
Untreated control	17.2 a[z]	38.3 a	30.6 ab	3,621 c
1,3-D plus MIT	8.4 b	21.2 b	20.2 abc	4,431 ab
Metham-sodium				
36 kg/ha	3.9 cd	7.0 c	15.2 abcd	4,633 ab
72 kg/ha	2.7 d	6.2 c	16.7 bcd	4,653 ab
NC 8C (resistant)				
Untreated control	7.9 bc	21.9 b	25.5 a	4,153 bc
1,3-D plus MIT	4.1 cd	11.7 bc	6.0 cd	4,703 a
Metham-sodium				
36 kg/ha	3.0 d	11.9 bc	4.4 d	4,773 a
72 kg/ha	0.9 d	6.0 c	3.9 d	4,780 a

[u] Metham-sodium applied 14–24 days preplant with two chisels placed 12.5 cm on each side of row centers.
[v] Counts in two 12.2-m rows before harvest.
[w] Percent recovery of *Cylindrocladium crotalariae* from 15 taproot samples per replicate at harvest in 1984 and 1985 and from 10 samples per replicate in 1986. Roots from the 1987 test were not assayed.
[x] Populations of microsclerotia (ms) of *C. crotalariae* before harvest in 1984, 1985, and 1986. Soil from the 1987 test was not assayed.
[y] Based on weight of peanuts with 7% moisture content.
[z] Means in columns followed by the same letter(s) are not significantly different (LSD, $P = 0.05$). Arcsine transformation of percent data and square root transformation of microslerotia data were made before analyses for statistical significance.

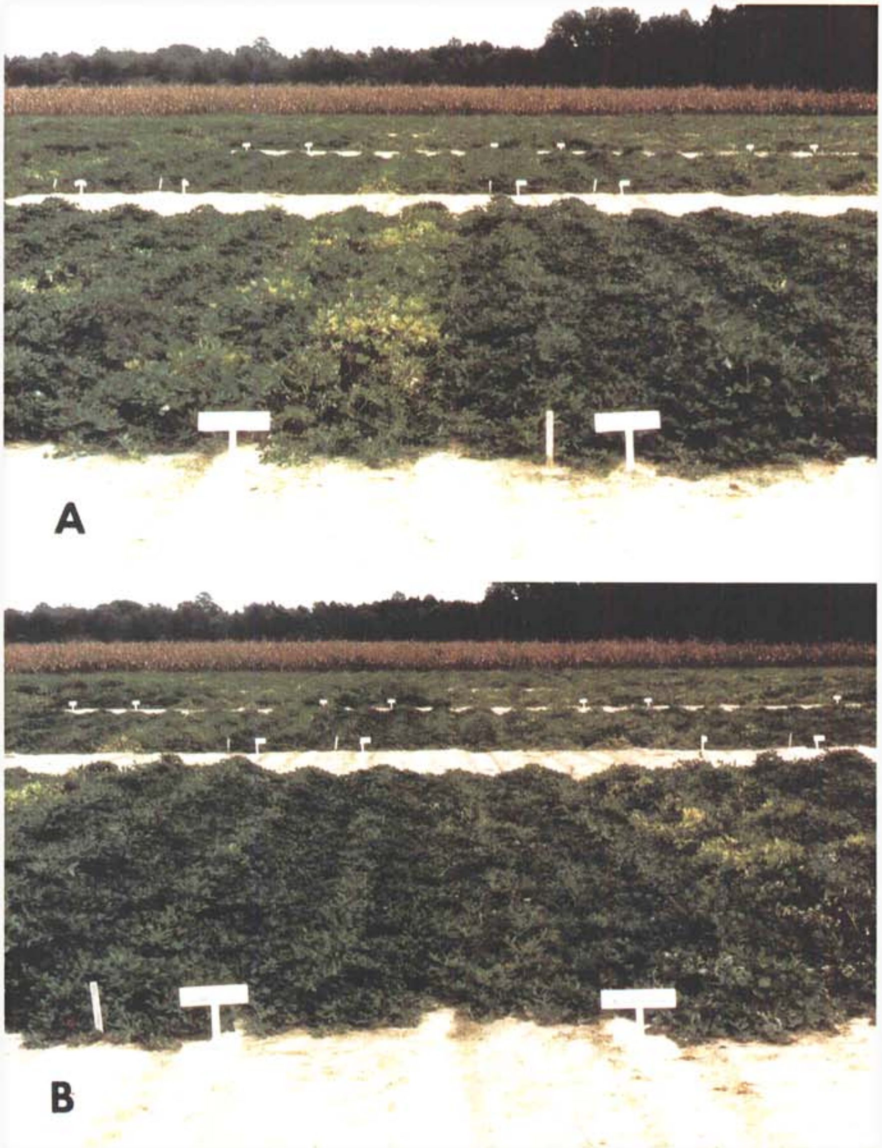

Fig. 1. Effect of application of metham-sodium at 72 kg/ha in 1984 on incidence and severity of Cylindrocladium black rot in **(A)** susceptible peanut cultivar Florigiant (untreated two rows left of center, treated two rows right of center) and **(B)** resistant cultivar NC 8C (treated two rows left of center, untreated two rows right of center).

losses caused by CBR in the Virginia peanut production area.

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