Granular Nematicides as Adjuncts to Fumigants for Control of Cotton Root-knot Nematodes[1]

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Abstract: Growth and yield of cotton were best with combinations of fumigants and organophosphate and carbamate nematicides. Organophosphates or carbamates used alone did not give season-long control of root-knot nematodes. Long-term control was poor because the temporary sublethal effects of these materials diminished soon enough that the nematodes could reproduce. The nematodes survived the treatments and a year of nonhost culture, and damaged a susceptible host crop 2 years after treatment. No such damage occurred in plots treated with fumigant, fumigant plus organophosphate, or fumigant plus carbamate. Treatment of seed and treatment of cotton, either in furrow at planting or sidedressing at midseason, with organophosphate and carbamate nematicides resulted in little or no yield increase, because nematode control was only minimal and temporary; or in a yield decrease, because the toxicity of the materials was manifested when nematode populations were low. *Key Words: Meloidogyne incognita,* organophosphates, carbamates, *Gossypium hirsutum,* pest management, phytotoxicity, seed treatment.

In California one species of root-knot nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood, is known to infest about 25% of the land upon which cotton (*Gossypium hirsutum* L.) is grown (7). In the United States the estimated reduction in cotton yield due to this and other nematodes for the years 1969–1976 exceeded 2 million bales (compiled from the loss estimates of the Cotton Disease Council for the years 1969-1976). If the conventional nematicidal soil fumigants had not been used in that period, the reduction would have been greater. Now, as a result of actions by agencies of the federal and state governments, some of the conventional nematicides may not be available for use on cotton.

The organophosphates and carbamates are being tried for management of root-knot nematodes, even though relatively high doses are required to control those parasites (2). Soil fumigants control nematodes by killing them. Organophosphates and carbamates are lethal to nematodes at high doses, but usually control nematodes in other ways, such as delaying hatching, impeding migration of invasive larvae to host roots, impairing feeding behavior, and disorienting males toward females (2, 3, 4, 8, 9, 10). They apparently cause dysfunction of the nematodes as components of complex diseases (6), and they inhibit development of females and egg production (4). Experiments were conducted to determine the feasibility of integrating organophosphate and carbamate nematicides into a management program to control root-knot nematodes on cotton.

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MATERIALS AND METHODS

The experiments were on fields of Hesperia sandy loam (ca. 76% sand, 17% silt, and 7% clay) naturally infested with cotton root-knot nematodes. The experimental design, a randomized complete block, was the same in all experiments. The number of treatments varied; there were always at least four replications of each treatment, although some experiments included 8 or 12. Individual plots were four rows wide on 1-m centers and were either 18 or 20 m long.

The following fumigants, applied as described in the tables, were used as preplanting treatments: 1,3-D (1,3-dichloropropene and related chlorinated C_3 hydrocarbons), chloropicrin (trichloronitromethane), and DBCP (1,2-dibromo-3-chloropropane). In one experiment a granular formulation of DBCP containing 50% by weight of the active ingredient was sidedressed after an at-planting treatment with aldicarb [2-methyl-2-(methylthio)propionaldehyde *O*-(methylcarbamoyl)oxime]. Granular formulations of the nematicides aldicarb, carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate), oxamyl (methyl *N'*,*N'*-dimethyl-N-[(methylcarbamoyl)oxy[-1-thiooxamimidate), phenamiphos [ethyl 4-(methylthio)-*n*-tolyl isopropylphosphoramidate], and aldoxycarb [2-methyl-2-(methylsulfonyl) propionaldehyde *O*-(methylcarbamoyl)oxime] were applied as preplanting, at-planting, or combinations with each other and the fumigants.

Fumigants and preplanting treatments of the granular compounds were applied in the centers of the rows by tractor-mounted chisels before preirrigation. The fumigants containing 1,3-D were applied at a depth of 56 cm; the fumigants containing DBCP, at 30 cm; and the granular compounds at 20 cm, with exceptions as indicated in Table 3. When applied at planting, granules were placed in a 5-cm band in the seed furrow at the center of the bed with an attachment to the planter. The granules not incorporated by the press wheel were lightly incorporated into the soil by a short loop of chain attached to the planter. In one experiment, aldoxycarb was used as a seed treatment. Postplanting applications of granules were about 15 cm deep and 10–15 cm from the center of the row on the side of the bed that was to be irrigated. Cotton was planted 3–4 weeks after treatment, when the soil was in good planting condition and the fumigants had dissipated enough to avoid phytotoxicity. The cotton was irrigated as needed to induce flowering, maintain plant growth, and produce the best possible yield in the untreated plots.

In four of the experiments, midseason bioassays were made to determine the early effectiveness of the treatments. Soil samples for these bioassays were collected from all plots, and the composited samples from each plot were arranged on the greenhouse bench in the same design as the respective plots in the field. The effects of the treatments on the root-knot nematodes were demonstrated by the average weighted nematode ratings (WNR's) of tomato plants grown in the soil samples from each treatment (5). WNR's were calculated with the following formula:

$$\text{WNR} = \frac{\sum_{i=1}^{5} ni\ wi}{(\Sigma\, ni)\ w_5} \times 100 = \frac{(n_1w_1 + n_2w_2 \ldots + n_5w_5)}{(n_1 + n_2 \ldots + n_5)\ w_5} \times 100$$

Where ni = number plants in ci
ci = i^{th} class
wi = weight of ci

Class	Rating	Weight
1	0	0
2	1	1
3	2	3
4	3	5
5	4	7

Thus, WNR is a weighted root-gall index describing the relative intensities of root galling in the various treatments. It compares the damage that occurred with the most damage that might occur under the conditions of the experiments.

At the end of the season, the cotton was machine-picked from the center two rows of each plot. After harvest, the tops of the cotton plants were shredded with a rotary stalk cutter, the roots were dug with a tractor-drawn lifter, the roots of 30 plants from each plot were rated on a 0–4 scale, from no galls to completely galled, and WNRs were calculated.

RESULTS

Cotton plants from plots treated with

TABLE 1. Yield and nematode root galling of Acala SJ-1 cotton in 1972 and nematode root galling of okra in 1974 as influenced by chemical soil treatments in 1972.[y]

Treatment (1972): Preplanting: Nematicide	Preplanting: Formulation (kg[a.i.] /liter)	Preplanting: Formulation (%[a.i.])	Preplanting: Rate (liters/ ha)	Preplanting: Rate (kg[a.i.] /ha)	Planting: Nematicide	Planting: Rate (kg[a.i.] /ha)	Postplanting: Nematicide	Postplanting: Rate (kg[a.i.] /ha)	Cotton (1972): Yield of lint (kg/ha)	Cotton (1972): WNR[z]	Okra (1974): WNR
1,3-D+pic	1.27		94.0		aldicarb	2.2	aldicarb	2.2	1137 ab	3 cd	43 cde
					carbofuran	2.2	aldicarb	2.2	1242 a	1 d	39 de
					oxamyl	2.2	none	–	990 abc	1 d	24 e
					none	–	none	–	1113 ab	9 cd	25 e
1,3-D	1.20		94.0		aldicarb	2.2	aldicarb	2.2	1115 ab	1 d	36 de
					carbofuran	2.2	aldicarb	2.2	847 bc	1 d	75 abcd
					oxamyl	2.2	none	–	1029 abc	1 d	29 e
					none	–	none	–	1144 ab	3 cd	57 bcde
DBCP	1.45		9.4		aldicarb	2.2	aldicarb	2.2	1111 ab	6 cd	64 abcde
					carbofuran	2.2	aldicarb	2.2	878 bc	3 cd	54 bcde
					oxamyl	2.2	none	–	1029 abc	13 bcd	61 abcde
					none	–	none	–	867 bc	32 abcd	82 abc
Aldicarb		10		4.5	none	–	none	–	1032 abc	33 abc	100 a
Carbofuran		10		4.5	none	–	none	–	775 c	49 a	100 a
Oxamyl		10		4.5	none	–	none	–	941 abc	42 ab	64 abcde
None (untreated)		–		–	none	–	none	–	939 abc	62 a	86 ab
LSD 0.05									263	27	36

[y]Data are means of four replications. Within a column, means followed by a letter in common are not significantly different according to Duncan's multiple-range test ($P < 0.05$).
[z]Weighted nematode rating: 0 = no galling, 100 = full galling.

fumigants, alone or in combination with other nematicides, usually had lower root-gall ratings (WNRs) than plants from plots treated with an organophosphate or a carbamate alone (Tables 1–4).

Carbofuran was toxic to cotton plants at all of the rates used; with one exception (Table 1), its use depressed cotton yields below those in untreated controls. This toxicity was always evident in the cotyledons and early leaves of the cultivars that were used in these experiments, although it did not always continue through the entire season to harvest. Aldicarb, oxamyl, phenamiphos, and aldoxycarb were less phytotoxic. Their use, particularly at low or moderate rates, tended to result in higher yields; aldicarb and phenamiphos were usually more effective than oxamyl or aldoxycarb. In two experiments (Tables 2, 4), there was evidence of toxicity to the extent that yields were reduced or were apparently not increased in plots given aldicarb and aldoxycarb at the highest rates. Control usually outweighed phytotoxicity, because the effects of high nematode populations masked the toxicity of those chemicals to cotton.

When nematode populations were relatively low (Tables 1, 4), yields from carbamate-treated plots did not significantly exceed yields from untreated plots. Some benefit accrued from the temporary sublethal effects of the carbamates on the cotton crop to which they were applied. Galling of okra, planted 2 years later, revealed that the nematodes had survived the treatments plus a year of nonhost culture. Then they produced the heaviest damage in aldicarb and carbofuran-treated plots (Table 1). Seed treatments with aldoxycarb (Table 5) were phytotoxic at both rates tested, and at-planting in-furrow treatments with aldicarb and phenamiphos were also phytotoxic. The phytotoxicity was offset, however, by a brief period of control in the in-furrow treatments, as indicated by the reduced root galling at midseason. Unfortunately, lint yields were not improved by these treatments. Sidedressing aldicarb (Table 6) increased lint yield and decreased root galling significantly.

Preplanting treatments with aldicarb were usually the most effective in decreasing root galling (WNRs) and increasing yields. The improved effectiveness at this time of application was probably a result of the movement of these materials, particularly the most water-soluble ones, in the soil by mass transfer (2, 4). When these

TABLE 2. Yield and nematode root galling of Acala SJ-1 cotton as influenced by preplanting treatment with nematicides.[y]

Nematicide	Formulation: Liquid (kg/liter)	Formulation: Granules (%a.i.)	Rate: Liquid (liters /ha	Rate: Granules (kg[a.i.] /ha)	Depth: Liquid (cm)	Depth: Granules (cm)	Yield of lint (kg/ha)	WNR[z]
1,3-D+pic+aldicarb	1.27	10	140	4.5	56	30	992 a	1 c
1,3-D+pic+carbofuran	1.27	10	140	9.0	56	30	816 abcd	4 c
1,3-D+pic	1.27	–	140	–	56	–	945 ab	15 c
1,3-D+aldicarb	1.20	10	140	4.5	56	30	996 a	4 c
1,3-D+carbofuran	1.20	10	140	9.0	56	30	714 bcd	3 c
1,3-D	1.20	–	140	–	56	–	865 abc	0 c
Aldicarb	–	10	–	4.5	–	10	724 bcd	69 ab
	–	10	–	9.0	–	20	940 ab	38 bc
	–	10	–	13.5	–	30	687 cd	75 ab
Carbofuran	–	10	–	4.5	–	10	614 d	75 ab
	–	10	–	9.0	–	20	602 d	100 a
	–	10	–	13.5	–	30	610 d	93 a
None (untreated)	–	–	–	–	56	–	677 cd	73 ab
LSD 0.05							219	43

[y]Data are means of four replications. Within a column, means followed by a letter in common are not significantly different according to Duncan's multiple-range test ($P < 0.05$).
[z]Weighted nematode rating: 0 = no galling, 100 = full galling.

TABLE 3. Yield and nematode root galling of Acala SJ-1 cotton as influenced by preplanting treatment with nematicides.[x]

Nematicide	Treatment: Formulation (kg/liter)	Formulation (%a.i.)	Rate (liters/ha)	Rate (kg[a.i.]/ha)	Yield of lint (kg/ha)	WNR[y] Mid-season[z]	WNR[y] Post-harvest
Aldicarb	–	15 G	–	2.2	941 bcd	19 bc	88 ab
	–	15 G	–	4.5	841 bcd	53 ab	92 ab
Aldoxycarb	–	75 WP	–	2.2	749 cd	55 ab	100 a
	–	75 WP	–	4.5	914 bcd	48 abc	100 a
Phenamiphos	–	36 EC	–	2.2	1019 bc	29 abc	88 ab
	–	36 EC	–	4.5	1088 ab	61 ab	72 b
1,3-D	1.20	–	140.0	–	1384 a	2 c	8 c
None (untreated)	–	–	–	–	683 d	71 a	98 a
LSD 0.05					270	43	24

[x]Data are means of four replications. Within a column, means followed by a letter in common are not significantly different according to Duncan's multiple-range test ($P < 0.05$).
[y]Weighted nematode rating: 0 = no galling, 100 = full galling.
[z]Tomato bioassay on soil samples.

materials are applied before the preirrigation, as they were in these experiments, the water movement can concentrate them in the areas of the bed where the seed is to be planted (1, 3). Generally, root galling (WNRs) was reduced most by the highest rates of each nematicide.

DISCUSSION

Yields were not always improved by treatment, for two reasons. First, the materials were toxic to the cotton plants (Tables 1, 4). Second, the systemic activity of some of the materials has very little effect, and perhaps no lethal effect, on root-

TABLE 4. Yield and nematode root galling of Acala SJ-4 cotton as influenced by preplanting, planting and postplanting treatment with nematicides, alone and in combinations.[u]

Nematicide(s)	Treatment: Formulation (kg/liter)	Formulation (% a.i.)	Rate (liters/ha)	Rate (kg[a.i.]/ha)	Yield of lint (kg/ha)	WNR[v] Mid-season[w]	WNR[v] Post-harvest
Aldicarb	–	15 G	–	4.5	1040 cd	27	7 b
1,3-D	1.2	–	94	–	1369 a	0	6 b
DPCP + pic	–	30+60	–	7.6	1363 a	0	2 b
	–	30+60	–	3.8	1397 a	0	0 b
DBCP	–	86 E	–	3.8	1390 a	0	0 b
Aldoxycarb	–	75 WP	–	2.25	1299 a	25	17 ab
	–		–	4.50	1156 bc	25	15 ab
	–		–	6.75	980 d	38	22 ab
Aldicarb[x]+DBCP[y]	–	–	–	1.1+2.25	1090 cd	25	15 ab
None (untreated)	–	–	–	–	1262 ab	38	32[z]a
LSD 0.05					129	NS	19

[u]Data are means of eight replications. Within a column, means followed by a letter in common are not significantly different according to Duncan's multiple-range test ($P < 0.05$).
[v]Weighted nematode rating: 0 = no galling, 100 = full galling.
[w]Tomato bioassay on soil samples.
[x]Applied at planting in the seed furrow.
[y]Sidedressed five weeks after planting.
[z]Indicates low nematode population.

TABLE 5. Yield and nematode root galling of Acala SJ-2 cotton as influenced by seed or at-planting in-furrow treatment with nematicides.[w]

Nematicide	Treatment rate (kg[a.i.]/ha)	Seed furrow	Yield of lint (kg/ha)	WNR[x] Midseason[y]	WNR[x] Postharvest
Aldoxycarb	1.12[z]	S	773	89	79
Aldoxycarb	0.56[z]	S	775	93	86
Aldicarb	2.24	F	882	63	71
Phenamiphos	3.36	F	884	50	83
None (untreated)	–		846	93	84
LSD 0.05			NS	18	NS

[w]Data are means of eight replications.
[x]Weighted nematode rating: 0 = no galling, 100 = full galling.
[y]Tomato bioassay on soil samples.
[z]Kg(a.i.)/112 kg of seed.

knot nematodes (2, 6); that is not to say, however, that the sublethal effects are of no value.

The results indicate that organophosphates and carbamates may control root-knot nematodes that parasitize cotton. But it is difficult to take advantage of the full lethal and sublethal effects of these nematicides while avoiding their phytotoxic effects. When the nematicides were applied before planting, lethal effects were fully utilized, and sublethal effects only partially, and phytotoxicity was largely avoided. At-planting treatments apparently were not activated by the soil water soon enough, and the chemicals did not move far enough to kill the nematodes. Under those conditions, sublethal and phytotoxic effects were greater. Plants given postplanting treatments did not benefit from preplanting reduction of nematode populations, but were less susceptible to phytotoxic effects and may have profited from the systemic and sublethal effects. Using those compounds before planting eliminates one of their possible advantages over fumigants. The evidence suggests that organophosphates and carbamates function primarily as contact nematicides, not as systemics, against root-knot nematodes of cotton (6).

Integration of fumigant and organophosphate or carbamate nematicides in a management program to control root-knot nematodes on cotton is worth further consideration. Even so, the advantages, biological and economic, of such integration are tenuous. The apparent yield increase obtained with combination treatments is usually not significantly higher than with fumigants alone and indeed may not justify the extra cost of additional materials and equipment. But organophosphates and carbamates are substitutes for or adjuncts to fumigants, not alternatives. Alone, the organophosphates and carbamates are inadequate or ineffective more often than they

TABLE 6. Yield and nematode root galling of Acala SJ-2 cotton as influenced by sidedressing with aldicarb.[w]

Treatment: Nematicide	Treatment: Rate (kg[a.i.]/ha)	Yield of lint (kg/ha)	WNR[x] Midseason[y]	WNR[x] Post-harvest
Aldicarb 10G	8	1069[z]	60	66[z]
None (untreated)	–	900	64	87

[w]Data are means of twelve replications.
[x]Weighted nematode rating: 0 = no galling, 100 = full galling.
[y]Tomato bioassay on soil samples.
[z]Means in column are significantly different according to *t*-test ($P < 0.01$).

are useful. With fumigants, they may help increase lint yields in cotton.

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