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Efficacy of Fumigant Nematicides to Control *Hoplolaimus columbus* on Cotton[1]

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Abstract: Four rates of methyl bromide (Mbr) (16.8, 33.6, 67.2, and 134.4 kg a.i./ha) and one rate of 1,3-dichloropropene (1,3-D) (28.1 liters a.i./ha) were evaluated over 2 years for control of *Hoplolaimus columbus* on cotton. All nematicide treatments were applied through a tarpless subsoiler-bedder prior to planting cotton, *Gossypium hirsutum* cv. Deltapine 90. Nematode population densities were monitored before and after treatment, at midseason, and at harvest, and yields were measured at maturity. Soil fertility variables (pH, P, K, Ca, Mg) were measured for each plot. Cotton yields were significantly increased by treatment with 1,3-D in 1988 and by all nematicidal treatments in 1989. Levels of nematode control varied from year to year among treatments. The responses of *H. columbus* numbers to rate of Mbr were best described by quadratic regression models. Levels of soil calcium and magnesium were significant factors in a multiple regression model relating a measure of control efficacy to rates of Mbr.

Key words: 1,3-dichloropropene (1,3-D), Columbia lance nematode, cotton, *Gossypium hirsutum, Hoplolaimus columbus,* methyl bromide, nematicide, soil fertility.

The Columbia lance nematode, *Hoplolaimus columbus* Sher, has been recognized as a serious pest of cotton (*Gossypium hirsutum* L.) in the southeastern United States since the late 1960s (5). This nematode has a wide host range, which includes many of the crops commonly grown in rotation with cotton (4,9,10). Where heavy infestations occur, 20–30% of the cotton crop may be destroyed (10,12,13). Population densities of the Columbia lance nematode will increase up to 300% under susceptible cotton or soybean (*Glycine max* (L.) Merr.) cultivars (10,11,13,14). The apparent range of this nematode is extending throughout the Southeast, as growers and cooperative extension agents become increasingly aware of the symptoms of *H. columbus* damage (8).

Bird et al. (2) determined that use of the nematicide 1,3-dichloropropene (1,3-D) in combination with subsoiling was no more effective than subsoiling alone in controlling *H. columbus* on cotton. Hussey (7) found similar results using 1,2-dibromo-3-chloropropane (DBCP) in combination with subsoiling. Mueller and Sullivan (12), working in a field infested concomitantly with *H. columbus* and *Meloidogyne incognita* (Kofoid & White) Chitwood, reported increases in cotton yields and decreases in *H. columbus* numbers after treatment with 1,3-D.

Ironically, as cotton production experiences a resurgence in the southeastern United States due to a favorable world markets, partial eradication of the boll weevil, and better insect pest control alternatives, fewer effective nematicides are available. Because of health and environmental concerns, several fumigant nematicides have been taken off the market. There is a critical need in cotton production areas for more effective nematicides, since current crop rotation alternatives are limited by the wide host range of *H. columbus.*

The purpose of this study was to evaluate the performance of a proprietary methyl bromide formulation (Brom-O-Sol) and application method (Great Lakes Chemical

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Corporation, West Lafayette, IN). This formulation was compared with the currently recommended treatment of 1,3-D (6) for control of *H. columbus* on cotton.

MATERIALS AND METHODS

Field tests were conducted at a site naturally infested with *H. columbus* on the Southeast Georgia Branch Experiment Station in Midville, Georgia. The soil was characterized as a Dothan sandy loam (fine-loamy, siliceous, thermic, plinthic paleudults; 69% sand, 13% silt, 18% clay; pH 5.8). Tests in 1988 and 1989 were done in the same field on adjacent sites. The average preplant nematode density was 25 ± 18 and 48 ± 58 *H. columbus*/100 cm^3 soil in 1988 and 1989, respectively.

Treatments applied in 1988 included three rates of the methyl bromide formulation (Mbr) (33.6, 67.2, and 134.4 kg a.i./ha; calibration rates of 0.8, 1.6, and 3.2 kg/100 m of row, respectively), the recommended rate of 1,3-D (28.1 liters/ha; calibration rate of 689 ml/100 m of row), and an untreated control. In 1989, the high rate (134.4 kg a.i./ha) of Mbr was replaced with a lower rate (16.8 kg a.i./ha; calibration rate 0.4 kg/100 m of row). All plots in both years were treated with aldicarb as a banded (20 cm) preplant incorporated systemic insecticide (0.5 kg a.i./ha).

To establish the plots, a subsoiler-bedder was run over the test site to mark rows 99 cm apart. Individual four-row plots were established (6 m long with 4-m alleys), and preplant, pretreatment nematode population densities were assayed on 28 April 1988 and 8 May 1989. Twelve individual soil cores (2.5 cm d, 20 cm deep) were collected in a systematic pattern from the center two rows of each plot and combined for analysis. Plant-parasitic nematodes were extracted from 500 cm^3 soil by elutriation and sucrose centrifugation (approximate extraction efficiency = 0.20) (1) and counted. Soil fertility factors were determined for each plot by the Georgia Cooperative Extension Service Soil Testing Lab using a subsample of the pretreatment assays. Soil pH was determined in H_2O, and levels of P, K, Mg, and Ca were determined with Mehlich 1 extraction followed by spectrography (15).

Treatments were applied on 4 May 1988 and 18 May 1989, when soil temperatures at 10 cm were 21.7 and 24.2 C, respectively. Each fumigant nematicide was applied in strips of eight contiguous plots. The treatments were replicated three times in a randomized complete block design, with subplots nested within treatments, giving a total of 24 plots per treatment. The Mbr treatments were applied with an experimental closed-system two-row subsoiler, and 1,3-D was applied with a conventional four-row gravity-flow subsoiler. The subsoilers were run at depths of 35–40 cm, varying with soil conditions across the field. The conventional four-row subsoiler then was run over the untreated plots to provide similar tillage effects.

Cotton cv. Deltapine 90 was planted 18 May 1988 and 26 May 1989. A poor stand resulted in 1988 and the cotton was replanted on 27 May 1988. After a stand was established, plots were assayed again for plant-parasitic nematodes on 8 June 1988 and 14 June 1989 (after planting, post-treatment). All nematode counts and yield data were taken from the center two rows of each four-row plot. As an estimate of nematicidal efficacy, the percentage change in *H. columbus* numbers after treatment was calculated as the difference between post-treatment and pretreatment counts divided by pretreatment numbers. Observations with pretreatment counts of zero were eliminated from further analysis of percentage change data.

Plant-parasitic nematodes were assayed again on 10 August 1988 and 10 August 1989 (midseason). Plots were harvested and final nematode assays were collected on 6 December 1988 and 16 November 1989. In the midseason and harvest nematode assays, cotton roots were collected from the eluted 500-cm^3 soil sample from each plot and incubated on a mist extractor for 48 hours. Root counts were added to soil counts for further analyses. All plots were managed by standard practices recommended for the area and irrigated as needed with lateral overhead irrigation. Alleys were planted and managed along with the plots to remove border effects.

Data were analyzed by standard analysis of variance procedures, and differences among means were analyzed by a Waller-Duncan mean separation test ($P < 0.05$) (16). In partitioning the sums-of-squares, strip subplots were analyzed as nested within treatment effects as appropriate for the field experimental design. A paired *t*-test ($P < 0.05$) was used to analyze the differences in *H. columbus* numbers before and after treatment, for each treatment in each year.

Linear and quadratic regression analyses were used to estimate Mbr dosage responses. Effects of the five soil factors were analyzed by multiple regression, with a 0.05 level of significance required for inclusion in the model. The large number of replications (24 per treatment each year) allowed determination with regression analysis of the relationship of cotton yields to preplant *H. columbus* densities within treatments. This analysis was used to determine the impact of fumigant nematicides on the relationship of cotton yields to preplant nematode densities.

RESULTS

Analysis of variance revealed a significant year × treatment interaction. This interaction resulted primarily from the change in ranking across years of the 1,3-D treatments compared with the Mbr treatments. Thus, results for each year are presented separately. The paired *t*-tests indicated that *H. columbus* numbers decreased significantly after application for all nematicide treatments in both years, whereas *H. columbus* numbers in the untreated plots increased significantly between pretreatment and posttreatment sampling dates in 1988 and did not differ significantly in 1989.

Only Mbr-treated and control plots were used for regression analysis of Mbr rate response. There was no significant year × treatment interaction among these treatments. Therefore, years were combined for the rate-response analysis and for analysis of the effects of soil factors on Mbr efficacy.

Regression analysis by treatment, combining years, revealed that cotton yields decreased significantly as preplant *H. columbus* densities increased within untreated control plots. The regression model indicated a loss of 3 kg lint/ha per unit increase in *H. columbus*/100 cm^3 soil ($R^2 = 0.21$, $P = 0.001$, $n = 48$). There was no significant relationship between cotton yield and preplant *H. columbus* numbers for any of the nematicidal treatments, except for the 67.2 kg a.i./ha rate of Mbr, where a slight positive relationship was detected ($R^2 = 0.12$, $P = 0.01$, $n = 48$).

First season, 1988: After nematicide applications, all treatments receiving fumigants had significantly lower *H. columbus* numbers than did the control plots (Table 1). Plots receiving Mbr at the highest rate had significantly fewer nematodes than did plots treated with 1,3-D or the lowest rate of Mbr. Percent changes in *H. columbus* counts before and after treatment showed significantly greater decreases in plots receiving Mbr than in plots receiving 1,3-D. The percent change analysis, which compensates for differences among plots in pretreatment nematode densities, reflected slightly different trends from the analysis done on unadjusted counts, by indicating significant differences between 1,3-D and all Mbr treatments.

Midseason and harvest *H. columbus* counts remained lower in treated than in untreated plots (Table 1), indicating season-long suppression from the fumigant nematicide applications. However, only those plots treated with 1,3-D had significantly higher yields than the control. Plots receiving the highest rate (134.4 kg a.i./ha) of Mbr had lower yields than control plots, because of some phytotoxicity at this high rate.

Second season, 1989: As was true in 1988, after treatment all plots receiving fumigant nematicides had significantly fewer *H. columbus* numbers than did untreated plots (Table 2). However, only the plots receiv-

TABLE 1. Effect of fumigant nematicides on *Hoplolaimus columbus* and yield of cotton, 1988.

Treatment	*Hoplolaimus columbus*/100 cm^3 soil				Lint cotton (kg/ha)
	After planting	Percent change†	Midseason	Harvest	
1,3-dichloropropene					
28.1 liters a.i./ha	15 b	−15 b	28 b	25 b	619 a
Methyl bromide					
33.6 kg a.i./ha	11 b	−52 a	11 bc	19 b	535 ab
67.2 kg a.i./ha	9 bc	−54 a	5 c	12 bc	472 bc
134.4 kg a.i./ha	2 c	−88 a	4 c	2 c	386 c
Control	41 a	75 c	116 a	108 a	511 b

Means within columns followed by the same letter are not significantly different, $P = 0.05$, according to the Waller-Duncan test.

† Calculated as (*H. columbus* number after treatment and planting − number before treatment)/number before treatment. Observations with *H. columbus* = 0 before treatment were excluded from the analysis, since division by zero is undefined.

ing 1,3-D and the highest rate of Mbr had significantly lower values than the control for percent change in *H. columbus* populations after treatment. The percent decrease after 1,3-D was considerably higher in 1989, ranking first among treated plots, compared to 1988 when 1,3-D had the least effect on *H. columbus* counts. As in 1988, compensating for differences in pretreatment counts among plots by use of a percentage calculation gave a different indication of control efficacy than did actual counts.

Hoplolaimus columbus population densities at midseason remained lower in plots receiving nematicide treatments than in untreated plots. By harvest, however, there were no significant differences among treated and untreated plots in *H. columbus* numbers. All treatments had higher cotton yields than the control (Table 2), unlike in 1988 when only plots with 1,3-D had higher yields. The two highest rates of Mbr resulted in greater yields than the lowest rate, suggesting that the lower rate may be suboptimal.

Methyl bromide rate response: When data from both years (Tables 1, 2) were pooled for those plots that received Mbr and the untreated control, the relation of the percent decrease (pd) in *H. columbus* counts after treatment to Mbr rate (x) was best described by the quadratic model $\text{pd} = 27 - 2.05x + 0.009x^2$ ($R^2 = 0.28$; $P < 0.001$; $n = 177$). The relation of final *H. columbus* population densities (Pf) to increasing rates of Mbr (x) was given by $\text{Pf} = 108 - 1.36x + 0.004x^2$ ($R^2 = 0.17$; $P < 0.001$; $n = 177$). The R^2 values were low for all models because of variability in estimates of *H. colum-*

TABLE 2. Effect of fumigant nematicides on *Hoplolaimus columbus* and yield of cotton, 1989.

Treatment	*Hoplolaimus columbus*/100 cm^3 soil				Lint cotton (kg/ha)
	After planting	Percent change†	Midseason	Harvest	
1,3-dichloropropene					
28.1 liters a.i./ha	12 b	−77 a	58 b	83 a	1,013 ab
Methyl bromide					
16.8 kg a.i./ha	17 b	−21 b	65 b	72 a	926 b
33.6 kg a.i./ha	25 b	−32 b	71 b	112 a	1,111 a
67.2 kg a.i./ha	24 b	−65 a	38 b	69 a	1,054 a
Control	59 a	−10 b	129 a	118 a	749 c

Means within columns followed by the same letter are not significantly different, $P = 0.05$, according to the Waller-Duncan test.

† Calculated as (*H. columbus* number after treatment and planting − number before treatment)/number before treatment. Observations with *H. columbus* = 0 before treatment were excluded from the analysis, since division by zero is undefined.

bus population densities, but overall model effects were significant ($P < 0.001$), indicating trends in the treatment means.

Soil factors: Of the five soil factors measured, only ppm of calcium and ppm of magnesium had significant effects in a multiple linear regression relating percent decrease (pd) in *H. columbus* numbers to Mbr rate (x). The best fit multiple regression model was given by $pd = -38.32 + 1.07x + 0.17Ca - 1.33Mg$ ($R^2 = 0.26; P < 0.001$; $n = 177$), where the significance level for inclusion in the model was $P < 0.05$ for all variables. Calcium was highly correlated with pH ($r = 0.51$, $P < 0.0001$), but pH was not a significant factor in any multiple regression models relating decreases in *H. columbus* numbers to Mbr rates.

DISCUSSION

The formulation of methyl bromide and experimental application method was effective in controlling *H. columbus* on cotton. Possible phytotoxicity was indicated by significant decreases in yields at the highest rates. Due to replanting, the actual time period between treatment and planting in 1988 was 23 days, but the highest rate of Mbr still had a significant negative effect on cotton yields. This effect is particularly surprising in view of the tarpless application method, and it indicates a considerable decrease in volatility for the formulation used. Soil temperatures at the time of application were 2.5 C lower in 1988 than in 1989, which may have decreased the volatility of the fumigant nematicides.

Optimal rates of Mbr compared favorably with the recommended treatment of 1,3-D in terms of nematode control. In 1988, however, only the 1,3-D treatment significantly increased yields, whereas in 1989 all nematicide treatments enhanced cotton yields. On the other hand, 1,3-D treatments varied considerably in terms of nematode control, ranking last among treated plots in 1988 and first in 1989. Variability in soil temperatures at the time of treatment and in the time periods between treatment and planting may have contributed to these differences among years.

Schmitt (17) reported that soil pH generally did not influence nematode control by DBCP, fenamiphos, or fensulfothion. In this study, pH was not a significant factor in multiple regression models relating efficacy of nematode control to Mbr rate and five soil fertility variables; however, Ca and Mg were significant factors in the best fit models. Interpretation of these results is limited to an indication that there is a combined effect of Ca, Mg, and Mbr rate on nematode populations. Cause and effect relationships among individual elements cannot be inferred from multiple regression models.

The percentage calculations used to evaluate nematicide effects on *H. columbus* population densities provided indications of significant differences among treatments slightly different from the analysis of actual counts (Tables 1, 2). High variability among plots in nematode counts is a common problem in field research. Percentage based calculations may reduce variability in population changes resulting from differences in pretreatment population levels. Additionally, pesticide toxicities are usually reported in terms of the percentage of individuals killed, i.e., lethal doses to kill a certain percentage (3). Percent decreases, as determined in this work, cannot be interpreted as percent killed, since the changes also result from other factors, including births, natural deaths, and migration in or out of the sampling area. This type of calculation, however, may be useful for evaluation of relative toxicities among treatments.

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